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GAMMA-RAY BRANCHING OF ENERGY LEVELS IN ^{24}Mg FROM THE ^{23}Na (p, γ) ^{24}Mg REACTION

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Abstract: The gamma-ray spectra at six ^{23}Na(p, γ)^{24}Mg resonances in the E_p = 300-750 keV region have been investigated with scintillation spectrometers. From single spectra, coincidence spectra and sum-coincidence spectra the gamma-ray branchings of the resonance levels and of eighteen lower ^{24}Mg levels were obtained. At most resonances a 1 63 MeV gamma ray was observed, from which the relative intensity of the ^{23}Na(p, α_1)^{20}Ne decay could be found

Thick target gamma-ray yields have been measured from which the resonance strengths were obtained

1. Introduction

The energies of eight ^{23}Na(p, γ)^{24}Mg resonances in the E_p = 250-750 keV region (E_x = 11.9-12.4 MeV) are known quite accurately [1-3]. In the present experiment the decay of the resonance levels at E_p = 308, 511, 591, 676,738 and 743 keV is investigated. The resonances at E_p = 251 and 374 keV are omitted because of their very low gamma-ray yield.

The lower levels in ^{24}Mg are known from the work of Hinds and Middleton [4]. They observed 40 levels below 11.9 MeV from the ^{23}Na(^{3}He, d)^{24}Mg reaction by high resolution magnetic analysis. This work completely covers the energy range below the investigated resonance levels, which greatly facilitated the analysis of our measured gamma-ray spectra.

The spins and parities of the lowest six levels are known from other experiments. In sect. 4 these experiments are quoted and the information available from other ^{23}Na(p, γ)^{24}Mg measurements is compared with the results from the present experiment.

2. Experimental Technique

Protons from a high frequency ion source were accelerated in the Utrecht Cockroft-Walton generator and were used to bombard thin targets containing sodium. The targets were prepared by evaporation of sodium chloride and sodium bromide in vacuo onto $\frac{1}{2}$ mm copper backings.

The sodium bromide targets were not very good, although they yield no other resonances than those of sodium. It was found that the resonances had a long "tail" at the high-energy side, caused by an uneven distribution of sodium bromide on the backing. Careful polishing of the backing did not decrease the tails much. For sodium chloride targets, however, this treatment proved to be successful, such that the resonances at 738 and 743 keV could be resolved almost completely. The ^{35,37}Cl(p, γ)^{36,38}A resonances [5]) are relatively weak. Even at the 738 and 743 keV resonances, which are quite close to known chlorine resonances, the chlorine contributions to the observed gamma spectra were unobservably weak. Another advantage of the sodium chloride targets is the fact that they can be stored for some weeks in a vacuum dry-box without apparent deterioration. This proved to be impossible with sodium bromide targets. The maximum beam power that water cooled sodium chloride and bromide targets can stand with a 6 mm^2 beam spot is about 15 W.

Single gamma-ray spectra were taken at all resonances with a 10.2 cm $\times$ 10.2 cm NaI crystal at an angle of $\vartheta = 55°$ to the proton beam and at distances of 20 and 100 mm between target and crystal; the latter diminished the effect of sum pulses. The spectra were recorded on a R.C.L. 256-channel analyser. At all resonances low energy spectra were also taken with increased amplifier gain.

At every resonance an average of six coincidence spectra has been taken using an additional 10.2 cm crystal. The crystals were put at angles of $\vartheta = +85°$ and $-85°$ to the proton beam at a distance of 40 mm from target to crystal. A coincidence circuit was used with a resolving time of $2\tau = 0.8$ μsec. The method used to analyse the complicated spectra is about the same as described in ref. [6]).

Sum-coincidence spectra [7]) were also taken at every resonance with the sum-channel set at full energy (E_x) and at reduced energy ($E_x - 1.37$ MeV), respectively. The measurements at full energy were sometimes useful to obtain low upper limits for possible ground-state transitions. A sum-coincidence spectrum, in combination with the spectrum coincident with the gamma de-exciting the first level, provides a direct method to measure branching ratios of lower levels. Another advantage of the sum-coincidence measurements is the high resolution which can be obtained. It amounted to a full width at half maximum of about 3 % for a 10 MeV photopeak. The sum spectra at reduced energy give the intensity of the gamma transitions to the first excited state, but these spectra are usually complicated by strong ground-state cascades.

The presence or absence of a ground-state transition γ_0 is a valuable argument for the spin and parity assignment of a resonance level. A weak γ_0, however, may be obscured by sum effects from strong two-step cascades. To get rid of these sum effects one can measure the intensity of γ_0 (including sum effects) as a function of the target-to-crystal distance [8]). The ratio of γ_0 (including sum effects) to any strong line in the gamma spectrum, plotted as a function of the detection efficiency (including solid angle) then gives a straight line, which can be extrapolated to zero efficiency (infinite distance) to yield the true intensity ratio. The relation between efficiency and distance has been measured at the $E_p = 773$ keV $^{27}Al(p, \gamma)^{28}Si$ resonance which shows a strong ground-state transition and relatively weak two-step cascades.

The method is based on the fact that the ratio of the efficiencies for two gamma rays of different energy is independent of the target-to-crystal distance. This has been tested experimentally for gamma rays in the 1-13 MeV region and for distances between 40 mm and 110 mm.

3. Results

3 1. YIELDS

In fig. 1 the gamma-ray yield is shown as a function of the proton energy using a sodium chloride target, with a 3-13 MeV discriminator channel.

Indicated are also the resonances due to the reactions $^{35}Cl(p, \gamma)^{36}A$ and $^{37}Cl(p, \gamma)^{38}A$. The proton energy was determined by measuring the field of the 90° analysing magnet with a proton resonance flux meter.

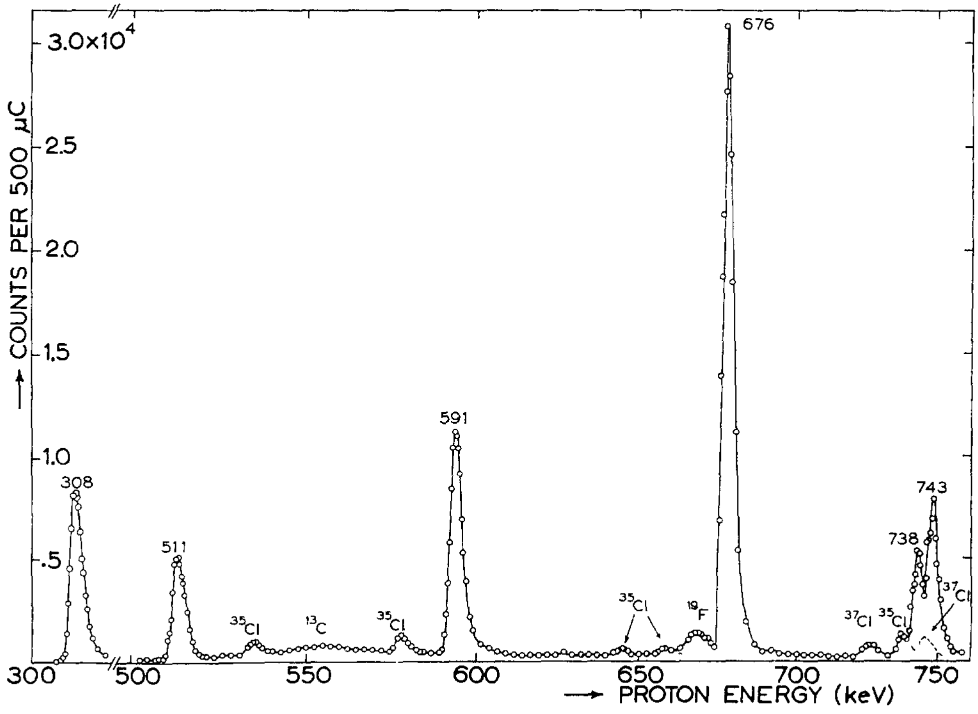

Fig. 1. Yield of the $^{23}Na(p, \gamma)^{24}Mg$ reaction in the $E_p = 300$-750 keV region as a function of the proton energy. Target NaCl, discriminator channel 3-13 MeV, distance target to crystal 20 mm, $\vartheta = 55°$.

