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Proposal to the ISOLDE Committee

TOWARDS THE PROTON DRIP-LINE ALONG THE CADMIUM ISOTOPIC CHAIN

1. *Identification of the N=Z nucleus* ^{96}Cd
2. *Study of Beta-Delayed Proton Precursor States of* ^{97}Cd
3. *Search for the Missing Gamow-Teller Strength in the Decay of* ^{98}Cd
4. Q_{EC} *and* B_{GT} *Determination for the Decay of* $^{99,101,103,105}Cd$ *with a Total Absorption Gamma Spectrometer (TAGS)*

CERN-ISOLDE

in collaboration with

Aarhus-Berkeley-Berlin-Darmstadt-Gothenburg-Jyvaskyla

Manchester-Michigan-Leuven-Liverpool-St.Petersburg-Warsaw

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Abstract

It is proposed to study at the new ISOLDE facility the decay of very neutron deficient cadmium isotopes produced with 1GeV protons on a molten tin target. These investigations will contribute to the understanding of the quenching of Gamow-Teller beta transitions in the ^{100}Sn region - a topic of basic interest for nuclear structure and providing essential information for nucleosynthesis models. The experimental programme consists of four projects. As a first one, asking for **two** runs of **10 shifts** each of the ISOLDE beam time in 1994, we would like to perform a study of ^{98}Cd decay to get a detailed decay scheme and to measure its decay energy with a precision better than 50 keV. In addition, we ask for **3 shifts** for a pilot gamma-spectroscopy experiment testing the actual mass dependence of cadmium production yields and the level of the previously observed $^{A}Br^{23}Na$ molecular contamination.

I. OUTLINE OF THE PROGRAMME

We propose to study at the new ISOLDE facility the neutron-deficient cadmium nuclei produced by 1 GeV protons on a molten tin target. The main aims of these investigations are related to the understanding of the quenching mechanism of the Gamow-Teller transition strength in the ^{100}Sn region. This question is important not only for the nuclear structure studies but it is relevant also for the interpretation of double-beta decay as well as for the nucleosynthesis scenarios.

During the past few years the studies of neutron-deficient cadmium isotopes at the ISOLDE-2 and ISOLDE-3 facilities included the decays of even-even isotopes like ^{102}Cd [1], ^{100}Cd [2] and ^{98}Cd [3] as well as the lightest known cadmium isotope, ^{97}Cd [4]. The achieved production yields of these isotopes are listed in table 1. Further investigations were limited due to the contamination of the separated beams by the molecules of ^{A}Br^{23}Na. For unknown reason these contaminations went up to three orders-of-magnitude (relative to ^{98}Cd) at our last experiments at ISOLDE-3.

We propose to continue these studies over next few years along the different research lines which will be outlined below with particular emphasis on project n^{o} 3. The necessary conditions with respect to the intensities and purity of separated beams requiring further target/ion source developments are also specified.

Project 1. *Identification of the N=Z nucleus ^{96}Cd.*

The nucleus ^{96}Cd would be the heaviest known isotope with equal proton and neutron numbers. Properties of such nuclei are of prime interest for nucleosynthesis calculations involving the astrophysical *rp*-process following the path close to the proton drip line after the breakout of the hot CNO-cycle [5]. A recently estimated half-life of 0.3 s [6] indicate that it may be possible to study this nucleus in a mass-separator based experiment. The beta delayed proton energy window is as large as 5 to 7 MeV, but the $\pi g_{9/2} \rightarrow \nu g_{9/2}$ GT channel occuring in addition to the $\pi g_{9/2} \rightarrow \nu g_{7/2}$ channel will result in strong beta branching to low excited states with subsequent gamma emission.

The study of ^{96}Cd with both gamma- and particle-spectroscopy methods would require a pure (contamination free) separated beam at a rate of at least one atom per second. Target/ion source development is clearly needed for this project and the achieved yields have to be verified in on-line conditions during preceding production tests.

