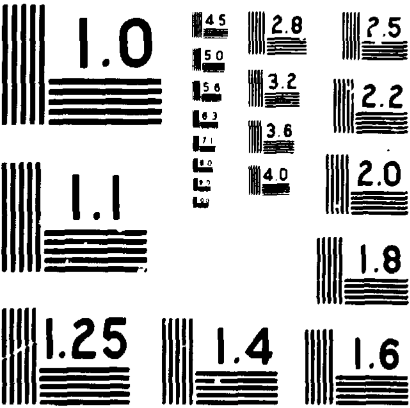

MICROCOPY RESOLUTION TEST CHART

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Comitato Nazionale Energia Nucleare

METHOD OF ANALYSIS OF NEUTRON CAPTURE GAMMA-RAY SPECTRA

A. Fubini, A. Napoli, D. Prosperi, F. Terrasi

RT/FI(70)47

CNEN - RT/ FI(70)47

A. Fubini, A. Napoli, D. Prosperi, F. Terrasi (CNEN, Laboratorio Fisica Nucleare Applicata)

METHOD OF ANALYSIS OF NEUTRON CAPTURE GAMMA-RAY SPECTRA

RIASSUNTO - Vengono descritte le tecniche utilizzate per tarare gli spettri di cattura dei rivelatori al Ge(Li). Viene proposto un metodo di calcolo che dall'energia dei gamma permette di ottenere uno schema di decadimento col metodo di Ritz. Il metodo è applicato alla reazione $Cl^{35}(n, \gamma)$.

CNEN - RT/ FI(70)47

A. Fubini, A. Napoli, D. Prosperi, F. Terrasi (CNEN, Laboratorio Fisica Nucleare Applicata)

METHOD OF ANALYSIS OF NEUTRON CAPTURE GAMMA-RAY SPECTRA

SUMMARY - The method used to calibrate the neutron capture gamma-ray spectra of a Ge(Li) detector is described in detail. The procedure used to obtain from the gamma-ray energy a decay scheme is reported. The method is applied to the $Cl^{35}(n, \gamma)$ reaction.

Comitato Nazionale Energia Nucleare

METHOD OF ANALYSIS OF NEUTRON CAPTURE GAMMA-RAY SPECTRA

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1 - Introduction

One of the most suitable methods for investigating the nuclear level structure is the analysis of the γ-ray spectra arising from reaction such as (n,γ) or from the decay of radiative isotopes. In spite of the complexity usually shown by these spectra it is possible to observe and analyse correctly a large number of γ-ray lines (tipically >100) with increasing precision, due to the development of high resolution Ge(Li) spectrometers, precise calibration curve determination, and methods of analysis of line shapes.
With such a number of transitions it would be very long and difficult to perform a complete analysis of the level scheme inserting in it more than a small number of transitions by means of coincidence experiments.
Then, starting from the knowledge of the energies of a small number of levels and of a large number of transitions one can try to construct a decay scheme by the Ritz combination principle. In the present paper such a method is described in detail and some results obtained for the reaction $^{35}Cl(n,\gamma)$ are reported.

The computer programs arranged for this purpose are described in section 2. In section 3 we report the method used for obtaining precise energy measurements. The application of the Ritz method to the construction of the ^{36}Cl level scheme is described in section 4.

2 - Computer codes

The computation are carried out by the programs PLOT and PROB. The procedure starts from some known levels of energy $E_L + \delta E_L$ and from the γ-ray energy $E_\gamma + \delta E_\gamma$. The program PLOT calculate for some discrete values of energy E how many times combinations (E_L, E_γ) such that $\left[|E-E_L| - E_\gamma\right]^2 < (\delta E_\gamma^2 + \delta E_L^2)$ are obtained.

The energy values E should vary in the chosed interval by steps of lenght smaller than the smallest value of $(\delta E_L^2 + \delta E_\gamma^2)$.

If more than a preset number of combinations is found for one of these values that energies is considered as a possible new level.

Because of the condition imposed to the lenght of the steps this will usually occur for several neighbouring values. The plot of the number of combinations vs. energy, provided by the program will thus show a number of peaks corresponding to the possible levels on a continuous background: this is due to the finite errors of the energy measurements that give rise to accidental combinations. If the spin I_i and I_f parities π_i and π_f of initial and final states are known as well as the multipolarity L of the transitions the program check if the relationship

$$I_I + L \geq I_f \geq (I_I - L)$$

are $\pi_I \cdot \pi = \pi_f$

are satisfied. The combinations not satisfying these selection rules may be disregarded thus reducing the number of accidental combinations.

The probability of obtaining such accidental combinations depends strongly on the magnitude of the energy errors. It is therefore very important to measure with good accuracy the transition energies; section 3 is devoted to this problem.

A computer code, PROB, was developed in order to calculate by means of a self consistent procedure, the energy of the levels as a weighted mean of the single values provided by pair (E_L, E_γ) where E_L is a known level connected to the new level by the transition E_γ.

The program calculates also the probability of the level candidate being purely accidental. The method is similar to that proposed in Ref. 1) and will not be described in detail here.

A list of PROB an PLOT program are reported in Appendix.

3 - Analysis of γ spectra

In the sample treated the capture γ-ray spectrum measurement in ^{35}Cl was performed by means of a Ge(Li)[2] spectrometer. The resolution was ~ 4 Kev at 1.3 MeV and ~10 Kev at 7 MeV. The measurement of the energies was carried out in the following manner. Below 2 MeV a spectrum was recorded with a Chlorine target and some calibration sources (Cs^{137}, Y^{88}, Na^{22}): from 2 to 8 MeV the Sodium lines at 2516.0, 3588.10, 3981.69, 5617.91, 6396.93 Kev were used for calibration purpose by irradiating a mixed target of Cl+Na.

The energy of the most intense lines of ^{36}Cl was calculated by

means of best fit with a fourth order polinomials.
The estimates of error δE_γ attributes to each energy value E_γ was calculated evaluating the error in the peak position and the quality of the fit. The energies of the weaker lines were obtained is a similar manner from the single target spectra using the strong linea as calibration.
Moreover the existence of some cascade was used for calibration purpose: in fact if we known the γ ray populating and depopulating some level, we can obtain several estimate of Q value. After a test of the statistical distribution of these estimates we calculate the high energy γ ray as the difference between the weighted mean of the Q value estimate and the corresponding low energy values and added them to the other calibration point for a new fitting. This procedure was repeated until the Q value converged to a fixed value. The calibration curve thus obtained is reported in fig. 1.

4 - Construction of a decay scheme

To construct the decay scheme of Cl^{36} a iterative procedure was used. From coincidence measurement and (d, p) studies(3) it has been possible to obtain the levels scheme shown in fig. 2. We use this decay scheme and the γ ray listed in Tab. 1 as the basis for the search of new levels. The most probable levels obtained was at 3633.6, 3964.5, 4497.6, 5958.6 KeV. The probability that one of these levels was randon was less than 35% and as the intensity balance was roughly correct they are added to the previous one. This procedure was repeated until no new level will be found with probability higher than 65% .

