Two-Nucleon Induced Λ Decay in NucleiW.M. Alberico^{a)}, A. De Pace^{a)}, M. Ericson^{b)} and A. Molinari^{a)}^{a)} *Dipartimento di Fisica Teorica dell'Università
and I.N.F.N., Sezione di Torino**corso M. d'Azeglio 46, I-10125 Torino, Italy*^{b)} *Institut de Physique Nucleaire, IN2P3, CNRS,
Université C. Bernard Lyon 1,**F-69621 Villeurbanne, Cedex, France
and CERN, CH-1211, Geneva 23, Switzerland*

CERN LIBRARIES, GENEVA

CM-P00052117

Abstract

The pionic channel for Λ decay in nuclei is forbidden by the Pauli principle. We discuss the decay in another state, the pion branch, a collective nuclear state which is a coherent superposition of pionic and $\Delta - h$ states and which lies at an energy lower than the physical pion. Its decay mode in the region concerned here is by two-particle emission. The Λ decay process is then a two-nucleon induced one: $\Lambda + p + n \rightarrow p + n + n$. We find a sizeable branching ratio.

The decay of the Λ bound in a nucleus has a long history in nuclear physics¹⁾. In free space the non-leptonic decay produces a pion and a nucleon: $\Lambda \rightarrow p + \pi^-$ or $\Lambda \rightarrow n + \pi^0$. The mass difference between the lambda and the proton is just enough for the decay to occur: $\Delta M \equiv M_\Lambda - M = 177 \text{ MeV}$ and the momentum of the emitted nucleon is small, $p \simeq 100 \text{ MeV}/c$. In nuclei this value is insufficient to lift the nucleon above the Fermi sea, and therefore the pionic decay is forbidden, as it has been experimentally confirmed. It was pointed out^{2,3)} that the decay can occur via a non-mesonic channel, a particle-hole (ph) pair replacing the pion. The process is then $\Lambda + N \rightarrow N + N$, a one-nucleon induced reaction. Subsequent calculations⁴⁻⁶⁾ for this process have shown that the experimental lifetimes can be reproduced. However there remains a difficulty concerning the ratio of neutron to proton emission, which is larger than expected from this mechanism.^{5,6)}

It is the purpose of this letter to point out the relevance of another mechanism for this decay, which has been hitherto overlooked. It follows from the existence of a collective state, the pion branch, which is a mixture of Δ -hole and pionic states and which lies below the free pionic branch. Actually the relevance of this state for the total decay rate has not been completely ignored. Oset⁷⁾ pointed out that the modification in the nuclear medium of the energy-momentum relation of the

$$\omega^2 = q^2 + m_\pi^2 \longrightarrow \omega^2 = q^2 + m_\pi^2 + q^2 \Pi(q, \omega), \quad (1)$$

increases the value of the pion momentum for a given energy release ω , thus making the Pauli blocking less effective. In eq. (1) $q^2 \Pi$ is the pion self-energy and the appropriate coupling constant (f_π^2/m_π^2) is included in the definition of Π . The modified relation indeed corresponds to the pion branch. However this does not imply that pion emission is less blocked. In fact if a real pion is emitted from the nucleus its energy-momentum relation can only be the one of a free particle.

Let us first assume that the modified energy-momentum relation makes the Pauli blocking ineffective and that the pion branch has zero width. We denote its energy by $\omega_1(q)$. Then the Λ decay in the nucleus would partly occur through the channel $\Lambda \rightarrow N + (A-1)^*$, where $(A-1)^*$ represents the pion branch, a stable collective state of the $(A-1)$ system. In this approximation the strength associated with this decay mode could be evaluated in the same way as for the free decay. In the latter case the decay width reads:

$$\begin{aligned} \Gamma_{\text{free}} &= -2\text{Im}\Sigma_\Lambda^{\text{free}} = \frac{3}{2\pi} \int_0^\infty dq q^2 \left(s_\pi^2 + \frac{p_\pi^2}{m_\pi^2} q^2 \right) \text{Im}\mathcal{D}_0(q, \omega) \\ &= \frac{3}{2\pi} \int_0^\infty dq q^2 \left(s_\pi^2 + \frac{p_\pi^2}{m_\pi^2} q^2 \right) \frac{1}{2\omega_q} \delta(\omega - \omega_q), \end{aligned} \quad (2)$$