The resonance strengths $\omega\gamma = (2J_r+1)\Gamma_p\Gamma_\gamma/\Gamma_t$ have been calculated from the thick target yields, see refs. [21, 22]). The results are given in table 1.

TABLE 1

Resonance strengths of ^{23}Na(p, γ)^{24}Mg resonances

Resonance energy (keV)	$\omega\gamma$ (eV)	Resonance energy (keV)	$\omega\gamma$ (eV)
308	0 36±0 09	676	2.0 ±0.5
511	0 30±0 08	738	0 34±0 09
591	0 69±0 17	743	0 45±0 11

3.2. GROUND-STATE TRANSITIONS

At all resonances the relative intensity of possible ground-state transitions has been measured with the method outlined in sect. 2. The results are presented in fig. 2. The 511 keV resonance shows a moderately strong γ_0, a weak γ_0 is present at the 308, 591 and 743 keV resonances, and no detectable γ_0 is present at the 676 and 738 keV resonances (intensity < 0.3 %).

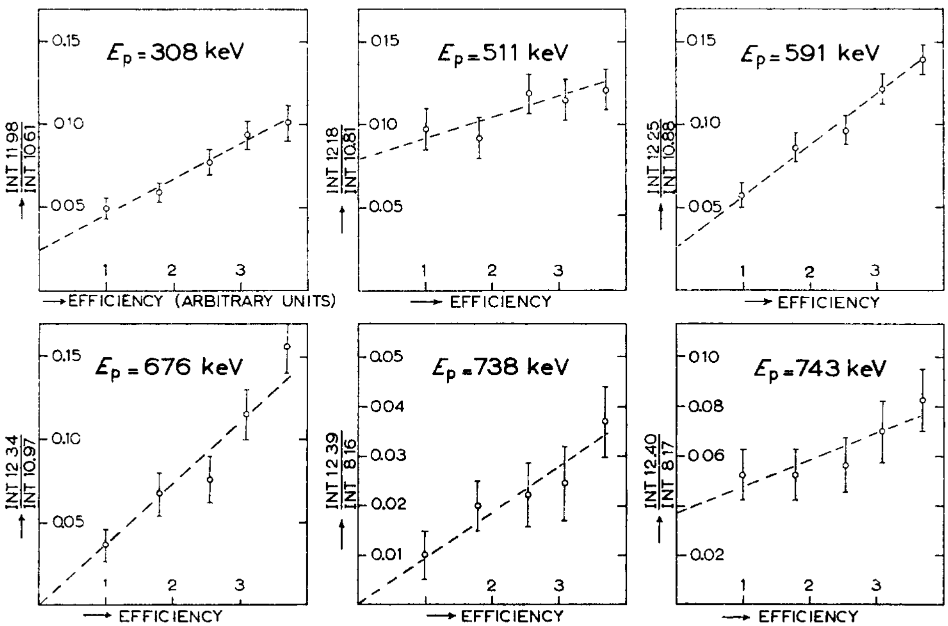

Fig. 2. Relative intensities of the ground-state transitions (including sum effects) as a function of the detection efficiency.

3.3. THE 308 keV RESONANCE

A single spectrum is given in fig. 3. This spectrum was taken at a distance of 100 mm to reduce sum effects.

The observed gamma rays are listed in table 2. In this and following tables the intensity of the 1.37 MeV gamma ray has been put equal to 100.

TABLE 2

Gamma rays observed at the $E_p = 308$ keV resonance

E_γ [a]) (MeV)	Relative intensity	Method of observation [b])	E_γ [a]) (MeV)	Relative intensity	Method of observation [b])
11.98	1.5±0.6	SSDV	(5.22)	<0.7	SCS
10.61	64 ±7	SS	4.63±0.07	2.0±1.0	CS
10.0 ±0.2	1.1±0.4	SCS	4.23	70 ±7	SS
(8.86)	<0.6	CSI	3.83±0.03	12 ±2	CS
8.7 ±0.1	3.0±0.6	CS	3.50±0.05	4.0±1.0	CS
8.44	4.0±1.0	CSI	3.12±0.03	7 ±1	CS
7.75	78 ±9	SS	2.86±0.02	16 ±2	SS
7.50±0.06	7 ±1	CS	2.00±0.02	2.4±1.0	SS
(7.07)	<0.4	CS	1.90±0.02	4.8±1.5	SS
6.77±0.04	13 ±2	SS	1.63±0.02	21 ±3	SS
6.0 ±0.1	2.7±1.4	CS	1.37	100	SS
5.81±0.06	0.8±0.6	CS			

[a]) For lines, which were used for energy calibration or for which only indirect evidence exists (see below) the values computed from known excitation energies were listed. No errors are indicated in these cases. For all other lines a weighted average has been taken of the energies measured in single and/or coincidence spectra. The energies of gamma transitions with intensities smaller than a given upper limit, are put in brackets. In the text and in the figures of spectra and decay schemes gamma-ray energies are quoted as following from the Hinds and Middleton [4]) excitation energies. These may differ slightly from the experimental results given in the tables.

[b]) In the column "Method of observation" SS stands for "single spectrum", SSDV for "single spectrum with distance variation" (see sect. 2), CS for "coincidence spectrum", SCS for "sum-coincidence spectrum", SSI for "single spectrum indirect" and CSI for "coincidence spectrum indirect". The latter two symbols apply to gamma rays, which have not been observed directly, but which have to be present to explain the presence and/or intensity of other gamma rays. Only that method is mentioned, which yields the energy and intensity of the gamma ray concerned most directly.

The decay scheme of the resonance level is shown in fig. 4. The intensities are normalized such that the sum of all primaries is 100. The sums of the intensities of gamma rays feeding and de-exciting a given level have been made equal by suitable averaging, if necessary. The energies of the levels indicated are those given by Hinds and Middleton [4]).

The emission of α particles to the first excited state of ^{20}Ne (indicated as α_1) can be deduced from the presence of a 1.63 MeV gamma ray in the single spectrum.