The decay scheme obtained is reported in fig. 3. All the

levels have probability to be true higher than 65% : as an exception the level at 4139.2 was accepted for his strong agreement with the (d,p) experiment. Moreover the intensity balance is roughly correct as shown in Tab. 2. Finally as estimate of the spin of the new level was obtained assuming than all the transitions inserted in fig. 3 are E1, M1 or E2. This assumptions will be justified observing that all the transitions inserted in the scheme of fig. 2 are of those multipolarity.
The value of the spin obtained are reported in fig. 3: this results was obtained taking also into account the restriction imposed by the angular momentum conservation for the levels for which the l_n values are known for (d.p) relation.

Tables caption

Table I - Summary of energy and intensity results for the gamma radiation following neutron capture in natural chlorine.

Table II - Intensity balance for the lowest lying levels. correction for electron losses have been neglected.

Table 1

γ transition	E_γ (keV)	I_γ (γ/100 cap)	γ transition	E_γ (keV)	I_γ (γ/100 cap)
1	8580.5±0.7	3.12	23	5586.5±1.2	0.50
2	7792.1±0.7	8.51	24	5544.0±1.5	0.21
3	7415.2±0.6	10.30	25	5519.1±1.1	1.67
4	7320.3±2.1	0.05	26	5473.4±1.5	0.11
5	6979.8±0.5	2.21	27	5405.3±1.5	0.10
6	6954.9±1.1	0.15	28	5374.5±1.4	0.10
7	6892.6±2.6	0.90	28'	5261.9±1.5	0.10
8	6869.9±2.9	0.90	29	5248.0±1.2	0.60
9	6628.9±1.0	5.00	30	5206.0±1.8	0.25
10	6620.9±1.0	8.50	31	5150.1±1.3	0.26
11	6552.8±1.8	0.17	32	5114.0±1.5	0.10
12	6491.5±0.9	0.18	33	5079.3±1.6	0.16
13	6423.2±1.2	0.28	34	5019.1±1.2	0.45
14	6383.5±1.2	0.10	35	4982.0±1.1	3.70
15	6346.3±2.3	0.16	36	4946.6±1.0	1.00
16	6269.8±0.9	0.41	36'	4881.8±2.8	0.12
17	6113.0±0.9	20.80	36"	4854.3±1.5	0.07
17'	6004.5±3.4	0.10	37	4829.8±1.5	0.16
18	5957.0±1.1	0.24	38	4816.7±1.5	0.15
19	5905.4±1.0	0.12	39	4793.4±1.5	0.09
19'	5735.8±1.5	0.15	40	4757.4±1.2	[illegible]
20	5716.9±1.1	5.86	41	4730.2±1.1	0.83
21	5640.1±1.4	0.13	41'	4713.0±1.5	0.09
22	5607.7±1.6	0.37	42	4707.9±1.4	0.45

Table 1 (continued)

γ transition	E_γ (keV)	I_γ (γ/100 cap)	γ transition	E_γ (keV)	I_γ (γ/100 cap)
43	4685.1±1.4	0.06	63	3858.7±1.6	0.22
44	4617.0±1.0	0.55	64	3823.4±0.7	1.56
45	4589.6±1.2	0.24	65	3775.2±1.3	0.25
46	4548.6±1.2	0.49	66	3756.4±1.2	0.10
47	4525.3±1.1	0.40	67	3748.0±1.2	0.22
48	4441.8±1.0	0.91	68	3737.6±1.2	0.27
49	4416.9±1.3	0.33	69	3707.2±1.6	0.23
50	4378.6±1.0	0.10	70	3662.2±0.8	0.26
51	4337.5±1.4	0.19	70'	3650.2±1.1	0.13
52	4299.6±1.0	0.46	71	3636.8±1.1	0.28
53	4207.4±1.8	0.15	72	3628.8±1.1	0.28
54	4140.1±1.3	0.16	72'	3616.8±1.1	0.16
55	4128.7±1.3	0.05	73	3601.4±1.2	0.93
56	4114.8±1.3	0.04	74	3585.6±1.1	0.82
57	4083.6±0.8	0.50	75	3562.5±1.1	1.04
58	4057.4±1.2	0.75	76	3548.0±1.1	0.10
58'	4047.2±1.5	0.11	77	3525.5±1.1	0.05
59	4033.1±2.4	0.15	78	3511.8±1.1	0.18
60	3999.6±1.2	0.12	79	3500.4±1.1	0.31
61	3981.4±1.2	1.10	80	3465.3±1.2	0.10
62	3965.7±1.2	0.43	80'	3445.5±1.5	0.10
62'	3914.5±1.5	0.13	81	3429.1±0.6	0.89
62"	3883.8±1.5	0.09	82	3371.4±0.6	0.47

Table 1 (continued)

γ transition	E_γ (keV)	I_γ (γ/100 cap)	γ transition	E_γ (keV)	I_γ (γ/100 cap)
83	3350.1±1.1	0.14	105	2705.7±1.0	0.36
84	3332.3±0.6	0.52	106	2676.5±0.4	1.30
85	3310.8±1.1	0.16	107	2649.5±1.1	0.18
86	3287.6±1.1	0.13	108	2622.5±0.5	0.22
87	3267.9±1.1	0.13	109	2592.3±1.0	0.11
88	3248.2±3.3	0.23	110	2578.6±1.0	0.11
89	3214.6±1.1	0.18	110'	2557.1±1.0	0.15
90	3199.9±1.4	0.21	111	2534.3±0.6	0.46
91	3161.0±2.6	0.12	111'	2517.5±1.0	0.08
92	3135.1±1.1	0.14	112	2491.0±0.4	0.51
93	3114.6±0.5	0.75	113	2468.4±0.3	0.68
93'	3088.3±1.1	0.10	114	2418.3±0.4	0.41
94	3061.0±0.5	3.07	114'	2384.3±1.0	0.14
95	3015.5±0.5	0.86	115	2362.5±1.0	0.12
96	2996.6±0.5	1.03	116	2346.5±1.5	0.15
97	2973.1±0.5	0.97	117	2323.7±1.0	0.24
98	2922.5±1.1	0.80	118	2309.7±0.6	0.50
99	2896.5±0.7	0.34	119	2287.6±2.5	0.14
100	2863.4±0.4	0.73	120	2270.0±1.0	0.13
101	2843.9±0.9	0.54	121	2247.0±1.0	0.29
102	2808.2±1.5	0.51	122	2199.3±0.6	1.85
103	2799.5±1.5	0.51	123	2179.0±1.0	0.30
104	2755.4±1.2	0.19	124	2157.6±0.5	0.39

Table 1 (continued)

