Index

THE ú1^{-},0ñ STATE IN ^{12}C REVISITED

M. Cristina A. Campos (1), P.von Neumann-Cosel (2), Paulo R. Pascholati (3), A.Richter (2)

(1) Instituto de Pesquisas Energéticas e Nucleares(IPEN/CNEN/SP), S.Paulo, Brazil

(2) Institut fuer Kernphysik, TU-Darmstadt, Darmstadt, Germany

(3) Instituto de Física (IFUSP), University of São Paulo, S.Paulo, Brazil

ABSTRACT

The $|J^{\pi}=1^{-},T=0\rangle$ state in ^{12}C, at E_x=10.84 MeV, has been investigated by inelastic electron scattering measurements at low values of momentum transfer (q<0.6 fm^{-1}). This state is electroexcited by an isospin forbidden (E1, ΔT=0) transition from the ground-state. At *low-q* values, the (E1, ΔT=0) transition occurs through isospin mixing, which has been investigated by exploring the longitudinal form factor sensitivity to small T=1 admixtures. Quantitative information on isospin mixing has been obtained by determining the Coulomb matrix element ($\langle H_C \rangle$). In present work, data analysis has been performed including the complete form factor data set measured at the *SENDAI* Laboratory [1]. As result, the momentum transfer range has been extended up to q $\cong$1.8 fm^{-1}. This procedure considerably improved the consistency of both data analysis and derived results, relative to the previously published work [2].

Keywords: (e,e') measurement, low-q form factors, isospin mixing in ^{12}C.

I. INTRODUCTION

It is well known [1,3-8], that E1 isoscalar transitions between T=0 states are forbidden, to first order, by the isospin selection rule in self-conjugate nuclei (N=Z). Nevertheless, E1, ΔT=0 transitions can occur under conditions for which the isospin selection rule is no longer expected to hold: (i) through deviations of the long-wavelength limit, or, (ii) in the presence of isospin mixing. Despite of being hindered in comparison to the isospin allowed ones, these transitions are fairly fast in some self-conjugate nuclei (^{16}O [4], ^{40}Ca [5], ^{32}S and ^{36}Ar [in ref.5]), with transition strengths comparable to those observed for the allowed ones.

For inelastic electron scattering at *low-q* values, the E1, ΔT=0 transitions proceed through an isospin mixing mechanism, since condition (i) is fulfilled. In this case, isospin mixing is evidenced by an isovector (T=1) contribution to the form factor. It has been shown for ^{16}O [4] and ^{40}Ca [5] that the T=1 term interferes destructively with the dominant isoescalar (T=0) one, resulting in a minimum of the form factor. Therefore, the form factor sensitivity to a T=1 component allows the investigation of isospin admixtures through (*e,e'*) measurements at *low-q* values.

In the present work, the broad state ($J^{\pi}=1^{-}$;T=0) in ^{12}C, at E_x=10.84 MeV, has been investigated by inelastic electron scattering measurements at low-q (q<0.6 fm^{-1}). Through a proper data analysis, which takes into account the isospin mixing, the reduced transition probability, B(E1), as well as related quantities - $\Gamma_{\gamma 0}$ (ground-state radiative width) and τ (mean lifetime) - have been extracted. Furthermore, isospin mixing has been investigated and the isospin symmetry breaking potential, given by the Coulomb matrix element $\langle H_C \rangle$, has been derived from experimental data. To best of our knowledge, for the first time such results have been determined for the $|J^{\pi}=1^-, T=0\rangle$ state of ^{12}C.

In section (2) of this paper, a brief description of the experimental procedure and data reduction is given. In section (3), the data analysis procedure is discussed and extracted results are presented. Finally, in section (4), a summary and the conclusions of present work are presented.