Project 2. *Study of the Beta-Delayed Proton Precursor States of ^{97}Cd*

For beta-delayed proton activity assigned to the ^{97}Cd precursor [7] the half-lives of $3 \pm {}^{4}_{2}$ s [8] and 2 ± 1 s [4] have been reported based on experiments employing heavy-ion fusion-evaporation reactions and proton spallation in a molten tin target, respectively. Three proton precursor states with spin and parities of $1/2^-$, $9/2^+$ and $25/2^+$ are expected in ^{97}Cd with half-lives ranging from tenths of a second to a few seconds [4,7,8]. For the identification of these precursors, measurements with better statistics are needed. It is also important to use different reactions, which would presumably selectively enhance the production of one of the states. Measurements employing fragmentation of ^{112}Sn ions are on the way at GANIL,Caen.

We propose to study $^{97m,g}Cd$ proton spectra at ISOLDE with particle telescopes mounted at the collection and measuring points of the tape transport system. Since protons are not emitted from the $^{74}Br^{23}Na$ molecular contamination and proton branching ratios of about 10% are expected for ^{97}Cd ground and isomeric states, even a low production rate of about one atom/s should be sufficient for such studies.

Project 3. *Search for the Missing Gamow-Teller Strength in the Decay of ^{98}Cd.*

This experiment focuses on:

(i) the search for new theoretically predicted $0^+ \rightarrow 1^+$ Gamow-Teller (GT) transitions of presumably low branching ratios but appreciable strength [3,9,10,11]

(ii) measurement of the decay energy Q_{EC}, crucial for the determination of the absolute GT strength.

The intention is to test predictions of advanced shell-model calculations and to contribute to the understanding of the origin of the splitting and quenching of the GT strength. The decay scheme will be studied with a set-up of several high efficiency Compton suppressed Ge detectors. For the Q_{EC} determination a measurement of the positron end-point energy is planned with the use of a summation-free β^+-endpoint spectrometer [12]. These experiments can be carried out only at ISOLDE as they require production rates of 50-100 atoms/s (already achieved at ISOLDE-3). However, an important prerequisit is that the A=98 beam is free of molecular contamination $^{75}Br^{23}Na$.

Project 4. *Q_{EC} and B_{GT} Determination for the Decay of $^{99,101,103,105}Cd$ with a Total Absorption Gamma Spectrometer (TAGS)*

The main aim of this experiment is to obtain systematic information on the distribution and magnitude of the GT strength for the beta decays of odd-A cadmium isotopes. Since three-quasiparticle states at high excitation energies and high level densities are populated in the decays of these cadmium isotopes, the only experimental way to determine the GT strength is 4π-γ spectrometry, see e.g. earlier ISOLDE results [13] and recently reported studies of ^{104}In and ^{100}Ag decays at GSI [14]. The advantage of having larger Q_{EC} values (i.e. GT strength observation windows) as compared to even-even isotopes decays can be explored for the analysis of the quenching phenomenon.

With the present, highly efficient and stabilized spectrometers [15], TAGS measurements could be performed with the yields achieved previously for odd-A cadmium isotopes, however with beams free from isobaric molecular contaminations $^{A}Br^{23}Na$. Complementary experiments applying the TAGS technique for studying odd-odd indium and silver isotopes have been recently accepted at GSI Darmstadt [16].

II. SCIENTIFIC OUTLINE AND BEAM TIME REQUEST

to carry out in 1994 project n° 3

" Search for the Missing Gamow-Teller Strength in the Decay of ^{98}Cd "

CERN-ISOLDE
in collaboration with
Liverpool-Manchester-Darmstadt-Jyvaskyla
Leuven-Berlin-Michigan-Warsaw

1. INTRODUCTION AND GENERAL MOTIVATION

Our previous experimental studies on the Gamow-Teller (GT) decay of nuclei near the doubly-magic ^{100}Sn, see [14], has raised much theoretical interest [3,9-11,17-24]. The essence of this research programme can be outlined as follows. The nuclei of interest are very far from the line of beta stability. With high decay energies Q_{EC}, they are particularly suitable for a study of beta decay. An inspection of the shell-model picture indicates that beta decay observed for N≥50 must be dominated here by allowed GT decay between the $g_{9/2}$ proton and the $g_{7/2}$ neutron orbits. Therefore, data on the EC/β^+ decay provide a unique opportunity for testing nuclear models. When confronted with experimental results, these models are expected to provide an insight into the origin of the distribution and quenching of the GT strength. This is one of the most important problems of modern low energy nuclear physics related to nucleonic and subnucleonic degrees of freedom.

