ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Napoli

INFN/BE-74/6
25 Luglio 1974

A. Brondi, R. Moro, P. Pelfer and F. Terrasi:
# LEVELS OF $^{59}$Co FROM THE $^{58}$Fe(p,$\gamma$)$^{59}$Co REACTION.

201

Reparto Tipografico
dei Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare
Sezione di Napoli

INFN/Be-74/6
25 Luglio 1974

A. Brondi, R. Moro, P. Pelfer and F. Terrasi: LEVELS OF $^{59}Co$ FROM THE $^{58}Fe(p,\gamma)^{59}Co$ REACTION.

ABSTRACT -

The yield curve for the $^{58}Fe(p,\gamma)^{59}Co$ reaction was measured for proton energies from 2150 to 2270 keV. Gamma-ray spectra were measured with a Ge (Li) detector at 4 resonances. A Q-value for this reaction of 7363.2 $\pm$ 1.4 keV was obtained. A decay scheme for levels up to 4.5 MeV is proposed.

## 1. - INTRODUCTION -

In the last few years a great effort has been devoted to study the structure of the odd Co isotopes. From the theoretical point of view the low-lying states of such nuclei are well reproduced by the intermediate-coupling unified model(1). The energy levels of $^{59}Co$ were investigated using inelastic scattering of protons and neutrons(2, 3, 4), stripping and pick-up reactions(5, 6). In recent years Coop et al.(7) and Swann(8), using $(\alpha, p\gamma)$ and resonance fluorescence reactions respectively, gained information about levels in $^{59}Co$ up to $\sim$ 3 MeV excitation energy. Only a few levels at an energy higher than 3 MeV have been reported by Swann with large uncertainties. In addition, the $\beta$-decay study of $^{59}Fe$(9) gave detailed information about spins and lifetimes of levels up to 1.5 MeV.

In the present work the $^{58}Fe(p,\gamma)^{59}Co$ reaction has been used to determine excitation energies and branching ratios of several bound levels and of four resonances. An excitation curve has been obtained for proton energies ranging from 2150 keV to 2270 keV, in the region of the analogue of the $^{59}Fe$ ground state(10). High-resolution gamma-ray spectra have been measured at four resonances using a Ge(Li) detector. The analysis of the gamma-ray spectra allowed for an accurate determination of the Q-value of the reaction relative to $^{56}Fe$ (p, $\gamma$) Q-value.

## 2. - EXPERIMENTAL PROCEDURE -

The proton beam was produced by the 7.5 MeV Van de Graaff accelerator of the Laboratori Nazionali di Legnaro (Padua). A $90^o$ magnetic analyser, equipped with an NMR fluxmeter, was used to define and control the proton energy. The experimental resolution of the proton beam was about 300 eV. Targets were prepared by vacuum evaporation of enriched iron (chemical form $Fe_2O_3$) onto 0.2 mm tantalum backings. The enrichment was 82% $^{58}Fe$, with 16% $^{56}Fe$ impurity. Target thicknesses were $\sim 2\mu$ g/cm$^2$ and $\sim 10\,\mu$ g/cm$^2$ for yield and spectra measurements respectively. The targets were water-cooled and no target deterioration was observed over periods of several hours of 5 $\mu$A beam current running time. A beam current integrator was used to measure the accumulated charge on the target. Yield curves were obtained detecting gamma-rays at $55^o$ with respect to the proton beam in a 4" x 4" NaI(Tl) crystal, 6 cm away from the target.

Gamma-ray spectra were recorded using a 50 cm$^3$ Ge(Li) Ortec detector at $55^o$ with respect to the proton beam, 4 cm away from the target. Pulses from the Ortec pre-amplifier were fed into two independent chains (a Tennelec TC 203 BLR Amplifier plus a Laben 4096 - channel analyser). The dispersion in the two chains was 0.7 keV/channel and 2.5 keV/channel, so that two spectra were accumulated simultaneously, taking energies up to 3 MeV (low-energy spectra) and up to 10 MeV (high-energy spectra) respectively. The energy resolution, including long-term instabilities, was 2.4 keV FWHM at 1.3 MeV and 8 keV at 9.5 MeV.

Gamma-ray spectra were analysed by the automatic computer code CERPI(11). Three low-energy gamma lines of $^{59}Co$ ($1099.3 \pm 0.1$, $1190.6 \pm 0.1$ and $1291.5 \pm 0.1$ keV) were accurately calibrated for comparison with sources of known energies ($^{60}Co$ and $^{22}Na$) by taking spectra with these sources placed near the target. The energy calibration of the spectra was determined by using a least-squares polynomial fit program for which the input data consist of known energies of gamma-rays from $^{59}Co$, from background and other reactions, of the positions of full-energy, single - and double - escape peaks, and the requirement that the energies of gamma-rays emitted in cascade add up to the excitation energy of the resonance.

The relative full-energy peak efficiency ($E_\gamma < 2.5$ MeV) of the detector was determined measuring gamma-ray intensities from an $^{116m}$In source produced by (n, $\gamma$) reaction[12]. Gamma-rays from the capture reaction $^{27}Al(p, \gamma)^{28}Si$ at $E_p$ = 992 keV was used for determining the efficiency in the high-energy range from 2 to 10 MeV[13].

