Study of low-lying levels in ^{59}Ni

1983 J. Phys. G: Nucl. Phys. 9 91

(http://iopscience.iop.org/0305-4616/9/1/014)

J. Phys. G: Nucl. Phys. 9 (1983) 91–97. Printed in Great Britain

Study of low-lying levels in ^{59}Ni

V K Mittal, D K Avasthi and I M Govil
Department of Physics, Panjab University, Chandigarh 160014, India

Received 5 May 1982, in final form 3 September 1982

Abstract. The levels (up to 2 MeV) in ^{59}Ni have been excited via the ^{59}Co(p, nγ)^{59}Ni reaction. Lifetimes were obtained from the Doppler-shift attenuation technique. The angular distribution data were analysed to assign the spin of the 1768 keV level and to determine the mixing ratios of γ transitions from this level. The lifetime of 1746 keV level has been determined for the first time.

1. Introduction

In the region of the 1f$_{7/2}$ shell, the nickel isotopes provide a good choice for testing nuclear model theories. This choice is due to the approximate shell closure at ^{56}Ni with proton and neutron numbers $Z=N=28$, corresponding to the filling of the 1f$_{7/2}$ shell. Different models and interactions have been used to study the structure of Ni isotopes. A great deal of experimental work has also been reported for this nucleus by Carola and Ohnuma (1971), Hutten and Roberson (1973) and Pichevar *et al* (1974, 1976). The available experimental information has been summarised by Kim (1976). However, the lifetime of the level at 1747 keV has not been reported and the presence of a level at 1779 keV is uncertain (Pichevar *et al* 1974, 1976, Kim 1976). Therefore we have undertaken a study of the ^{59}Co(p, nγ)^{59}Ni reaction to obtain information about the various unknown parameters and to remove the existing discrepancies in the level scheme of ^{59}Ni.

2. Experimental procedure

A proton beam of energy 4.2 MeV was provided by the variable energy cyclotron at Chandigarh. A spectroscopically pure thin ($\simeq$100 keV) ^{59}Co target on a thick backing of Ni foil was exposed to the proton beam at an angle of 45° to ensure identical geometries from 0–90°. Angular distributions were measured with a 50 cm^3 true coaxial Ge(Li) detector with a resolution of about 2 keV for the 1.33 MeV ^{60}Co line. The gamma-ray spectra were taken in 15° steps between 0 and 90°. The signal from the Ge(Li) detector was analysed using an ND-100, 4096-channel pulse-height analyser. A typical gamma-ray spectrum at 90° with respect to the incident beam direction is shown in figure 1. The energies of different peaks in the spectrum at 90° were calculated using the computer code SAMPO written by Routti and Prussian (1969). Branching ratios for the observed transitions were extracted from the singles spectrum obtained with the detector at 60° with respect to the beam direction to avoid the effect of angular distribuition.

0305-4616/83/010091 + 07 $02.25

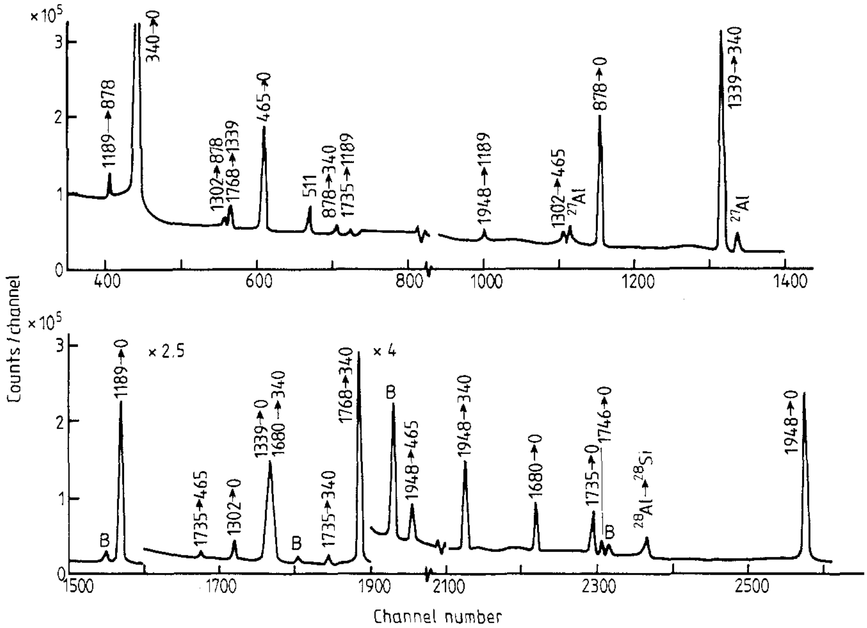

Figure 1. Gamma-ray spectra at 90° with respect to the 4.2 MeV proton beam.