γ transition	E_γ (keV)	I_γ (γ/100 cap)	γ transition	E_γ (keV)	I_γ (γ/100 cap)
125	2076.0±0.6	0.40	139	1716.8±1.5	0.22
126	2039.2±0.9	0.40	140	1641.2±0.7	0.51
127	1959.5±0.2	9.60	141	1601.1±0.2	3.00
128	1951.5±0.2	14.70	142	1327.3±0.4	1.06
129	1903.8±1.0	0.18	143	1266.5±0.5	0.10
130	1889.4±1.4	0.14	144	1164.9±0.2	23.90
131	1875.4±1.4	0.11	145	1131.4±0.3	1.66
132	1860.9±1.1	0.36	146	789.3±0.3	10.80
133	1847.8±1.5	0.18	147	786.5±0.3	13.00
134	1833.3±0.9	0.40	148	632.5±0.4	0.19
135	1814.3±1.5	0.27	149	517.0±0.2	21.90
136	1791.2±1.5	0.30	150	436.4±0.3	0.83
136'	1774.8±2.0	0.10	151	358.5±0.4	0.18
137	1748.6±1.6	0.15	152	291.9±0.3	0.21
138	1733.0±1.5	0.22			

Table 2

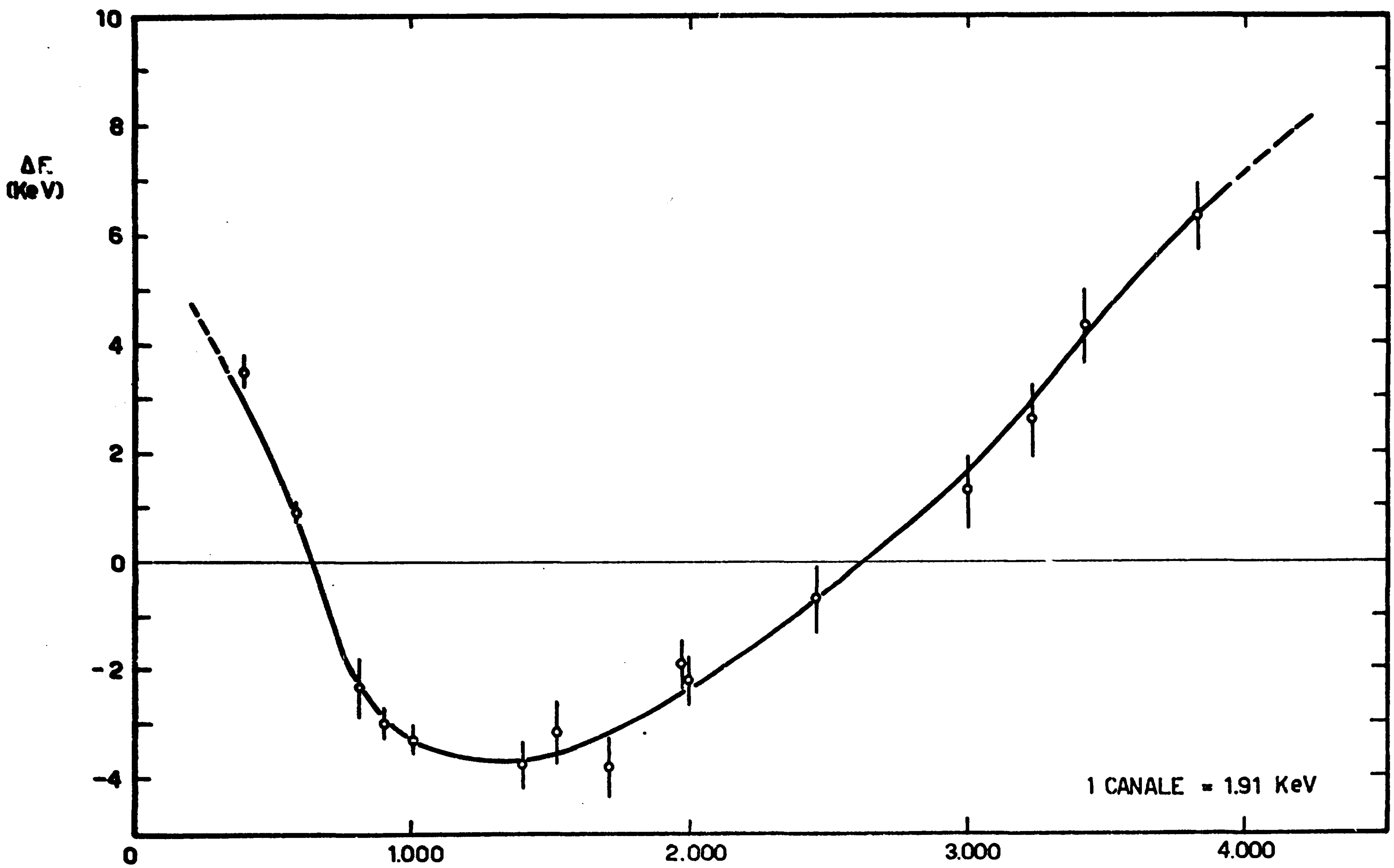
$E_{\gamma1} \pm \delta E_{\gamma1}$ (keV)	$E_{\gamma2} \pm \delta E_{\gamma2}$ (keV)	$Q \pm \delta Q$ (keV)
2622.6±0.5	5958.6±0.4	8581.2±0.6
4442.1±1.0	4139.3±0.3	8581.4±1.0
4617.3±1.1	3964.9±0.4	8582.3±1.1
6113.6±0.9	2468.6±0.2	8582.2±0.9
6621.4±0.8	1959.6±0.2	8581.0±0.8
6980.5±0.5	1601.2±0.2	8581.7±0.5
7416.4±0.5	1164.9±0.2	8581.3±0.5
7792.7±0.5	789.3±0.2	8582.0±0.5
8581.9±0.7		8581.9±0.7