## 3. - RESULTS -

### 3.1. - Excitation curves and Q - value. -

The excitation curve for the reaction $^{58}$Fe (p, $\gamma$), shown in fig. 1, extends from 2150 keV to 2270 keV in steps of about 0.7 keV. Each point corresponds to a deposited charge on the target of 300 $\mu$C. Gamma rays of energy greater than 4.0 MeV were counted. Resonances at which gamma-ray spectra were measured are marked with an asterisk in Fig. 1.The proton energies for these resonances were obtained utilizing the small contamination of $^{56}$Fe in the target. From a spectrum measurement at $\nu$ = 12794 kc with thin target we deduced that the difference between the cross-over transitions to the ground states of $^{57}$Co and $^{59}$Co is 1336.5 $\pm$ 0.7 keV. As the Q-value of the $^{56}$Fe(p, $\gamma$) reaction is known to be 6026.7 $\pm$ 0.7 keV[14], the Q-value for the $^{58}$Fe(p, $\gamma$) reaction turnes out to be 7363.2$\pm$1.4 keV, where the error takes into account the indetermination in the proton energy due to target tkickness. This value is to be compared with 7369.8 $\pm$ 2.9 keV based upon the 1972 mass table[15]. From the Q-value and the excitation energy of the resonance levels we obtain for the proton energies at the four resonances 2198, 2215, 2224, 2228 keV.

Gamma-ray spectra were recorded with the NaI(Tl) crystal in the proton energy range $E_p$ = 2200 ÷ 2240 keV in steps of 0.7 keV. Yields of selected primary radiations to low-lying levels were thus obtained. The analysis of the partial yield of the transition to the ground state has shown that all the observed resonances in this region are due to the $^{58}$Fe(p, $\gamma$) reaction. Inelastic proton widths to the first excited level in $^{58}$Fe were found to be comparable with radiation widths, by measuring the yield of the 810 keV gamma-ray transition de-exciting the $2^+$ level of $^{58}$Fe.

### 3.2. - Gamma-ray spectra -

The high-energy gamma-ray spectrum from the proton capture resonance at $E_p$ = 2228 keV, is shown in Fig. 2. The peaks in the spectrum are labelled by the gamma-ray energies (in keV), corrected for Doppler and recoil effects. Primes and double primes indicate single - and double - escape peaks. Energies and intensities of gamma-rays relative to the four resonances investigated are listed in table 1.

Several peaks in the spectra were identified as background lines or

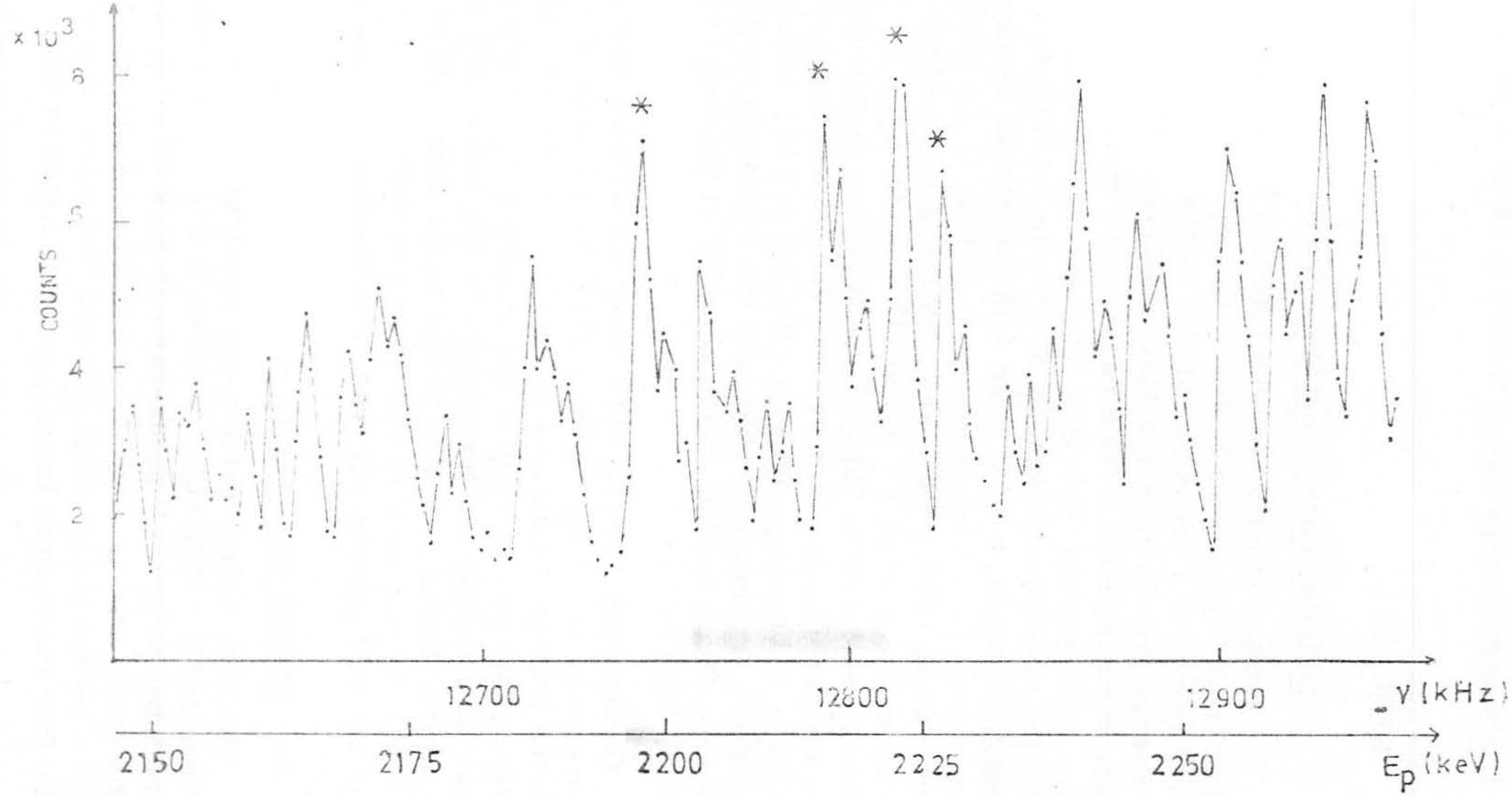


FIG. 1 - Excitation curve for the $^{58}Fe\,(p,\ \gamma)^{59}Co$ reaction.