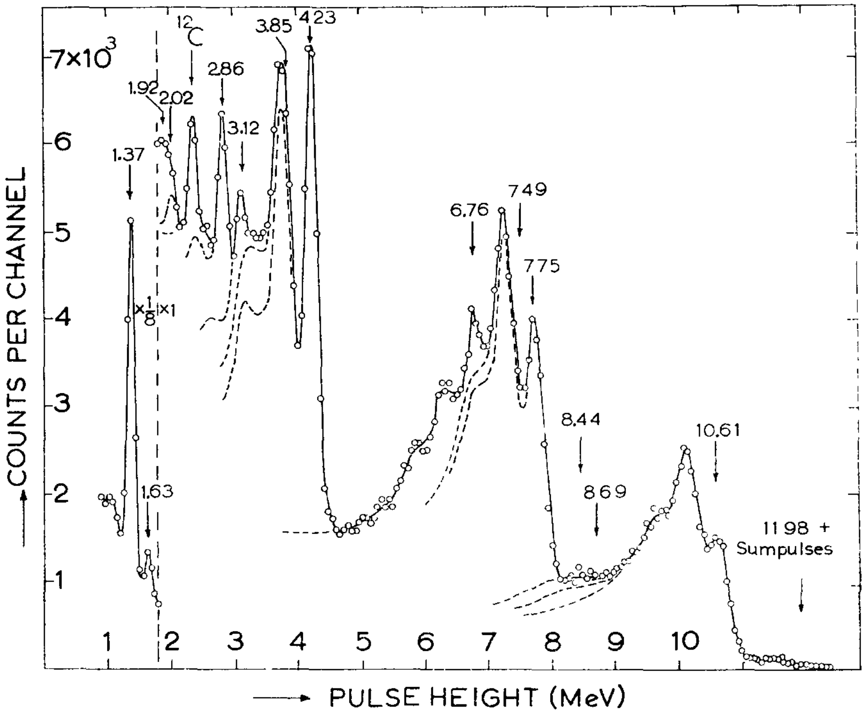

Fig 3 Single spectrum at the $E_p = 308$ keV resonance ($\vartheta = 55°$, distance = 100 mm).

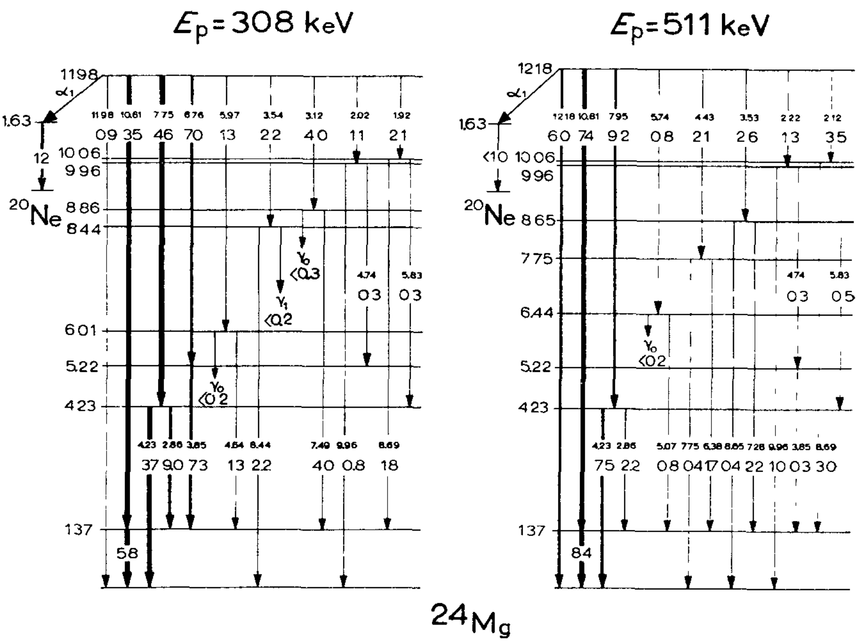

Fig 4 Decay schemes of the $^{23}Na(p, \gamma)^{24}Mg$ resonances at $E_p = 308$ and 511 keV

The gamma rays of 2.02 and 1.92 MeV which excite the 9.96 and 10.06 MeV levels, respectively, are seen more clearly in a single spectrum with increased amplifier gain. There is an uncertainty concerning the branching of the levels at 9.96, 10.03 and 10.06 MeV. The energies and intensities of the measured gamma rays make it probable that at this resonance only the 9.96 and 10.06 MeV levels are excited. The branchings of these two levels were determined by also using the information obtained at the 511 keV resonance.

In our work no excitation of the 7.75 MeV level was observed. The 7.75 MeV line observed in the single spectrum was explained as being a primary to the 4.23 MeV level, since the de-excitation of the 7.75 MeV level to the first excited state (see sect. 3.4 below) was not found in coincidence spectra. Recent measurements elsewhere † with a larger crystal (12.7 cm $\times$ 12.7 cm) have in fact shown that this 6.38 MeV line is present. Consideration of the intensity of the 4.23 MeV line in the spectrum coincident with the 1.37 MeV gamma ray shows that it is consistent to assume that this resonance does in fact have a 2 % branching to the 7.75 MeV level.

The level at 6.01 MeV is only excited at this resonance. This level has no detectable ground-state transition as follows from a sum-coincidence spectrum at full energy and a coincidence spectrum with the 5.97 MeV primary exciting this level.

3.4 THE 511 keV RESONANCE

A single spectrum is given in fig. 5. It is characterized by a very strong transition to the first excited state. The peak at 1.88 MeV is due to accidental summing of 1.37 and 0.51 MeV gamma rays.

A coincidence spectrum with a 1.6-1.30 MeV channel is given in fig. 6.

In this spectrum several weak lines were observed not found in the single spectra. The peak at 10.81 MeV is only due to accidental pulses.

The 9.96 and 10.06 MeV levels are excited most clearly at this resonance. Coincidence measurements show that the 5.8 ± 0.1 MeV gamma ray is a doublet, partly the primary of the 6.44 MeV level, partly a 10.06 $\to$ 4.23 MeV transition. From sum-coincidence measurements and from coincidence measurements with a channel on the 5.8 MeV line it is found that the 6.40 ± 0.06 MeV gamma ray is not the ground-state transition of the 6.44 MeV level, but that it has to be explained as a 7.75 $\to$ 1.37 MeV transition. The 8.67 ± 0.07 MeV gamma ray is partly a 10.06 $\to$ 1.37 MeV transition, and partly it de-excites the 8.65 MeV level to the ground-state.

The observed gamma rays are listed in table 3 and the decay scheme is given in fig. 4.

† T. Graff av Øhr and R. Nordhagen, University of Oslo, private communication.

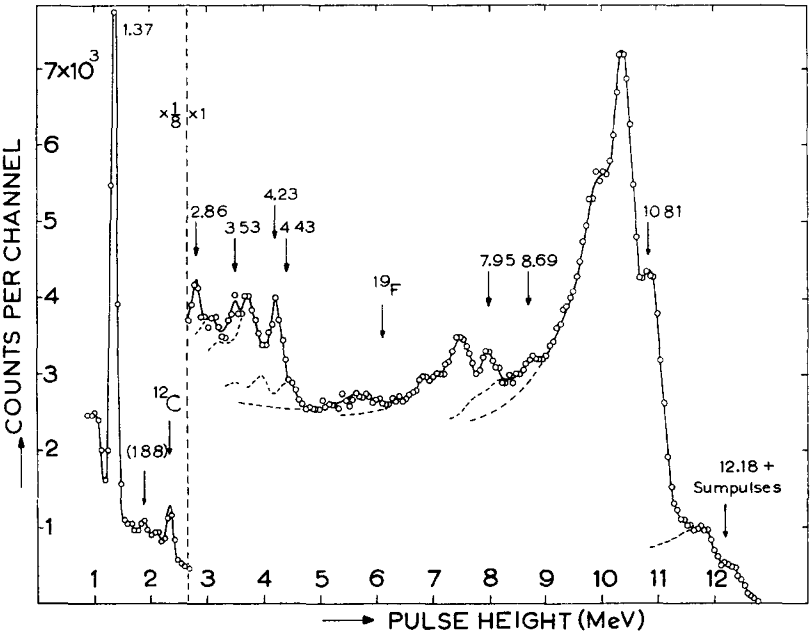

Fig. 5. Single spectrum at the $E_p = 511$ keV resonance ($\vartheta = 55°$, distance 20 mm)