II. EXPERIMENT AND DATA REDUCTION

The present measurements have been performed at the superconducting continuous wave electron accelerator S-DALINAC, from the Institut für Kernphysik, TU-Darmstadt, Germany. Inelastically scattered electrons have been detected with the large solid angle QCLAM spectrometer. Both are described in detail in [9] and [10], respectively. The data acquisition and analysis system *GOOSY* [11], running on a μVax3600 with a Starbus CAMAC interface, has been used.

Data have been taken at an incident electron energy E_i=60 MeV and scattering angles θ = 117°, 135° and 154°. Under these conditions the corresponding momentum transfers are [12],: q= 0.47, 0.50 and 0.54 fm^{-1}, respectively. For θ = 117°, transmission geometry (target normal bisecting the scattering angle) has been used. At the other two angles, the target has been positioned under reflexion geometry (target bisecting the scattering angle). At the most backward angle, θ =154°, for which line broadening effects are more intense, an energy resolution (*FWHM* of the elastic line) $\Delta E \cong$ 120 keV has been achieved. Measurements have been performed with a thin natural carbon (ρx=40 mg/cm^2) target.

The excitation energy spectra have been fitted with program *FIT* [13], using the least-squares method. Asymmetric gaussian shapes, with a hyperbolic parametrization at the higher excitation energy side of the peak, to empirically account for the radiative tail, have been chosen to describe the lines. In addition, a (first-order) polinomial fit to the background has been simultaneously performed. Figure 1, shows the excitation energy spectrum for scattering angle θ=154°. The dashed lines shown in the figure represent the fitted curves, as described above.

To extract the cross section the area under the fitted lines have been corrected for radiative effects (Schwinger, bremsstrahlung and ionization). Inelastic cross sections have been determined relative to the elastic ones [12] and normalized to the calculated value.

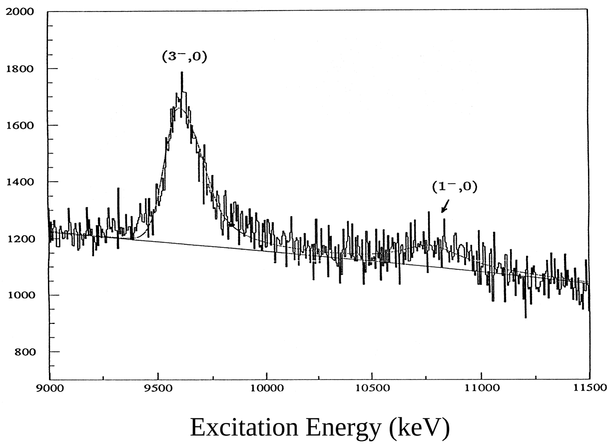

Figure 1. Excitation energy spectrum measured at θ=154°. Dashed lines represent the least-squares fitting.

The elastic cross section has been calculated in *DWBA* (distorted wave Born approximation) with the code *PHASHI* [13], which performs a phase-shift analysis. The *two-parameter Fermi distribution* (2pF) has been used in this calculation. Relevant parameters describing the charge distribution have been taken from [14].

III. DATA ANALYSIS AND RESULTS

In order to determine the longitudinal form factor, the transverse contribution to the experimental form factor has been subtracted according to Siegert's theorem, which relates the longitudinal and the transverse form factors by:

$$\left[F_{C\lambda}^{\;L}(q)\right]^2 = \left(\frac{\lambda}{\lambda+1}\right)\left(\frac{\hbar c q}{\hbar w}\right)^2 \left[F_{E\lambda}^{\;T}(q)\right]^2 \qquad (1)$$

To extrapolate the longitudinal form factor, $F_{C\lambda}^{L}(q)$, to the photon point, $k = E_x / \hbar c$, an analytical expression derived within the framework of the harmonic oscillator shell model [16,17] has been fitted to the data. As shown in (2), the parametrization of this expression included the contribution of a T=1 component, to account for the isospin mixing.

$$\left[F_L^{exp}(q)\right] = \left|\left(A_0\, qb + A_1\, q^3 b^3 + A_2\, q^5 b^5\right) * \exp\left(-\frac{b^2 q^2}{4}\right)\right| \qquad (2)$$

The least-squares fitted coefficients, treating all parameters in (2) as fitting variables, are: A_o= (-0.0022 ± 0.0020); A_1= (0.014 ± 0.002); A_2=(-0.0076 ± 0.0012) 10^{-1}; and finally, for the oscillator parameter, b = (1.76 ± 0.13) fm. The present fit resulted in a chi$^2/\nu \cong$ 0.73, where ν=15 degrees of freedom, representing a confidence level CL≅76%. The experimental results are shown in Figure 2.