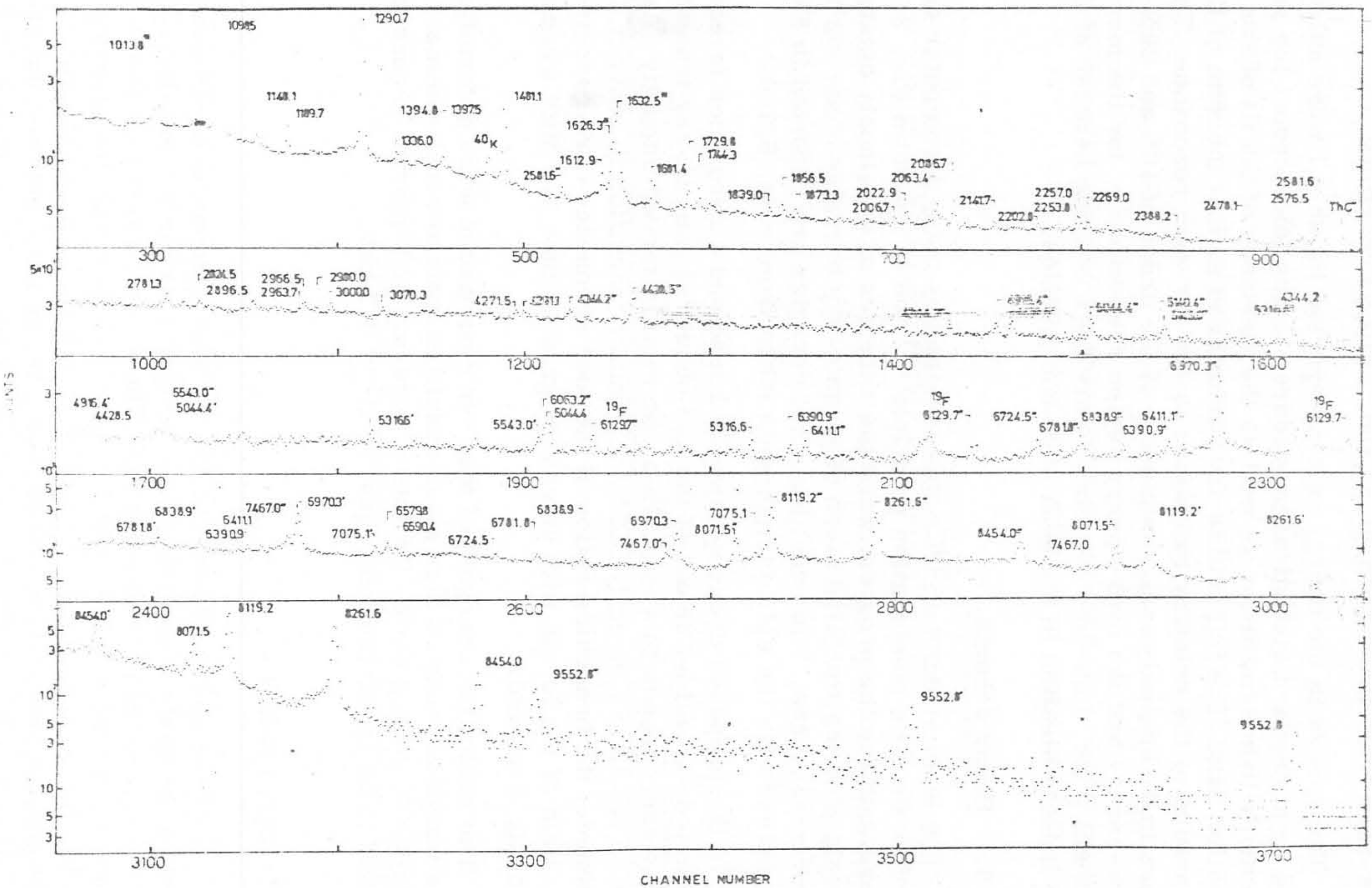


FIG. 2 - High-energy $\gamma$-ray spectrum from the proton capture resonance in $^{59}Co$ at $E_p$ = 2228 keV.

as being due to spurious reactions. A spectrum was accumulated at $E_p$ = 2228 keV with the protons on the tantalum backing. The broad peak at ~ 1630 keV is believed to be due to the superposition of gamma-rays from the $^{23}Na(p, p' \gamma)$ and $^{19}F(p, \gamma)$ reactions.

The errors in the energy values reported in table 1 were calculated by a standard statistical procedure, taking into account the peak centroid indetermination as well as the goodness of the fit of the calibration data. The intensities are normalized so that the sum of the intensities of the primary radiations is 100 for each resonance. The errors in the intensity assignments are of the order of 10% and 20% for the low-energy and the high-energy region respectively, for the most prominent lines. Low-intensity values are less reliable because of the large indetermination in the peak area computation.