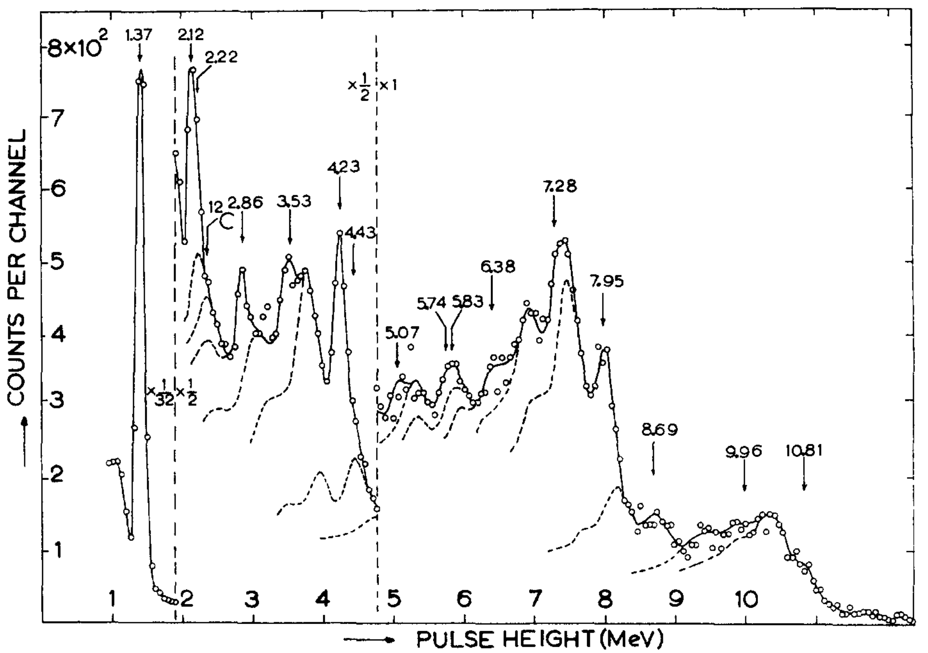

Fig. 6. Coincidence spectrum with a 1.6-13 0 MeV channel at the $E_p = 511$ keV resonance.

TABLE 3

Gamma rays observed at the E_p = 511 keV resonance

E_γ (MeV)	Relative intensity	Method of observation[a])	E_γ (MeV)	Relative intensity	Method of observation[a])
12.18	8 ±2	SSDV	4.75±0.06	0.4±0.2	CS
10.81	97 ±16	SS	4.44±0.04	3.0±0.5	SS
10.0 ±0.1	1.4± 0.4	CS	4.23	10 ±1	SS
8.67±0.07	4.5± 1.0	CS	3.85	0.4±0.2	CSI
7.95	12 ± 2	SS	3.49±0.04	3.0±0.6	CS
7.65±0.15	0.5± 0.2	SCS	2.86±0.02	2.8±0.4	SS
7.3 ±0.1	2.9± 0.8	CS	2.24±0.05	1.4±0.5	CS
6.40±0.06	2.2± 0.4	CS	2.12±0.02	3.8±0.7	CS
5.8 ±0.1	1.8± 0.7	CS	(1.63)	<1.0	SS
5.03±0.07	1.1± 0.5	CS	1.37	100	SS

[a]) For the meaning of the symbols used see sect. 3.3.

3.5. THE 591 keV RESONANCE

A single spectrum is shown in fig. 7. The observed gamma rays are listed in table 4 and the decay scheme is given in fig. 8.

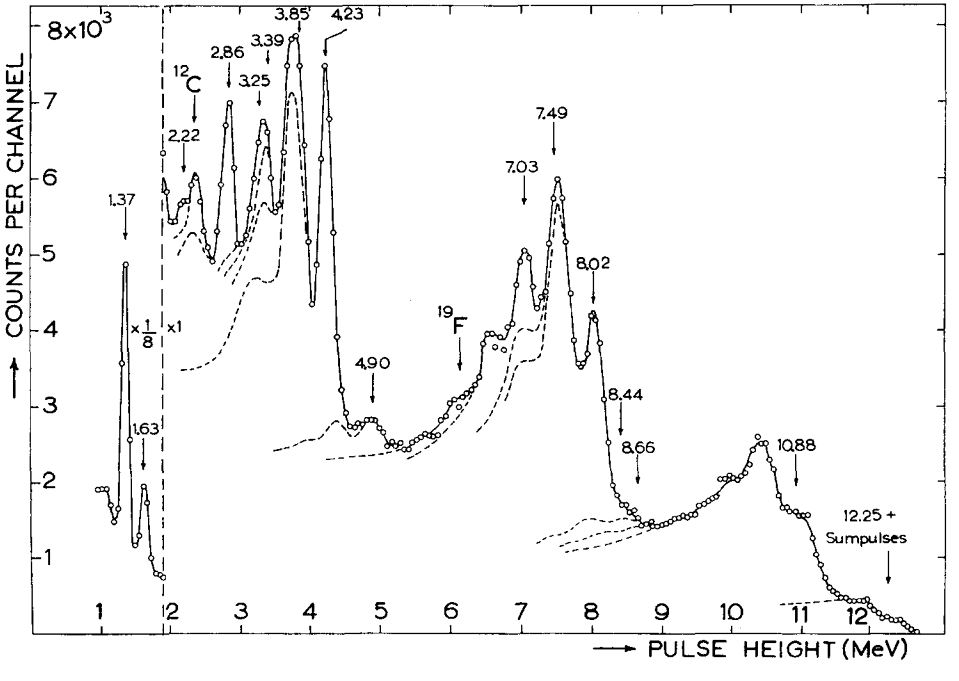

Fig. 7. Single spectrum at the E_p = 591 keV resonance (ϑ = 55°, distance 20 mm).

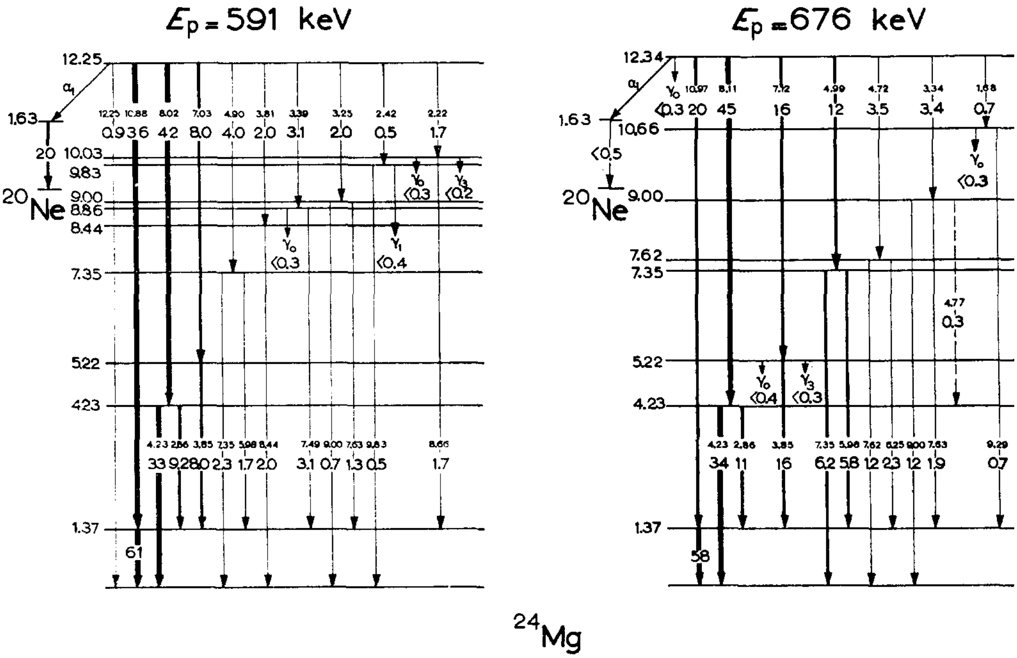

Fig. 8. Decay schemes of the $^{23}Na(p, \gamma)^{24}Mg$ resonances at E_p = 591 and 676 keV.