CEKN - FKE 30-07C
- 2 - 55 3108 C

where $\omega_q = \sqrt{q^2 + m_\pi^2}$ and $\omega = \Delta M - q^2/2M$ is the available energy for the emitted pion. The two terms in s_π ($= 2.34 \cdot 10^{-7}$) and p_π ($= 1.17 \cdot 10^{-7}$) represent the parity violating and parity conserving amplitudes, s_π corresponding to an s -wave pion and p_π to a p -wave pion, respectively. In the nucleus we obtain the decay width associated with the pion branch by replacing, in eq. (2), the imaginary part of the free pion propagator $\mathcal{D}_0$ with

$$\text{Im}\mathcal{D}(q, \omega) = \frac{Z_1(q)}{2\omega_1(q)} \delta(\omega - \omega_1(q)), \quad (3)$$

where $Z_1(q)$ reflects the pion content of this state⁹⁾. The knowledge of $\omega_1(q)$, together with energy conservation, fixes the corresponding pion momentum: the latter turns out to be close to the Fermi momentum p_F , for which Z_1 takes the value $0.6 \div 0.7$. But for this reduction and the modifications of the phase space factor induced by the change in q , the pion branch would act as a substitute for real pion emission, with a decay rate of similar magnitude.

However the decay width of the pion branch is not zero⁹⁾. Moreover even in the zero width approximation the Pauli blocking would still be effective. To enlighten this point let us recall the kinematical constraints for a Λ decay into a nucleon and a (real or virtual) pion (Fig. 1). We assume the Λ to be at rest. Denoting by ω and q the pion energy and momentum one has

$$\omega = \omega_m \equiv \Delta M + V_\Lambda - V_N - \frac{q^2}{2M}, \quad (4)$$

V_Λ and V_N being the potential energies of the Λ and the nucleon, respectively. In the following we will take $V_\Lambda - V_N = 20 \text{ MeV}$ ¹⁰⁾ (we shall also discuss the case $V_\Lambda - V_N = 10 \text{ MeV}$). Fig. 2 shows the intercept in the ω, q plane of the parabola represented by eq. (4) with the pion branch in the zero width approximation. It occurs at $q \simeq 1.09 \text{ fm}^{-1}$, larger than the one of the free decay, but still slightly below the Fermi momentum, thus preventing the decay into the pion branch to occur.

In contrast, when we introduce the finite width of the pion branch, which in the low energy region ($\omega \simeq m_\pi$) decays via 2p-2h emission¹¹⁾, the collective branch overlaps the parabola (4) also outside the Pauli blocked region, making possible the decay into this state. In this case the final state is a 3p-2h one, as illustrated in Fig. 3b.

We can infer the importance of this decay channel from a kinematically similar process, namely photoabsorption. On a free nucleon the photoabsorption cross

section starts at the pion production threshold, $\omega \simeq m_\pi$. In the nucleus the cross section extends below threshold since instead of a real pion a p - h pair with the same quantum numbers can be produced. This is the quasideuteron mechanism. Above $\omega \simeq m_\pi$ the real pion production channel in principle opens but, as in the Λ decay, it is largely blocked by the Pauli principle. Nevertheless the experimental data show that the photoabsorption cross section per nucleon rises after $\omega \simeq m_\pi$, rapidly reaching the value for a free proton (see for example ref[12]). This cannot be explained with the quasideuteron mechanism alone, which predicts a smooth frequency behaviour^{13,14)}. One is thus inclined to conclude that a new channel is opening. Indeed it was pointed out¹⁵⁾ that the modified pion energy-momentum relation, i.e. the occurrence of the pion branch, makes the Pauli blocking less effective. This means, as we discussed previously for the Λ decay, that the final state is a 3p-3h one. The absorption of the photon by three nucleons was first considered by Christillin¹⁶⁾. If we extrapolate smoothly the quasideuteron cross section above pion threshold, the photoabsorption cross section at $E_\gamma \simeq 200 \text{ MeV}$ seems to split into two components of similar magnitude, the quasideuteron one and the rest, which we link to 3N absorption and to the pion branch. Although the kinematics is not identical in photoabsorption and Λ decay, we believe that it is sufficiently similar to provide at least an indication for the Λ decay and we have thus been stimulated by this analogy.

