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Masses and energy levels of ^{62}Fe and ^{68}Ni: (^{14}C,^{16}O) reaction on even Ni and Zn isotopes

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The (^{14}C,^{16}O) reaction on even Ni and Zn isotopes has been investigated at 72 MeV bombarding energy. The mass excesses of ^{62}Fe and ^{68}Ni are determined to be -58.84 ± 0.04 and -63.55 ± 0.04 MeV, respectively. Previously unknown excited states are found. Spectroscopic factors for transitions to ground states and to the first excited states are shown to increase with the neutron number.

[NUCLEAR REACTIONS ^{58,60,62,64}Ni(^{14}C, ^{16}O) and ^{64,66,68,70}Zn(^{14}C, ^{16}O), $E=72$ MeV; measured $\sigma(E,\theta)$; deduced binding energies of ^{62}Fe and ^{68}Ni and excited states energies. DWBA analysis, deduced spectroscopic factors.]

Two-proton transfer reactions provide an excellent tool to study proton correlations in nuclei. Furthermore, on neutron-rich targets, the two-proton pickup reaction leads to nuclei further from the line of stability. Since the (n, ^{3}He) transfer reaction has obvious experimental difficulties, previous studies have been performed with (^{18}O, ^{20}Ne).[1-3] However, the ^{20}Ne levels at 1.63 and 4.25 MeV are strongly excited and Doppler broadened, obscuring the residual nucleus spectra. A better alternative is now available with the (^{14}C, ^{16}O) reaction, using a ^{14}C beam.[4,5] Clean spectra, free from ejectile excitation, are obtainable up to 6 MeV excitation energy. Furthermore, the lack of levels at low excitation energy in ^{14}C and in ^{16}O makes predominant direct transfer very likely, since projectile and ejectile excitation should not play a role. Both (^{18}O, ^{20}Ne) and (^{14}C, ^{16}O) reactions have positive Q values and comparable cross sections are expected for the two reactions.

In this report we present the first results of a systematic (^{14}C, ^{16}O) measurement on the even Ni and Zn isotopes. The aim is to study the variation of proton configurations in both series of isotopes as the neutron number increases. Of particular interest are the neutron rich targets ^{70}Zn and ^{64}Ni leading to ^{68}Ni and ^{62}Fe, the masses of which have been measured only with (^{18}O, ^{20}Ne).[2,3] No excited states have been reported for ^{68}Ni and only one for ^{62}Fe. The level scheme of ^{60}Fe is known only from the (^{3}He, ^{7}Be) reaction.[6]

A beam of 72 MeV ^{14}C from the Orsay MP tandem was used to bombard self-supporting ^{58,60,62,64}Ni targets and ^{64,66,68,70}Zn targets on 20 μg/cm^2 carbon backings. The target thickness was approximately 100 μg/cm^2 except for the ^{66}Zn target, the thickness of which was 380 μg/cm^2. The reaction products were detected at the exit of a 180°, $n=\frac{1}{2}$ magnetic spectrometer. Two position sensitive proportional counters, separated by 46 cm were set near the focal plane. This arrangement allows the reconstruction of the ion trajectories and leads to an angular resolution of 0.2° with a total aperture of 5°.[7] A multianode ionization chamber provided measurements of ΔE as well as a determination of E total. The 2.5% resolution for the ΔE's and the 0.6% resolution for the E provided a clean particle identification. The overall energy resolution was about 250 keV, due mainly to target effects. The mass and excitation energy determination was based on a calibration arising from measurements of the (^{14}C, ^{16}O) reaction itself for the series of Ni and Zn isotopes. The precision obtained varies from 0.04–0.08 MeV depending on the position of the ^{16}O peak in the focal plane and on the statistics.

All the targets except ^{70}Zn are isotopically enriched to better than 96.5%, hence the only spurious peaks come from ^{16}O and ^{12}C (Zn targets only). For the ^{70}Zn target, however, the enrichment is only 67.56% and the measurements on other Zn isotopes were used to identify the peaks due to these contaminants.

The energy spectra for the (^{14}C, ^{16}O) reaction on the four most neutron-rich targets are shown in Fig. 1. A number of previously unreported levels (see Fig. 1) are selectively populated. The bump observed around 6 MeV excitation energy may be attributed to the excitation of the ^{16}O ejectile.

The mass excess of ^{62}Fe is found to be -58.84 ± 0.04 MeV, in agreement with the previous result of Ref. 1 (58.87 ± 0.2) but less negative than the other two results: 58.93 ± 0.05,[2] and 58.945 ± 0.022.[3] Three levels are observed at energies of 0.86 ± 0.04 MeV, 2.00 ± 0.06 MeV, and 4.97 ± 0.08 MeV. However, the spectra do not show any indication of the excited state at 0.58 ± 0.05 MeV which was reported in an (^{18}O, ^{20}Ne) experiment,[2] where mass resolution was questionable. Furthermore, the present location of the first

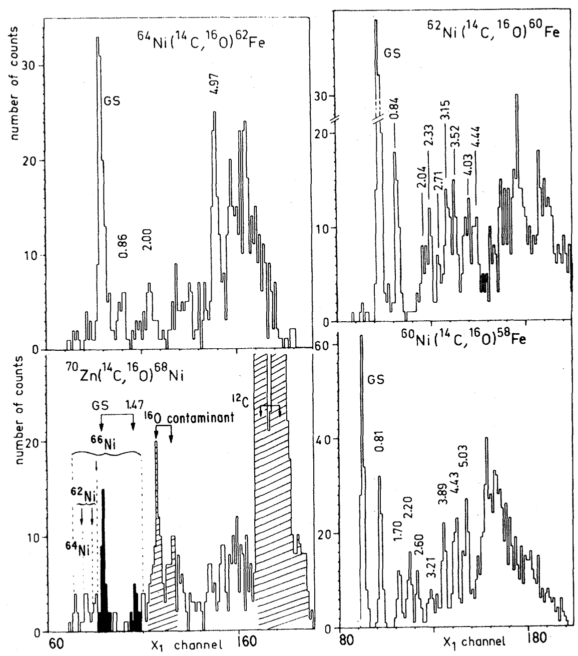

FIG. 1. Energy spectra for (^{14}C, ^{16}O) reaction on $^{60,62,64}Ni$ and ^{70}Zn targets at 72 MeV. These spectra, measured with a 5° aperture, contain broad structures arising from light contaminants for which the kinematic correction was not appropriate.

