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J. Physique Lett. **45** (1984) L-851 - L-855 1er SEPTEMBRE **1984,** PAGE L-851

Classification
Physics Abstracts
21.10

Halflife of the first excited state (0^+) of ^{68}Ni

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(*Reçu le 21 mai 1984, accepté le 3 juillet 1984*)

Résumé. — La période du premier niveau (0^+) du ^{68}Ni a été déterminée à partir du spectre en temps obtenu dans la mesure des coïncidences des ^{16}O de la réaction ^{70}Zn(^{14}C, ^{16}O)^{68}Ni* et des électrons, associés à la décroissance de ce niveau. L'attribution du spin 0^+ a été ainsi confirmée.

Abstract. — The confirmation of the 0^+ spin assignment and the halflife value of the first excited state of ^{68}Ni has been derived from the time spectra obtained in the coincidence measurement of the ^{16}O from the ^{70}Zn(^{14}C, ^{16}O)^{68}Ni * reaction with the electrons associated to the decay of this level.

The spectroscopy of the ^{68}Ni nucleus provides a good illustration of a shell closure effect. We have recently reported on the ^{68}Ni spectra studied with the ^{70}Zn (^{14}C, ^{16}O)^{68}Ni reaction [1]; the first excited state was observed at an excitation energy of 1.77 MeV. From accurate angular distribution measurements performed around 0°, a spin 0^+ was assigned to this level.

The γ-decay of this level towards the ground state ($0^+ \rightarrow 0^+$ transition) is forbidden and it decays either *via* E_0 internal conversion or *via* electron-positron pair emission. While the detection of the electrons associated to both decays would confirm the 0^+ spin attribution, the halflife determination will provide an insight into the ^{68}Ni(0_2^+) and ^{68}Ni(0_1^+) g.s. wave functions involved in the transition.

In this Letter we report on a time measurement of electrons emitted by the ^{68}Ni 0_2^+ level, populated with the same ^{70}Zn(^{14}C, ^{16}O)^{68}Ni transfer reaction. From the 0_2^+ halflife determination, the nuclear matrix element of the monopole transition can be deduced rather accurately.

The Orsay MP tandem delivers a 72 MeV beam of ^{14}C, pulsed at a rate of 2.5 MHz (400 ns) for $\sim$ 3 ns pulse width. The average beam current used was 10 nA. The ^{16}O ejectiles were identified and their energy spectra measured as described in reference [1], in which a cross-section of $\sim$ 20 n barn/sr has been measured for the formation of the ^{68}Ni 0_2^+ level, averaged over 5° at $\theta = 6°$ lab. Given this low yield, the present experiment was designed so as to optimize the detection efficiency while maintaining a reasonable random coincidence rate (Fig. 1). A 300 $\pm$ 30 µg/cm^2 thick Zn target, enriched to 70 % with ^{70}Zn was used, for which the 1.77 MeV level is no longer resolved from the g.s. ^{16}O produced on the O contaminant contribution (Fig. 2).

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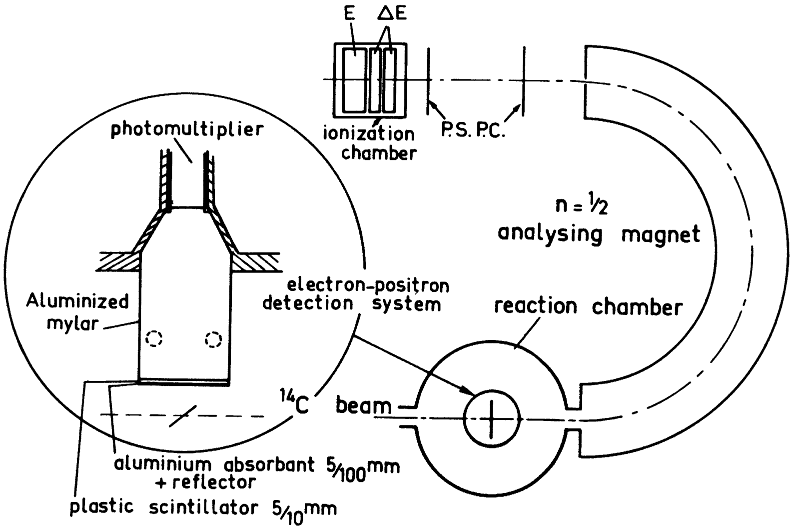

Fig. 1. — Experimental set-up.