Figures caption

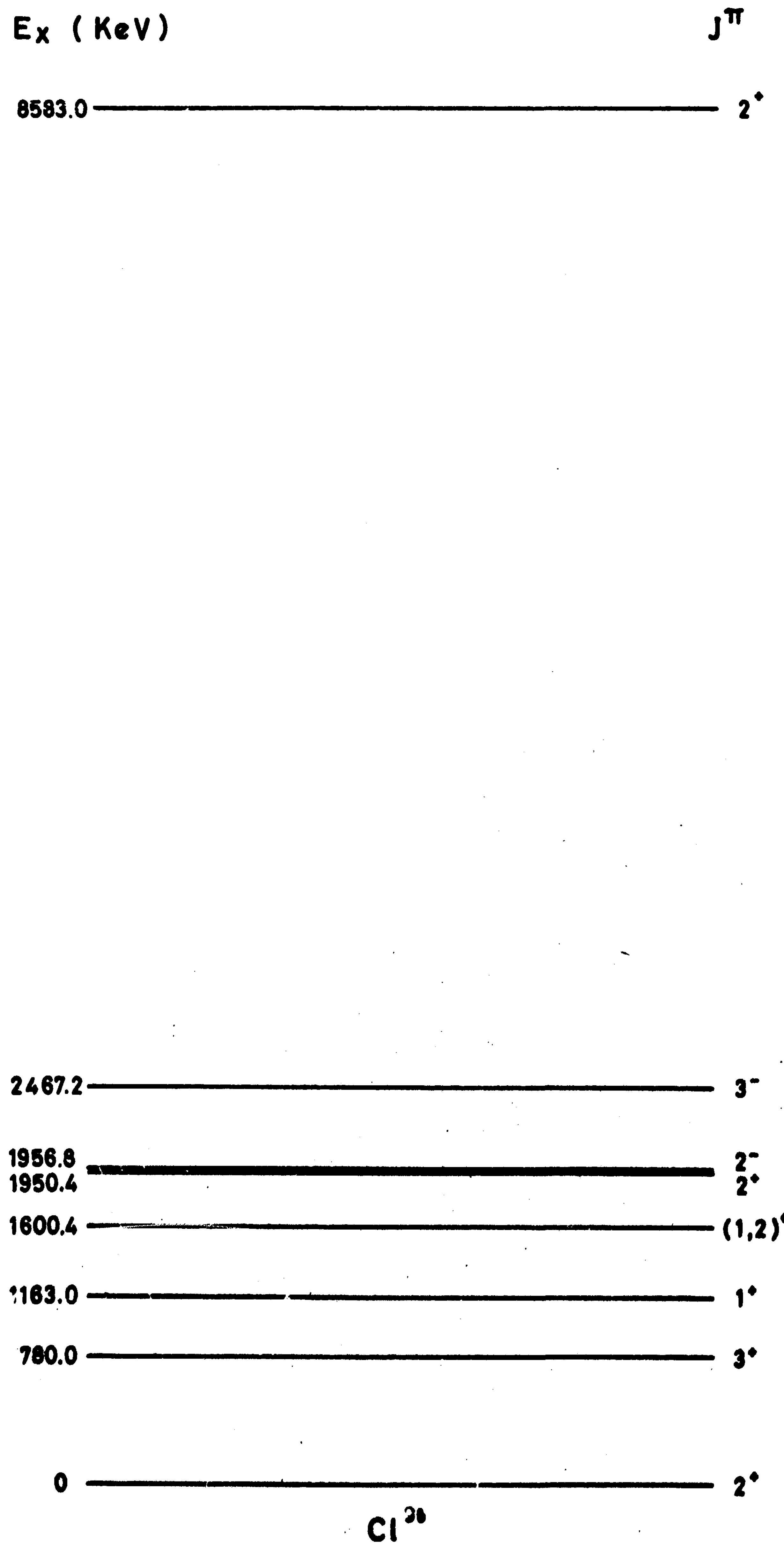
Fig. 1 - Calibration curve for the Ge(Li) detector.

Fig. 2 - Decay scheme obtained from coincidence measurement and (d,p) studies.

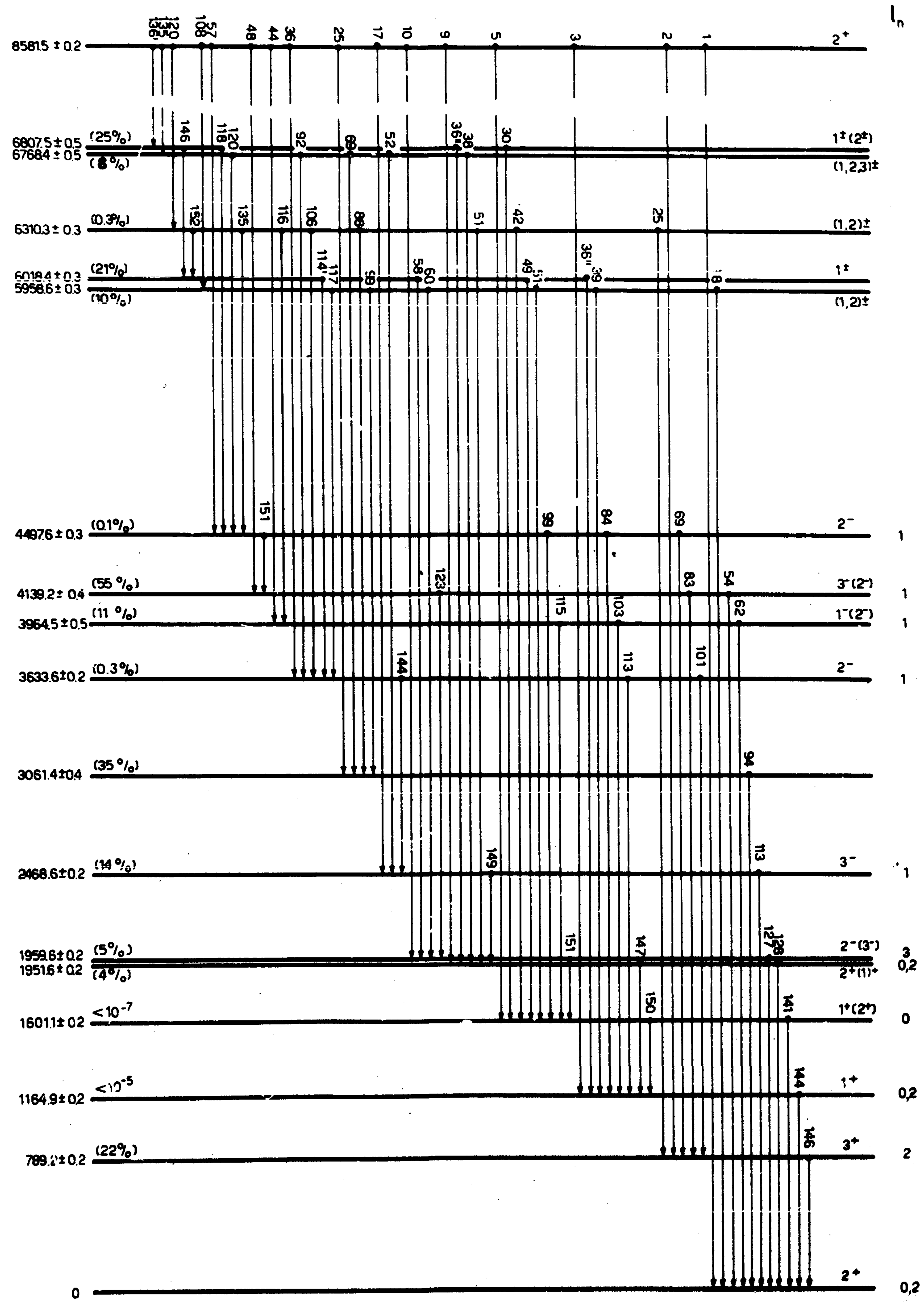
Fig. 3 - Decay scheme obtained by the Ritz combination principle. The relative probability of the existence of the levels, spin and parity are also reported.



ΔF.
(KeV)
10
8
6
4
2
0
-2
-4
0
1.000
2.000
3.000
4.000
1 CANALE = 1.91 KeV



Ex (KeV)
Jπ
8583.0
2+
2467.2
3-
1956.8
2-
1950.4
2+
1600.4
(1,2)+
1163.0
1+
780.0
3+
0
2+
Cl 36



ln
8581.5 ± 0.2
2+
6807.5 ± 0.5
(25%)
1± (2±)
6768.4 ± 0.5
(8%)
(1,2,3)±
6310.3 ± 0.3
(0.3%)
(1,2)±
6018.4 ± 0.3
(21%)
1±
5958.6 ± 0.3
(10%)
(1,2)±
4497.6 ± 0.3
(0.1%)
2-
1
4139.2 ± 0.4
(55%)
3-(2-)
1
3964.5 ± 0.5
(11%)
1-(2-)
1
3633.6 ± 0.2
(0.3%)
2-
1
3061.4 ± 0.4
(35%)
2468.6 ± 0.2
(14%)
3-
1
1959.6 ± 0.2
(5%)
2-(3-)
3
1951.6 ± 0.2
(4%)
2+(1)+
0,2
1601.1 ± 0.2
< 10-7
1+(2+)
0
1164.9 ± 0.2
< 10-5
1+
0,2
789.2 ± 0.2
(22%)
3+
2
0
2+
0,2

Fig. 3

Appendix

The computer programs PLOT and PROB have been written in a IBM 7094 FORTRAN language.