In the following we evaluate both decay channels, the one leading to 2p-1h states, already investigated by several authors^{4-7,17)}, and the one leading to 3p-2h states. The decay of a Λ bound in a nucleus will be explored in the infinite nuclear matter framework. Detailed calculations have already been performed on the one-nucleon induced decay in finite nuclei^{5,6,18,19)} as well as in nuclear matter^{20,4,7,21)}. We do not wish to focus on these reactions, but rather to show that another decay channel is possible, the two-nucleon induced decay, $\Lambda + N + N \rightarrow N + N + N$, that its branching ratio may be large and that it enhances the emission of neutrons.

The width for the decay of a Λ at rest into a nucleon and a virtual pion, subsequently absorbed in the nuclear medium, is

$$\Gamma = -\frac{3}{\pi^2} \int_{k_F}^{q_{\max}} dq q^2 \left(s_\pi^2 + \frac{p_\pi^2}{m_\pi^2} q^2 \right) \text{Im}\mathcal{D}(q, \omega) \Big|_{\omega=\omega_m}, \quad (6)$$

where $q_{\max} = \sqrt{2M(\Delta M + V_\Lambda - V_N)}$ and we have assumed total Pauli blocking. The pion propagator in the medium, $\mathcal{D}$, is related to the pion self-energy $q^2\Pi$ by

$$\mathcal{D}(q, \omega) = \frac{1}{\omega^2 - q^2 - m_\pi^2 - q^2\Pi(q, \omega)}. \quad (7)$$

The virtual pion is absorbed mostly into 1p-1h or 2p-2h states. In the Λ decay an additional nucleon is emitted at the weak pion production vertex and therefore the final states are 2p-1h or 3p-2h ones.

Before discussing the weak pion production vertex, let us consider the absorption of the virtual pion. The π self-energy arising from 1p-1h excitations is rather well known and commonly written as:

$$q^2 \Pi_{1p-1h}(q, \omega) = \frac{q^2 \Pi^0(q, \omega)}{1 - g'(q) \Pi^0(q, \omega)} \quad (8)$$

where Π^0 contains both the free NN^{-1} and ΔN^{-1} propagator and $g'(q)$ is the short-range repulsive Landau-Migdal force. For the latter we shall use the q -dependent parametrization of Oset *et al.*^[9],

$$g'(q) = \Gamma_\pi^2(q, \omega) \frac{1}{3} \frac{q^2 + q_c^2}{q_c^2 + \mu_\pi^2 + q^2} + C_\rho \Gamma_\rho^2(q, \omega) \frac{2}{3} \frac{q^2 + q_c^2}{q_c^2 + \mu_\rho^2 + q^2}, \quad (9)$$

with $q_c = 600$ MeV, Γ_π and Γ_ρ are the usual dipole meson-nucleon form factors, with cutoff $\Lambda_\pi = 1$ GeV and $\Lambda_\rho = 2$ GeV, respectively.