2. EXPERIMENTAL AND THEORETICAL STUDIES OF ^{98}Cd

A study on the decay of the doubly-magic ^{100}Sn would be of particular importance. Unfortunatly, this very exotic nucleus has not yet been identified. It is therefore important to study the decay of its closest even-even N = 50 isotone ^{98}Cd. Some data on the ^{98}Cd decay are already available [3].

At ISOLDE, after the first observation [7] of a component in a beta spectrum decaying with a half-life of about 8 s, tentatively ascribed to ^{98}Cd , this activity was unambiguously identified, and studied in some detail, by γ-ray and conversion-electron spectroscopy [3]. The half-life was determined to be 9.2 ± 0.3 s and the decay scheme was established with 9 excited states of the daughter ^{98}Ag, see fig.1. The states at 1691, 1861, 2164 and 2544 keV have spin and parity 1^+. They are fed directly by $0^+ \rightarrow 1^+$ GT beta transitions with a summed strength $B_{GT} = 3.5^{+0.8}_{-0.7}$. The large error is mainly due to the inaccuracy of decay energy Q_{EC}. The latter was estimated as 5.33 ± 0.14 MeV by a linear extrapolation of Q_{EC} values for neighbouring even-even N = 50 and Z = 48 nuclei, and it definitely has to be measured.

Sensitivity of the B_{GT} value to the adopted energy is illustrated in table 2. In addition, the experimental sensitivity limit for detection of $0^+ \rightarrow 1^+$ transitions, see fig.2, was rather low due to the presence of $^{75}Br^{23}Na$ contamination in the investigated samples. It means that there may be additional 1^+ levels, particularly at higher excitation energies, fed with low beta branchings, but non-negligible GT strengths. These considerations are strongly supported by shell-model calculations presented in [3,9,10], and very recently, see fig.3, by Brown [11]. All the model calculations predict the states at about 3 to 4 MeV excitation energy which should be detectable in a more sensitive experiment.

It is important to notice that the calculations of Brown predict that all the GT-strength for ^{98}Cd decay is contained in the energy window set by Q_{EC} and other calculations allocate as small as 2 to 7 % to 1^+ states energetically non-accesible by beta transitions. With ^{100}Sn and ^{102}Sn remaining non-identified until now, the ^{98}Cd nucleus is so far the only even-even isotope that can be produced and experimentally studied and that exhibites such a feature.

3. MEASUREMENTS PROPOSED

This project reflects our conviction that an essential improvement of the ^{98}Cd decay data is within reach. In view of the remarks given above this will be a substantial contribution to the studies of GT-quenching phenomenon in the ^{100}Sn region.

3.1. Search for new $0^+ \rightarrow 1^+$ GT transitions

The ^{98}Cd activity will be studied with an array of twelve Compton suppressed germanium detectors (TARDIS) mounted in two rings of six, giving 66 pairs of detectors for coincidences. Spectra recorded with this set-up are expected to be very clean. This should enable us to look for new gamma transitions of intensity $\leq$1 percent. Assignment of these transitions will be based on coincidence relations with γ-transitions placed already in the decay scheme. The identification of 1^+ states will be derived from *log ft* values. Coincidences of particular interest will be those between new $\geq$ 1 MeV transitions and known lines of 107,347 and 898 keV, see fig.1. The corresponding coincidence efficiences are about $6.6 \cdot 10^{-4}$, $2.6 \cdot 10^{-4}$ and $1.3 \cdot 10^{-4}$. Assuming a source strength of 50 to 100 atoms per second throughout 10 shifts, a one percent branch for a ($\geq$ 1 MeV-347 keV) cascade would yield about 40 to 80 coincidences. The search for transitions with intensities below one percent is thus realistic.