3.3. - Decay scheme. -

The level scheme of $^{59}Co$ was obtained by using a computer code based on the Ritz combination principle(16) and is shown in Fig. 3. The input data for the program were the energies of previously established levels plus the weighted mean of gamma-ray energies observed at the four resonances. The resulting level energies are reported in Fig. 3 toghether with the spin assignments taken from refs. 6, 7, 8.

In the proposed decay scheme 36 bound and 4 resonance levels are inserted as well as 88 out of the 123 observed gamma-ray transitions. This corresponds to about 95% of the total observed intensity. As many as 35 levels are directly fed by a primary transition in at least one resonance; the branching ratios of the four resonances are reported in Fig. 3. Most of the levels with an energy greater than 2.5 MeV were not previously observed.

The excitation energies of the four resonances were determined by the weighted mean of the values resulting from several gamma-ray cascades to ground state. Statistical external and internal errors were found to be consistent and equal to about 0.3 keV.

## 4. - DISCUSSION -

Tentative spin assignments for the four resonance levels were obtained on the basis of previous spin assignments for the low-lying levels and of the measured branching ratios. The strong transitions to the $7/2^-$ ground state and to the $1/2^-$ level at 1433 keV together with the absence of appreciable feedings to the $9/2^-$ level at 1190 keV, rule out a spin 1/2 or 7/2 assignment for the four resonances. As the ratio between the proton penetrabilities at $E_p$ = 2200 keV on $^{58}Fe$ for an $\ell_p = 3$ and an $\ell_p = 2$ resonance is $\sim 10^{-1}$, also a $5/2^-$ assignment does not seem to be compatible with

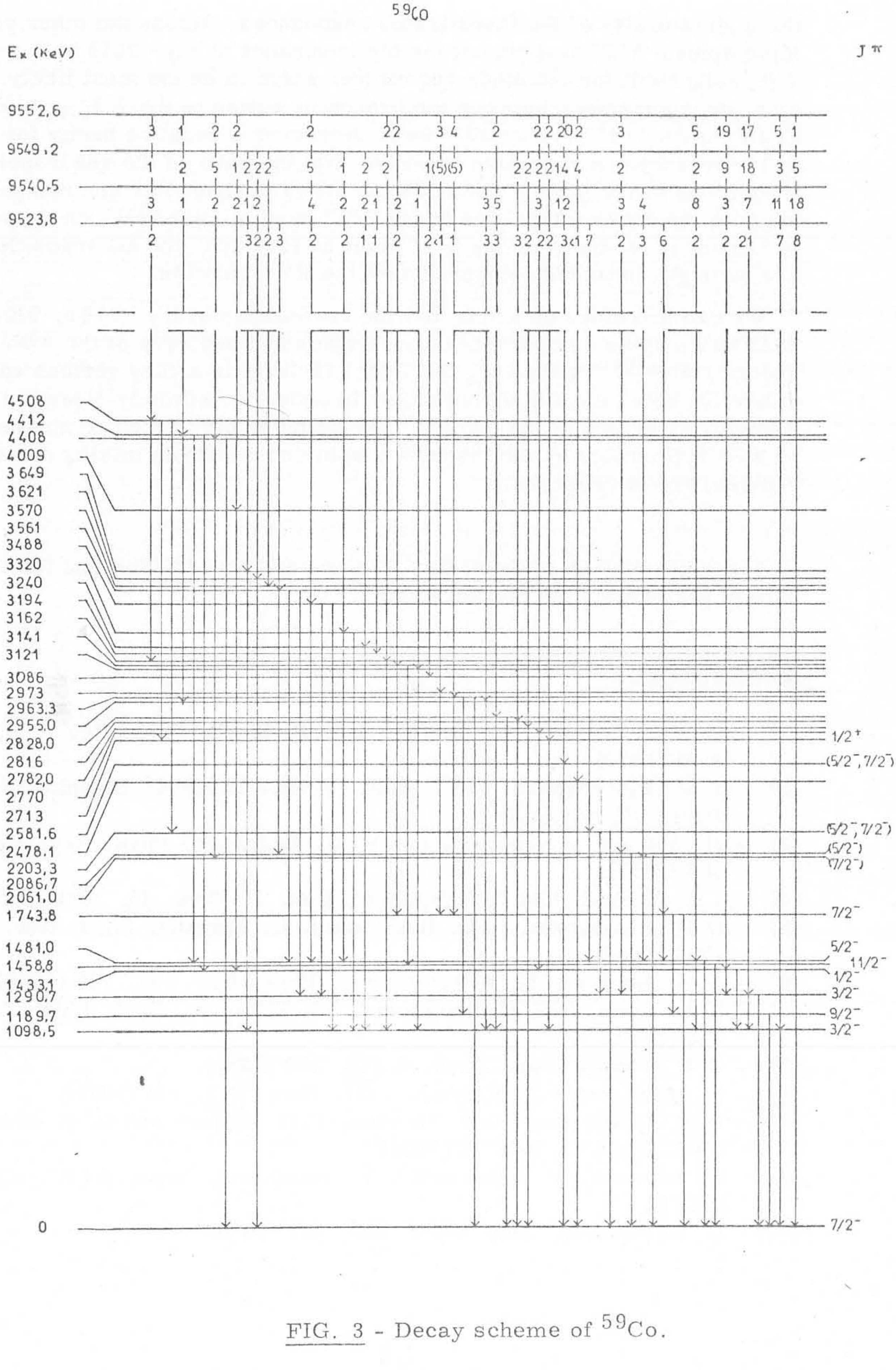


FIG. 3 - Decay scheme of $^{59}$Co.