3. Analysis for lifetimes

Mean lifetimes were determined for many transitions using the DSA method from the singles gamma-ray spectra obtained at different angles between 0 and 90°. The centroids of the photopeaks were determined with the aid of a first-moment analysis. The centroids of a few photopeaks at different angles are plotted against cos θ as shown in figure 2. The straight lines in the figure represent a least-squares fit to the experimental data. The experimental value of $F(\tau)$ was calculated from the slope of this straight line. As the beam energy was close to threshold for most of the levels the recoiling ^{59}Ni nucleus could move only in a small forward cone. At these low bombarding energies, the (p, n) reaction is predominantly a compound nucleus one; therefore with a thick target this would lead to a symmetric neutron angular distribution about 90° in the CM system, resulting in an average neutron velocity in the beam direction of zero. It is therefore safe to assume that the mean forward recoil velocity of the ^{59}Ni nuclei is just the CM velocity.

Theoretically the quantity $F(\tau)$ as a function of mean nuclear lifetime was calculated for ^{59}Ni recoiling in Ni backing using the stopping power theory of Lindhard *et al* (1963) taking the Blaugrund (1966) approximation for the effect of nuclear scattering into account. In these calculations, the target thickness was taken into account explicitly by dividing the target into ten layers. The effect of cascade feeding was taken into account by the method of Hoffman *et al* (1973).

4. Analysis of angular distribution data

The angular distributions of the 1428 and 429 keV gamma rays were normalised with respect to the isotropic 465 keV gamma ray from the 465 keV level with well known spin

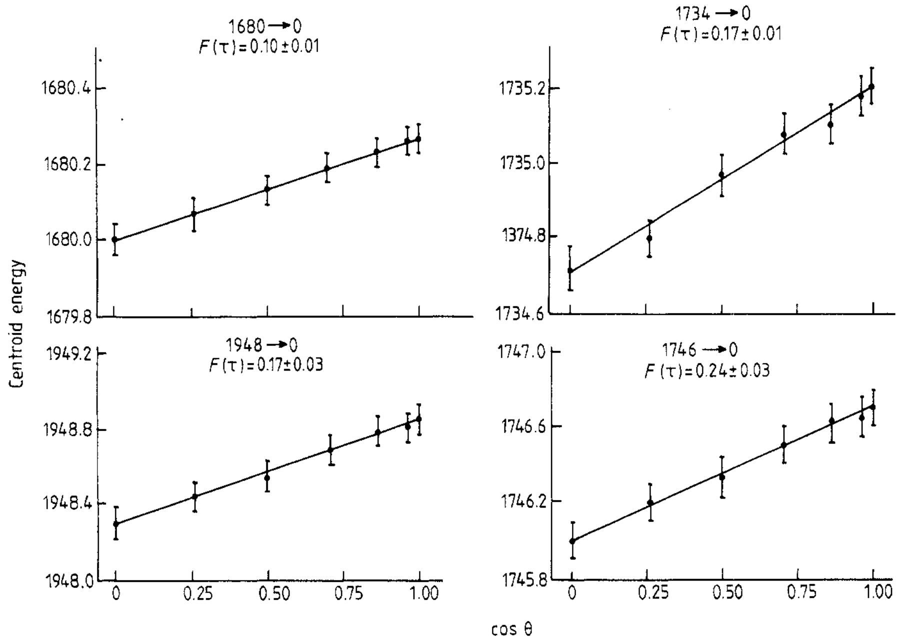

Figure 2. Linear fits to the energy dependence of a few transitions as a function cos θ. The slope of the straight line is proportional to the average attenuation factor $F(\tau)$.

