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Light ions induced charge exchange reactions at Saturne

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Abstract : Spin isospin excitations are studied at Laboratoire National Saturne using charge exchange reactions. New data, completing the (^{3}He,t) one, have been recently obtained. We present measurements done on the (d,2p) reaction with a special emphasis on the quasi free and Δ regions. Spin observables are also discussed. We also present the results of a systematic study of the characteristics of the Δ excitation by ^{12}C, ^{14}N, ^{16}O and ^{20}Ne scattering. The cross section dependence with respect to projectile and ejectile is qualitatively understood. As observed in all other charge exchange reactions, the Δ peak on nuclei is shifted by ~70 MeV with respect to the free Δ.

Introduction

Charge exchange reactions have been studied at Saturne for now 6 years using various projectiles with an energy ranging from 200 MeV to 1100 MeV per nucleon. Above 500 MeV aside from the nuclear excitations already seen in the Indiana (p,n) experiments [1], a well developed bump shows up with a strength comparable to the one corresponding to the particle hole states sector[2]. This corresponds to the spin isospin flip of one quark in a target nucleon leading to the Δ. These reactions appear to be direct reactions selectively exciting the spin isospin modes of the nucleus. With the good quality heavy ions beam delivered by Saturne, we were able to study both (p,n) like and (n,p) like reactions induced by ^{12}C, ^{14}N, ^{16}O and ^{20}Ne projectiles. In parallel, a program was developed to study the ($\vec{d}$,2p[$^1S_0$]) reaction with a polarised beam. All these experiments were performed using the SPES4 magnetic spectrometer[3]. The properties of the spectrometer and of the associated detection system is quite suitable to realize measurements at small angle (including 0°) up to a maximum rigidity of 4.2 GeV/c. The ion identification is done by the association of two thick scintillators which determine the charge and a 17 m long time of flight basis which gives the mass. Ray tracing is carried out by two sets of drift chambers. Their resolution (300 μm FWHM) allows us to measure angular distributions with a resolution of ~ 2 mrd. I will in this paper mainly focus on quasi free charge exchange and Δ production.

The (d,2p) reaction

The 2 protons were detected simultaneously in the SPES4 spectrometer. Its angle and momentum acceptance selects the two protons in the L=0 state. One then has a pure ΔS=1 ΔT=1 probe. Statistics are not very good in the low energy loss region for two reasons. On one hand, as the cross section for charge exchange is forward peaked, we have to face the intense background due to the deuteron breakup. This leads us to use a rather low

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beam intensity, especially in the region of the discrete states and at small angles ($\leq 2°$), in order to be able to separate the (d,2p) process from the very large amount of accidentals induced by the (d,pn) reactions. On the other hand the detection efficiency for two protons, independent of angle, is of the order of 15% at 2 GeV and 3% at 400 MeV. The complete excitation spectrum can be divided in three parts : the discrete states,the quasi free and the Δ excitations.

The discrete states

On hydrogen, the neutron peak is easily separated. In an impulse approximation calculation[4] with the NN amplitudes of H. Esbensen[5], one follows the cross section over 3 decades. The agreement with the polarisation observable M, shown by the curve on fig 1, is good. The deviation at $q \geq 2\ fm^{-1}$ might be explained either by distortion effects or by our poor knowledge of the nucleon nucleon charge exchange amplitude in this momentum transfer region. On nuclei, the statistics is too poor to allow the extraction of a valuable nuclear structure information. With the future availability of a polarised ^6Li beam at Saturne, one then should be able to extract nuclear informations of good quality analogous to those obtained by the $(\vec{p},\vec{n})$ reaction.

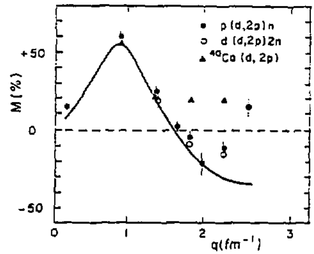

Fig 1. Polarisation signal of the free and quasi free peaks at 2 GeV. M is defined by $M = \frac{1}{2}\rho_{20}(T_{20} + \sqrt{6}T_{22} < \cos 2\varphi >)$ where ρ_{20} is the beam polarisation and the mean value takes into account the finite size angular aperture effects.