the high intensity of the investigated resonances. Among the other possible spins a $5/2^+$ assignment for the resonance at $E_p$ = 2215 keV and a 3/2 assignment for the other resonances seem to be the most likely ones from the comparison between the branching ratios to the $7/2^-$ ground state and to the $1/2^+$ level at 2713 keV. Moreover a negative parity for the 3/2 resonances is suggested from the high intensity of the quadrupole transitions to the ground state. These above assignments are compatible with the decay intensities to the $3/2^-$ level at 1098 keV. An opposite behaviour is shown by the $3/2^-$ level at 1290 keV: the M1 transitions are strongly enhanced compared with the E1 transition.

We can therefore conclude that the resonances at $E_p$ = 2198, 2224 and 2228 keV may be components of the fragmented analogue of the $^{59}Fe$ ground state[10]. Moreover, the 1290 keV level is a very serious candidate for being the antianalog state. In order to definitely clear out the different structure of the two $3/2^-$ low-lying levels, which do not seem to be well reproduced by the theory[1], spin and multipole mixing measurements are in progress.

The authors wish to thank Dr. V. Roca and Dr. M. Romano for their help in performing the measurements.

REFERENCES -

(1) - K.W.C. Stewart, B. Castel and B.P. Singh, Phys. Rev. C 4, 2131 (1971).
(2) - J.M. Bjerregaard, P.F. Dahl, O. Hansen and G. Sidenius, Nucl. Phys. 51, 641 (1964).
(3) - M. Mazari, A. Sperduto and W.W. Buechner, Phys. Rev. 107, 365 (1957).
(4) - J.M. Daniels and J. Felsteiner, Can. J. Phys. 46, 1849 (1968).
(5) - D.D. Armstrong, A.G. Blair and H.C. Thomas, Phys. Rev. 155, 1254 (1967).
(6) - A.G. Blair and D.D. Armstrong, Phys. Rev. 151, 930 (1966).
(7) - K.L. Coop, I.G. Graham and E.W. Titterton, Nucl. Phys. A 150, 346 (1970).
(8) - C.P. Swann, Nucl. Phys. A 172, 569 (1971).
(9) - I. Arens and H.J. Korner, Zeit. Phys. 242, 138 (1971).
(10) - D.P. Lindstrom, H.W. Newson, E.G. Bilpuch and G.E. Mitchell, Nucl. Phys. A 168, 37 (1971).
(11) - M. Giannini, P. Oliva and M.C. Ramorino, Report CNEN-RT/FI (72) 14.
(12) - D. Rabenstein, Zeit. Phys. 240, 244 (1970).

(13) - R.E. Azuma, L.E. Carlson, A.M. Charlesworth, K.P. Jackson, N. Anyas - Weiss and B. Lalovic, Can. J. Phys. 44, 3075 (1966).
(14) - B.J. O'Brien and G.E. Coote, Nucl. Phys. A 153, 593 (1970).
(15) - N.B. Gove and A.H. Wapstra, Nucl. Data Tables A 11, 127 (1972).
(16) - A. Fubini, A. Napoli, D. Properi and F. Terrasi, Report CNEN-RT/FI (70) 47.