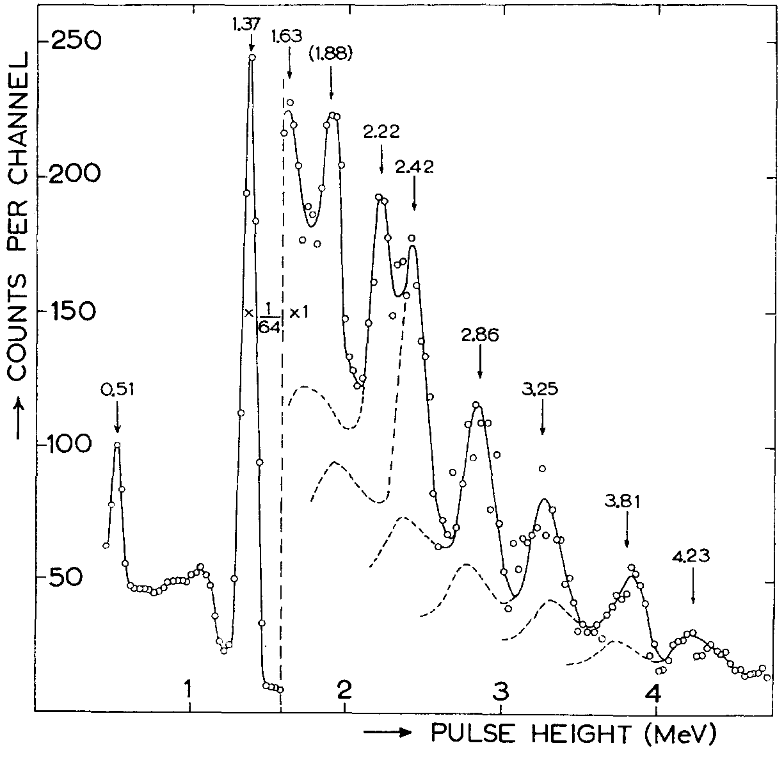

Fig. 9. Coincidence spectrum with 8.5-13.0 MeV channel at E_p = 591 keV.

TABLE 4

Gamma rays observed at the E_p = 591 keV resonance

E_γ (MeV)	Relative intensity	Method of observation[a])	E_γ (MeV)	Relative intensity	Method of observation[a])
12 25	1.8± 1 0	SSDV	6.0 ±0 1	3 1±1.6	CS
10 88	70 ±13	SS	(5 80)	<0.4	CS
(10 03)	<0 6	SCS	4 92±0 04	8 ±2	SS
9 83	1 0± 0 3	CSI	(4 81)	<0 4	CS
9 00	1.3± 0 5	CSI	4.23	66 ±7	SS
(8 86)	<0 5	CSI	3 84±0.04	20 ±4	CS
8 69	3.0± 1 5	CSI	3 38±0 04	6 ±2	CS
8 40±0 06	4 0± 1.3	SCS	3 26±0 04	4 0±1.6	CS
8 02	87 ±10	SS	2 86±0.02	18 ±2	SS
7 63	2 6± 1 3	CSI	2 42±0 04	1 0±0 3	CS
7 49	6 ± 2	CSI	2 21±0.03	3 0±1 5	CS
7 38±0.06	4.7± 1 6	CS	1 63±0.02	40 ±5	SS
7.02±0 04	16 ± 3	SS	1 37	100	SS

[a]) For the meaning of the symbols used see sect 3.3.

Fig. 9 gives the coincidence spectrum with a 8.5-13.0 MeV channel. In this spectrum several lines were observed, hardly visible in single spectra. The 4.23 and 1.63 MeV lines are due to accidental pulses. The 1.88 MeV line is explained by sum pulses of 1.37+0.51 MeV. The 2.86 MeV line originates from 8.03+1.37 MeV sum pulses in the channel. A small contribution to the 3.81 MeV line is due to sum pulses in the channel giving 3.85 MeV.

Coincidence measurements yield, that the gamma ray of 8.40±0.06 MeV has to be regarded as a ground-state transition from the 8.44 MeV level, whereas the 9.83 MeV level has no detectable transition to the first excited state.

At this resonance most probably only the 10.03 MeV level is excited. This follows from the facts that the energy of the primary is determined as 2.21±0.03 MeV and that no decay to the 5.22 and 4.23 MeV levels could be detected, which should have been present, if the 9.96 and/or 10.06 MeV levels were excited, according to the information obtained at E_p = 511 and 308 keV.

This resonance has a weak ground-state transition and decays with emission of α particles to the first excited state (1.63 MeV) and to the ground state [9]) of ^{20}Ne.

3.6. THE 676 keV RESONANCE

This is the strongest resonance in the investigated region. In fig. 10 the single spectrum is given. One of the coincidence spectra is shown in fig. 11. The peaks marked with (s) originate from sum pulses of the strong three-step cascades through the first excited state.

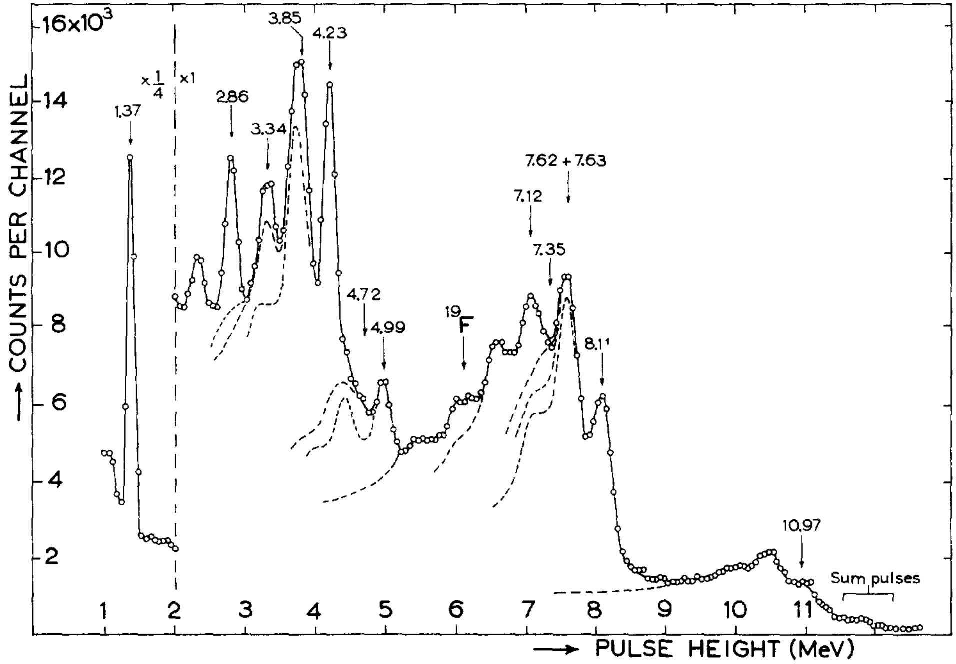

Fig. 10. Single spectrum at the $E_p = 676$ keV resonance ($\vartheta = 55°$, distance 20 mm).