The quasi free bump

Fig 2 displays in a $(\|\vec{q}\|,\omega)$ plot the position of the maximum of the quasi free peak. One notes that (^{3}He,t) and (d,2p) data are consistent. However, the peak position seen in (p,p') [6] and (e,e') [7] is different. For these two reactions, the experimental slope corresponds to the free nucleon one with a shift in the electron case. For the two charge exchange reactions the departure from the electron line increases with tranfer to reach 40 MeV at $2.5\ fm^{-1}$. Such

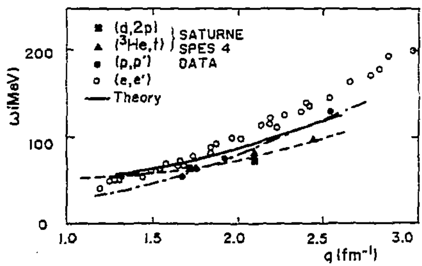

Fig 2. Comparison of the quasi free peak position. The dot dashed line is the free position. The dashed one is drawn as a guide line for our data. The full curve is the theoretical calculation [9].

an effect can be attributed neither to distortions nor to the (d,2p) form factor variation across the peak[8]. One can interpret it as due to NN^{-1} attractive correlations in the longitudinal channel. Such an interpretation has been tested by a recent calculation[9]. Nevertheless, although this calculation gives an effect of the correct sign, it is still unable to explain the size of the effect. The polarization response in the quasi free was also measured(fig 1). Up to 1.2 fm^{-1}, the response on ^1H, ^2H and ^{12}C coincide. Above, the nuclear response deviates appreciably indicating that the (d,2p) reaction is mainly a transverse probe. This fact is difficult to reconcile with the shift attributed to nuclear correlations in the longitudinal channel and should be further studied on both experimental and theoretical sides.

The Δ bump

The unpolarized response shows similar effects to those already observed in the (^3He,t) reaction, namely that the position of the Δ peak on nuclei is shifted with respect to the free Δ^0 created from a free proton by ~ 60±10 MeV. The cross section on the deuterium is twice the proton one. This is consistent with the 1/2 absorption factor, deduced from the comparison of the reactions d(d,2p)2n and p(d,2p)n, if one takes into account the Clebsh-Gordan coefficients for the production of the Δ^0 on a proton and of the Δ^- on a neutron. Spin observables were also measured, namely iT_{11} and M(see fig 1 for definition of M), at 2 GeV and 1.6 GeV from 0° to 7.2° over the Δ (Fig 3). With a pure longitudinal probe (π exchange)one would expect a negative signal (~ -40%) whereas a pure transverse one (ρ exchange) would give a positive signal (~ +20%). The ($\vec{d}$,2p) reaction in the Δ region appears to be mostly transverse. Moreover, the contrast between hydrogen, deuterium and carbon target is rather weak, indicative of the smallness of medium effects.

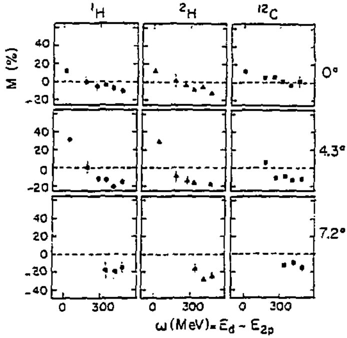

Fig 3. Polarisation signal M at 2 GeV and 0° in the Δ region. See fig 1 for definition of M.