$J=\frac{1}{2}$. Theoretical angular distributions were calculated according to the Hauser–Feshbach theory (1952) of nuclear reactions using the computer code CINDY written by Sheldon and Rogers (1973). The optical potential parameters of Perey and Buck (1962) for neutrons and Perey (1963) for protons were used. The χ^2 fits were made between experimental and theoretical angular distributions as shown in figures 3 and 4. The 0.1% confidence limit was used to exclude unacceptable fits. The errors in the mixing ratios correspond to the value $\chi^2_{\min} + (\chi^2_{\min}/N)$, where N denotes the number of degrees of freedom as described by Ezell and Scott (1974). The sign convention used for the mixing ratios is that of Rose and Brink (1967).

5. Results and discussion

The decay modes of excited states in ^{59}Ni observed in the present work are shown in figure 5. A 1779 keV gamma ray present in the spectrum was assigned by earlier workers as being due to the transition from the 1779 keV level to the ground state. No other branch from this level was reported. However, we found that this gamma ray was due entirely to the background peak from the 2.24 min activity of ^{28}Al produced through the (n, γ) reaction from the detector casing. This gamma ray was present even when we replaced the cobalt target by carbon or tantalum. Therefore the possibility of the level at 1779 keV is ruled out.

The excitation energies, level lifetimes and the results available in the literature are given in table 1. The errors in the lifetimes represent only the errors due to the experimental measurement of $F(\tau)$. The error due to the uncertainty (up to 20%) in the stopping power theory has not been included in the results. The present lifetime measurements are in

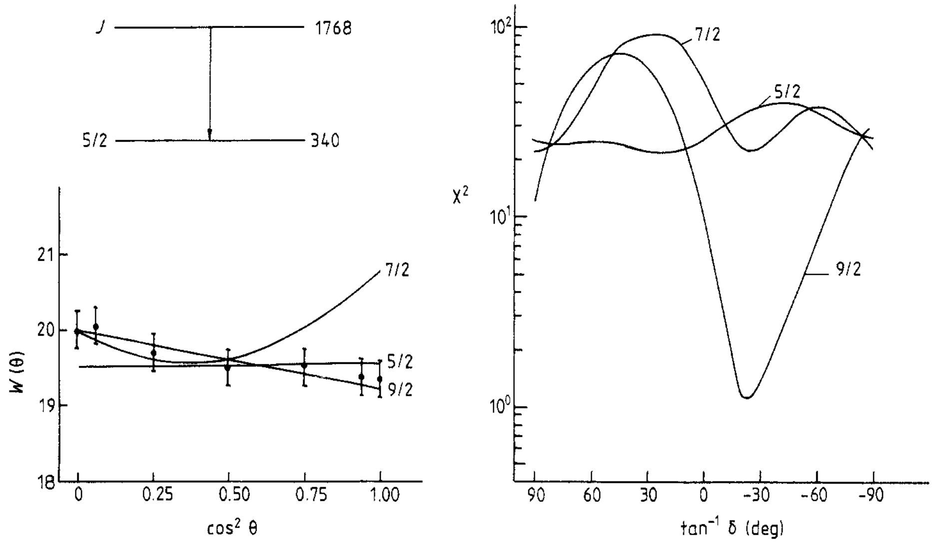

Figure 3. χ^2 curve and angular distribution of the 1768–340 keV transition in ^{59}Ni.

general agreement with earlier results within experimental errors. However, the lifetime of the 1746 keV state is measured for the first time and the present value of τ for the 1302 keV state is more in agreement with the value reported by Hutten and Roberson (1973) than with the value reported by Pichevar *et al* (1974, 1976).

Table 2 shows the measured multipole mixing ratios and transition probabilities B(E2) and B(M1) of two gamma transitions from the 1768 keV level. The 1768–340 keV transition is reported as a pure M3 transition by Pichevar *et al* (1976) from the results of

