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STUDY OF THE REACTION ^{76}Br(n_{th},p)^{76}Se

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Abstract

Study of the reaction ^{76}Br(n_{th},p)^{76}Se by G. Andersson (Department of Physics, Chalmers University of Technology, Göteborg, Sweden), M. Asghar (Institut Laue-Langevin, Grenoble, France), A. Emsallem (Institut de Physique Nucléaire, Lyon, France), E. Hagberg, B. Jonson and P. Tidemand-Petersson (CERN, Geneva, Switzerland).

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A target of 16.1 h ^{76}Br, prepared by on-line isotope separation at the ISOLDE facility, CERN, has been exposed to thermal neutrons from the Grenoble high-flux reactor. Four proton branches from the capturing state at 11 MeV in ^{77}Br to the 0^+ ground state and the three lowest 2^+ states of ^{76}Se were observed. The total (n_{th},p) cross-section was measured as 224 ± 42 b and the Q-value for the reaction as 5730 ± 15 keV.

The program [1,2,3] to study (n_{th},p) and (n_{th},α) reactions in neutron-deficient nuclei, using targets prepared with the ISOLDE on-line separator facility at CERN and a thermal neutron beam from the high-flux reactor of Institut Laue-Langevin (ILL) in Grenoble, has continued with an experiment on 16.1 h ^{76}Br. This nuclide was expected to constitute a good target for the (n_{th},p) reaction, judging primarily from the favourable relation between the Q-value of the process (about 5.7 MeV) and the height of the Coulomb barrier (about 7.7 MeV). Further support was obtained from statistical-model calculations of partial level widths (with due recognition of the fact that the average properties predicted in this way may deviate considerably from those characteristic of individual states), which indicated the possibility of de-excitation to more than 95% by proton emission of the capturing state at 11010 ± 15 keV [4] in ^{77}Br. It was also noticed that the density of appropriate levels ($1/2^-$ or $3/2^-$ being formed from the 1^- target nucleus) should be fairly high around that energy, favourably influencing the cross-section for thermal neutron capture.

A half-life of 16 hours may seem rather short in view of the time it takes to transport the target from Geneva to Grenoble and to set up the experiment (about 8 hours). By collecting the parent nuclide 14.8 h ^{76}Kr, however, we could obtain the bromine isotope as a decay product, the similar periods of the two isobars implying a much longer effective target half-life. In fact, the timing was such that the amount of ^{76}Br had not yet reached its flat maximum when the target was mounted at ILL.

The ISOLDE production data were as follows. A 53 g cm^{-2} target of Nb powder, kept at 2000°C, was bombarded with a 1.4 μA, 600 MeV proton beam from the synchro-cyclotron (SC) machine. Of the continuously out-diffusing spallation products, krypton isotopes were allowed to reach the isotope separator and be processed. During a 34 hour collection, ^{76}Kr was deposited in a 10 μm foil of ultrapure aluminium, forming a sample of about 0.1 cm^2 area and containing 5×10^{12} atoms each of ^{76}Kr and ^{76}Br at the end of the collection.

The target thus prepared was exposed for 72 hours in a thermal neutron flux of 10^9 cm^{-2} s^{-1} at ILL. Charged particles emitted within a solid angle of 1.1%

of 4π Sr were recorded with a 300 μm, 300 mm^2 silicon surface barrier detector, energy calibrated by means of lines from the ^{6}Li(n_{th},α)^{3}H reaction and the α decays of ^{237}Np and ^{241}Am. Corrections have been applied for energy losses of the various particles in the detector surface layer and, as far as the capture experiment is concerned, in the aluminium layer covering the implanted atoms. We assign a systematic error of ±15 keV to the energy determinations.

Figure 1 shows the relevant part of the spectrum obtained with the ^{76}Br target. The resolution was impaired by the high total counting rate during the experiment, caused mainly by the radioactivity of the target, and was found to correspond to 40 keV FWHM.

One of the five prominent peaks, marked with an arrow in the figure, is known to be composed of the 4.769 and 4.786 MeV alpha lines of ^{237}Np, contaminating the measuring chamber. The other four show up at energies expected [4,5] for proton branches from the capturing state in ^{77}Br to levels in ^{76}Se (see Fig. 2).

