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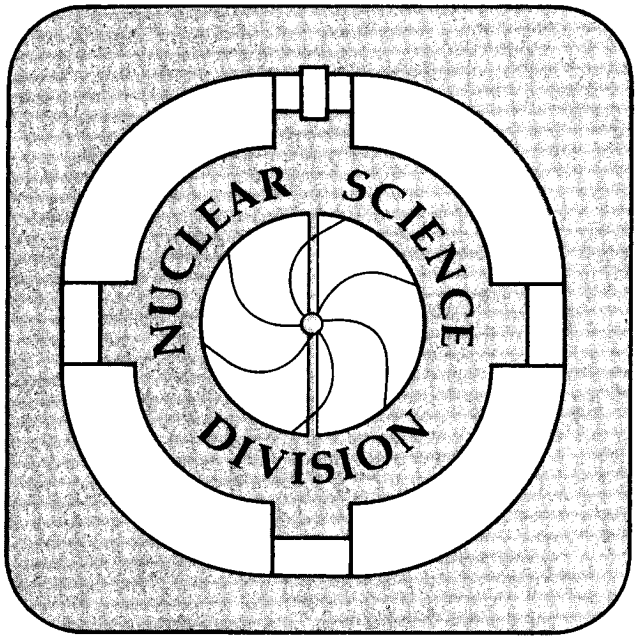
May 1992



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SECOND FORBIDDEN ELECTRON-CAPTURE DECAY OF ^{55}Fe

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Second-Forbidden Electron-Capture Decay of ^{55}Fe

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Superimposed on the continuous inner-bremsstrahlung spectrum of ^{55}Fe, we observe a weak γ-ray line at an energy of 126.0 keV. The intensity of this line with respect to the inner-bremsstrahlung spectrum does not change with time. We interpret this γ-ray line to be produced by the second-forbidden nonunique decay of ^{55}Fe to the first excited state of ^{55}Mn with a branching of $(1.3 \pm 0.1) \times 10^{-7}\%$.

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^{55}Fe undergoes a ground-state to ground-state electron-capture (EC) decay to ^{55}Mn with a Q_{EC} = 231.7 keV and $t_{1/2}$ = 2.73 y [1]. The energetically allowed second-forbidden nonunique electron-capture decay to the first excited state of ^{55}Mn (125.95 keV above the ground state) has not been observed so far [2], in part because of the intense background radiation due to the inner-bremsstrahlung (IB) (3.2×10^{-3} photons per 100 ^{55}Fe disintegration) which produces a continuous spectrum up to 231.7 keV.

To carry out a detailed study of the IB spectrum of ^{55}Fe, in which we are looking for minute distortions from the theoretical spectrum, an ^{55}Fe sample was obtained from New England Nuclear Co. The sample was made by the (n,γ) reaction on natural iron. Because γ-ray counting showed that the sample contained impurities of ^{60}Co, ^{54}Mn and ^{59}Fe, we chemically purified the iron using ion-exchange techniques. The sample was mixed with concentrated HCl and HNO_3 and then sorbed onto a column of AG1-X8 anion-exchange resin which had been treated with $10M$ HCl. Washes with more $10M$ HCl removed the manganese. The cobalt fraction was then eluted with $4M$ HCl. Finally, the iron fraction was eluted with water. ^{60}Co and ^{54}Mn in the iron fraction were reduced to activity levels smaller than 1 nCi. The strength of the purified ^{55}Fe source was ~25 mCi at the beginning of the measurement. To be able to subtract the contribution from ^{59}Fe, we made a separate source of ^{59}Fe by the (n,γ) reaction on a foil of natural iron.