The most delicate term is the pion absorption in the 2p-2h channel. For this we have used the information available from the transverse response in the deep inelastic (e, e') scattering, which also involves a spin-isospin coupling. In the region of the dip, between the 1p-1h and the Δ excitation, the experimental cross section for an energy transfer close to the pion mass has been interpreted by Alberico *et al.*^[13]. According to this calculation, part of the cross section is due to meson exchange effects expressed by the graphs of Fig. 4a, but these are absent in the case of pion absorption. The remaining and dominant part of the cross section, which is present both in pion and photon absorption, arises from the graphs displayed in Fig. 4b,c. For the corresponding 2p-2h polarization propagator, in the vicinity of $\omega \approx m_\pi$, the following parametrization has been suggested^[13]:

$$\text{Im} \Pi_{2p-2h}^* = -4\pi\rho^2 \text{Im} C_0, \quad (10)$$

where ρ is the nuclear density and $\text{Im} C_0 \simeq 0.18 m_\pi^{-6}$. This value for $\text{Im} C_0$, which accounts for the (e, e') scattering data has also been obtained in several theoretical evaluations^[11,22]. It is compatible as well with the mesic atom data, provided the real, dispersive part of C_0 is introduced with a value $\text{Re } C_0 \simeq 0.40 m_\pi^{-6}$ ^[23], which we have used here.

The above parametrization for $\text{Im} \Pi_{2p-2h}^*$ only holds for energies near the pion mass. In our calculation we shall see that this is the energy range of interest and

thus a more detailed evaluation of the 2p-2h term is not needed. The 1p-1h and the 2p-2h contributions are then inserted into the pion self-energy according to:

$$q^2 \Pi(q, \omega) = \frac{q^2 [\Pi^0(q, \omega) + 4\pi\rho^2 C_0]}{1 - g'(q) [\Pi^0(q, \omega) + 4\pi\rho^2 C_0]}. \quad (11)$$

Indeed in this work we want to be conservative in assessing the importance of the two-nucleon induced decay channel. Since the extrapolation of the 2p-2h absorptive contribution into the 1p-1h region is a delicate problem, we adopted the cautious attitude of suppressing the 2p-2h absorption in the 1p-1h region: we assume $\text{Im} \Pi_{2p-2h}^* \neq 0$ only when $\text{Im} \Pi_{1p-1h} = 0$. This restriction limits the pion momentum in the 2p-2h absorption to $q \leq 1.65$ fm⁻¹ (see Fig. 2) and makes the corresponding rate rather insensitive to the cutoff parameters. It also limits the energy range around the pion mass, which justifies our approximation for $\text{Im} \Pi_{2p-2h}^*$. This procedure obviously underestimates the effect of the 2p-2h contribution since some 2p-2h excitations are certainly present in the region of the 1p-1h ones. By inserting (11) into eq. (6) we will get correspondingly two separate contributions to the Λ decay width from the 1p-1h sector and the 2p-2h one, which intervene in different q -ranges.

Concerning the weak pion production amplitude, in the above expression (6) we have assumed that it is not affected by the medium. Here however the pion is off shell and its momentum can become quite large, enhancing the p -wave contribution, which represents only 13% of the rate in the free case. In order to limit its magnitude it is thus necessary to introduce a form factor at the weak pion production vertex. For this quantity we will use, in the absence of experimental information, the strong πNN form factor. Moreover the parity conserving p -wave term should be renormalized as it is the case for the strong p -wave πN vertex, an effect of the short range correlations between the Λ particle and the nucleons. This is achieved through the introduction of a Lorentz-Lorenz (LL) parameter g'_Λ at the weak production vertex. We utilize here the renormalization procedure of ref.[7] in which the RPA pion propagator $\mathcal{D}$ is firstly written in terms of the free one $\mathcal{D}_0$ and of the polarization propagator Π as

$$\mathcal{D}(q, \omega) = \mathcal{D}_0(q, \omega) + \mathcal{D}_0(q, \omega) \frac{q^2 \Pi(q, \omega)}{1 - \mathcal{D}_0(q, \omega) q^2 \Pi(q, \omega)} \mathcal{D}_0(q, \omega). \quad (12)$$