The following date are needed for the PLOT program, as shown in fig. 1A.

First card

Number of levels, numbers of gamma rays, number of regions analysed, multipolarity of γ rays accepted

Format 16 I 5

Second card

Energy levels with their errors and spin. One level for card

Format 2F 8.3, 7 I 4

Third card

Gamma rays energy and error. One gamma for card Format 2F 10.3

Fourth card

Boundary limits of the energy region analysed, step width, spin and parity of probe level.

Format 3F 7.2, 29 X, 7 I 4

We need the same first three cards for the PROB program. The fourth card must contain: boundary limits of the energy region analysed, step width, number of combinations with the probe level E, number of levels in the energy region E-G ÷E+G, number of steps in G,[1] spin and parity of the probe level

Format 2F 7.2, F 6.3, 3 I 10, 7 I 4

The interval G should be large enough to include many combinations, so that it gives a good average value.

The FORTRAN of the program PLOT is reported in fig. 2A.

The FORTRAN of the main program of PROB is reported in fig. 3A: in fig. 4A and 5A are reported the subroutine PROB and POISON.

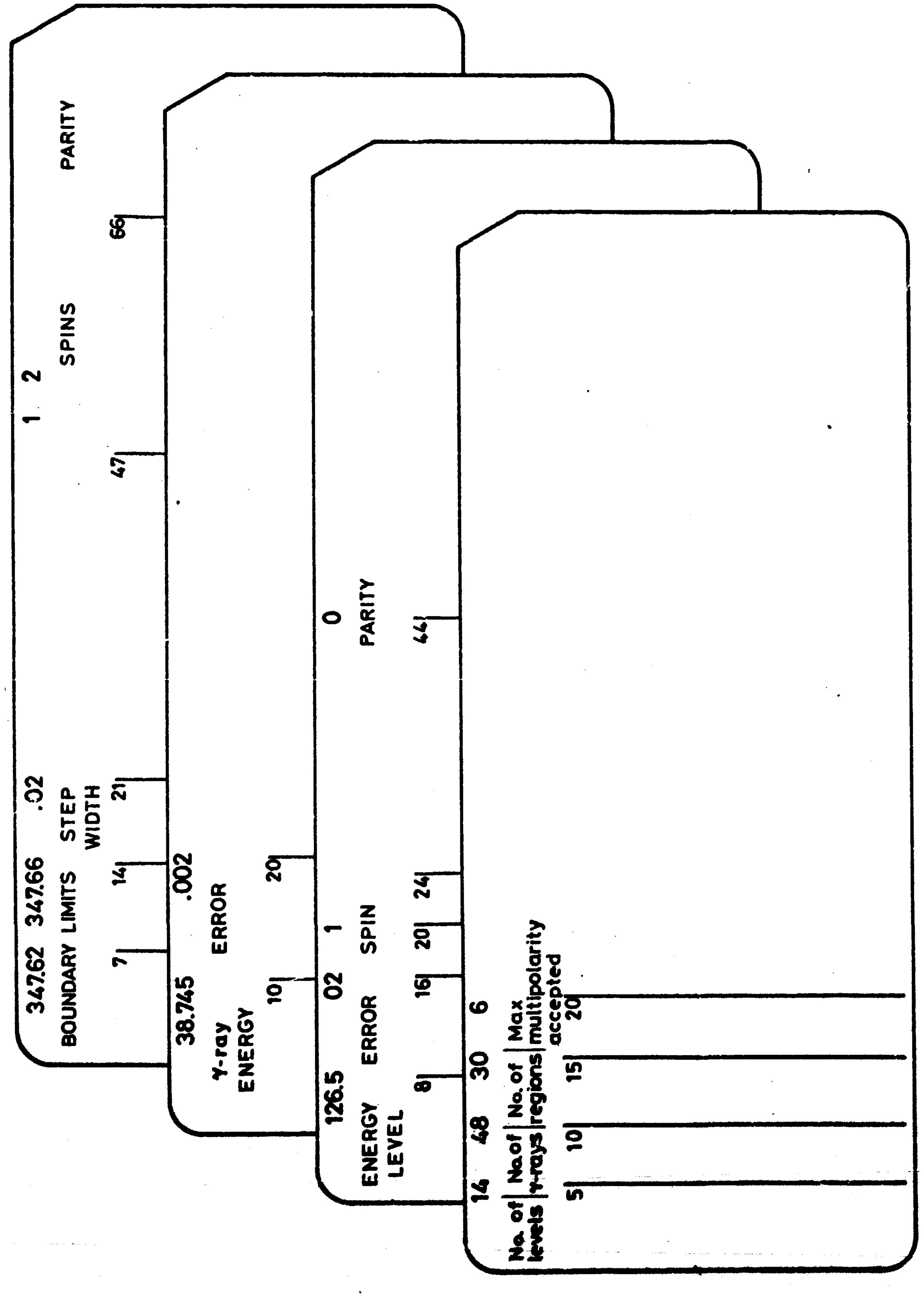


Fig. 1.a

```
C GRAFICO NUMERO INCASTRI VS ENERGIA LIVELLC
      DIMENSION EN(90),DEN(90),E(250),DE(250),EINF(99),ESUP(99),PASS(99)
      DIMENSION IPAR(100),JPAR(100),ISPIN(100,6),JSPIN(100,6)
      DIMENSION INK(5000),EEP(5000),KMIF(100),SPAZ(30)
      READ(5,1111) AST,(SPAZ(L),L=1,30)                                  1
      READ(5,1000) IMAX,KMAX,JMAX,JJ,INDICE,JDELTA,INRINC                8
      READ(5,1002)(EN(I),DEN(I),(ISPIN(I,L),L=1,6),IPAR(I),I=1,IMAX)    16
      READ(5,3001)(E(K),DE(K),K=1,KMAX)                                 29
      READ(5,1004)(EINF(J),ESUP(J),PASS(J),(JSPIN(J,L),L=1,6),JPAR(J),J=
     11,JMAX)                                                           37
      IF(INRINC.NE.0) READ(5,1003) VALRIN                               51
      IF(INRINC.EQ.0)GO TO 2
      DO 499 K=1,KMAX
  499 E(K)=E(K)&E(K)*E(K)/VALRIN
    2 WRITE(6,222) IMAX,JMAX,KMAX                                       66
      WRITE(6,1005)                                                     67
      WRITE(6,333)(EN(I),DEN(I),(ISPIN(I,L),L=1,6),IPAR(I),I=1,IMAX)    68
      WRITE(6,444)                                                      81
      WRITE(6,1008)(E(K),DE(K),K=1,KMAX)                                82
      WRITE(6,1005)                                                     90
      WRITE(6,555)(EINF(J),PASS(J),ESUP(J),(JSPIN(J,L),L=1,6),JPAR(J),J=
     11,JMAX)                                                           91
      WRITE(6,7777) INDICE                                             105
      WRITE(6,100)                                                     106
  100 FORMAT(//8X,7HLIVELLO,9X,88H1  2  3  4  5  6  7  8  9 10 11 12 13
     114 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30//)
  222 FORMAT(//2X,5HIMAX=,I3,5X,5HJMAX=,I3,5X,5HKMAX=,I3)
  333 FORMAT(3(1X,3HLV=,F8.3,4H ER=,F4.2,4H 2I=,6I2,5H PAR=,I1))
  444 FORMAT(//2X,22HTRANS GAMMA CON ERRORI)
  555 FORMAT(2(1X,8HLIM INF=,F7.2,7H PASSO=,F4.2,5H SUP=,F7.2,6H SPIN=,6
     1I2,5H PAR=,I2))
 1000 FORMAT(16I5)
 1001 FORMAT(10F8.3)
 1002 FORMAT(2F8.3,7I4)
 1003 FORMAT(5F15.3)
 1004 FORMAT(3F7.2,29X,7I4)
 1005 FORMAT(//)
 1008 FORMAT(14F9.3)
 1009 FORMAT(12F10.3)
 1111 FORMAT(26A3)
 2222 FORMAT(3X,F12.3,I4,31A3)
 3001 FORMAT(2F10.3)
 3333 FORMAT(5X,48HPASSC TROPPO PICCOLO OD INTERVALLO TROPPO GRANDE)
 7777 FORMAT(//5X,24HCODICE REGOLA SELEZIONE=,I2)
      J=1
    5 CONTINUE
      LMAX=INT((ESUP(J)-EINF(J))/PASS(J)&1.)
      IF(LMAX.GT.9000) WRITE(6,3333)                                   112
      IND=0
      NE=0
      IPR=1
      DO 234 LF=1,LMAX
      EP=EINF(J)&PASS(J)*FLOAT(LF)
   41 I=1
   49 DELTA=EP-EN(I)
```

```
      INDC=0
      GO TO (53,50,53,51,53,55),INDICE
   50 IF(IPAR(I)&JPAR(J).NE.1) INDC=1
      GO TO 53