We measured γ-ray spectra with a coaxial HPGe detector (110-cm^3 active volume), placed inside an active shield of NaI scintillator consisting of 30 cm $\times$ 30 cm annular detector and a 7.5 cm $\times$ 15 cm plug detector. The NaI detectors acted as veto for room background, coincident, and Compton scattered γ-rays. Pileup suppression was done with an Ortec 572 amplifier. The singles counting rate of the germanium detector was ~8000 s^{-1} during the course of data aquisition. Data were recorded in

2-3 days intervals on a PC-based acquisition system. Three separated spectra were recorded simultaneously on three separated ADC's: 1) germanium singles, 2) germanium with pileup suppression, 3) germanium with pileup suppression and Compton suppression. The purified iron source was placed in a 1-mm thick plastic container and an additional absorber made of Cu and Al foils was added between source and detector to reduce the Mn x-rays from EC decays. This assembly was then placed up against the Be window of the germanium detector. The data were taken during an eight month period and combined into nine successive runs. The energy scale was calibrated using background Pb x-rays and γ-ray lines from ^{59}Fe present in the raw spectra, and verified with standard γ-ray calibration sources. A 0.1 keV overall calibration uncertainty affected γ-ray energies within the range of 100-250 keV. Room background and ^{59}Fe spectra were accumulated and recorded between the runs and normalized to the peaks in the ^{55}Fe data. Fig. 1 shows the spectrum of ^{55}Fe after ^{59}Fe and room background subtraction.

To search for the presence of weak lines superimposed on the intense IB spectrum, we applied the second derivative method [3] (Fig. 2). In all nine sets of the data, taken with all three ADC's, we observed peaks at the energies $\sim$126 keV and $\sim$159 keV. The intensity of the 126-keV line was normalized to the known intensity of the IB spectrum in the energy range from 121 to 131 keV (1.66×10^{-4}%). We calculated the intensity of the IB spectrum based on the papers cited in Ref. [4] and verified with values given in Ref. [1]. By following the decay of the 126 and 159 keV lines, we find that the intensity of the 126 keV line does not change with respect to the intensity of the IB spectrum. We also took data with lower amplifier gain to look for the presence of radio-impurities and none were found. *Ergo*, we attribute this γ-ray to the decay of ^{55}Fe. Additional evidence for this conclusion comes from our analysis of γ-ray spectra of an older source of ^{55}Fe ($\sim$ 4 mCi), taken with different detectors

and electronic setups 2.5 years ago. Here also the intensity of the 126-keV γ-ray relative to that of the IB remained unchanged during the entire experiment (Table 1). The 159-keV γ-ray decayed with $t_{1/2} = 113 \pm 7$ days (1-σ confidence level) and thus belongs to a ^{123}Te ($t_{1/2} = 119.7 \pm 0.1$ days [1]) activity contained in the source. A weak 417-keV γ-ray identified in the total data set very likely belongs to ^{127}Te. These tellurium impurities apparently were not completely removed by the chemical separation and may have originated from neutron activation of tellurium contained in the iron source.

Our deduced EC branching to the first excited state in ^{55}Mn is $(1.3 \pm 0.1) \times 10^{-7}\%$ (see Table 1), where the uncertainty accounts for changes in the detector efficiency within a 10-keV bin at about 126 keV, and for the precision in the calculation of IB intensities. The uncertainty in the counting statistics ($0.02 \times 10^{-7}\%$) shown in Table 1, and the conversion coefficient (0.018 [1]) of the 126-keV γ-ray transition are negligible. The log *ft* value for this EC decay is 14.2, in agreement with systematics of allowed log *ft* values for second-forbidden nonunique transitions [5]. Our proposed decay scheme is shown in Fig. 3.

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†On leave from Rugjer Bošković Institute, Zagreb, Croatia.

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TABLES

TABLE I. The energy and the absolute γ-ray intensity of the 126 keV peak in the measurements with the 25 mCi source (runs 1-9), and with the 4 mCi source over a 2-year span. Uncertainties in the γ-ray intensities are statistical only.

Run	Time [days]	Peak position [keV]	Absolute γ-ray intensity [10^{-7}%]
1	0 - 56	126.0±0.1	1.36±0.05
2	66 - 85	126.0±0.1	1.20±0.07
3	85 - 103	126.0±0.1	1.28±0.07
4	103 - 115	126.0±0.1	1.31±0.08
5	115 - 135	126.0±0.1	1.20±0.07
6	135 - 153	126.0±0.1	1.26±0.08
7	153 - 163	126.0±0.1	1.53±0.10
8	167 - 182	126.0±0.1	1.23±0.08
9	182 - 213	126.0±0.1	1.20±0.07
Jun.89		125.9±0.1	1.26±0.12
Jul.89		125.8±0.1	1.15±0.18
Jun.91		125.8±0.1	1.58±0.33
Adopted value		126.0±0.1	1.28±0.02

FIGURES

FIG. 1. Photon spectrum accumulated for eight months using the 25 mCi ^{55}Fe source after subtraction of room background and contributions from ^{59}Fe. The continuum above the IB endpoint is due to complete pileup events that are not removed by the pileup suppression.