TABLE I. Cross sections of the two first levels populated in the (^{14}C, ^{16}O) reaction on even Ni and Zn targets. The cross section magnitude is averaged over $3.5 \leq \theta_{lab} \leq 8.5°$.

Transition	Excitation energy (MeV)	J^π	$d\sigma/d\Omega$ mb/sr
$^{58}Ni \rightarrow ^{56}Fe$	0	0^+	0.048
	0.84 ± 0.04	2^+	0.048
$^{60}Ni \rightarrow ^{58}Fe$	0	0^+	0.223
	0.81 ± 0.04	2^+	0.117
$^{62}Ni \rightarrow ^{60}Fe$	0	0^+	0.20
	0.84 ± 0.04	2^+	0.093
$^{64}Ni \rightarrow ^{62}Fe$	0	0^+	0.137
	0.86 ± 0.08	2^+	0.032
$^{64}Zn \rightarrow ^{62}Ni$	0		0.172
	1.10 ± 0.06	2^+	0.061
$^{66}Zn \rightarrow ^{64}Ni$	0	0^+	0.36
	1.43 ± 0.09	2^+	0.100
$^{68}Zn \rightarrow ^{66}Ni$	0	0^+	0.30
	1.43 ± 0.04	2^+	0.051
$^{70}Zn \rightarrow ^{68}Ni$	0	0^+	0.120
	1.47 ± 0.06	(2^+)	0.070

excited state at 0.86 ± 0.04 MeV is compatible with the other previous observation, 0.875 ± 0.01 MeV[3], and consistent with the systematics of the first excited state in other Fe isotopes. The two other excited states are observed here for the first time.

The mass excess of ^{68}Ni is found to be -63.55 ± 0.04 MeV, 80 keV more negative than the only previous result[3] reported at -63.466 ± 0.028 MeV. Comparing these mass excess values with predictions,[8] we find that ^{62}Fe is 600 keV less bound than predicted by Janecke-Garvey-Kelson (JGK), whereas the ^{68}Ni value is very close to both predictions of JGK (140 keV more bound) and Liran-Zeldes (100 keV less bound).

The first excited state of even Ni isotopes (Table I) lies at progressively higher energies as the neutron number increases. This feature is consistent with a subshell closure at $N = 40$. In ^{68}Ni this first excited state might even be a 0^+, as indicated by a preliminary calculation[9] using the high level density scheme.

The cross sections leading to the ground states and first excited states are reported in Table I. For the g.s. to g.s. transitions the cross sections are smaller for the four target isotopes located on the sides of the valley of stability, i.e., ^{58}Ni, ^{64}Zn and ^{64}Ni, ^{70}Zn. On the whole, the (^{14}C, ^{16}O) cross sections are larger by a factor of 2 to 5 than compared to those arising from (^{18}O, ^{20}Ne) at 63, 84 (Ref. 3) and 96 MeV.[2] Distorted-wave Born approximation (DWBA) calculations have been performed with the code LOLA[10] using the optical potentials of Ref. 4 and a cluster form factor. The quality of the fits lends confidence in the extracted spectroscopic factors S_1S_2 defined by $\sigma_{exp}/\sigma_{theor}$.

For the g.s. to g.s. transitions, S_1S_2 behaves differently in the two series of isotopes (Fig. 2). The S_1S_2 values are stable for three of the Zn to Ni transitions, consistent with the continuous filling of neutron subshells obtained with shell-model calculations of Zn (Ref. 11) and Ni (Ref. 12) series based on the restrictive hypothesis of a doubly closed ^{56}Ni nuclei. For the Ni-Fe transi-

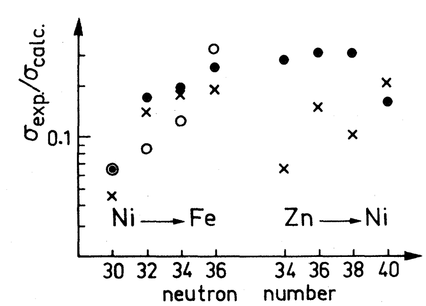

FIG. 2. Spectroscopic factors S_1S_2 as function of neutron numbers; "•" refer to this work, "ᴓ" are from Ref. 1 normalized at $N = 30$, both for g.s. to g.s. transitions, and "x" corresponds to g.s. to 2_1^+ transitions (this work). The first excited state of ^{68}Ni was assumed to be $J^\pi = 2^+$.

tions, S_1S_2 decreases with decreasing neutron number N from a maximum value equal to that of Zn-Ni. A similar behavior was previously obtained in the Ni isotopes with (^{18}O, ^{20}Ne).[1] This variation for the Ni-Fe transitions implies a strong influence of the neutron filling on the proton structure which is not taken into account in the current shell-model calculations.[13]

The (^{14}C, ^{16}O) two proton pickup reaction has been utilized for two purposes: (1) to measure the masses and spectra of the neutron-rich nuclei ^{62}Fe and ^{68}Ni, and (2) to determine the influence of the neutron number on the spectroscopic parentage between Ni and Fe and between Zn and Ni.

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