3.2. Decay energy determination.

The Q_{EC} value for ^{98}Cd decay can be obtained via a measurement of the endpoint-energy of the β^+ spectrum for the transition to the 1691 keV level. For planning the experiment we take the estimate from [3], $Q_{EC} = 5.3$ MeV, i.e. the endpoint-energy of 2.6 MeV.

We intend to carry out the measurement with the use of a summation-free β^+-endpoint spectrometer [12]. The positron spectrum will be measured in a thick Si-detector in coincidence with γ-rays. By gating on the 625, 1176 and 1523 keV γ-lines, the β^+-component corresponding to the transition to 1691 keV level can be selected, see fig.1. Summing with annihilation radiation will be prevented by detecting both 511 keV quanta in opposite segments of an array of BGO detectors surrounding the Si-detector. With a measurement lasting 10 shifts and the rate of 50 atoms/s, more than 1000 counts in the γ-511-511 coincident positron spectrum will be recorded. From comparison to the similar measurements for ^{104}Sn decay [25], where an endpoint energy of 2400 ± 60 keV has been determined, it is clear that with such a statistics the uncertainty of the Q_{EC} value will be below 50 keV. This accuracy is sufficient for GT-strength determination, see table 2.

4. SUMMARY AND BEAM TIME REQUEST

We would like to start our programme from advanced gamma spectroscopy studies of ^{98}Cd decay asking for the **10 shifts** of the beam time in a first half of 1994. The main experiment should be preceded by a yield test **(3 shifts)** checking also the level of molecular contamination. *Ion source development* should be considered if e.g. the contamination activities would disable the proposed measurements.

In the fall of 1994 we would like to measure the decay energy of ^{98}Cd with the summing free β^+-endpoint spectrometer during **10 shifts**. Construction of a tape station for transporting the samples into air at ISOLDE is a main technical issue. This system is expected to be used later for the total absorption gamma spectroscopy measurements of odd cadmium isotopes, see project 4.

Laboratories collaborating with ISOLDE group within Project n° 3 - Search for the Missing Gamow-Teller Strength in the Decay of ^{98}Cd :

a) γ-spectroscopy

Liverpool-Manchester-Darmstadt-Leuven-Berlin-Michigan-Warsaw

b) Q_{EC} measurement

Darmstadt-Jyvaskyla-Berlin-Leuven-Michigan-Warsaw

Tables

Table 1. Yields (atoms/s at 1 μA) of neutron deficient cadmium isotopes achieved in previous studies at the ISOLDE-2 and ISOLDE-3 facilities.

Mass number	104	102	100	98	97
Rate	10^8	10^6	10^4	$\simeq 10^2$	$\simeq 1$

Table 2. Dependence of summed GT strength on the ^{98}Cd decay energy for branching ratios as given in fig.1.

Q_{EC}	5.10	5.25	5.30	5.35	5.50
B_{GT}	4.25	3.95	3.65	3.39	2.70

Figure Captions

1. Decay scheme of ^{98}Cd, see [3] for details.

2. Experimental GT-strength distribution for ^{98}Cd decay obtained assuming the decay scheme as given in fig. 1 and the extrapolated Q_{EC} value of 5.33 MeV, see [3]. Summed GT-strength amounts to $B_{GT}=3.5\pm^{0.8}_{0.7}$. Sensitivity limit achieved in preceeding experiment [3] is indicated by a dashed line.

3. GT-strength distribution as predicted for ^{98}Cd decay by Brown [11]. Total expected GT-strength (all within the Q_{EC} window) amounts to $B_{GT}=3.7$.