FIG. 2. The second derivative of the data shown in Fig. 1. Data were binned in 1 keV bins. Energies are in keV. Pb x-rays are from fluorescence in the passive shielding behind the germanium detector.

FIG. 3. Proposed decay scheme of ^{55}Fe .

Fig. 1

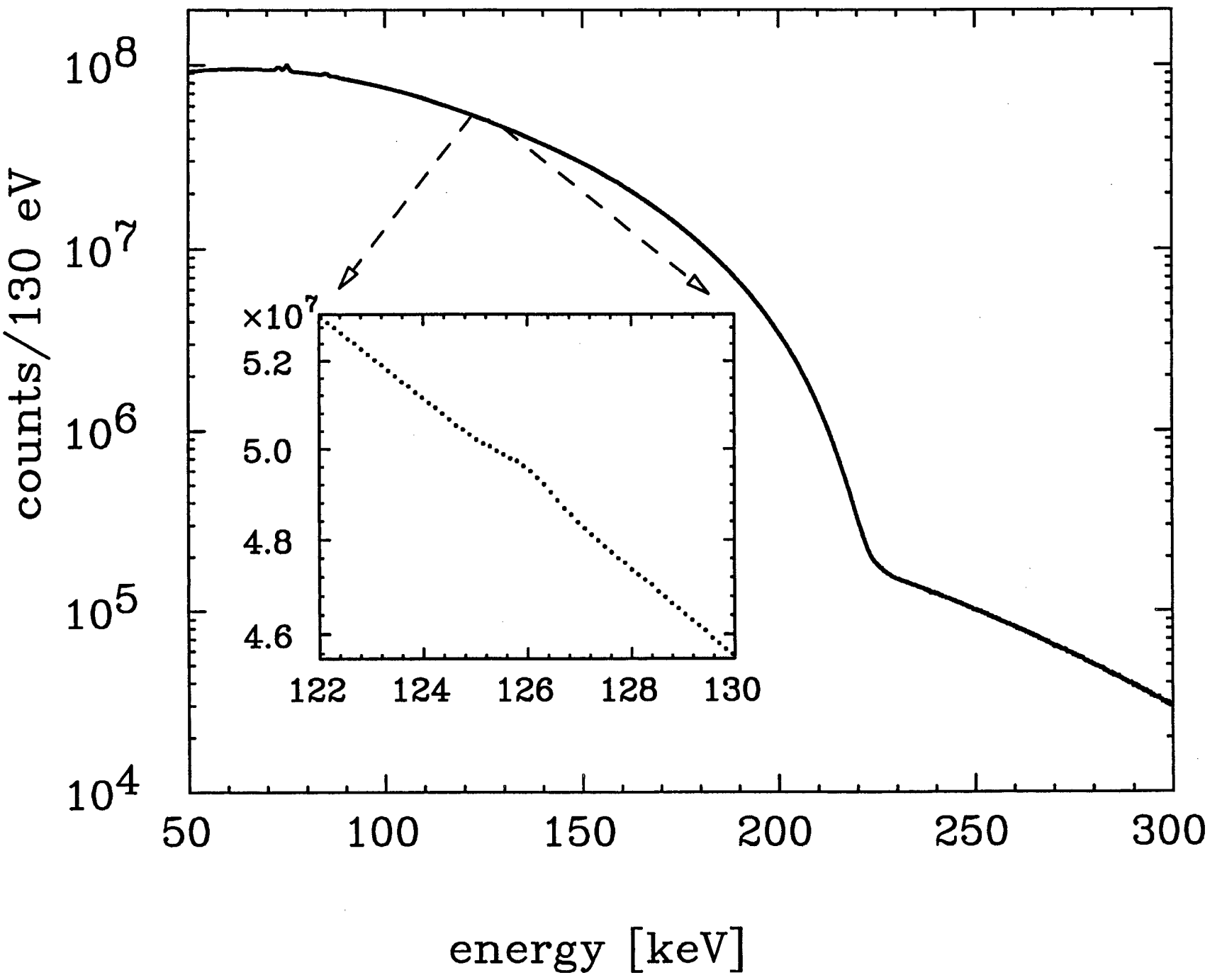

counts/130 eV
10^8
10^7
10^6
10^5
10^4
50
100
150
200
250
300
energy [keV]
$\times 10^7$
5.2
5.0
4.8
4.6
122
124
126
128
130