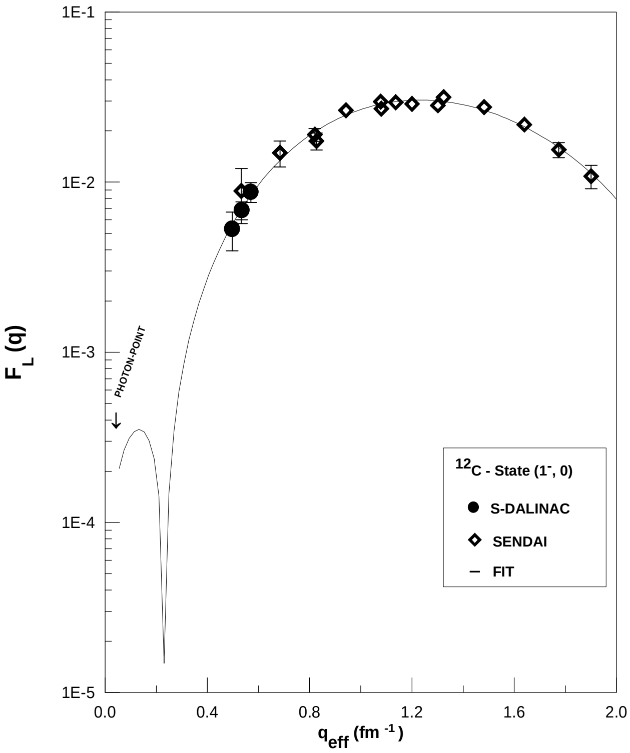

Figure 2. Longitudinal form factor, $F_L(q)$, as a function of the effective momentum transfer, q_{eff}. Results from present work are represented by (•) S-DALINAC. Solid line represents the form factor fitted by expression (2). Extrapolation to the photon point is indicated in the figure.

By extrapolating the fitted form factor to the photon point, the reduced transition probability has been determined to be: $B(E1) = (3.7 \pm 2.0)\ 10^{-4}\ e^2fm^2$. From this result, the radiative ground-state width and the mean lifetime have been obtained: $\Gamma_{\gamma o} = (0.16 \pm 0.08)$ eV and $\tau = (3.98 \pm 2.10)\ 10^{-15}$ s, respectively.

To calculate the Coulomb matrix element a simple two-state mixing model [18-21], has been used. By assuming that the mixing occurs with the closest T=1 level, at E_X = 17.23 MeV, wave functions for the T=0 and T=1 levels, including the mixing amplitudes α and β, can be written as:

$$\left| 1^- ; 10.84\ \text{MeV} \right\rangle = \alpha \left| T = 0 \right\rangle + \beta \left| T = 1 \right\rangle \qquad (3)$$

and,

$$\left| 1^- ; 17.23\ \text{MeV} \right\rangle = \alpha \left| T = 1 \right\rangle - \beta \left| T = 0 \right\rangle \qquad (4)$$

At this point, examining expression (2), an approximation can be made: for low-q values, the last term in ‘q^5b^5‘ brings a small contribution and will be neglected. Thus, the isoescalar part of the form factor is accounted for by ‘$A_1q^3b^3$ ‘. Now, the form factors for both states can be written as:

$$\left| F_L(10.84) \right| = \left| \alpha.\ M_{T=0} \, .\, q^3 + \beta \, .M_{T=1} \, .\, q \right| \quad (5)$$

and,

$$\left| F_L(17.23) \right| = \left| \alpha \, .M_{T=1} \, .\, q - \beta .\ M_{T=0} \, .q^3 \right| \quad (6)$$