References

[1] Keller H *et al* 1991 *Zeit. Phys.* **A339** 355

[2] Rykaczewski K *et al* 1989 *Zeit. Phys.* **A332** 275

[3] Plochocki A *et al* 1992 *Zeit. Phys.* **A342** 43

[4] Grawe H *et al* 1989 *Status Report of Exp. IS01-33, CERN-ISOLDE, SR1989*

[5] Wallace R K and Woosley S E 1981 *Astrophys. Jour. Suppl.* **45** 389

[6] Biehle G T and Vogel P 1992 *Phys. Rev.* **C46** 1555

[7] Elmroth T *et al* 1978 *Nucl. Phys.* **A304** 493

[8] Kurcewicz W *et al* 1982 *Zeit. Phys* **A308** 21

[9] Johnstone I P 1991 *Phys. Rev.* **C44** 1476

[10] Skouras L D and Manakos P 1993 *J.Phys.***G** *Part.Phys.* **19** 731

[11] Brown B A and Rykaczewski K 1993 *to be published*

[12] Keller H *et al* 1991 *Nucl. Instr. Methods in Phys. Res.* **A300** 609

[13] Duke C L *et al* 1970 *Nucl. Phys.* **A151** 493

[14] Rykaczewski K 1993, *Proc. 6th Int. Conf. on Nuclei far from Stability and 9th Int. Conf. on Atomic Masses and Fundamental Constants*, NFFS-6/AMCO-9, Bernkastel-Kues 1992, Germany, IOP Proc. 132, Bristol 1993, p.517

[15] Nitschke J M *private communication al* 1992

[16] Rykaczewski K *et al* 1992 *proposal for GSI exp. U085* unpublished

[17] Towner I 1985 *Nucl. Phys.* **A444** 402

[18] Dobaczewski J *et al* 1988 *Zeit. Phys.* **A329** 267

[19] Suhonen J *et al* 1988 *Nucl. Phys.* **A486** 91

[20] Kuzmin V A and Soloviev V G 1988 *Mod. Phys. Lett.* **A 3** 1533

[21] Borzov I.N. *et* al 1990 *Sov. Jour. Nucl. Phys.* **52** 985

[22] Suhonen J 1991 *Phys. Lett.* **B 255** 159

[23] Schubart R *et al* 1992, *Proc. 6th Int. Conf. on Nuclei far from Stability and 9th Int. Conf. on Atomic Masses and Fundamental Constants*, NFFS-6/AMCO-9, Bernkastel-Kues 1992, Germany, IOP Proc. 132, Bristol 1993, p.527

[24] Ogawa K *et al* 1992, *Proc. 6th Int. Conf. on Nuclei far from Stability and 9th Int. Conf. on Atomic Masses and Fundamental Constants*, NFFS-6/AMCO-9, Bernkastel-Kues 1992, Germany, IOP Proc. 132, Bristol 1993, p.533