Heavy ion reactions

With such reactions,we were able to measure the charge exchange at 0° for both (p,n) like and (n,p) like reactions and to investigate the Δ production in different experimental conditions. Of importance is of course the important question whether medium effects in the longitudinal channel, advocated by several groups[10] to explain the shift observed in (^3He,t) , subsist in so peripheral reactions. Because of the high incident energy, one covers, with SPES4[3], the response of the target nucleus over 1 GeV within only one magnetic setting. Moreover, with the large entrance square collimator (± 0.8° in both directions), one integrates the angular distribution almost entirely. One very important feature to have in mind is that we measure a yield which corresponds in fact to a summation over all transitions to states of the ejectile which are bound against particle emission. The resolution of the spectrometer in the GeV per nucleon energy domain (20 to 30 MeV) does not allow to separate these different contributions. This effect of mixing will be discussed in greater details later. We have measured the (^{12}C,^{12}N) , (^{12}C,^{12}B) , (^{14}N,^{14}O) , (^{14}N,^{14}C) , (^{16}O,^{16}N) , (^{20}Ne,^{20}F) and (^{20}Ne,^{20}Na) at energies between 400 MeV and 1100 MeV per nucleon on ^{1}H, ^{2}H, ^{12}C, ^{89}Y and ^{208}Pb. Only qualitative data had been obtained before 1987. With Mimas, a small synchrotron inserted between the ebis type source Dioné and the Saturne ring, the gain in intensity was important (~ 20), then allowing us to measure precisely position, width and intensity of the different structures appearing in energy loss spectrum. On fig 4, one sees a typical spectrum. It reveals essentially two structures : one at low energy loss value ($\omega \leq m_\pi$) which corresponds to nuclear spin isospin transitions and an another one around 300 MeV, the Δ bump.

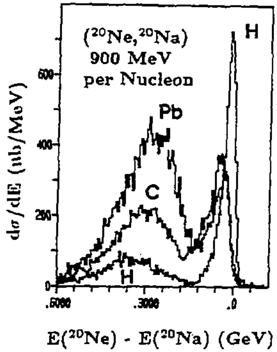

Fig 4. Angle integrated energy loss spectrum at 900 MeV per nucleon for the (^{20}Ne,^{20}Na) reaction.

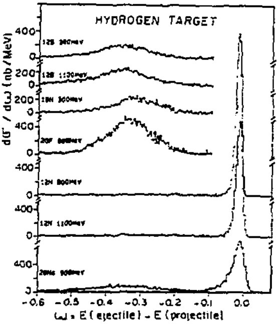

Fig 5. Angle integrated energy loss spectra on hydrogen.

The region below the π threshold

On hydrogen in (n,p) like reactions one observes the neutron peak(fig 5). Its asymmetrical shape reflects the combined effects of the strong kinematics and of the angular distribution. The fact that the width is larger in (^{20}Ne,^{20}Na) indicates that the transition form factor ^{20}Ne $\rightarrow$ ^{20}Na is less steep than the corresponding one for the (^{12}C,^{12}N) reaction. The comparison of 900 MeV and 1100 MeV per nucleon data indicates that the $\sigma\tau$ term in the NN amplitude is still decreasing with energy. This is consistent with a recent analysis[11]. On nuclei it includes the Gamow-Teller as well as the other multipole spin resonances. Since the angular distributions of all these different contributions is weighted by sinθ, the fraction of the cross section corresponding to the L=0 transition (very forward peaked) is low and the spectrum is dominated by higher multipoles. An estimate based on the (^{3}He,t) data indicates that the relative contribution of the Gamow Teller in the (^{12}C,^{12}N) on ^{12}C is of the order of 8%. The quasi free charge exchange cannot be isolated on such an integrated spectrum though it is likely to contribute to the high energy loss tail of the low energy peak. From the (^{3}He,t) one knows that this process is important at q=1.4 fm^{-1} (4° in (^{3}He,t)). This corresponds, for an incident ^{12}C, to the angular acceptance limit of our collimator.

