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TRANSIENT FIELD g-FACTOR MEASUREMENT OF THE FIRST 4^+ STATES IN ^{22}Ne

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ABSTRACT

Precessions of the first 2^+ and 4^+ states in ^{22}Ne have been measured employing the transient field method. The g-factor of the 4^+ state has been deduced to be g = 0.55 (14) using the known value of the 2^+ as normalization. The obtained result agrees with the shell model prediction. The value of the magnetic transient field for Ne in Fe at $v/v_0 \sim 1.5$ points to a weak dependence on the velocity up to v/v_0 about 5.

[NUCLEAR REACTIONS $^{19}F(\alpha, p)^{22}Ne$, E = 8.05 MeV and 8.97 MeV; measured $p\gamma(\theta, B)$ in thin polarized Fe; deduced $g(4^+)$ and transient field.]

1. - INTRODUCTION

As has been recently reviewed[1] the strong magnetic transient field acting at swift ions in Fe provides a unique tool for the measurement of magnetic moments of short lived nuclear states ($\tau \sim 0.1$ ps).

The g-factor of short lived states in s-d nuclei other than the first excited one have only been measured in a few cases[2, 3]. Such measurements can then provide a severe test of computed nuclear wave functions.

The measurement of the first 4^+ state in ^{20}Ne[3] excited great interest because a g-factor of -0.01(14) was measured which is inconsistent with the value g = 0.50(4) expected for self coniugate nuclei. This discrepancy has ingenerated some doubts on the applicability of the transient field method for short lifetimes.

We have been concerned with the 3357 keV 4^+ state in ^{22}Ne (τ = 324(6) fs) with the twofold aim to measure the g-factor and check the reliability of the method.

Since the value of the transient field at present is described only fenomenologically, in order to get accurate g-factor determination it is necessary to calibrate the transient field using known g-factors. The g-factor has therefore been measured relative to that of the 2^+ at 1275 keV. The scheme of the low lying levels in ^{22}Ne is shown in Fig. 1.

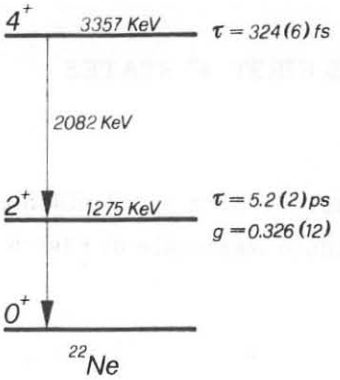

Fig. 1 - Investigated part of the ^{22}Ne level scheme.

A thin magnetic iron foil was used in order to allow the ^{22}Ne ions to traverse it without stopping. In such a way (differential method) one can derive an accurate g-factor by easily comparing the angular precessions.

Another interesting information we have deduced is the value of the transient field for Ne in Fe at velocity of about $2 v_o$ (with $v_o = c/137$) since the data reported in the literature were obtained usin thick iron backing (integral method) and could therefore be affected by the static field perturbation[5].

2. - EXPERIMENTAL PROCEDURE

The Implantation Perturbed Angular Correlation (IMPAC) technique with the transient magnetic field is described in a review paper[1]. Therefore only details pertaining to the present experiment are discussed.

The yrast 2^+ and 4^+ states were populated in the $^{19}F(\alpha,p)^{22}Ne$ reaction. A doubly charged helium beam of about 50 nA intensity was obtained from the 7 MV Van de Graaff accelerator of the Laboratori Nazionali di Legnaro (LNL). The 1275 keV $2^+ \rightarrow 0^+$ and 2082 keV $4^+ \rightarrow 2^+$ gamma rays were detected by four 10.2 cm x 10.2 cm NaI scintillators in coincidence with backscattered protons. The NaI detectors were located on a turnable platform and positioned at 16 cm from the target at angles 70 and 110 degrees. Protons were detected by a 300 μm thick annular detector subtending angles between 173 and 155 degrees respect to the beam direction. The detector was shielded with a 100 μm thick mylar foil in order to stop backscattered alfa particles.

A schematic picture of the experimental set-up is shown in Fig. 2.