[25] Keller H *et al* 1991 *Zeit. Phys.* **A340** 363

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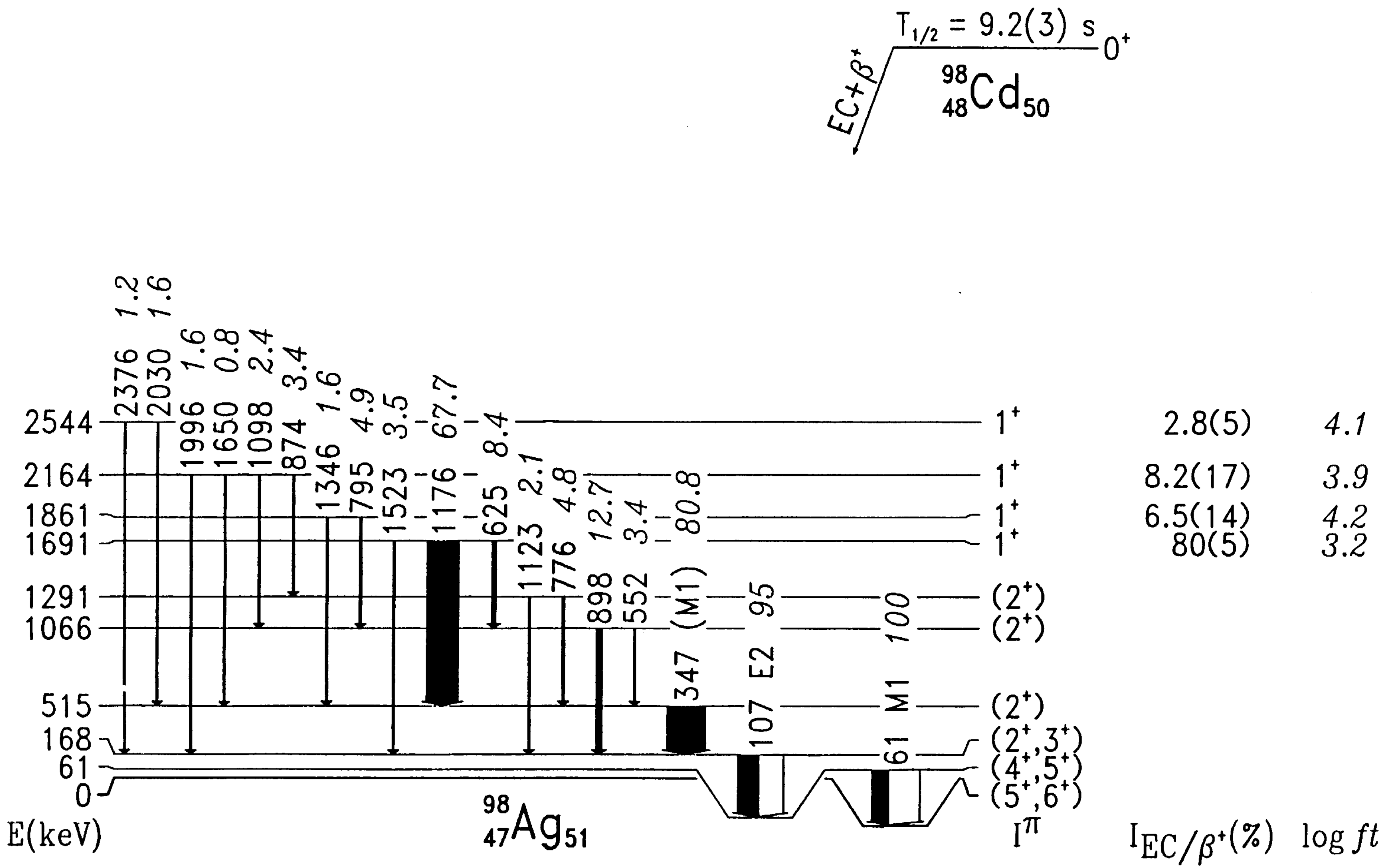
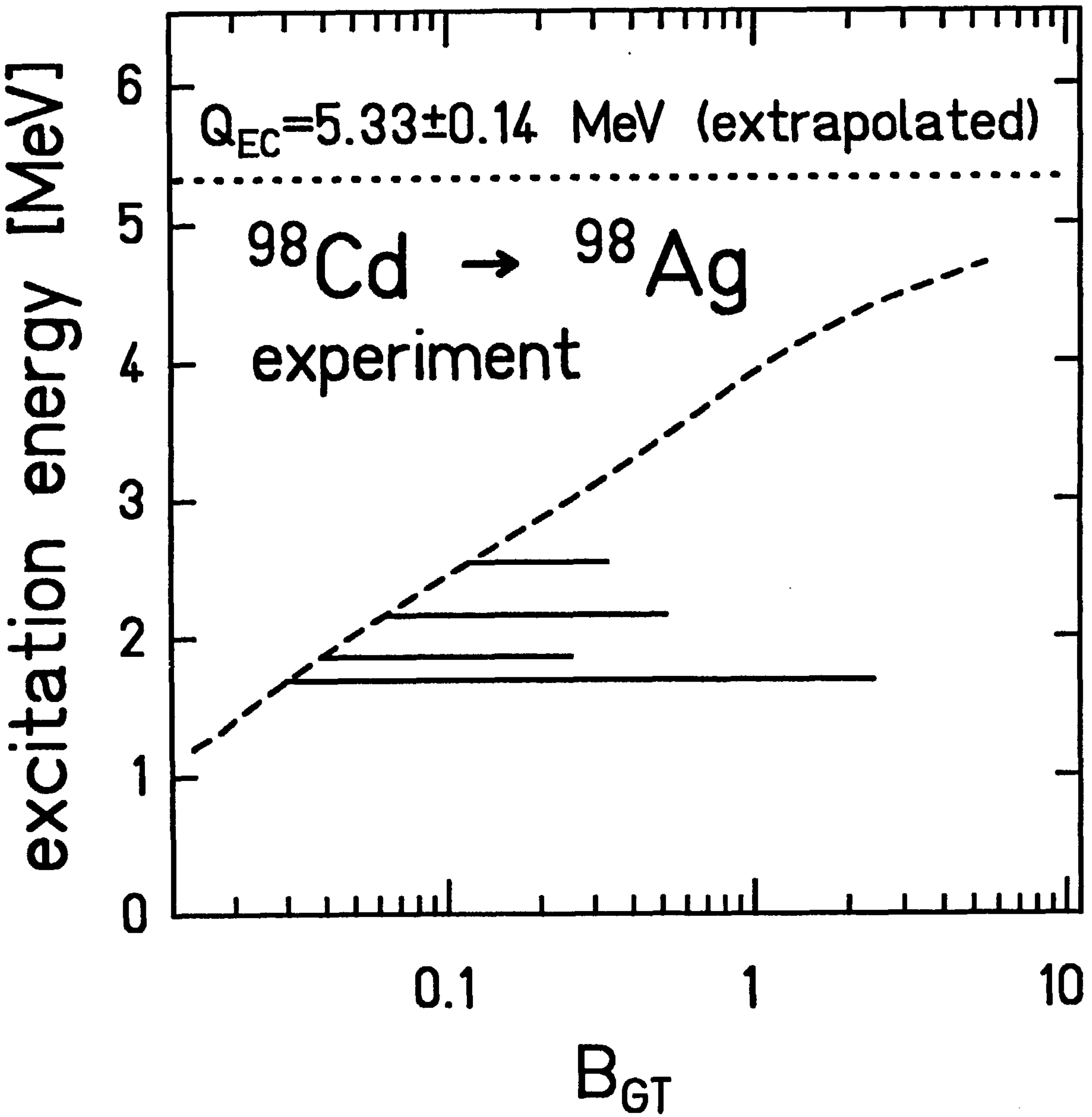
FIG. 1