   51 IF(IPAR(I)&JPAR(J).GT.3.OR.IPAR(I)&JPAR(J).EQ.1)INDC=1
   53 IF(INDC.EQ.1)JDELTA=JDELTA&2
      DO 54 L=1,10
      IF(JSPIN(J,L).EQ.0) GO TO 210
      DO 54 LG=1,10
      IF(ISPIN(I,LG).EQ.0) GO TO 54
      IF(IABS(ISPIN(I,LG)-JSPIN(J,L)).LE.JDELTA) GO TO 55
   54 CONTINUE
   55 ABSDEL=ABS(DELTA)
      IF(IND)500,71,75
   71 K=1
      GO TO 91
   75 K=KMIF(I)
   91 D=ABSDEL-E(K)
      F=SQRT(DEN(I)*DEN(I)&DE(K)*DE(K))                              172
      C=ABS(D)-F
      IF(C) 140,132,132
  132 IF(D)160,160,133
  133 K=K&1
      IF(K-KMAX)91,91,210
  140 NE=NE&1
  160 KMIF(I)=K-1
      IF(KMIF(I))205,205,210
  205 KMIF(I)=1
  210 I=I&1
      IF(INDC.EQ.1)JDELTA=JDELTA-2
      IF(I-IMAX)49,49,230
  230 IND=1
  232 INK(IPR)=NE
      EEP(IPR)=EP
      IPR=IPR&1
  233 NE=0
  234 CONTINUE
      IJ=IPR-1
      IF(IJ.LE.?) GO TO 237
      DO 236 NU=1,IJ
      NNE=INK(NU)
      IF(NNE.LT.JJ.AND.INK(NU&1).GE.JJ) GO TO 235
      IF(NNE.LT.JJ.OR.NNE.GT.30) GO TO 236
      WRITE(6,2222) EEP(NU),NNE,(SPAZ(K),K=1,NNE),AST                214
      GO TO 236
  235 WRITE(6,1005)                                                  221
  236 CONTINUE
  237 IPR=1
  260 J=J&1
      WRITE(6,1005)                                                  227
      DO 261 M=1,IMAX
  261 KMIF(M)=1
      IF(J.LE.JMAX) GO TO 5
  400 WRITE(6,100)                                                   238
  500 CONTINUE
      STOP
```



```
C  RICERCA NUOVI LIVELLI METODO INCASTRI E CALCOLO PROBABILITA' CHE IL LIVELLO
C  SIA CASUALE
      COMMON IMAX,KMAX,INKMIN(50),ELV(70),ERRLV(70),EGAM(250),ERRGAM(250
     1),EINF(50),ESUP(50),NUMLV(50),NUMPAS(50)
      DIMENSION W(202),INK(202),EEP(202),KLIV(70),KDUP(70),VV(202,30)
      DIMENSION ISPIN(70,6),IPAR(70),JSPIN(50,6),JPAR(50),PASS(50)
      DIMENSION KK(202,30),II(202,30)
      READ(5,111) IMAX,KMAX,JMAX,ICODE,JDELTA,INRINC                   1
  111 FORMAT(16I5)
      READ(5,222) (ELV(I),ERRLV(I),(ISPIN(I,L),L=1,6),IPAR(I),I=1,IMAX)   8
  222 FORMAT(F8.3,F8.3,7I4)
      READ(5,333) (EGAM(K),ERRGAM(K),K=1,KMAX)                        21
  333 FORMAT(2F10.3)
      READ(5,444) (EINF(J),ESUP(J),PASS(J),INKMIN(J),NUMLV(J),NUMPAS(J),
     1(JSPIN(J,L),L=1,6),JPAR(J),J=1,JMAX)                             29
  444 FORMAT(2F7.2,F6.3,3I10,7I4)
      IF(INRINC.EQ.0) GO TO 2
      READ(5,555)  VALRIN                                               48
  555 FORMAT(5F15.3)
      DO 1 K=1,KMAX
    1 EGAM(K)=EGAM(K)&EGAM(K)*EGAM(K)/VALRIN
    2 WRITE(6,666)IMAX,KMAX,JMAX,ICODE,JDELTA,INRINC                   59
  666 FORMAT(//10X,7HNUM LV=I3,9H NUM GAM=I3,9H NUM INT=I3,14H CODE REG
     1SEL=2I2,22H INIZ GAM DA TOGLIFRE=I3,9H RINCULO=I2//)
      WRITE(6,777)(ELV(I),ERRLV(I),(ISPIN(I,L),L=1,6),IPAR(I),I=1,IMAX)  60
  777 FORMAT(3(1X,3HLV=,F8.3,4H ER=,F4.2,4H 2I=,6I2,5H PAR=,I1))
      WRITE(6,888)                                                      73
  888 FORMAT(//2X,28HTRANSIZIONI GAMMA CON ERRORI)
      WRITE(6,999)(EGAM(K),ERRGAM(K),K=1,KMAX)                          74
  999 FORMAT(14F9.3)
      WRITE(6,2222)                                                     82
 2222 FORMAT(//)
      WRITE(6,1111)(EINF(J),ESUP(J),PASS(J),INKMIN(J),NUMLV(J),NUMPAS(J)
     1,(JSPIN(J,L),L=1,6),JPAR(J),J=1,JMAX)                             83
 1111 FORMAT(  2X,8HLIM INF=F7.2,9H LIM SUP=F7.2,7H PASSO=F5.3,13H NUM I
     1NK MIN=I2,21H NUM LIV NELL'INTERV=I2,11H NUM PASSI=I6,4H 2I=6I3,5H
     1 PAR=I2)
      WRITE(6,2222)                                                    100
      JINF=1
      NUMEVN=0
      INNULV=0
      J=1
    5 CONTINUE
      DO 10 M=1,IMAX
   10 KLIV(M)=1
      KINC=0
      LMAX=INT((ESUP(J)-EINF(J))/PASS(J)&1.)
      IF(LMAX.GT.202) WRITE(6,3333)                                    117
 3333 FORMAT(10X,48HPASSO TROPPO PICCOLO OD INTERVALLO TROPPO GRANDE)
      NE=0
      IPR=1
      W(1)=0.
   15 CONTINUE
      DO 120 LF=1,LMAX
      EP=EINF(J)&PASS(J)*FLOAT(LF)
```

```