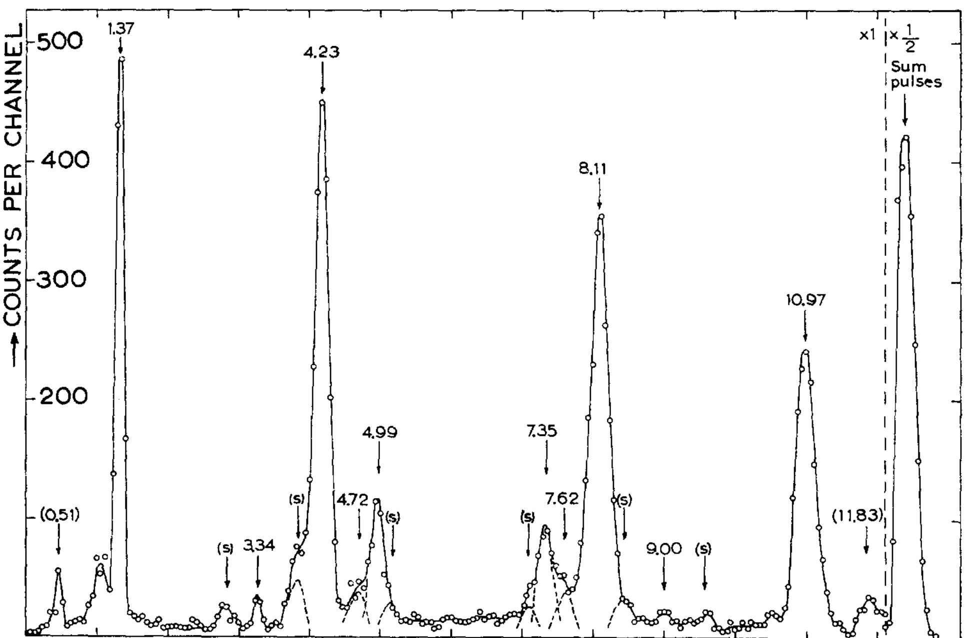

Fig. 11. Sum-coincidence spectrum at $E_p = 676$ keV. Sum channel 12.2–12.6 MeV.

This resonance was especially useful to obtain the branchings of the 5.22, 7.35, 9.00 and 10.66 MeV levels. The 9.00 MeV level has a possible transition to the 4.23 MeV level. No measurable ground-state transition is found, nor any sign of an α transition to ^{20}Ne(1). The 1.66±0.03 MeV gamma ray was only observed in a coincidence spectrum. The 7.6±0.1 MeV gamma ray has to be regarded partly as a ground-state transition, from the 7.62 MeV level, and partly as a transition from the 9.00 MeV level to the first excited state. The observed gamma rays are listed in table 5 and the decay scheme is given in fig. 8.

TABLE 5

Gamma rays observed at the E_p = 676 keV resonance

E_γ (MeV)	Relative intensity	Method of observation [a])	E_γ (MeV)	Relative intensity	Method of observation [a])
(12.34)	<0.7	SSDV	(5.22)	<0.9	CS
10.97	50 ± 9	SS	4 98±0.03	29 ±6	SS
(10.66)	<0.6	SCS	4.70±0.06	9 ±3	CS
9 3 ±0 1	1 7± 0.8	SCS	4.23	85 ±9	SS
9 00	3 0± 1.0	CSI	3.85±0 02	38 ±6	SS
8 11	118 ±15	SS	3 33±0.03	8 ±3	CS
7.6 ±0.1	8 ± 3	SCS	2.86±0 02	27 ±4	SS
7 35±0.05	15 ± 3	CS	1 66±0 03	1.8±0.6	CS
7 09±0 05	44 ± 7	SS	1.37	100	SS
6.25±0 10	6 ± 2	CS	(0 99)	<0.6	CS
5.99±0.04	14 ± 3	CS			

[a]) For the meaning of the symbols used see sect. 3.3.

3 7. THE 738 keV RESONANCE

A single spectrum is given in fig. 12.

Only at this resonance the level at 4.12 MeV is fed. This could be concluded from the peak at 2.8 MeV, which is too broad for a single gamma ray. The excessive width of this peak is most clearly seen in a single spectrum taken with increased amplifier gain.

Most probably the 10.06 MeV level is excited, although excitation of the 10.03 MeV level is not excluded. Remarkable is the very strong α_1 emission as concluded from the intensity of the 1.63 MeV gamma ray. A spectrum with increased amplifier gain has shown the existence of a strong 0.44 MeV line, which is due to the reaction ^{23}Na(p, p'). The observed gamma rays are listed in table 6 and the decay scheme is given in fig. 13.

3.8 THE 743 keV RESONANCE

Here the main transition from the resonance level occurs to the 4.23 MeV level as shown in fig. 14.

In fig. 15 a coincidence spectrum with a 8.7-13.0 MeV channel is given.

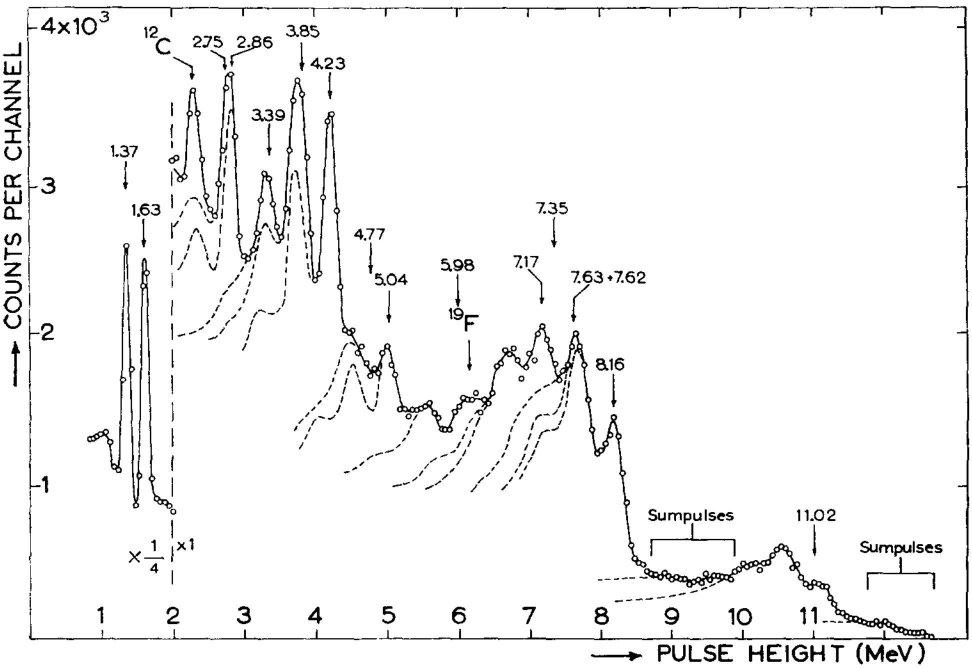

Fig. 12. Single spectrum at the $E_p = 738$ keV resonance ($\vartheta = 55°$, distance = 20 mm).