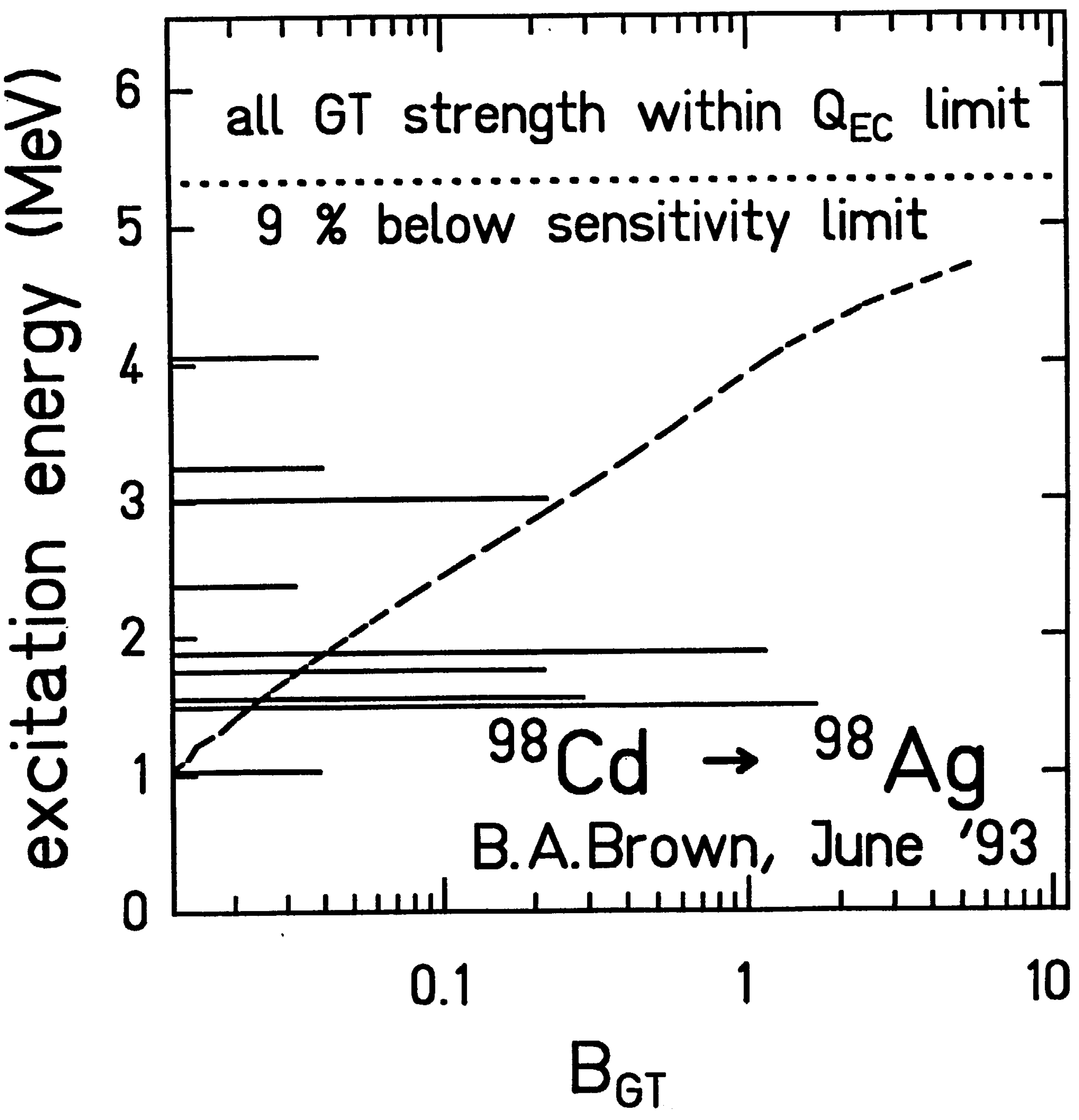
T1/2 = 9.2(3) s
0+
98 48 Cd 50
EC+β+
2376 1.2
2030 1.6
1996 1.6
1650 0.8
1098 2.4
874 3.4
1346 1.6
795 4.9
1523 3.5
1176 67.7
625 8.4
1123 2.1
776 4.8
898 12.7
552 3.4
347 (M1) 80.8
107 E2 95
61 M1 100
2544
2164
1861
1691
1291
1066
515
168
61
0
E(keV)
98 47 Ag 51
1+
1+
1+
1+
(2+)
(2+)
(2+)
(2+,3+)
(4+,5+)
(5+,6+)
Iπ
2.8(5) 4.1
8.2(17) 3.9
6.5(14) 4.2
80(5) 3.2
IEC/β+(%) log ft

FIG. 2



excitation energy [MeV]
6
5
4
3
2
1
0
Q_EC=5.33±0.14 MeV (extrapolated)
98Cd → 98Ag
experiment
0.1
1
10
B_GT

FIG. 3



all GT strength within Q_EC limit
9 % below sensitivity limit
98Cd → 98Ag
B.A.Brown, June '93
excitation energy (MeV)
0
1
2
3
4
5
6
0.1
1
10
B_GT