Once inserted in eq. (6), this expression allows us to write the Λ width as $\Gamma = \Gamma^{(*)} + \Gamma^{(p)}$, with

$$\Gamma^{(*)} = -\frac{3}{\pi^2} g_\pi^2 \int_{k_F}^{q_{\text{max}}} dq q^4 \mathcal{D}_0^2(q, \omega) \text{Im} \Pi_L(q, \omega) \Big|_{\omega=\omega_m} \quad (13a)$$

and

$$\Gamma^{(p)} = -\frac{3}{\pi^2} \frac{p_\pi^2}{m_p^2} \int_{k_F}^{q_{\max}} dq q^6 \bar{D}_0^2(q, \omega) \text{Im} \Pi_L(q, \omega) \Big|_{\omega=\omega_m} \quad (13b)$$

In the above Π_L is the spin-longitudinal polarization propagator,

$$\Pi_L(q, \omega) = \frac{\Pi^*(q, \omega)}{1 - V_L(q, \omega) \Pi^*(q, \omega)}, \quad (14)$$

V_L being the full ph interaction in the spin-longitudinal channel $|V_\pi + g'(q)|$ and Π^* the irreducible polarization propagator ($\Pi^0 + \Pi_{2p-2h}^*$).

The LL correction amounts then to replacing the free pion exchange (which is proportional to $q^2 \bar{D}_0$) in eqs. (13) with a correlated pion exchange, according to the prescription of ref.[7]. This in turn gives rise to a spin-transverse component at the weak vertex, so that the full width is now $\Gamma = \Gamma^{(*)} + \Gamma^{(p,L)} + \Gamma^{(p,T)}$, with

$$\Gamma^{(*)} = -\frac{3}{\pi^2} \frac{p_\pi^2}{m_\pi^2} \int_{k_F}^{q_{\max}} dq [V^{(*)}(q, \omega)]^2 \text{Im} \Pi_L(q, \omega) \Big|_{\omega=\omega_m} \quad (15a)$$

$$\Gamma^{(p,\sigma)} = -\frac{3}{\pi^2} \frac{p_\pi^2}{m_\pi^2} \int_{k_F}^{q_{\max}} dq q^2 [V^{(p,\sigma)}(q, \omega)]^2 \text{Im} \Pi_\sigma(q, \omega) \Big|_{\omega=\omega_m} \quad (15b)$$

In eq. (15b) $\sigma = L$ (longitudinal) or T (transverse), Π_T being the spin-transverse polarization propagator. Moreover

$$V^{(*)}(q, \omega) = q^2 \bar{D}_0(q, \omega) - q^2 \bar{\bar{D}}_0(q, \omega) \quad (16a)$$

$$V^{(p,L)}(q, \omega) = g'_\Lambda + q^2 \bar{D}_0(q, \omega) - \frac{2}{3} q^2 \bar{\bar{D}}_0(q, \omega) \quad (16b)$$

$$V^{(p,T)}(q, \omega) = g'_\Lambda + \frac{1}{3} q^2 \bar{\bar{D}}_0(q, \omega), \quad (16c)$$

where g'_Λ is taken as a free (positive) parameter and $\bar{\bar{D}}_0(q, \omega)$ is the free pion propagator with $q^2 \rightarrow q^2 + q_c^2$, as in eq. (9) the momentum q_c sets the range of the correlations. The form factors are meant to be included at the various vertices, although not explicitly written.

We now turn to the discussion of the results. We have performed the calculation using an average Fermi momentum $k_F = 1.2 \text{ fm}^{-1}$. We first consider the one-nucleon induced process, which we call for short 1p-1h decay width. In Table I the corresponding ratio R_1 between the calculated width and the free one is reported, for several values of g'_Λ . For $g'_\Lambda = 0$ only pion exchange is considered and the 1p-1h states have therefore to be pion-like. Instead the introduction of g'_Λ couples the parity conserving weak vertex also to rho-like excited states (p-wave transverse component). This last contribution, which we denote by $R_1^{(p,T)}$,

is reported separately in the Table. As expected it increases with the value of g'_Λ . However this behaviour is somehow artificial since a realistic treatment should incorporate explicitly the weak ρ -meson production⁶⁾, which should suppress the overall transverse component. Note that the pion-like p-wave term (denoted by $R_1^{(p,L)}$) decreases when g'_Λ increases, owing to the well known suppression effect of the LL correction. As a result our overall parity conserving decay width is rather insensitive to the g'_Λ value. Obviously the parity violating component ($R_1^{(*)}$) is not affected by this parameter, which is introduced in the parity conserving vertex only.