A detailed analysis of the spectrum is made difficult by the presence of numerous background bumps, most often of unknown origin. The possibility of contributions from capture in ^{76}Kr must, of course, be recognized. Whereas the protons following this process cannot have energies above 2 MeV, there might be alpha branches of 4.50, 4.80, 4.42, 4.36, and 4.10 MeV, of which the first two would fall within the p_3 complex. Since the amount of ^{76}Kr kept decreasing relative to that of ^{76}Br during the experiment, a comparison between spectra taken at different times should reveal significant contributions from ^{76}Kr(n_{th},α)^{73}Se. No such evidence has been found, however.

When the activity of the target was measured several months after the capture experiment, it turned out that a line-rich particle spectrum was still obtained, showing in particular that the high-energy satellites of the peaks p_1, p_3, and p_6 are, at least partly, due to long-lived alpha emitters. A well-defined peak at 5.12 MeV could be ascribed to ^{208}Po, present as a "memory" in the ISOLDE machine, and used in the decomposition of p_1 after calculating its intensity back to the time of the neutron exposure. As to p_3 and p_6, the contaminants have not been identified, and these complexes were resolved by fitting standard peak shapes.

Especially the p_6 intensity has to be assigned a considerable error, since in addition to being composite the peak rides on a high continuous background. It is still worth noticing, however, that it is about as strong as p_0 and p_1, although its energy is lower by 1.75 and 1.20 MeV, respectively. Unfortunately the intensity uncertainties are so great throughout as to make a detailed discussion of the relative level widths meaningless. May we just remark that the generally favoured feeding of 2^+ states would seem to indicate that the capturing state is $3/2^-$ rather than $1/2^-$.

With a target containing a time-dependent number n(t) of atoms, the reaction cross-section is determined as

$$\sigma = N/\phi\varepsilon \int_{t_1}^{t_2} n(t)\, dt \ , \tag{1}$$

where N is the number of counts registered in the time interval t_2-t_1, ϕ is the neutron flux, and ε the over-all detection efficiency. The integral was calculated as $(4.14 \pm 0.40) \times 10^{17}$ s using simultaneously measured absolute activities of ^{76}Kr and ^{76}Br in the target. In order to obtain the product $\phi\varepsilon$, an accurately known amount of ^{6}Li was used as target under otherwise identical experimental conditions, and the count rate of 2.73 MeV tritons from the well-known $^6\mathrm{Li}(n_{th},\alpha)^3\mathrm{H}$ reaction recorded, yielding $\phi\varepsilon = (5.85 \pm 0.43) \times 10^{-18}\ \mathrm{b}^{-1}\ \mathrm{s}^{-1}$. The final results of the spectrum analysis are collected in Table 1.

From the particle energies p_0, p_1, and p_3 we determine the energy available for proton emission from the neutron capturing state in ^{77}Br to be 5730 ± 15 keV. This is to be compared with the adjusted Q-value of -5738.4 ± 15 keV reported [4] for the inverse reaction $^{76}\mathrm{Se}(p,n)^{76}\mathrm{Br}$.

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Table 1

Peak	Energy (keV)		Contents counts	Cross-section (barn)*)
	Expected [4,5]	Measured		
p_0	5664	5653 ± 15	137 ± 20	57 ± 11
p_1	5112	5104 ± 15	139 ± 30	58 ± 14
p_2	4556	-	< 20	< 8
p_3	4464	4457 ± 15	90 ± 30	37 ± 13
p_4	4350	-	-	-
p_5	3997	-	-	-
p_6	3899	3903 ± 20	175 ± 60	72 ± 26
		Total	541 ± 77	224 ± 42

*) The errors were calculated from the peak content uncertainties and from a systematic error arising from the uncertainties of the neutron flux, the detection efficiency, and the number of target atoms.

Figure captions

Fig. 1 : The spectrum of charged particles obtained from a 72 h long neutron irradiation of the ^{76}Br target (upper part) and the same spectrum after subtraction of an exponential background originating from the 3.5 mCi target (lower part). Two error bars at different energies in the lower spectrum show the statistical accuracy obtained after the background subtraction. The arrow indicates a background alpha peak from ^{237}Np present as a contamination in the measuring chamber. The other four peaks have been identified as due to protons from the ^{76}Br(n_{th},p)^{76}Se reaction.

Fig. 2 : Level scheme of the ^{76}Br(n_{th},p)^{76}Se reaction. The Qp value was determined to be 5730 ± 15 keV.