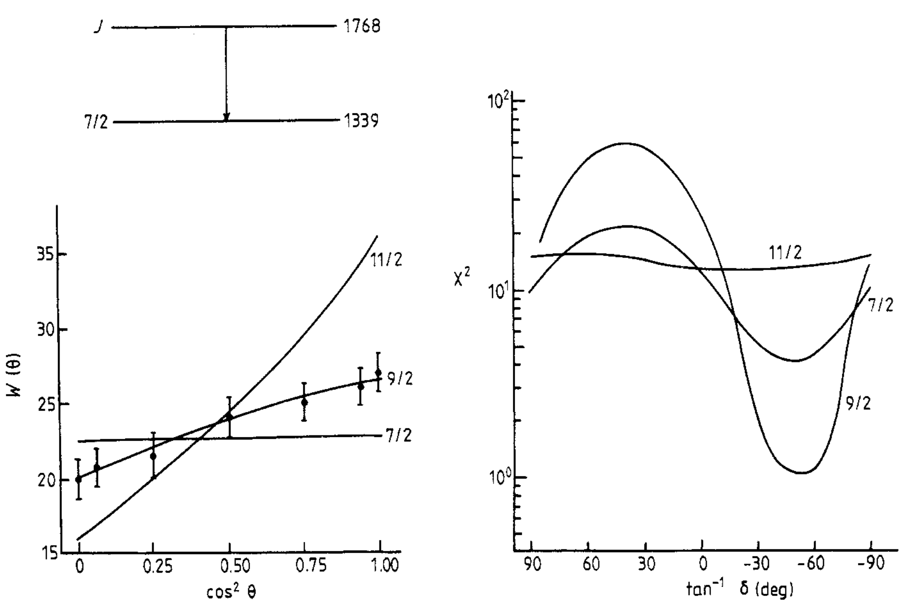

Figure 4. χ^2 curve and angular distribution of the 1768–1339 keV transition in ^{59}Ni.

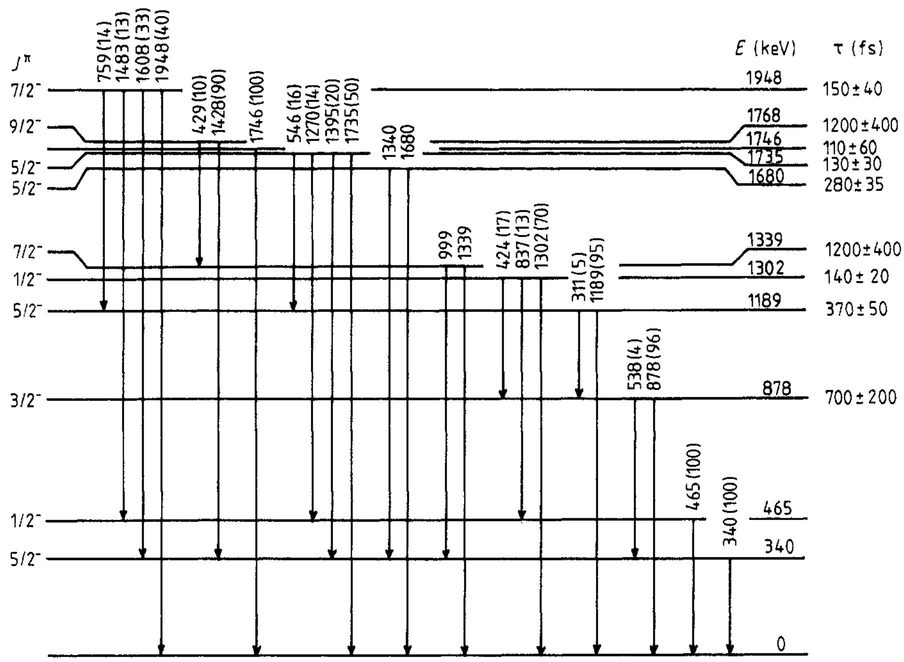

Figure 5. Decay scheme of ^{59}Ni. The energies are given in keV. The percentage branching ratios are given in parentheses. Uncertainties in the gamma-ray energies are less than 1 keV and in the branching ratios are within 10%. Lifetimes are given on the extreme right of the figure. The spin–parities of the levels given on the extreme left of the figure are from *Nuclear Data Sheets.*

their angular distribution measurement (see their table 3), but they have mentioned in the text that it could be a pure E2 transition on the basis of their DCO measurement (see their table 2). Our measurements indicate a good percentage of E2 mixing, in agreement with the DCO measurements of Pichevar *et al.* The 1768–1339 keV transition is almost pure M1 according to the measurements of Pichevar *et al* while our measurements predict an almost equal percentage of E2 mixing.

Table 1. Energies and lifetimes of various levels in ^{59}Ni.