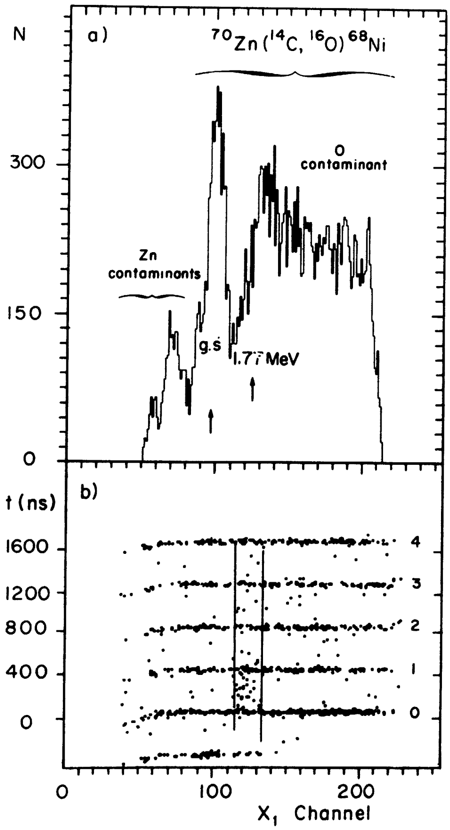

Fig. 2. — a) energy spectrum of ^{16}O; the g.s. of ^{68}Ni is clearly seen but the 0_2^+ excited state is masked by the reaction on ^{16}O contaminant in the Zn target. b) plot of the TAC events *versus* the energy of the ^{16}O (X_1-position in the focal plane). The time width of the strips ($\sim$ 40 ns) corresponds to the overall time accuracy of the ^{16}O signal which starts the TAC. It gives an approximate lower limit for the decay time, which could be measured with the present experimental set up.

The monopole transition of the ^{68}Ni $0_2^+ \rightarrow 0_1^+$ occurs by emission of monoenergetic conversion electrons of 1.77 MeV with a yield of 1/3 and by (e^+, e^-) pair emission, with a yield of 2/3 [2]. In this latter case, both electrons have an energy ranging between 0 and 0.748 MeV, the maximum kinetic energy available. Both electrons are more likely emitted with an equipartition of energy and thus with a small angular separation [3].

The detection of any of those electrons is insured by a thin disk of plastic scintillator, facing the target with a solid angle of $\sim 4\pi/3$ sr centred on a direction perpendicular to the reaction plane. The light emitted, is reflected along the wall of a thin aluminized mylar well, and converted in a 58 DVP photomultiplier (PM). The whole system is placed in the vacuum of the reaction chamber. As in the recent design of reference [4], this device is made as light as possible, to reduce the production of Compton electrons.

The scattered beam ions and evaporation charged particles are stopped by an aluminium foil of 0.05 mm thickness. This screen introduces a threshold of 100 keV for the minimum energy of electrons reaching the scintillator. This, combined with the electronic threshold, reduces the detection efficiency to about 90 %. However, the detection of one or the other electron of the pair enhances the counting efficiency by a factor evaluated to $\sim$ 1.2 with the chosen geometry.

The time distribution of the electrons associated with the decay of the ^{68}Ni 0_2^+ level is measured with a time amplitude-converter (TAC). Triggered with particles crossing the first counter after the magnet [5], this TAC is stopped by the PM signal properly delayed. The ^{16}O ions are selected on the $\Delta E - E$ plot from the ionization chamber and their energy spectra deduced from the position in the focal plane are shown in figure 2a. The bidimensional plot of the TAC output signals *versus* the energy of the ^{16}O particles is reported in figure 2b.

The TAC time window is set on 2 μs, i.e. approximately five times the period of the pulsed beam. Due to the high instantaneous counting rate of the PM five strips of concentrated events are clearly seen. While the one labelled as « 0 » corresponds to both real and fortuitous coincidences, the following ones are only chance coincidences. The observed similar density of those four strips shows that no TAC saturation effect has to be considered.

In the energy region corresponding to the 0_2^+ state of ^{68}Ni, an accumulation of time signals between the beam bursts is clearly seen and is attributed to the expected decay of this level. Other true coincidence events occur within the 40 ns step width of line « 0 ». They correspond to short period decay as that of the ^{16}O first 0^+ excited state — showing on the right end of line 0 — or to electrons produced with the nuclear reaction.

Between beam bursts, chance coincidences are also observed which can modify the time distribution of the true events; since the ^{16}O counting rate is of six counts/hour, the probability for two ^{16}O to occur within 2 μs is negligible. On the PM side, however, the high counting level introduces a background almost random, which has been subtracted.

On figure 3, the corrected number of counts integrated over 67 ns time intervals and for the relevant energy (indicated on Fig. 2b) is plotted *versus* time. The dashed areas correspond to forbidden strips due to beam bursts. The total number of events reported corresponds approximately to one third of the number of the ^{68}Ni nuclei populated in the 0_2^+ state and identified by the detection of the associated ^{16}O. Given the geometrical and detection efficiencies it confirms that all these nuclei decay by electron emission.

The detailed time distribution of the events has been fitted with a Poisson law as in reference [6]. It drives to a value of the halflife of the 0_2^+ level $\tau_{1/2} = 211 \pm 50$ ns. The corresponding decay curve is reported on figure 3.