The target consisted of a 120 $\mu g/cm^2$ LiF layer evaporated on 0.7 μm thick com-

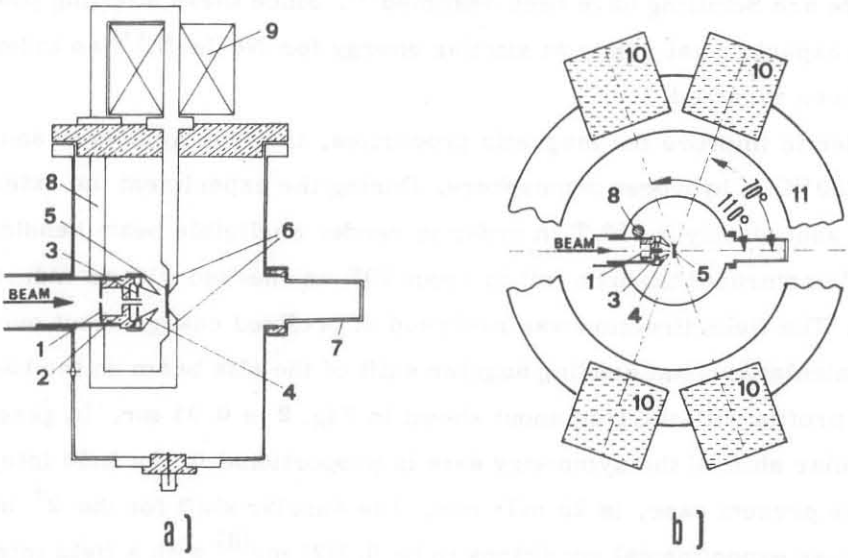

Fig. 2 - a) Scattering chamber ; b) Horizontal section of the experimental set-up. 1 - 2 mm diaphragm ; 1 - insulating detector holder ; 3 - annular detector ; 4 - soft iron snout ; 5 - sandwich target ; 6 - pole tips ; 7 - Faraday cup ; 8 - ARMCO yoke ; 9 - coil ; 10 - 10.2 cm x 10.2 cm NaI detectors ; 11 - turnable platform sustaining the NaI detectors.

mercial iron foil (Goodfellow, 99.8% purity), which was backed with a 1 μm of evaporated gold. The thickness and the homogeneity were checked with an Am alfa source.

The 2^+ and 4^+ states were populated at the bombarding energies of 8.05 MeV and 8.97 MeV respectively which correspond to the most suitable resonances. In order to select these resonances the yield of the $^{19}F(\alpha,p)$ reaction was measured in the energy range 7-11 MeV (see Fig. 3). Among the strongest resonances those have been chosen which give the biggest logarithmic derivative measured as described in the following. The detector angles of 70^o and 110^o were chosen as a reasonable compromise on a theoretical basis.

The recoil velocity of the ^{22}Ne nuclei in both the 2^+ and 4^+ measurements was 2.3 v_o. The average entrance and exit velocity in iron were 2.0 v_o and 1.1 v_o respectively. In the present work the interpolated stopping power

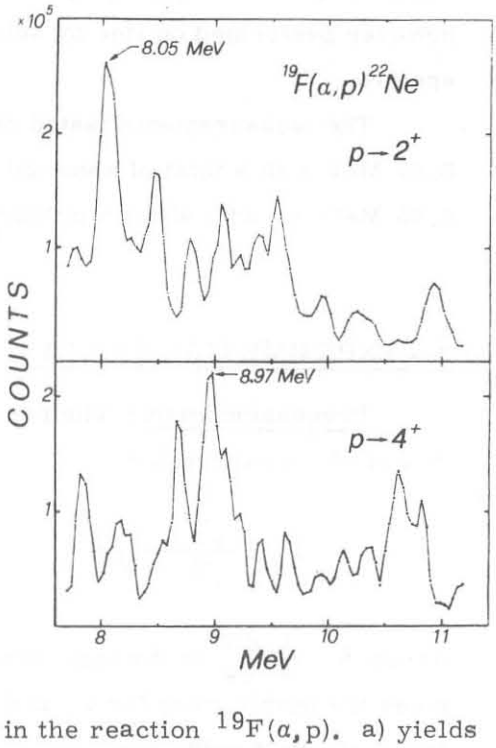

Fig. 3 - Yield of backscattered protons in the reaction $^{19}F(\alpha,p)$. a) yields for the level at 1275 keV ; b) yields for the level at 3357 keV.

of Northcliffe and Schilling have been assumed[6]. Since these stopping powers well reproduce the experimental points at similar energy for Ne in Ni[7] an indeterminancy of 10% has been assumed.