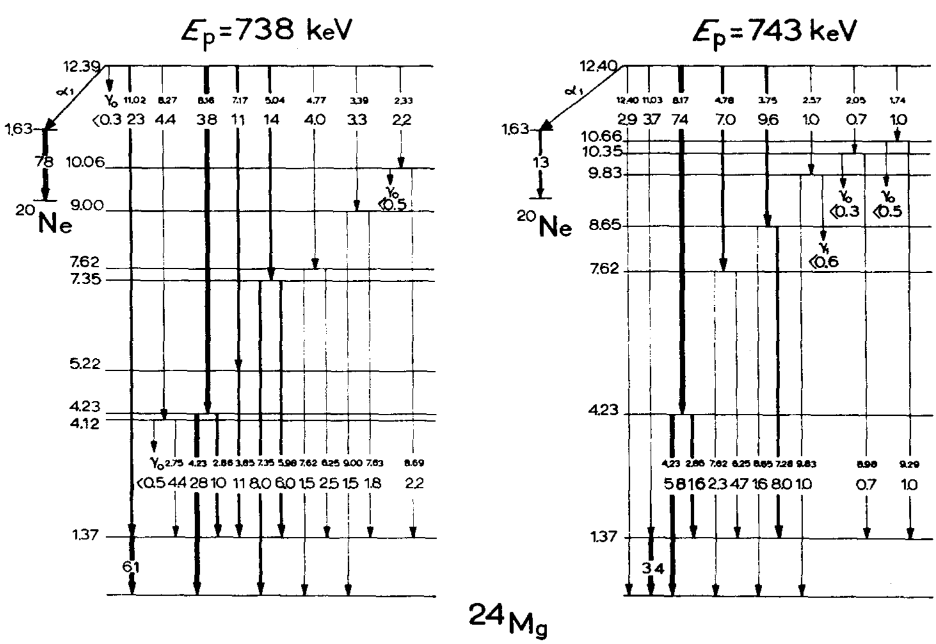

Fig. 13. Decay schemes of the ^{23}Na(p, γ)^{24}Mg resonances at $E_p = 738$ and 743 keV.

TABLE 6

Gamma rays observed at the E_p = 738 keV resonance

E_γ (MeV)	Relative intensity	Method of observation [a])	E_γ (MeV)	Relative intensity	Method of observation [a])
(12.39)	<0 5	SSDV	5 03±0.03	24 ±4	SS
11 02	40 ±6	SS	4.76±0 04	8 ±3	SS
(10 06)	<0 8	SCS	4 23	50 ±6	SS
9 0 ±0 1	2 6±1.3	SCS	(4 12)	<1 0	SS
8.69	3 8±1.5	CSI	3.84±0 02	19 ±3	SS
8 27	8 ±3	SSI	3.37±0.03	6 ±2	SS
8.16	66 ±8	SS	2 86±0 02	18 ±4	SS
7 6 ±0 1	6 ±3	SCS	2.75±0 05	8 ±3	SS
7 35±0 08	14 ±4	SCS	2 33±0 03	3.8±1 5	CS
7 18±0 04	21 ±4	SS	1 63±0.02	137 ±15	SS
6 25±0 06	4 0±2 0	CS	1 37	100	SS
6 03±0 08	12 ±3	SS	0 44±0.02	24 ±4	SS

[a]) For the meaning of the symbols used see sect. 3 3.

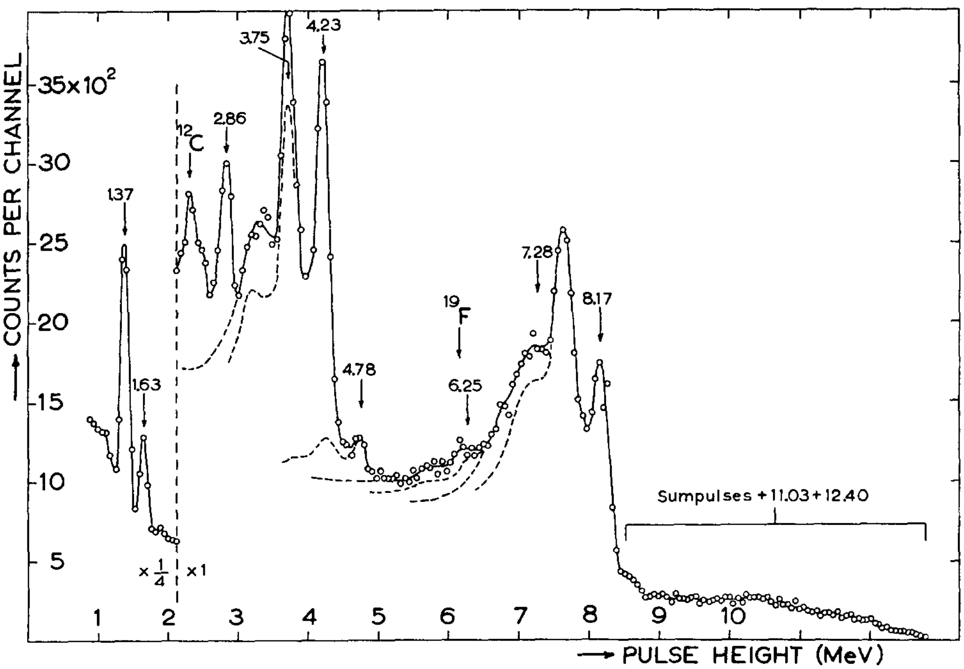

Fig. 14. Single spectrum at the E_p = 743 keV resonance (ϑ = 55°, distance = 20 mm)

This resonance forms an exception to the rule, that all resonances show a relatively strong transition to the first excited state. The existence of such a transition could be proved only by distance variation, from which also followed a weak ground-state transition. The resonance decays by α_1 emission to ^{20}Ne, and the strong 0.44 MeV line, seen in a low energy spectrum, is due to the reaction ^{23}Na(p, p').

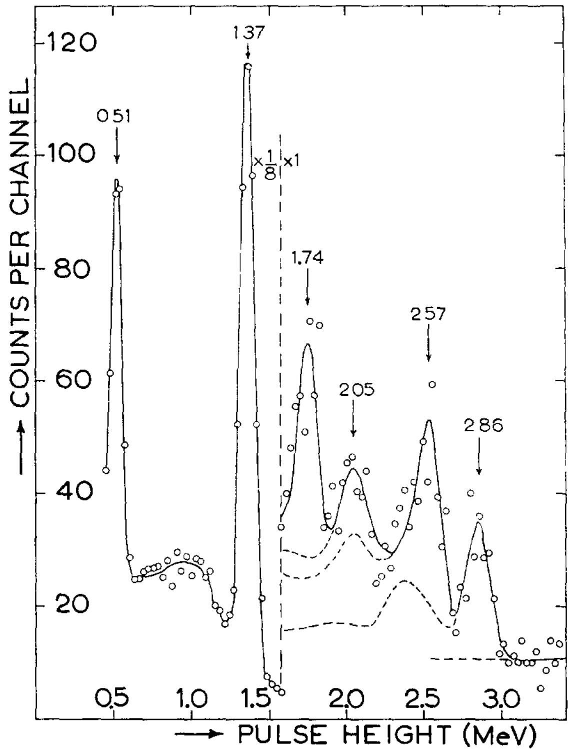

Fig 15 Coincidence spectrum with a 8.7–13.0 MeV channel at the E_p = 743 keV resonance