# TABLE 1

ENERGIES, INTENSITIES AND ASSIGNMENTS OF $\gamma$-RAYS OBSERVED IN THE $^{58}Fe(p,\gamma)$ REACTION

| Res. $E_p$ = 2198 keV | | Res. $E_p$ = 2215 keV | | Res. $E_p$ = 2224 keV | | Res. $E_p$ = 2228 keV | | Level (keV) | |
|---|---|---|---|---|---|---|---|---|---|
| $E_\gamma$ (keV) | $I_\gamma$ a) | $E_\gamma$ (keV) | $I_\gamma$ a) | $E_\gamma$ (keV) | $I_\gamma$ a) | $E_\gamma$ (keV) | $I_\gamma$ a) | from | to |
| 9524.1±0.3 | 8 | 9540.3±0.4 | 18 | 9548.7±0.4 | 5 | 9552.8±0.5 | 1 | res. | - g.s. |
| 8424.9±0.3 | 7 | 8441.6±0.4 | 11 | 8450.6±0.5 | 3 | 8454.0±0.2 | 5 | res. | - 1098.5 |
| 8233.0±0.2 | 21 | 8249.2±0.5 | 7 | 8258.3±0.3 | 18 | 8261.6±0.2 | 17 | res. | - 1290.7 |
| | | 8203.8±0.6 | | | | | | $^{56}Fe(p,\gamma)$ | |
| 8089.3±0.6 | 2 | 8106.7±0.7 | 3 | 8115.9±0.4 | 9 | 8119.2±0.2 | 19 | res. | - 1433.1 |
| 8044.4±0.5 | 2 | 8058.9±0.5 | 8 | 8067.5±0.5 | 2 | 8071.5±0.2 | 5 | res. | - 1481.0 |
| 7780.0±0.3 | 6 | | | | | | | res. | - 1743.8 |
| 7462.5±0.5 | 3 | 7479.5±0.6 | 4 | | | | | res. | - 2061.0 |
| 7436.7±0.4 | 2 | 7454.1±0.6 | 3 | 7465.0±0.6 | 2 | 7467.0±0.3 | 3 | res. | - 2086.7 |
| 7320.8±0.2 | 7 | | | | | | | res. | - 2203.3 |
| 7047.7±0.4 | <1 | unresolved line | | 7072.0±0.4 | 4 | 7075.1±0.6 | 2 | res. | - 2478.1 |
| 6942.3±0.9 | 3 | 6958.8±0.4 | 12 | 6967.7±0.3 | 14 | 6970.3±0.2 | 20 | res. | - 2581.6 |
| 6808.3±0.6 | 2 | | | 6834.9±0.5 | 2 | 6838.9±0.4 | 2 | res. | - 2713 |
| 6753.9±0.7 | 2 | 6770.2±0.5 | 3 | 6779.3±0.6 | 2 | 6781.8±0.3 | 2 | res. | - 2770 |
| 6743.6±0.5 | 2 | | | 6767.3±0.9 | 2 | | | res. | - 2782.0 |
| 6708.7±0.7 | 3 | | | 6731.6±0.6 | 2 | | | res. | - 2816 |
| 6695.0±0.5 | 3 | 6712.2±0.4 | 5 | | | 6724.5±0.4 | 2 | res. | - 2828.0 |
| 6568.5±0.4 | 3 | 6585 ±2 | 3 | | | | | res. | - 2955.0 |
| 6561.4±0.8 | 1 | | | 6586.1±0.4 | (5) | 6590.4±0.6 | (4) | res. | - 2963.3 |
| 6552 ±2 | <1 | | | 6576.3±0.8 | (5) | 6579.8±0.3 | (3) | res. | - 2973 |
| 6437.4±0.5 | 2 | | | 6463.0±0.8 | 1 | | | res. | - 3086 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 6420.0±0.7 | 1 | | | | | res. - 3121 |
| 6381 ±1 | 2 | 6402 ±2 | 2 | | | 6411 ±1 | 2 | res. - 3141 |
| | | | | 6387.8±0.4 | 2 | 6390.9±0.6 | 2 | res. - 3162 |
| 6330.3±0.5 | 1 | 6346.8±0.8 | 1 | | | | | res. - 3194 |
| 6284.3±0.6 | 1 | 6300.6±0.7 | 2 | 6309.1±0.7 | 2 | | | res. - 3240 |
| 6204.1±0.5 | 2 | 6221.7±0.5 | 2 | 6229 ±1 | 1 | | | res. - 3320 |
| 6129.7±0.2 | - | | | | | | | $^{19}F$ (p,αγ) |
| 6037 ±1 | 2 | 6055.4±0.5 | 4 | 6061.1±0.5 | 5 | 6063.2±0.7 | 2 | res. - 3488 |
| 5962.9±0.4 | 3 | | | | | | | res. - 3561 |
| 5953.2±0.6 | 2 | | | 5979.5±0.3 | 2 | | | res. - 3570 |
| 5902.7±0.3 | 2 | 5920.2±0.9 | 2 | 5930.4±0.7 | 2 | | | res. - 3621 |
| 5874.9±0.3 | 3 | 5892.0±0.6 | 1 | 5898.9±0.5 | 2 | | | res. - 3649 |
| | | 5532.0±0.6 | 2 | 5541.0±0.6 | 1 | 5543.0±0.5 | 2 | res. - 4009 |
| | | | | | | 5316.6±0.2 | 3 | |
| 5255.9±0.4 | 2 | | | | | | | |
| | | 5134.5±0.5 | 2 | 5142.3±0.3 | 5 | 5145.8±0.4 | 2 | res. - 4408 |
| | | 5128.5±0.7 | 1 | 5137.5±0.9 | 2 | 5140.4±0.7 | 1 | res. - 4412 |
| 5015.4±0.4 | 2 | 5034.5±0.4 | 3 | 5038 ±1 | 1 | 5044.4±0.2 | 3 | res. - 4508 |
| 4919.2±0.5 | 2 | | | | | | | |