The RPA dressing of the 1p-1h states only slightly changes the rate R_1 with respect to the independent particle picture, as shown in Table I. As we shall see below, this is at variance with the two-nucleon induced process, which is instead quite affected by RPA correlations owing to the presence of the collective pion branch. We should also mention the sensitivity of R_1 to the weak pion form factor; for example a 20% increase of Λ_π induces a 20% increase in R_1 . We thus see how the one-nucleon induced rate is affected by uncertainties inherent to the problem.

Turning now to the two-nucleon induced process, we also report in Table I the corresponding ratio to the free Λ width, denoted by R_2 . Again we give, separately, the parity violating term and the two (pion-like and rho-like) parity conserving contributions. In contrast to the previous channel, the decay rate is now dominated by the parity violating process. Note the large enhancement introduced by RPA correlations. It is even more pronounced if one partially releases the Pauli blocking by replacing the Fermi gas momentum distribution $\theta(k_F - k)$ with a more realistic one, such as the one of ref.[24]. In this case not only the low energy wing of the pion branch contributes, but also the peak region, which intersects the parabola (4) at $q < k_F$. As a result the ratio R_2 increases by $\sim 60\%$.

In the same way the sensitivity to the energy release $\Delta M + V_\Lambda - V_N$ is large. For example by reducing its value by 10 MeV (186 MeV instead of 196 MeV) the parabola (4) moves down reducing R_2 by 35%. An additional sensitivity is the one linked to the Λ momentum. Here the Λ was assumed at rest, but if we introduce some finite momentum, e.g. $k_\Lambda \simeq 50 \text{ MeV}/c$, the pion branch is favoured and the 2p-2h decay width is increased by $35 \div 40\%$.

In the last line of Table I the total decay width $R_{\text{tot}} = R_1 + R_2$ is reported. In spite of the above mentioned large uncertainties affecting the partial widths, the relevance of the two-nucleon induced channel clearly emerges.

As a final remark, we like to remind that the presence of this channel, which

has been neglected till now, affects the emission of neutrons. Indeed the absorption of pions occurs on correlated neutron-proton pairs. The two-nucleon process is then $Apn \rightarrow pnn$. Twice as many neutrons as protons are emitted in the two-nucleon induced decay, while the one-nucleon emission process should be predominantly $Ap \rightarrow pn$, since the channel $An \rightarrow nn$ is expected to be strongly suppressed^[5,6]. Experimentally the ratio of neutron to proton emission is larger than expected from the one-nucleon induced process: our suggestion is that the two-nucleon induced process cannot be ignored and could eventually improve the agreement with the experimental data.

We wish to thank Dr. M. Rey-Campagnolle and Dr. J. Delorme for discussions and information.

	low.ord.	RPA	RPA	RPA	RPA	RPA	RPA
g'_Λ	0	0	0.1	0.2	0.3	0.4	0.5
$R_1^{(*)}$	0.30	0.36	0.36	0.36	0.36	0.36	0.36
$R_1^{(p,L)}$	0.83	1.02	0.69	0.42	0.22	0.091	0.024
$R_1^{(p,T)}$	0.011	0.008	0.012	0.096	0.26	0.51	0.83
R_1	1.14	1.39	1.06	0.88	0.84	0.96	1.22
$R_2^{(*)}$	0.11	0.40	0.40	0.40	0.40	0.40	0.40
$R_2^{(p,L)}$	0.12	0.40	0.31	0.24	0.18	0.12	0.079
$R_2^{(p,T)}$	0.0003	0.0002	0.0009	0.005	0.013	0.025	0.040
R_2	0.23	0.79	0.71	0.64	0.59	0.54	0.52
$R = R_1 + R_2$	1.37	2.18	1.77	1.52	1.43	1.50	1.74

Table 1 Various contributions to the ratio R between the Λ decay widths in nuclear matter and in the vacuum for different values of g'_Λ ; in the second and the third columns the lowest order and the RPA results are compared for $g'_\Lambda = 0$; for further details see the text.