The halflife measurement provides a valuable information on the nuclear wave functions involved in the monopole decay. The transition rate is given by $1/\tau = \Omega . \rho^2$.

In first order, the monopole strength parameter ρ is defined as $\frac{\langle i | \sum r_p^2 | f \rangle}{R^2}$ where $| i \rangle$ and $| f \rangle$ denote the initial and final wave functions, r_p the position vector of the pth proton and R,

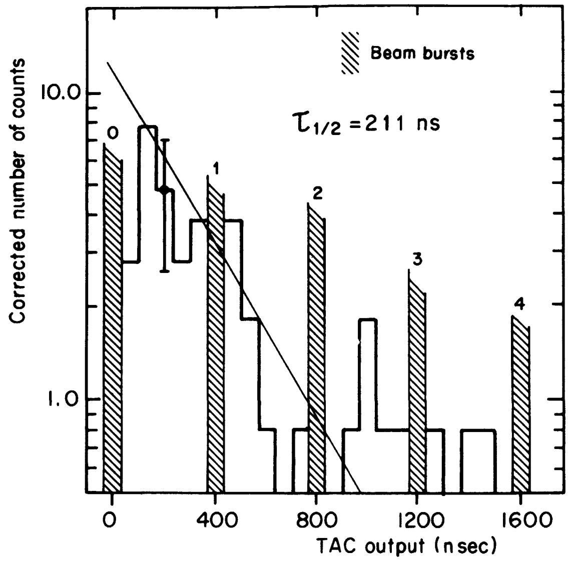

Fig. 3. — Decay curve of the 0_2^+ ^{68}Ni excited state.

the mean nuclear radius. The term Ω, which describes the atomic processes, is written as $\Omega_e + \Omega_\pi$ where Ω_e represents the internal conversion in electron shells K, L, M, N ($\Omega_e = \Omega_K + \Omega_{LMN}$) and Ω_π, the pair production. The electronic factor Ω_K has been calculated by Passoja [2]. Using his work and reference [7] the experimental value of ρ is deduced and reported in table I, with the relevant quantities.

Both nuclei ^{68}Ni ($Z = 28$, $N = 40$) and ^{90}Zr ($Z = 40$, $N = 50$) show a spin 0^+ first excited state. The measurement of the half-life of the ^{90}Zr 0_2^+ level was performed earlier [8] since it can be populated with a large cross-section. In both nuclei, the inversion of the 0_2^+ and 2_1^+ levels can be similarly explained by the shell closure effect, associated with the reduction of the two-quasi-particle energy for N (or Z) = 40 [1]. However, for the ^{68}Ni nuclei, the quasi-particles to consider would be neutrons, and therefore the ρ matrix element would be divided by almost a factor of 10 (compared to ^{90}Zr) squared ratio of the neutron *versus* proton effective charges. This ρ value would thus be too small and proton quasi-particles should be considered.

The Hartree-Fock-Bogoliubov calculations, performed by M. Girod [9], provide wave functions for the two 0^+ states of ^{68}Ni. The calculation of the binding energy as a function of the defor-

Table I. — *Data on* $0_2^+ \to 0_1^+$ *transition probabilities for* ^{90}Zr (*Ref.* [8]) *and* ^{68}Ni (*this work*).

	^{90}Zr	^{68}Ni
Energy (MeV)	1.76	1.77
$\tau_{1/2}$ (ns)	61.3 ± 2	211 ± 50
Ω_K (s^{-1})	2.04×10^9	1.85×10^8
Ω_e/Ω_K	1.142	1.126
Ω_e/Ω_π	2.38	0.576
ρ_{exp}	0.059	0.076

mation β shows that the ^{68}Ni 0_2^+ level corresponds to a deformed isomeric state ($\beta \cong 0.35$) [10]. The ^{68}Ni Nilson orbitals indicate a crossing of the $1f_{7/2}$- and $2p_{3/2}$- subshells around $\beta \sim 0.22$, subshells which concern the last protons in ^{68}Ni. The two 0^+ levels in ^{68}Ni can be represented, as in reference [11], by a mixture of two orthonormized configurations of the two valence protons: the ground state wave function can be written as $a \mid 1f_{7/2} \rangle^2 + b \mid 2p_{3/2} \rangle^2$. With a small value of $b = 0.13$, consistent with the occupation numbers obtained by Girod, and assuming the nucleon radius $r_0 = 1.25$ fermi, the ρ value is calculated to be 0.083 compatible with the value of 0.076 resulting from our measurement.

In spite of the very small formation cross section of the 0_2^+ level of ^{68}Ni, the halflife of this state has been measured. The comparison of the associated ρ value with the ^{90}Zr results and with the H.F.B. calculations of ^{68}Ni suggests that the two-proton quasi-particle excitation is a configuration entering this state which explains the monopole transition strength towards the ground state.

Acknowledgments.

We wish to acknowledge useful suggestions and comments from D. Balamuth and R. Lombard.

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