In order to improve the magnetic properties, the iron foils were annealed for half an hour at 700 °C in hydrogen atmosphere. During the experiment the external magnetic field was kept at only 0.012 T in order to render negligible beam bending effects. The external field saturated the iron foil to about 90% as checked with an induction coil magnetometer. The field direction was reversed at prefixed charge about every 3 minutes.

The calculated beam bending angular shift of the alfa beam on the basis of the magnetic field profile with the iron snout shown in Fig. 2 is 0.05 mr. In general the beam bending angular shift of the symmetry axis is proportional to the field integral $\int B \cdot ds$ which, in the present case, is 25 mT· mm. The angular shift for the 2^+ has been measured in similar experimental conditions to be 0.2(2) mr[8] with a field integral of 110 mT· mm. Therefore a scaling of at least a factor four is expected which gives a limit of 0.05 mr in the present case. Moreover several measurements in light nuclei reviewed in Refs. (8) and (10) agree with this limit.

A fresh target was replaced about every day in order to avoid effects due to radiation damage.

The electronic set-up consisted of four fast-slow coincidence branches. The data were taken with the SADIC[9] acquisition system of the LNL. The coincidence events were dumped on magnetic tape for the off-beam analysis. A preliminary analysis was however performed on line by selection of proper windows on the time and particle spectra.

The measurements lasted one week of effective time: four days for the run at 8.97 MeV with a total of about 20 million useful coincidences and three days for the 8.05 MeV run with about 5 million events.

3. - EXPERIMENTAL RESULTS

Precession angle: The precession angle of the investigated states is deduced by means of the expression

$$\Delta\theta = \frac{\sqrt{r} - 1}{\sqrt{r} + 1} \Big/ S \; ; \qquad r = \frac{N_i\uparrow}{N_i\downarrow} \Big/ \frac{N_j\uparrow}{N_j\downarrow} \qquad (1)$$

where $S = \frac{1}{W}\frac{dW}{d\theta}$ is the logarithmic derivative of the angular correlation while r denotes the double ratio for a couple of contigous detectors i, j. The measured quantity is the effect $\varepsilon = \Delta\theta \cdot S$.

The reported formula gives zero for the two pairs of opposite detectors and is used as a consistency test for the data.

The logarithmic derivative was measured by rotating the platform supporting the detectors by ± 1.5 degrees. The angular rotation has been measured with a precision of 0.01% by means of a telescope fixed to the platform. For such a rotation the formula is precise within 1% assuming A2 and A4 coefficients characteristic for our transitions.

The analysis of the collected tapes was done automatically analyzing each cycle field-up field-down and subtracting the background due to chance coincidences whose contribution however was lower than 1%. Fig. 4 shows examples of coincidence spectra.