The Δ bump

Fig 5 displays on the same scale free Δ production spectra for seven different experimental conditions. First one notices the weakness of the Δ^0 excitation by (^{12}C,^{12}N) reaction. This can be easily understood if one realizes that the only state involved in the ejectile is the ground state which corresponds to a L=0 transition. This transition form factor can be deduced from the inverse reaction $^{12}C(p,n)^{12}B$ measured at 800 MeV [12]. It falls off by a factor 100 between 0 and 1 fm^{-1} which is the transfer at the Δ peak position. Detailed calculations by M. Soyeur et al[13] reproduce quantitatively both the absolute cross section and the energy dependence on ^1H and ^{12}C. On the (^{12}C,^{12}B) side the Δ^{++} cross section is large for two reasons : first, the Clebsch-Gordan coefficient is three times bigger and secondly the contribution of the 2^+ state at 0.96 MeV in ^{12}B, which cannot be separated from the ground state contribution, is large. This state corresponds to a L=2 transfer which presents a maximum at q ~ 1 fm^{-1}. This interpretation explains also the variation of the cross section with the energy. As the energy increases the minimum momentum transfer decreases and the variation of the cross section then just reflects the variation of the form factor in the 1 fm^{-1} transfer region. A steep form factor as in the (^{12}C,^{12}N) reaction leads to a rapid increase with energy[13] as observed experimentally. On the contrary, for the (^{12}C,^{12}B) reaction, a smoother form factor gives an moderate increase. The cross sections for the Δ^{++} are also large in the (^{16}O,^{16}N) and (^{20}Ne,^{20}F) reactions as several states corresponding to L=1 transfer in the ejectile contribute. The transition form factor has also important effects on the position and width of the free Δ. The steeper it is, the more shifted and the narrower the Δ peak is. One then should be very careful when comparing raw positions and widths.

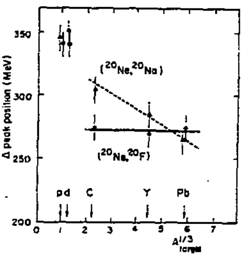

Fig 6. Δ bump position versus target mass.

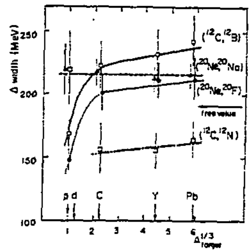

Fig 7. Δ bump width versus target mass.

On nuclei the Δ excitation is comparable or even bigger than to the excitation of the low energy sector. The important difference between the Δ^0 and the Δ^{++} excitations is washed out by the presence of neutrons which can be turned respectively into Δ^- and Δ^+. As a consequence, the ratio of the Δ cross section for (p,n) like and (n,p) like reactions on a T=0 target nucleus is droven by the number of possible transitions between the incident ion and the outgoing ion and the associated form factors. The effects of the distortions is very important : without distortions one would expect a cross section proportional to N+3Z in (n,p) like and Z+3N in (p,n) like reactions since there is no Pauli blocking for Δ's in nuclei. Taking out these factors one has a measure of the distortion. For the (^{20}Ne,^{20}F) reaction on ^{208}Pb one has only 4 effective target nucleons. A comparison with theory can be made for the ^{12}C target. The reaction appears to be very peripheral : a skin of only 2 fm gives 71% of the cross section[13]. Fig 6 shows the position of the Δ peak for different reactions. Besides the absolute position with is sensitive to the projectile ejectile form factor, as for the hydrogen case, one notices different target dependences. In (p,n) like reaction the shift with respect to the free Δ^{++} is stable from ^{12}C to ^{208}Pb. On the contrary, in (n,p) like reactions the Δ peak moves continuously from ^1H to ^{208}Pb. This is the first indication that medium effects can be different in mirror reactions. If one now plots the width of the Δ versus the target mass one observes also differences(fig 7). For (p,n) like reactions, the variation of the Δ width with the target mass seems to be explainable by the onset of the Fermi momentum. For the (^{20}Ne,^{20}Na) reaction the target dependence is small. For the (^{12}C,^{12}N) case the width of the free Δ^{o} is very large. In that case, because of the weakness of the excitation and the subtraction method used, one cannot rule out completely a possible background which would enhance artificially the width.However, from this systematics on widths and positions one may think that we have at hand a way to determine the isospin dependence of the Δ interaction with the nucleus. In heavy target nuclei proton and neutron density differences might suppress certain decay channels (For example, in such a model for neutron rich nucleus the decay process through the absorption of a Δ^- with a neutron is forbidden). Future experiments are planned to look for the decay channels of the Δ bump.

conclusion

A complete set of data on the Δ production have been obtained at Laboratoire National Saturne using various charge exchange reactions. The position, width and intensity, as well as polarisation observables were measured. A common observation is made : the Δ peak in nuclei is shifted with respect to the free one by ~ 70 MeV. Further experiments are still on the way at Saturne. They should lead to a better understanding of the interaction of a Δ with the nuclear field.

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