Fig. 2

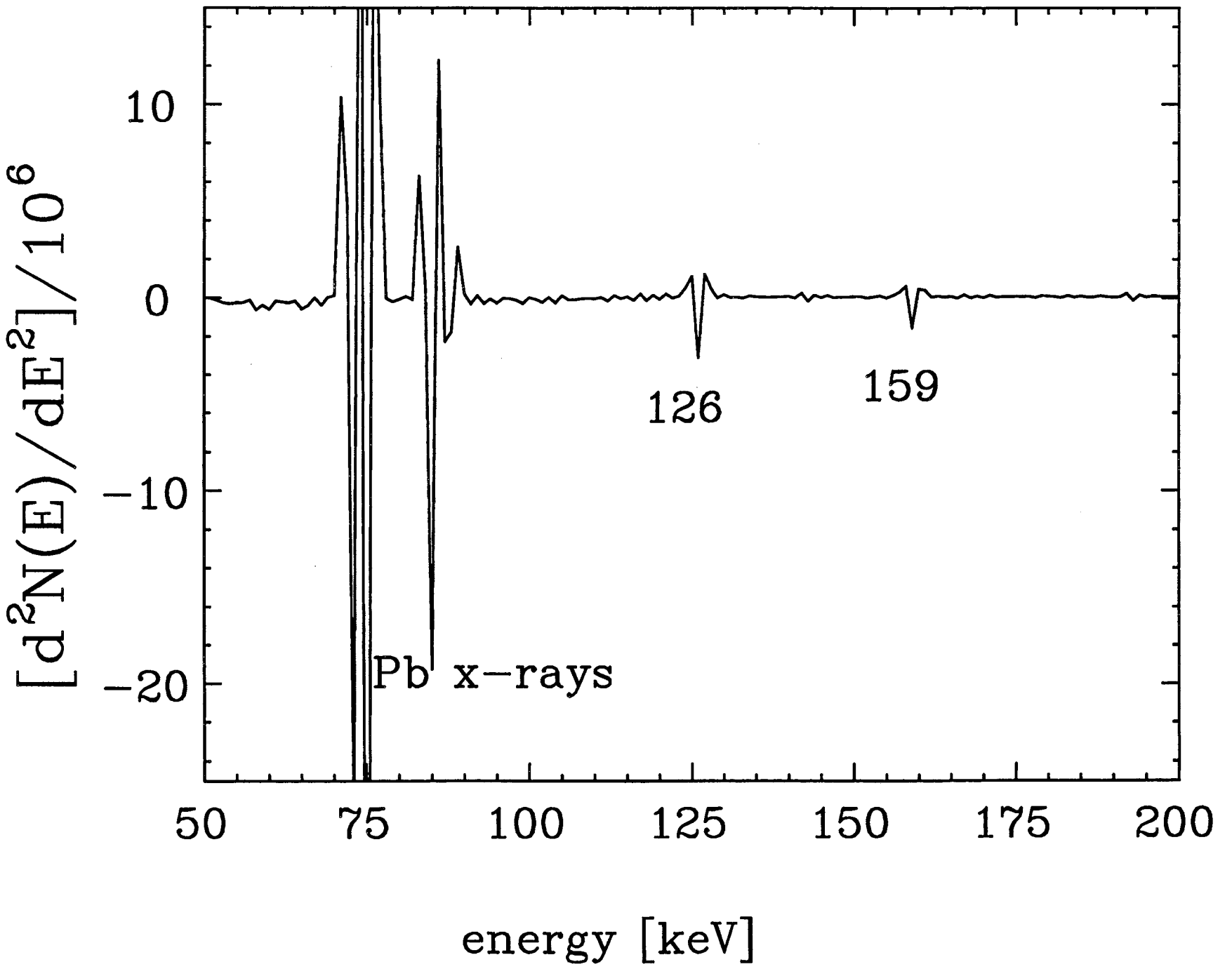
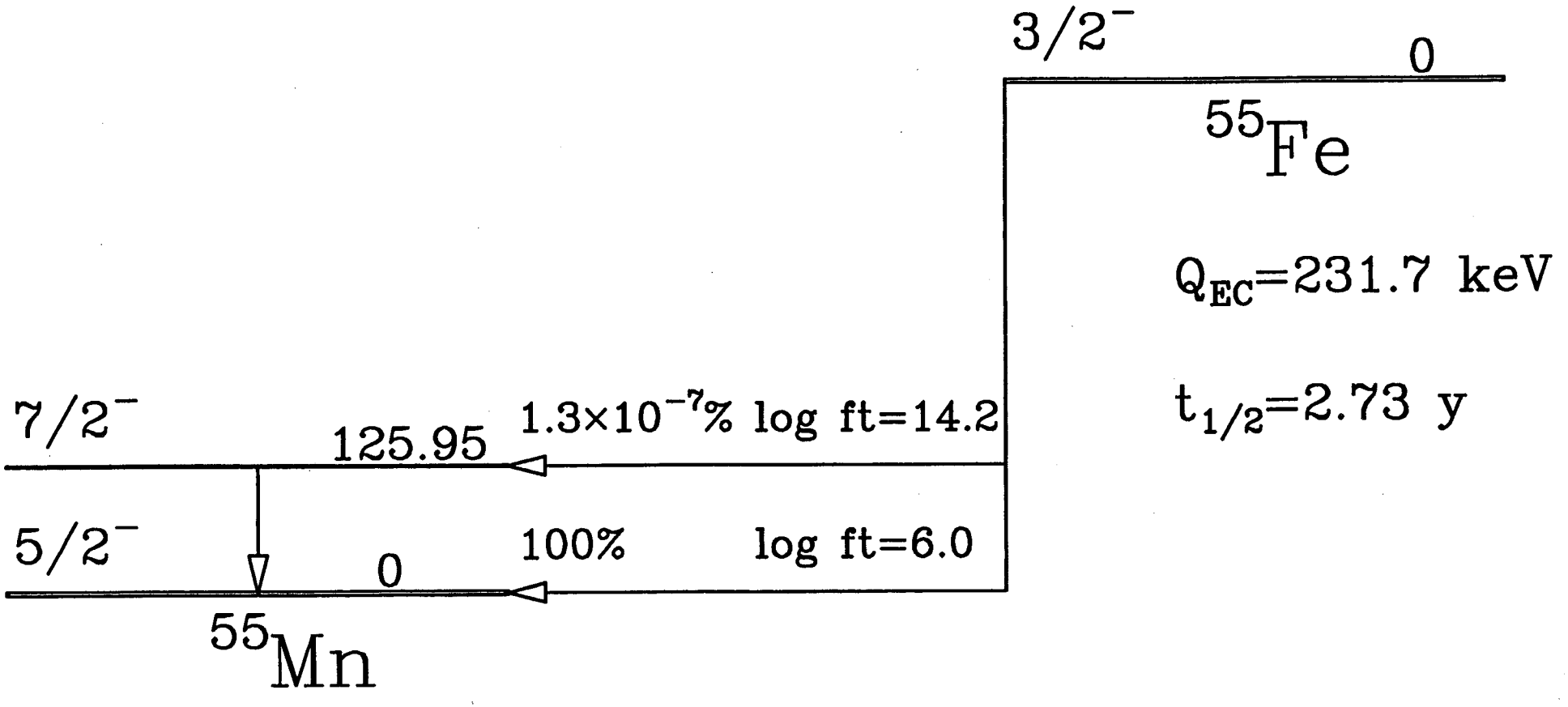

10
0
−10
−20
$[d^2N(E)/dE^2]/10^6$
Pb x−rays
126
159
50
75
100
125
150
175
200
energy [keV]

Fig. 3


3/2⁻
0
55Fe
QEC=231.7 keV
t1/2=2.73 y
7/2⁻
125.95
1.3×10⁻⁷% log ft=14.2
5/2⁻
0
100%
log ft=6.0
55Mn

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