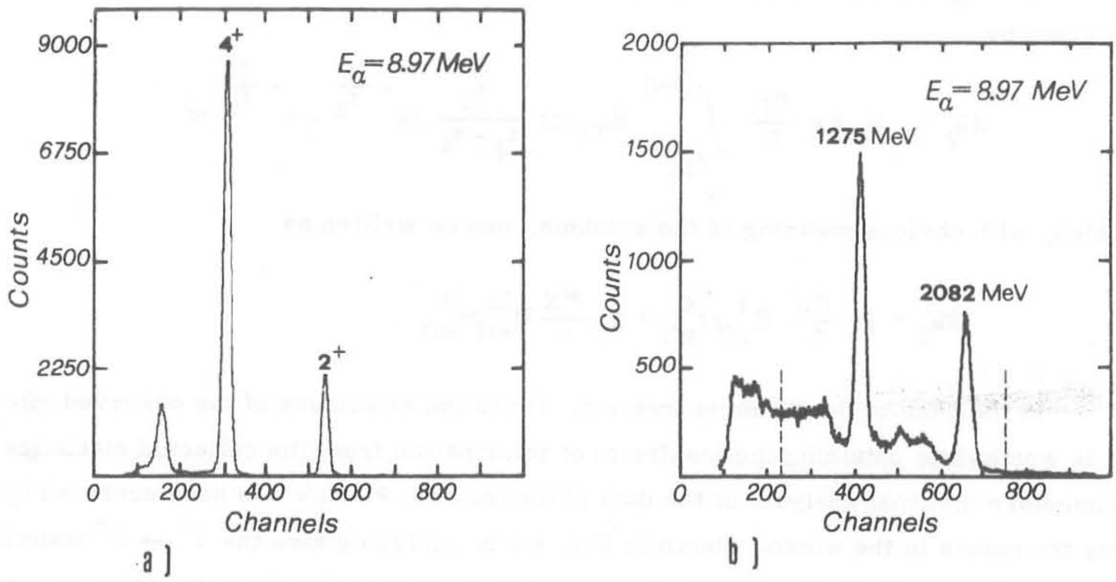

Fig. 4 - Coincidence spectra at E_α = 8.97 MeV. a) protons ; b) gammas. The dashed lines in the gamma spectrum delimit the region used to extract the effect.

The g-factor deduction: The precession angle is connected with the transient field by the formula

$$\Delta\Theta = g \, \frac{\mu_N}{\hbar} \int_{t_{in}}^{t_{out}} B_{TF}(t) \, e^{-\frac{t}{\tau}} \, dt \qquad (2)$$

where τ is the lifetime of the decaying level while t_{in} and t_{out} are the entrance and exit times in the iron. It is useful[10] to define an effective time t_{eff} such as

$$t_{eff} = \int_{t_{in}}^{t_{out}} e^{-\frac{t}{\tau}} \, dt \qquad (3)$$

which is the interaction time if the transient field in (2) is assumed to be constant during the transit of the recoil ion in the iron. In a very general way one can then write

$$\Delta\theta = g \frac{\mu_N}{\hbar} B_{eff}\, t_{eff} \tag{4}$$

with

$$B_{eff} = \frac{1}{t_{eff}} \int_{t_{in}}^{t_{out}} B_{TF}(t)\, e^{-\frac{t}{\tau}}\, dt \tag{5}$$

B_{eff} depends only weakly on the lifetime of the state.

The angular precession of the gamma-rays from the 2^+ populated via the 4^+ state is given by

$$\Delta\theta_2^i = \theta_4 + g \frac{\mu_N}{\hbar} \int_{t_{in}}^{t_{out}} B_{TF}(t) \frac{\tau_2}{\tau_2 - \tau_4} \left(e^{-\frac{t}{\tau_2}} - e^{-\frac{t}{\tau_4}}\right) dt \tag{6}$$

which, with obvious meaning of the symbols, can be written as

$$\Delta\theta_2^i = g_4 \frac{\mu_N}{\hbar} B^4_{eff} \cdot t^4_{eff} + g_2 \frac{\mu_N}{h} B^{2i}_{eff} \cdot t^{2i}_{eff} \;. \tag{7}$$

In the case of the 4^+ measurement, due to the smallness of the observed effects, it is worthwhile obtaining the maximum of information from the collected statistics. Therefore the final analysis of the data collected at 8.97 MeV has been achieved by taking the counts in the window shown in Fig. 4 i. e. including also the $2^+ \rightarrow 0^+$ transition. In accordance with (7) the 1275 keV line is mainly affected by the precession accumulated by the recoil nucleus during its stay in the preceding 4^+ state.

As a check of possible systematic errors in Fig. 5 the effect for the 8/97 MeV measurement is displayed as function of measure time in runs of about 2 hours.

The observed effect in the case of a composit spectrum is the weighted average of the individual effects : in our case

$$\varepsilon_T = (1 - F_2^i)\, \varepsilon_4 + F_2 \varepsilon_2^i \tag{8}$$

where F_2^i is the fraction of the gammas depopulating the indirectly fed 2^+ level.

By comparison of the effects from the two measurements one obtains the expression

$$g_4 = g_2 \frac{B^2_{eff} \cdot t^2_{eff}}{B^4_{eff} \cdot t^4_{eff}} \left(\frac{\varepsilon_T}{\varepsilon_2} - F_2^i \frac{S_2^i}{S_2} \frac{B^{2i}_{eff} \cdot t^{2i}_{eff}}{B^2_{eff} \cdot t^2_{eff}} \right) \frac{S_2}{(1 - F_2) S_4 + F_2^i S_2^i} \tag{9}$$

Table I reports the data relevant to the present analysis. From these values and a fraction F_2^i = = 0.4(1) of indirect gamma one obtains the value

$$g(4^+) = 0.55(14) .$$

The main contribution to the quoted error comes from the statistics. In fact most of the usual contributions cancel out in the ratio of the observed effects. The assumption of a linear dependence of the transient field from the velocity or any other reasonable dependence changes the deduced g-factor only by 2%. In the given error is not explicitly included the beam bending contribution.