References

- [1] See, for example, H. Bandō, T. Motoba and J. Žofka, to be published in Int. J. Mod. Phys.A.
- [2] M. Primakoff, Nuovo Cimento **3** (1956) 1394.
- [3] R. M. Dalitz, Phys. Rev. **112** (1958) 605; R. M. Dalitz and L. Liu, Phys. Rev. **116** (1959) 1312.
- [4] B. M. J. Mc Kellar and B. F. Gibson, Phys. Rev. **C30** (1984)322.
- [5] K. Tacheuchi, H. Takaki and H. Bandō, Progr. Theor. Phys. **73** (1985) 841.
- [6] J. Dubach, Nucl. Phys. **A450** (1986) 71c.
- [7] E. Oset and L. L. Salcedo, Nucl. Phys. **A443** (1985) 704; Nucl. Phys. **A450** (1986) 371c.
- [8] G. Chanfray, Ann. de Phys. **15** (1990) 151.
- [9] E. Oset, H. Toki and W. Weise, Phys. Rep. **83** (1982) 281.
- [10] D. J. Miller, C. B. Dover and A. Gal, Phys. Rev. **C38** (1988) 2700.
- [11] W. M. Alberico, M. Ericson and A. Molinari, Phys. Lett. **B136** (1984) 307.
- [12] T. E. O. Ericson and W. Weise, *Pion and Nuclei* (Clarendon Press, Oxford, 1988), p.237.
- [13] W. M. Alberico, M. Ericson and A. Molinari, Ann. of Phys. **154** (1984) 356.
- [14] E. Oset and W. Weise, Nucl. Phys. **A319** (1979) 477; **A329** (1979) 365; E. Oset and L. L. Salcedo, Nucl. Phys. **A468** (1987) 631.
- [15] W. M. Mc Donald, E. T. Dresler and J. S. O'Connell, Phys. Rev. **C19** (1979) 445.
- [16] P. Christillin, J. Phys. **G10** (1984) L65.
- [17] J. Cohen, Charlottesville Univ. prepr. (1990) and references therein.

- [18] H. Bandō, *Progr. Theor. Phys. Suppl.* **81** (1985) 181.
- [19] D. P. Heddle and L. S. Kisslinger, unpublished (1987).
- [20] J. B. Adams, *Phys. Lett.* **22** (1966) 463; *Phys. Rev.* **156** (1967) 1611.
- [21] G. Nardulli, *Phys. Rev.* **C38** (1988) 832.
- [22] J. Delorme, private communication.
- [23] L. Tauscher, private communication.
- [24] O. Benhar, A. Fabrocini and S. Fantoni, *Phys. Rev.* **C41** (1990) R24.

Figure Captions

- Fig. 1 Λ self-energy in the vacuum (a) and in the medium (b).
- Fig. 2 The intersection, in the (q, ω) plane, of the parabola of eq. (4) with the π h response region (dashed area), the free π h branch (dotted line) and the collective π h branch (dashed line).
- Fig. 3 Examples of Λ decay into $2p-1h$ (a) and $3p-2h$ (b) final states.
- Fig. 4 Examples of diagrams contributing to the transverse response in (e, e') scattering: (a) represents the MEC, (b) the Δ -isobar $2p-2h$ contribution and (c) the ground state $2p-2h$ correlations.

(a)

(b)

(a)

(b)

(c)

Fig. 4

(a)

(b)

Fig. 3