In expressions (5) and (6), $\alpha^2 + \beta^2 = 1$. Using (5) and (6), plus the relation:

$$\left\langle H_C \right\rangle = \alpha\, \beta \left| E_x^{T=1} - E_x^{T=0} \right|, \qquad (7)$$

the Coulomb matrix element has been determined to be: $<H_C>$= (750± 325) keV. Such a magnitude for $<H_C>$ is too high in comparison to the well known systematics for the M1 isospin doublet in ^{12}C.

Therefore, the occurrence of isospin mixing with the largest E1GR fragment, at E_x=22.6 MeV has also been investigated. Using the same procedure as above resulted in: $<H_C>$= (350± 125) keV, in good agreement with the observed systematics.

IV. SUMMARY AND CONCLUSIONS

The broad state $\left| J^\pi = 1^-, T = 0 \right\rangle$ in ^{12}C, at E_x=10.84 MeV, has been investigated by inelastic electron scattering measurements at low-q values (q<0.6 fm^{-1}). Through a proper data analysis, which takes into account the isospin mixing, the reduced transition probability, B(E1), as well as related quantities - $\Gamma_{\gamma o}$ (ground-state radiative width) and τ (mean lifetime) - have been determined for the first time. Furthermore, isospin mixing has been investigated and the isospin symmetry breaking potential, given by the Coulomb matrix element $<H_C>$, has been derived from experimental data.

The experimental data analysis resulted in a T=1 contribution to the longitudinal form factor, which interferes destructively with the predominant T=0 part, accounting for the minimum at low-q values. It should be pointed out, that the good agreement between the fitted oscillator parameter and values quoted in literature [15,22], demonstrates the consistency of experimental data, as well as of the analysis procedure developed in this work.

Regarding the isospin mixing investigation, the results obtained for the Coulomb matrix element indicate an admixture with the E1 Giant Resonance levels.

ACKNOWLEDGEMENTS

One of the authors (M.C.A.Campos) wishes to acknowledge the financial support by CNPq (Brazil).

REFERENCES

[1] TORIZUKA, Y.; OYAMADA, M.; NAKAHARA, K.; SUGIYAMA, K.; KOJIMA, Y.; TERASAWA, T.; ITOH, K.; YAMAGUCHI, A.; KIMURA, M.; **Electroexcitation of the 10.8 MeV (1^-; T=0) Level of ^{12}C and the 7.12 MeV (1^-,T=0) Level of ^{16}O**; *Phys. Rev. Lett., v. 22, n. 11, p. 544-546,* (1969).

[2] CAMPOS, M.C.A.; VON NEUMANN-COSEL, P.; RICHTER, A.; SCHRIEDER, G.; SPAMER, E.; BROWN, B.A.; PETERSON, R.J.; **Isospin Mixing in the Electroexcitation of the E_x =10.84 Mev; J^p,T=1^-,0, State in ^{12}C at Low Momentum Transfers**; *Phys. Lett. B 349, 433, (1995)*

[3] J.M. EISENBERG and W.GREINER, **Excitation Mechanisms of the Nucleus; *North-Holland*** (1976)

[4] MISKA, H.; GRÄF, H.D.; RICHTER, A.; SCHÜLL, D.; SPAMER, E.; TITZE, O.; **Isospin-Forbidden Electroexcitation of the 1^-, T=0 State at 7.12 MeV in ^{16}O at Low Momentum Transfers**; *Phys. Lett., v. B59, n. 5, p. 441-443,* (1975).

[5] GRÄF, H.D.; HEIL, V.; RICHTER, A.; SPAMER, E.; STOCK, W.; TITZE, O.; **Isospin Forbidden Electroexcitation of the 1^-, T=0 State at 6.95 MeV in ^{40}Ca, Continuum Shell-Model and Effective Charge of the Convection Current**; *Phys. Lett., v. B72, n. 2, p. 179-182,* (1977).