   20 I=1
      DO 25 M=1,IMAX
   25 KDUP(M)=0
   30 DIFF=EP-ELV(I)
      INDC=0
      GO TO (45,35,45,40,45,55),ICODE
   35 IF(IPAR(I)&JPAR(J).NE.1) INDC=1
      GO TO 45
   40 IF(IPAR(I)&JPAR(J).GT.3.OR.IPAR(I)&JPAR(J).EQ.1) INDC=1
   45 IF(INDC.EQ.1) JDELTA=JDELTA&2
      DO 50 M=1,6
      IF(JSPIN(J,M).EQ.0) GO TO 80
      DO 50 MG=1,6
      IF(ISPIN(I,MG).EQ.0) GO TO 50
      IF(IABS(ISPIN(I,MG)-JSPIN(J,M)).LE.JDELTA) GO TO 55
   50 CONTINUE
   55 ABSDIF=ABS(DIFF)
      IF(KINO.EQ.0) GO TO 60
      K=1
      GO TO 65
   60 K=KLIV(I)
      AMEZER=ERRLV(I)*ERRLV(I)
   65 D=ABSDIF-EGAM(K)
      F=SQRT(AMEZER&ERRGAM(K)*ERRGAM(K))                                185
      IF(ABS(D).LT.F) GO TO 85
      IF(D) 75,75,70
   70 K=K&1
      IF(K-KMAX) 65,65,80
   75 KLIV(I)=K-1
      IF(KLIV(I).LE.0) KLIV(I)=1
   80 I=I&1
      IF(INDC.EQ.1) JDELTA=JDELTA-2
      IF(I.LE.IMAX) GO TO 30
      GO TO 110
   85 NE=NE&1
      KDUP(I)=KDUP(I)&1
      V=C*D/(F*F)
      IF(KDUP(I).EQ.1) GO TO 90
      IF(V.GT.RR) GO TO 100
      W(IPR)=W(IPR)&V-RR
      NE=NE-1
      GO TO 95
   90 W(IPR)=W(IPR)&V
   95 VV(IPR,NE)=V
      RR=V
      KK(IPR,NE)=K
      II(IPR,NE)=I
      GO TO 105
  100 NE=NE-1
  105 IF(NE.GT.30) WRITE(6,4444) EP                                     231
 4444 FORMAT(3X,14H PER IL VALOREF9.3,49H  TROPPI INCASTRI AUMENTARE DIM
     1ENSION DI VV,KK,II)
      IF(D.LT.0.01) GO TO 75
      KLIV(I)=K
      K=K&1
      IF(K-KMAX) 65,65,80
```



```
  110 KINO=1
      INK(IPR)=NE
      EEP(IPR)=EP
      IPR=IPR&1
  115 NE=0
      W(IPR)=0.
      IF(IPR.GT.202) GO TO 125
  120 CONTINUE
  125 IJ=IPR-1
      NUM=0
      WRITE(6,2222)                                                     254
      INCAB=1
      DO 130 NU=1,IJ
      IF(INK(NU).LT.INKMIN(J)) GO TO 126
      NUM=NUM&1
  126 CONTINUE
      GO TO (127,128,129),INDAB
  127 WRITE(6,5555) EEP(NU)                                             266
 5555 FORMAT(3X,11HDA ENERGIA=F9.3)
      INDAB=2
  128 IF(INK(NU).NE.INK(NU&1)) INDAB=3
      IF(NU.EQ.IJ) GO TO 129
      IF(INDAB.EQ.2) GO TO 130
  129 WRITE(6,6666) EEP(NU),INK(NU)                                     279
 6666 FORMAT(26X,16HFINO AD ENERGIA=F9.3,11H  INCASTRI=I3)
      INDAB=1
  130 CONTINUE
      IJM=1
      MAX=INK(1)
      MAX1=0
      DO 137 M=2,IJ
      IF(INK(M)-MAX) 137,133,131
  131 MAX=INK(M)
      IJM=M
      GO TO 136
  133 NNE=INK(M)
      DO 135 MU=1,NNE
      IF(II(M,MU).NE.II(IJM,MU)) MAX1=INK(M)
      IJMM=M
  135 CONTINUE
      GO TO 137
  136 IF(INK(M).GT.MAX1) MAX1=0
  137 CONTINUE
  138 WM=W(IJM)/FLOAT(INK(IJM))
      WRITE(6,7777) EEP(IJM),MAX,W(IJM),WM,J                            321
 7777 FORMAT(//10X,8HENERGIA=F9.3,10H INCASTRI=I3,17H SOMMA DEI DD/FF=F7
     1.4,22H (DD/FF)/NUM INCASTRI=F7.4,12H NELL'INT J=I3/)
      BARIC=0.
      SIGMA=0.
      DO 150 MU=1,MAX
      III=II(IJM,MU)
      KKK=KK(IJM,MU)
      VVV=VV(IJM,MU)
      D=ABS(EEP(IJM)-ELV(III))-EGAM(KKK)
      F=ERRLV(III)*ERRLV(III)&ERRGAM(KKK)*ERRGAM(KKK)
      IF(ELV(III).GT.EEP(IJM)) GO TO 140
```

```
      BARIC=BARIC&(ELV(III)&EGAM(KKK))/F
      GO TO 145
  140 BARIC=BARIC&(ELV(III)-EGAM(KKK))/F
  145 SIGMA=SIGMA&1./F
      R=SQRT(F)                                                      351
      WRITE(6,8888) III,ELV(III),KKK,EGAM(KKK),D,R,VVV               352
 8888 FORMAT(5X,2HI=I3,12H   LIV NOTO=F9.3,5H   K=I3,14H   TRANS GAMMAF9
     1.3,5H   D=F8.3,5H   F=F8.3,9H   DD/FF=F8.3)
  150 CONTINUE
      BARIC=BARIC/SIGMA
      SQM=SQRT(1./SIGMA)                                             358
      WRITE(6,9999) BARIC,SQM                                        359
 9999 FORMAT(/20X,19HENERGIA BARICENTRO=F12.4,22H  SCARTO QUADRO MEDIO=F
     19.4)
      IF(MAX1.EQ.0) GO TO 160
      MAX=MAX1
      IJM=IJMM
      MAX1=0
      GO TO 138
  160 INNULV=INNULV&1
      NUMEVN=NUMEVN&NUM
      IF(INNULV.LT.NUMLV(J)) GO TO 165
      CALL PROB(NUMEVN,JINF,J)                                       373