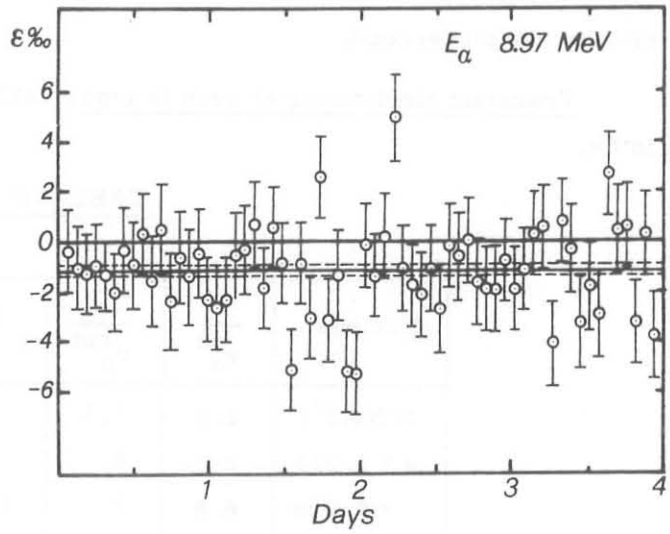

Fig. 5 - Measured effects for the part of gamma spectrum indicated in Fig. 4. The single points correspondond to measure time bits of about 2 hours.

TABLE I

E (MeV)	state	$\frac{1}{W}\frac{dW}{d\theta}$	ε (‰)	$t_{eff}(fs)^{(a)}$	Δθ (mr)
8.05	2^+ (b)	3.20(4)	3.17(40)	203	0.99(12)
8.97	4^+ (b)	0.91(5)	1.15(35)	132	1.26(31)
	2^+(ind)	0.94(3)		74	
	$4^+ + 2^+$(ind)		1.15(21)	206	1.25(23)

(a) - The reported effective times are values averaged over the kinematics.
(b) - Including in the analysis also part of the compton tail of the spectrum.

4. - DISCUSSION

g-factor of the 4^+ state: The deduced value g = 0.55(14) is consistent with the theoretical prediction of multishell model calculation g = 0.51(11).

In the present case no reduction of the observed effect can be suspected as in the case of the 4^+ level in $^{20}Ne^{(2)}$. The present measurement confirms the reliability of the transient field method for the measurement of g-factor of states with lifetime shorter than one picosecond.

<u>Transient field acting at neon in iron</u>: Table II shows all the existing data for Ne in Fe.

TABLE II

Nucleus	$\frac{v_{in}}{v_o}$	$\frac{v_{out}}{v_o}$	$\frac{\Delta\theta}{g}$ (mr)	Ref.
$^{22}Ne(2^+)$	2.0	1.1	3.0(4)	present work
g = 0.326	2.0	0	3.6(9)	(5)[(a)]
= 5.2 ps	6.6	0	19.2(4.2)	(5)[(a)]
$^{20}Ne(2^+)$	7.80	6.0	6.1(2.1)	(11)
g = 0.54	7.90	0	8.5(1.2)	(12)
= 1.04 ps	5.85	0	4.6(1.0)	(12)
	5.14	0	3.3(6)	(12)

(a) - The data of Ref. (5) have been denied by the authors. See Ref. (12).

The transient field for Ne in Fe has been found to be rather peculiar, in fact in the frame of a systematic study using the integral method it has been found to be about an half of that in the neighbouring atoms[(12)]. Assuming as in that reference a linear dipendence on the velocity one would expect an angular shift of about 0.4 mr for the 2^+ state while we observe 0.99(14) mr in spite of the uncomplete magnetization of the ferromagnetic layer. This implies that the transient field at low velocities is much higher then predicted assumin a linear dependence. A similar evidence[(10)] has been found also in ^{24}Mg and ^{26}Mg. What is rather striking is that the normalized angular shift observed in our differential measurement is of the order of that observed in the integral measurement at $v/v_o = 5.14$.

Our data can be put in agreement with the integral measurement if one assumes a constant magnetic field up to $v/v_o = 5$ and then a steep increase for higher velocities. Anyhow more detailed differential measurements would be highly desiderable in order to clarify this point.

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