| | | | | | | 4916.4±0.4 | 1 | |
| 4761.7±0.6 | 2 | | | | | | | |
| | | | | | | 4428.5±0.3 | 4 | |
| | | | | 4408.6±0.5 | 2 | | | 4408 - g.s. |
| | | | | | | 4344.2±0.4 | 2 | |
| | | | | | | 4281.1±0.4 | 1 | |
| | | | | | | 4271.5±0.4 | 1 | |
| 3765.9±0.6 | 1 | | | | | | | |
| 3667.7±0.5 | 1 | | | | | | | |
| | | | | 3635.2±0.7 | 3 | | | |
| | | | | 3621.7±0.6 | 3 | | | 3621 - g.s. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 3606.1±0.8 | 2 | | | |
| 3293.0±0.9 | 1 | | | | | | | |
| | | | | | | 3070.3±0.6 | 1 | |
| 3000.7±0.5 | <1 | | | 3000.7±0.7 | <1 | 3000.0±0.4 | 1 | |
| | | | | | | 2980 ±1 | <1 | 4412 - 1433.1 |
| 2966.0±0.8 | <1 | | | 2965.7±0.6 | 1 | 2966 ±1 | <1 | |
| 2963.3±0.8 | 1 | | | 2963.2±0.6 | 1 | 2964 ±1 | 1 | 2963.3 - g.s. |
| | | | | 2930.4±0.5 | 1 | | | 4412 - 1481.0 |
| | | | | | | 2896.5±0.5 | 1 | |
| 2825.6±0.6[b)] | 2 | 2825.3±0.5[b)] | 2 | 2826 ±1 | 1 | 2824.5±0.7[b)] | 1 | 2828.0 - g.s. |
| 2816.7-0.9 | 1 | | | | | | | 2816 - g.s. |
| 2782.4±0.5 | 3 | 2782.4±0.6 | 2 | 2781.9±0.4 | 1 | 2781.3±0.5 | 2 | 2782.0 - g.s. |
| 2614.5±0.1 | | | | | | | | ThC" |
| 2581.8±0.4 | 2 | 2581.6±0.3 | 5 | 2581.6±0.2 | 7 | 2581.6±0.2 | 9 | 2581.6 - g.s. |
| 2575.7±0.6 | 1 | 2575.6±0.5 | 1 | 2577.5±0.4 | 1 | 2576.5±0.6 | 2 | 4009 - 1433.1 |
| 2551.2±0.4 | 2 | 2550.7±0.5 | 1 | 2550.2±0.4 | 1 | 2550 ±1 | <1 | 3649 - 1098.5 |
| 2526 ±1 | 1 | | | | | | | |
| 2486.3±0.6 | 1 | 2485 ±2 | <1 | | | | | |
| 2478.2±0.3 | 4 | 2478.1±0.4 | 2 | 2478.2±0.2 | 4 | 2478.1±0.2 | 3 | 2478.1 - g.s. |
| 2388.2±0.5 | <1 | 2390 ±1 | 3 | 2389.5±0.5 | 1 | 2388.2±0.4 | 1 | 3488 - 1098.5 |
| | | | | 2345.0±0.5 | 1 | | | 4408 - 2061.0 |
| 2306 ±1 | <1 | 2305 ±1 | <1 | 2307.0±0.6 | <1 | | | 4508 - 2203.3 |
| 2291.9±0.8 | <1 | | | 2292.6±0.4 | <1 | | | |
| 2269.6±0.4[b)] | 1 | 2270.7±0.8 | 1 | 2269.5±0.5 | 1 | 2269.0±0.6 | 1 | 3561 - 1290.7 |
| | | 2267.5±0.4 | <1 | 2267.0±0.7 | <1 | | | |
| 2257.9±0.2 | 2 | 2258.0±0.5 | 1 | 2256.9±0.5 | 1 | 2257.0±0.6 | 1 | |
| 2253.8±0.3 | 1 | 2254.2±0.4 | 1 | 2253.8±0.4 | 1 | 2253.8±0.7 | 1 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2218 ±2 | <1 | | | 2220.8±0.5 | <1 | 2220.9±0.8 | <1 | 3320 - 1098.5 |
| 2203.8±0.2 | 2 | 2204 ±1 | <1 | 2203.2±0.3 | 1 | 2202.8±0.4 | <1 | 2203.3 - g.s. |
| 2196 ±2 | <1 | 2199 ±1 | <1 | | | | | 3488 - 1290.7 |
| 2142.4±0.2 | 2 | 2142.2±0.3 | 2 | 2143.0±0.5 | 1 | 2141.7±0.5 | 1 | 3240 - 1098.5 |
| 2086.7±0.2 | 4 | 2086.8±0.2 | 3 | 2086.4±0.2 | 3 | 2086.7±0.2 | 3 | 2086.7 - g.s. |
| 2082 ±2 | <1 | 2082.8±0.5 | 1 | 2083.2±0.5 | <1 | | | 3561 - 1481.0 |
| 2064.4±0.3 | 1 | 2063.2±0.2[b)] | 1 | 2063.5±0.2[b)] | 2 | 2063.4±0.3[b)] | 2 | 3162 - 1098.5 |
| 2061.7±0.5 | 1 | | | | | | | 2061.0 - g.s. |
| 2023.5±0.2 | 2 | 2023.3±0.2 | 2 | 2023.3±0.2 | 1 | 2022.9±0.3 | 1 | 3121 - 1098.5 |
| 2007.0±0.4 | 1 | 2006.2±0.3 | 1 | 2006.9±0.6 | 1 | 2006.7±0.3 | 1 | 3488 - 1481.0 |
| 1972.1±0.7 | <1 | 1971.5±0.4 | <1 | 1970 ±1 | 1 | | | |
| | | | | 1874.2±0.2 | <1 | 1873.3±0.4 | <1 | |
| 1856.5±0.2 | 3 | 1856.4±0.2 | 2 | 1856.5±0.2 | 2 | 1856.5±0.3 | 1 | 2955.0 - 1098.5 |
| 1838.7±0.5 | <1 | 1839.3±0.3 | 1 | 1839.0±0.2 | 1 | 1839.0±0.5 | 1 | 3320 - 1481.0 |
| 1796.4±0.2 | 1 | 1796.8±0.4 | 1 | 1796.7±0.7 | <1 | | | 4508 - 2713 |