      NUMEVN=0
      INNULV=0
      JINF=J&1
  165 J=J&1
      IF(J.LE.JMAX) GO TO 5
      STOP
      END
```



```
      SUBROUTINE PROB(M,JMIN,JFIN)
      COMMON IMAX,KMAX,INKMIN(50),ELV(70),ERRLV(70),EGAM(250),ERRGAM(250
     1),EINF(50),ESUP(50),NUMLV(50),NUMPAS(50)
      DIMENSION S(70),T(70),LMIN(70),LMAX(70),INE(70),LZ(70)
      J=JMIN
      G=(EGAM(KMAX)-EGAM(1))/FLOAT(KMAX)
      PROBMD=0.
      EINCR=25.
      ENERG=(EINF(J)&ESUP(J))/2.-25.
      NENERG=0
    5 I=1
   10 S(I)=0.
      DELTA=ABS(ENERG-ELV(I))
      K=1
      IND=0
      IF(DELTA-EGAM(K)-G) 15,20,20
   15 IF(DELTA-EGAM(K).LT.0.) GO TO 20
      IND=1
   20 D1=EGAM(K)-DELTA
      D2=ABS(D1)
      IF(D2-G) 30,30,25
   25 IF(D1) 35,35,40
   30 S(I)=S(I)&ERRGAM(K)&ERRLV(I)
   35 K=K&1
      IF(K.LE.KMAX) GO TO 20
   40 IF(IND.EQ.0) GO TO 45
      GI=(G&DELTA-EGAM(1))/2.
      GO TO 55
   45 IF(DELTA.GT.EGAM(KMAX)) GO TO 60
      IF(DELTA&G.GT.EGAM(KMAX)) GO TO 50
      GI=G
      GO TO 55
   50 GI=(G&D1)/2.
   55 S(I)=S(I)/GI
      GO TO 65
   60 S(I)=0.
   65 T(I)=1.-S(I)
      I=I&1
      IF(I.LE.IMAX) GO TO 10
      RUA=1.
      DO 70 I=1,IMAX
   70 RUA=RUA*T(I)
      N=INKMIN(J)
   75 SUM=0.
      LMIN(1)=1
      LMAX(1)=IMAX-N&1
      PI=RUA
      DO 80 M=1,N
   80 INE(M)=0
      MU=2
   85 LMIN(MU)=LMIN(MU-1)&1
      LMAX(MU)=LMAX(MU-1)&1
      LL=LMIN(MU-1)
      IF(S(LL)) 95,95,90
   90 PI=PI*S(LL)/T(LL)
```

```
      GO TO 100
   95 INE(MU-1)=2
  100 MU=MU&1
      IF(MU.LE.N) GO TO 85
      DO 105 M=1,N
  105 LZ(M)=LMIN(M)
      INDA=0
      DO 110 M=1,N
  110 INDA=INDA&INE(M)
      IF(INDA.GT.0) GO TO 115
      P=PI
      MU=N
      LL=LZ(MU)
      P=P*S(LL)/T(LL)
      SUM=SUM&P
  115 MU=N
  120 IF(LZ(MU).GE.LMAX(MU)) GO TO 125
      LMIN(MU)=LMIN(MU)&1
      GO TO 100
  125 MU=MU-1
      IF(MU.LE.0) GO TO 135
      LL=LMIN(MU)
      IF(S(LL).GT.0.) GO TO 130
      INE(MU)=0
      GO TO 120
  130 PI=PI*T(LL)/S(LL)
      GO TO 120
  135 WRITE(6,111) ENERG,N,J,SUM                                          147
  111 FORMAT( /10X,11HALL'ENERGIAF8.2,4H CONI2,21H INCASTRI NELL'INT J=I
     12,19H LA PROBABILITA' E'E12.7//)
      NENERG=NENERG&1
      PROBMD=PROBMD&SUM
      ENERG=ENERG&EINCR
      IF(ENERG.LT.ESUP(J)&25.) GO TO 5
      IF(J.EQ.JFIN) GO TO 140
      J=J&1
      GO TO 5
  140 PROBMD=PROBMD/FLOAT(NENERG)
      WRITE(6,222) PROBMD,EINF(JMIN),ESUP(JFIN),NENERG                    158
  222 FORMAT(//5X,18HPROBABILITA MEDIA=E12.7,15H FRA LE ENERGIE2F9.3,11H
     1 MEDIATA SUI3,7H VALORI//)
      CALL POISON(PROBMD,M,JMIN)                                          161
      RETURN
      END
```



```
      SUBROUTINE POISON(P,NU,J)
      COMMON IMAX,KMAX,INKMIN(50),ELV(70),ERRLV(70),EGAM(250),ERRGAM(250
     1),EINF(50),ESUP(50),NUMLV(50),NUMPAS(50)
      ENNE=P*FLOAT(NUMPAS(J))
      ENU=ENNE*FLOAT(NUMLV(J))/FLOAT(NU)
      PROBFN=0.
      PROBNY=0.
      EMME=1.
      EXPNU=EXP(ENU)                                                      4
      DO 10 M=1,20
      EMME=EMME*FLOAT(M)
      PR=(ENU**M)/(EXPNU*EMME)                                            8
      PROBNY=PROBNY&PR
      IF(M.LT.NUMLV(J)) GO TO 10
      PROBFN=PROBFN&PR
      PR=PR*1000.
      IF(PR.LT.PROBNY) GO TO 20
   10 CONTINUE
   20 WRITE(6,111) NU,INKMIN(J),J,ENNE,ENU                                19
  111 FORMAT(//3X,3HCONI4,18H VOLTE CHE VI SONOI2,28H O PIU' INCASTRI NE
     1LL'INT J=I3,7H CON N=F9.4,13H NU=N*MU/EMMEF10.7/)
      PROBNY=PROBNY*100.
      PROBFN=PROBFN*100.
      WRITE(6,222) PROBNY                                                 21
  222 FORMAT(3X,49HLA PROBABILITA' CHE UN LIVELLO SIA CASUALE E' DELF10.
     15,10H PER CENTO/)
      WRITE(6,333) NUMLV(J),PROBFN                                        22
  333 FORMAT(3X,20HE QUELLA CHE TUTTI EI3,31H I LIVELLI SIANO CASUALI E'
     1 DELF10.5,10H PER CENTO///)
      RETURN
      END
```

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