[6] HEISENBERG, **J.; Inelastic Electron Scattering from Nuclei**; *Ann.Rev.Nucl.Part.Sci., v. 33, p. 569-609,* (1983).

[7] ARIMA, A.; MANAKOS, P.; **The Isospin Forbidden $1^- \rightarrow 0^+$ transition in ^{16}O;** *Phys.Lett. B 56, 301, (1975)*

[8] HEIL, V.; STOCK, W.; **The Isospin Forbidden 7.12 MeV Transition in ^{16}O;** *Phys.Lett. B 65, 412,* (1976)

[9] AUERHAMMER, J.; GENZ, H.; GRÄF, H.D.; HAHN, R.; STASCHECK, P.-H.; LÜTTGE, C.; NETHING, U.; RÜHL, K.; RICHTER, A.; RIETDORF, T.; SCHARDT, P.; SPAMER, E.; THOMAS, F.; TITZE, O.; TÖPPER, J.; WEISE, H.; **The S-DALINAC Facility: Experimental Experience from the Accelerator and the Experimental Installations;** In: ***Proc. International Nuclear Physics Conference***, *Wiesbaden (26/06-01/08),* (1992).

[10] HUMMEL, K.D.; **Entwicklung, Aufbau und Inbetriebnahme eines Vieldrahtdriftkammer-Detektorsystems für das QCLAM-Spektrometer am supraleitenden Elektronenbeschleuniger SDALINAC; *Dissertation, Institut für Kernphysik***, *Technische Hochschule Darmstadt,* (1992).

[11] **Program GOOSY**; *Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany.*

[12] CAMPOS, M.C.A.; **Doctorate Thesis**, *Instituto de Pesquisas Energéticas e Nucleares, São Paulo, Brazil,* (2002)

[13] STRAUCH, S.; **Entwicklung eines interaktiven Auswerteprogramms für Elektronenstreumessungen**; ***Diplomarbeit, Institut für Kernphysik***, *Technische Hochschule Darmstadt,* (1993).

[14] BAEHR, C.; **Diplomarbeit**, *Technische Hochschule Darmstadt* (1996)

[15] H.VRIES, et al.; *At. Data Nucl. Data Tables 36, 495* (1987)

[16] DONNELLY, T.W.; WALECKA, J.D.; **Electron Scattering and Nuclear Structure;** *Ann.Rev.Nucl.Sci. 25, p.329-,* (1975)

[17] MILLENER, D.J.; SOBER, D.I.; CRANELL, H.; O'BRIEN, J.T:; FAGG, L.W.; KOWALSKI, S.; WILLIAMSON, C.F.; LAPIKÁS, L.; **Inelastic Electron Scattering from ^{13}C**.; Phys.Rev.C, v.39, n.1, p. 14-46,

[18] ADELBERGER, E.G.; MARRS, R.E., SNOVER, K.A., BUSSOLETTI, J.E.;**Radiative Transitions and Isospin Mixing in *^{12}C***.; *Phys.Rev.C***,** v.15-2**,** *p.484-497*, (1977).

[19] J.B.FLANZ, R.S.HICKS, R.A.LINDGREN, G.A.PETERSON, J.DUBACH; **Electron Scattering, Isospin Mixing, and the Structure of the 12.71- and 15.11 MeV Levels in ^{12}C**; *Phys.Rev.Lett., v.43, n.26, p.1922-1925,* (1979).

[20] F.E.CECIL, L.W.FAGG, W.L:BENDEL, E.C:JONES; **Measurement of the Radiative Width of the 12.71 MeV level in *^{12}C***; *Phys.Rev.C, v.9, n.2, p.798-799,* (1974).

[21] HARNEY, H.L; *Proc. XVth Winter School, 341, Poland,* (Feb. 1977)

[22] ENDT, P.M; *At. Data Nucl. Data Tables, v.55, p.171,* (1993).