| 1778.0±0.3 | 2 | | | | | | | |
| 1774.1±0.6 | <1 | | | | | | | 2963.3 - 1189.7 |
| 1762.7±0.4 | 1 | 1762.6±0.4 | 1 | | | | | |
| 1757.5±0.3 | | | | | | | | $^{56}Fe(p,\gamma)$ |
| 1743.9±0.1 | 7 | 1743.9±0.1 | 4 | 1743.7±0.1 | 4 | 1744.3±0.3 | 3 | 1743.8 - g.s. |
| 1729.5±0.1 | 2 | 1729.6±0.1 | 5 | 1729.3±0.3 | 2 | 1729.8±0.2 | 2 | 2828.0 - 1098.5 |
| 1682.4±0.3 | 2 | 1683 ±3 | 1 | 1681.8±0.3 | 3 | 1681.4±0.2 | 3 | 3141 - 1458.8 |
| 1679.7±0.8 | <1 | 1681 ±2 | 2 | 1679.5±0.8 | 1 | | | |
| 1632.5±0.5 } | | | | | | | | |
| 1626.3±0.5 | | | | | | | | B[c)] |
| 1613.0±0.3 | 1 | 1613.0±0.1 | 2 | 1613.1±0.1 | 2 | 1612.9±0.2 | 2 | 2713 - 1098.5 |
| 1481.0±0.1 | 24 | 1481.0±0.1 | 22 | 1481.0±0.1 | 20 | 1481.1±0.1 | 19 | 1481.0 - g.s. |
| 1475.9±0.3 | 2 | | | 1476.0±0.3 | 1 | | | 3561 - 2086.7 |
| 1460.75±0.06 | | | | | | | | $^{40}K(\beta^+)$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1458.9+0.4 | 2 | 1459.1+0.5 | 1 | 1458.6+0.3 | 3 | 1458.8+0.5 | 2 | 1458.8 - g.s. |
| 1456.8+0.7 | 1 | | | 1457.0+0.6 | 1 | 1456.9+0.6 | 1 | 4412 - 2955.0 |
| 1397.0+0.1[b)] | (3) | 1396.6+0.2[b)] | (4) | 1397.4+0.2 | 1 | 1397.5+0.2 | 1 | 3141 - 1743.8 |
| | | | | 1395.2+0.3 | <1 | 1394.8+0.5 | <1 | |
| 1376.8+0.2 | | | | | | | | $^{56}$Fe(p,γ) |
| 1367.8+0.2 | | | | | | | | $^{23}$Na(p,γ) |
| 1364.1+0.3 | 1 | | | | | | | |
| 1346 +1 | <1 | | | 1345.7+0.3 | <1 | | | 4508 - 3162 |
| 1335.7+0.1 | 3 | 1335.8+0.2 | 2 | 1335.6+0.1 | 2 | 1336.0+0.2 | 2 | 2770 - 1433.1 |
| 1290.7+0.1 | 45 | 1290.7+0.1 | 37 | 1290.7+0.1 | 49 | 1290.7+0.1 | 52 | 1290.7 - g.s. |
| 1230.8+0.9 | <1 | | | | | | | 2973 - 1743.8 |
| 1219.9+0.4 | <1 | | | 1218.7+0.3 | 1 | 1219.6+0.3 | 1 | 2963.3 - 1743.8 |
| 1189.7+0.1 | 14 | 1189.7+0.1 | 10 | 1189.7+0.1 | 10 | 1189.7+0.1 | 7 | 1189.7 - g.s. |
| | | | | 1148.3+0.1 | 2 | 1148.1+0.2 | 2 | |
| 1114.8+0.3 | | | | | | | | $^{65}$Cu(p,p'γ) |
| 1098.5+0.1 | 46 | 1098.5+0.1 | 52 | 1098.5+0.1 | 40 | 1098.5+0.1 | 43 | 1098.5 - g.s. |
| 1013.8+0.2 | | | | | | | | B[c)] |
| 1001.3+0.3 | 2 | 1001.3+0.4 | 1 | 1000.8+0.3 | <1 | | | |
| 913.1+0.2 | 2 | 914.4+0.9 | 1 | 912.8+0.3 | 1 | | | 2203.3 - 1290.7 |
| 867.7+0.5 | 1 | | | 866.4+0.3 | 1 | 866.1+0.2 | 2 | |
| 846.3+0.2 | | | | | | | | $^{56}$Fe(p,p'γ) |
| 810.5+0.1 | | | | | | | | $^{58}$Fe(p,p'γ) |
| 795.5+0.1 | 2 | 795.4+0.1 | 2. | 795.4+0.1 | <1 | | | 2086.7 - 1290.7 |
| 722.9+0.1 | 3 | 722.3+0.5 | 1 | 722.7+0.1 | 1 | 722.6+0.2 | 1 | 2203.3 - 1481.0 |
| 579.7+0.1 | 1 | 579.6+0.1 | 2 | 579.7+0.1 | 1 | 580.0+0.3 | <1 | 2061.0 - 1481.0 |
| 554.0+0.1 | 4 | 553.9+0.1 | 3 | 553.8+0.1 | 3 | 553.8+0.1 | 2 | 1743.8 - 1189.7 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 511.006±0.002 | | | | | | | | Ann. $\beta^+$ |
| 495.0±0.2 | | | | | | | | $^{16}O(p,\gamma)$ |
| 439.6±0.2 | - | | | | | | | $^{23}Na(p,p'\gamma)$ |
| 382.4±0.1 | 7 | 382.3±0.1 | 6 | 382.1±0.1 | 6 | 382.1±0.2 | 5 | 1481.0 - 1098.5 |
| 334.7±0.1 | 2 | 334.6±0.1 | 3 | 334.4±0.1 | 4 | 334.5±0.2 | 5 | 1433.1 - 1098.5 |
| 301.5±0.3 | | | | | | | | C.E. $^{181}Ta$ |

a)- Intensities are in $\gamma$/100 captures. Values in parathensis are less reliable.

b)- Double line .

c)- Background line