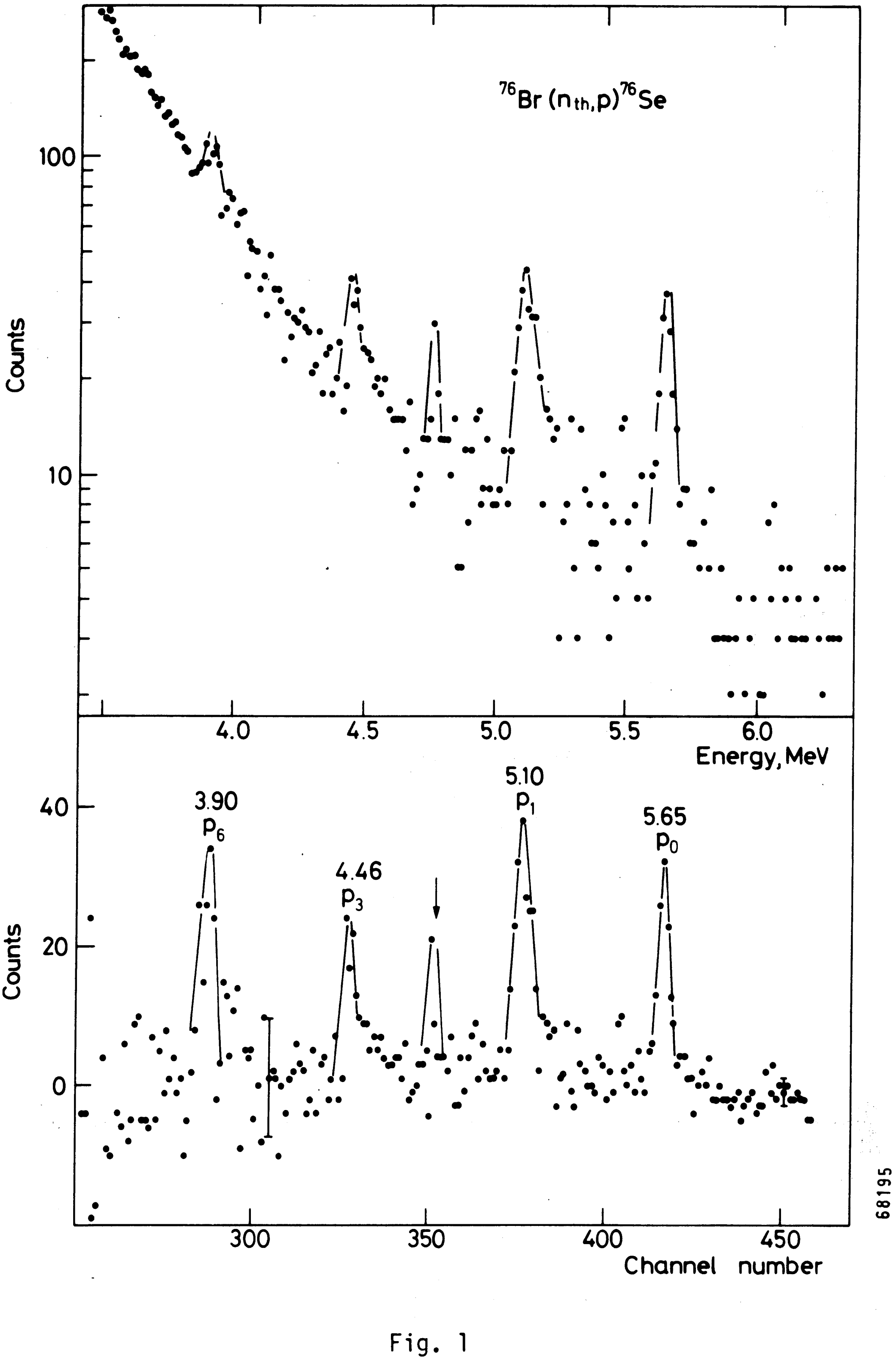
^{76}Br (n$_{th}$,p)^{76}Se
100
10
Counts
4.0
4.5
5.0
5.5
6.0
Energy, MeV
3.90
p$_6$
4.46
p$_3$
5.10
p$_1$
5.65
p$_0$
40
20
0
Counts
300
350
400
450
Channel number
68195