TABLE 7

Gamma rays observed at the E_p = 743 keV resonance

E_γ (MeV)	Relative intensity	Method of observation [a])	E_γ (MeV)	Relative intensity	Method of observation [a])
12.40	8 ± 2	SSDV	6 25±0 05	12 ± 3	CS
11.03	11 ± 4	SSDV	4 77±0 03	20 ± 4	SS
(10.66)	<1.2	SCS	4 23	148 ±18	SS
(10 35)	<0 7	SCS	3 75±0 02	25 ± 5	SS
9.83	3.0± 1 2	CSI	2 86±0 02	41 ± 6	SS
9.29	3 0± 1 3	CSI	2.54±0 03	3 0± 1 2	CS
8 98	1 8± 0 8	CSI	2 05±0 03	1 8± 0 8	CS
8 65	4 0± 2 5	CSI	1.74±0.03	3 0± 1 3	CS
(8.46)	<1.8	CSI	1 63±0 02	35 ±12	SS
8.17	210 ±30	SS	1 37	100	SS
7.62	6 ± 1	CSI	0 44±0 02	33 ± 5	SS
7.26±0 05	21 ± 5	CS			

[a]) For the meaning of the symbols used see sect. 3 3.

The 10.35 MeV level is excited at this resonance only.

Table 7 gives the observed gamma rays and fig. 13 shows the decay scheme. Coincidence measurements show that the 7.6 ± 0.1 MeV gamma ray has to be regarded as a mixture of a 7.62 MeV ground-state transition and a transition from the 9.00 MeV level to the first excited state.

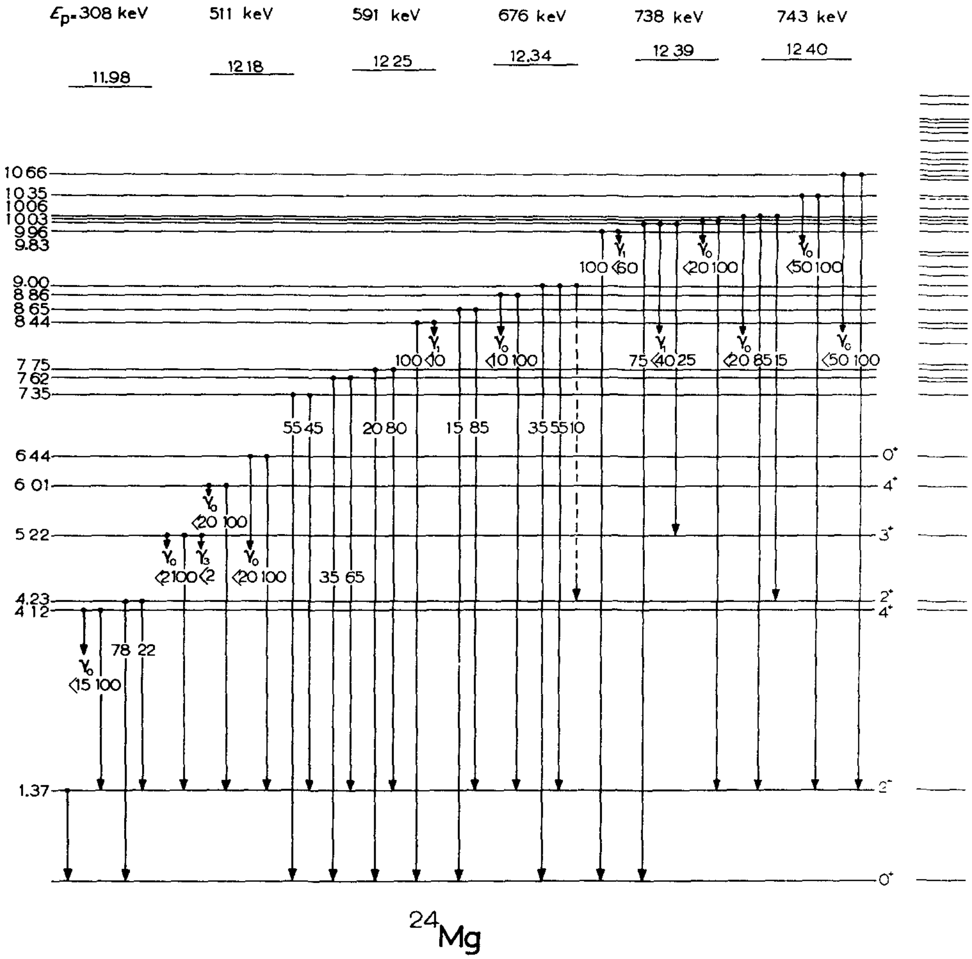

Fig. 16. Level scheme of ^{24}Mg. The excitation energies are those obtained by Hinds and Middleton [4]) All the levels they have observed are indicated at the right of this figure. The spins and parities are from refs [15, 16])

At this resonance the single quantum escape peak of the 4.23 MeV transition is too high, not by the presence of a 3.85 MeV gamma ray (decay of the 5.22 MeV level) as at all other resonances, but by the existence of a 3.75 MeV gamma ray, which is the primary exciting the 8.65 MeV level.

The resonance is especially useful to obtain the branching of the 7.62 MeV level.

4. Conclusions

The gamma ray spectrum at the 308 keV resonance has also been investigated by others [9-14]. They only observed the five or six strongest transitions with relative intensities not much different from those given in table 2. The relative intensities of the stronger lines found at the 511, 591 and 676 keV resonance check reasonably with those given in ref. [13].

Apparently, at all resonances the ground-state transition is weak or absent. Transitions to levels (1) (1.37 MeV) and (3) (4.23 MeV) are usually strong, and at many resonances also a strong transition is observed to level (4) (5.22 MeV). Levels (2) (4.12 MeV), (5) (6.01 MeV) and (6) (6.44 MeV) are weakly excited, each at one resonance only.

The lowest $T = 1$ level in ^{24}Mg, corresponding to the ^{24}Na ground state, is expected at an excitation energy of about 9.5 MeV. This estimate is obtained from a comparison [18] with ^{28}Si where the lowest $T = 1$ state has been located at 9.31 MeV (ref. [19]). No evidence has been found in the present work for strong transitions to ^{24}Mg states around 9.5 MeV.

The weighted averages of branching ratios of ^{24}Mg lower levels, obtained at different resonances, are presented in fig 16. The excitation energies are given as measured by Hinds and Middleton [4]). Spins and parities are from refs. [15, 16]. All levels decay to the ground state and/or first excited state, except for the 9 96 and 10.06 MeV levels which weakly decay also through levels (4) and (3), respectively. The branching ratio of level (3) : $(3 \rightarrow 0)/(3 \rightarrow 1) = 3.5 \pm 0.4$ agrees with the value 2.9 ± 0.5 given in ref. [17].

Some gamma-ray angular distributions and γ-γ angular correlations at the 308, 511, 591 and 676 keV resonances have been measured by Grant *et al.* [20]. The resulting resonance spin and parity assignments are 2^-, 1^+, 2^- and 3^+, respectively.

The 2^- assignment to the 308 keV resonance is quite improbable. The (weak) transitions to both 0^+ and 4^+ states observed in the present work are only in agreement with a 2^+ assignment. This can also explain the angular distributions and correlations presented in ref. [19], if it is only assumed that some d-wave capture is present.

An analogous remark holds for the 591 keV resonance. The presence of a (weak) ground-state transition very much favours a 2^+ over a 2^- assignment. The 2^+ assignment is also in accord with the fact that this resonance has been observed to emit alpha particles to the ^{20}Ne ground state [13].

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