			Lifetime (fs)		
E_x (keV)	E (keV)	$F(\tau)$	Present	Hutten and Roberson (1973)	Pichevar *et al* (1974, 1976)
878.0 ± 0.3	878.0	0.05(2)	700 ± 200	620 ± 120	700 ± 80
1189.0 ± 0.3	1189.0	0.08(1)	370 ± 50	440 ± 70	375 ± 30
1302.0 ± 0.2	1302.0	0.19(3)	140 ± 20	180 ± 20	265 ± 25
1339.5 ± 1.0	999.2	0.02(1)	1200 ± 400	>1000	1630 ± 250
1680.5 ± 0.5	1680.5	0.10(1)	280 ± 35	—	290 ± 15
1734.5 ± 0.2	1734.5	0.20(3)	130 ± 30	180 ± 40	172 ± 25
1746.1 ± 0.7	1746.1	0.23(7)	110 ± 60	—	—
1768.0 ± 0.9	1428.2	0.02(1)	1200 ± 400	>1000	815 ± 100
1948.1 ± 0.5	1948.1	0.18(4)	150 ± 40	200 ± 60	190 ± 20

Table 2. Multipole mixing ratios, B(E2) and B(M1), for gamma transitions.

E_i (keV)	E_f (keV)	A_2	A_4	Mixing ratio: Present	Mixing ratio: Pichevar *et al* (1974, 1976)	B(E2) (Wu)	B(M1) ($\times 10^{-3}$ Wu)
1768($\frac{9}{2}$)	340($\frac{5}{2}$)	-0.026 ± 0.004	0.009 ± 0.004	-0.36 ± 0.47	∞	6.7 ± 3.0	—
	1339($\frac{7}{2}$)	0.201 ± 0.013	0.007 ± 0.016	-1.28 ± 0.15	-0.03 ± 0.07	213.0 ± 32.3	11 ± 3

Recently, several positive- and negative-parity rotational bands in $1f_{7/2}$ nuclei have been predicted by Kasagi and Ohnuma (1978), Styczen *et al* (1976) and Dhar *et al* (1977). The linear variation of the excitation energies of the levels at 878 keV ($\frac{3}{2}^-$), 1189 keV ($\frac{5}{2}^-$), 1339 keV ($\frac{7}{2}^-$) and 1768 keV ($\frac{9}{2}^-$) in ^{59}Ni against their $J(J+1)$ values suggests the possibility of a rotational ($K^\pi = \frac{3}{2}^-$) band of states in this nucleus. The 1768 keV state, being a member of this rotational band, is likely to exhibit enhanced E2 rates for gamma transitions from this level. Thus the present experimental results seem to be more justified.

Acknowledgments

The authors wish to express their thanks to Professor H S Hans for encouragement and useful discussions during the course of this work and to the accelerator crew for their cooperation in running the machine.

References

Blaugrund A E 1966 *Nucl. Phys.* **88** 501–12
Carola T P G and Ohnuma H 1971 *Nucl. Phys.* A **165** 259–76
Dhar A K, Kulkarni D R and Bhatt K H 1977 *Nucl. Phys.* A **285** 93–108
Ezell R L and Scott H L 1974 *Nucl. Phys.* A **218** 470–94
Hauser W H and Feshbach H 1952 *Phys. Rev.* **87** 366–73
Hoffman E H, Van Patter I M, Sarantites D G and Barker J H 1973 *Nucl. Instrum. Methods* **109** 3–11
Hutten J D and Roberson N R 1973 *Nucl. Phys.* A **206** 403–16
Lindhard J, Scharff M and Schiøtt H E 1963 *K. Danske Vidensk. Selsk., Mat.-Fys. Meddr.* **33** no 14
Kasagi J and Ohnuma H 1978 *J. Phys. Soc. Japan* **45** 1099–110
Kim H J 1976 *Nuclear Data Sheets* **17** 485
Perey F G 1963 *Phys. Rev.* **131** 745–63
Perey F G and Buck B 1962 *Nucl. Phys.* **32** 353–80
Pichevar M, Delaunay J and Delaunay B 1974 *Nucl. Phys.* A **224** 34–44
Pichevar M, Delaunay J, Delaunay B, Kim H J, El Masri Y and Vervier J 1976 *Nucl. Phys.* A **264** 132–50
Rose H J and Brink D M 1967 *Rev. Mod. Phys.* **39** 306–47
Routti J T and Prussian S G 1969 *Lawrence Radiation Laboratory, Berkeley, California, Report UCRL–19452*
Sheldon E and Rogers V C 1973 *Comput. Phys. Commun.* **6** 99–131
Styczen J, Chevallier J, Haas B, Schulz N, Taras P and Toulemonde M 1976 *Nucl. Phys.* A **262** 317–29