Fig. 1

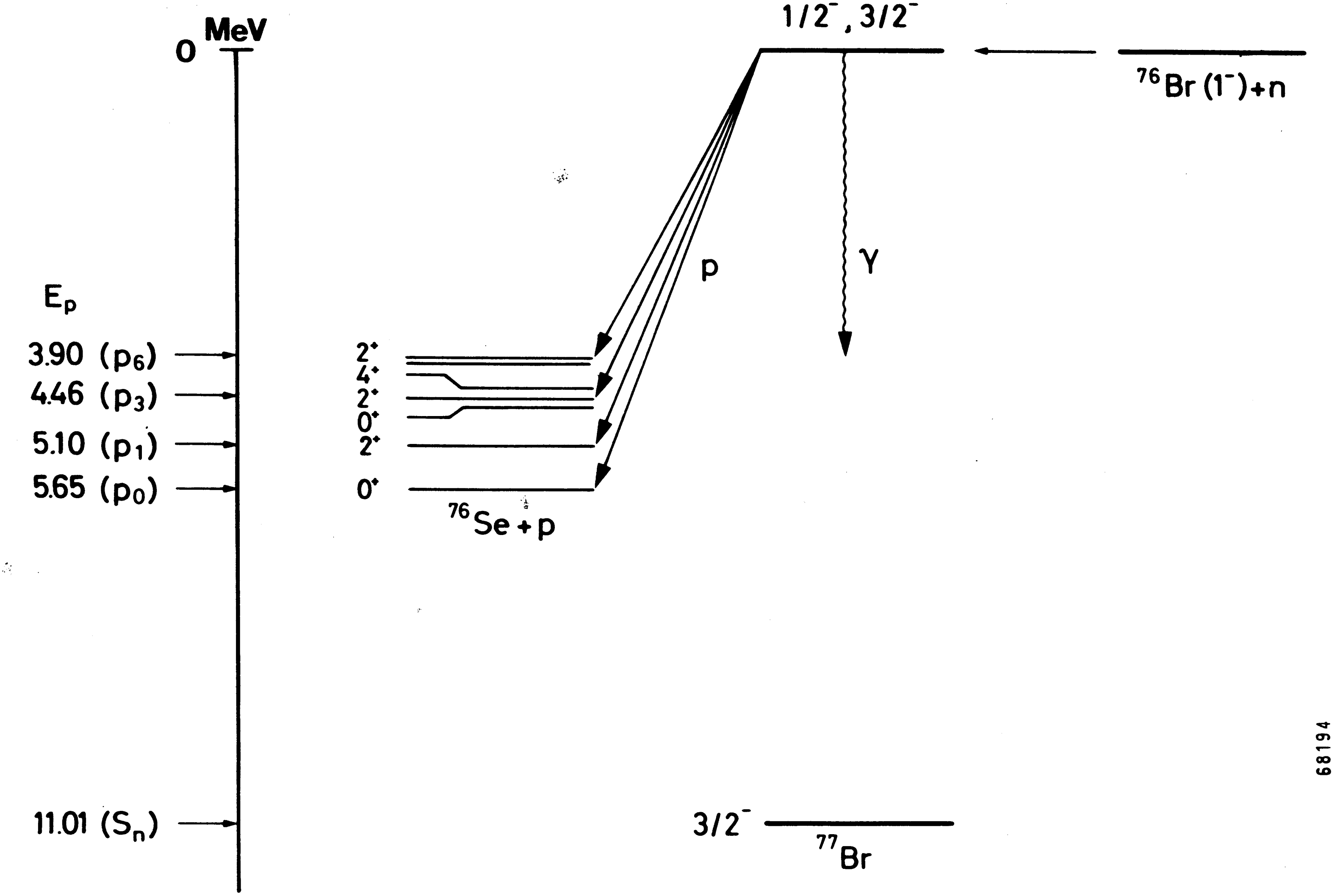
0 MeV
E_p
3.90 (p_6)
4.46 (p_3)
5.10 (p_1)
5.65 (p_0)
11.01 (S_n)
2^+
4^+
2^+
0^+
2^+
0^+
^{76}Se + p
p
γ
$1/2^-, 3/2^-$
^{76}Br (1^-)+n
$3/2^-$
^{77}Br
68194

Fig. 2