Grouping of neutron resonance positions

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Neutron resonance spectroscopy is a part of nuclear spectroscopy which provides data on a large number of excitations. This information can be used to check nuclear microscopic models including a statistical model of highly excited states.

Many authors draw attention to deviations from the statistical approach to describe distributions of positions and spacings in neutron resonances.

Fundamental character of the observed grouping of neutron resonance positions was marked in 1950s.

Measurements of the neutron cross sections of heavy nuclei and their analysis at the IAE and ITEP, carried out in the 1950s and later, made it possible to find groupings of neutron resonance positions in target nuclei with Z=92, 94 and 95.

Two groupings were found in neutron resonance positions.

The first one, about 0.3 eV, in
^{235}U (0.2738 eV), ^{239}Pu (0.296 eV), ^{241}Pu (0.264 eV),
^{241}Am (0.3051 eV) and ^{243}Am (0.419 eV).

The second grouping of ~5.5 eV – in
^{232}U (5.980 eV), ^{234}U (5.1570 eV),
^{236}U (5.45 eV), ^{238}U (6.67 eV).

This grouping is conserved on the sum distribution of resonance positions of all nuclei known in the 1966, and is shown in Fig. 1.

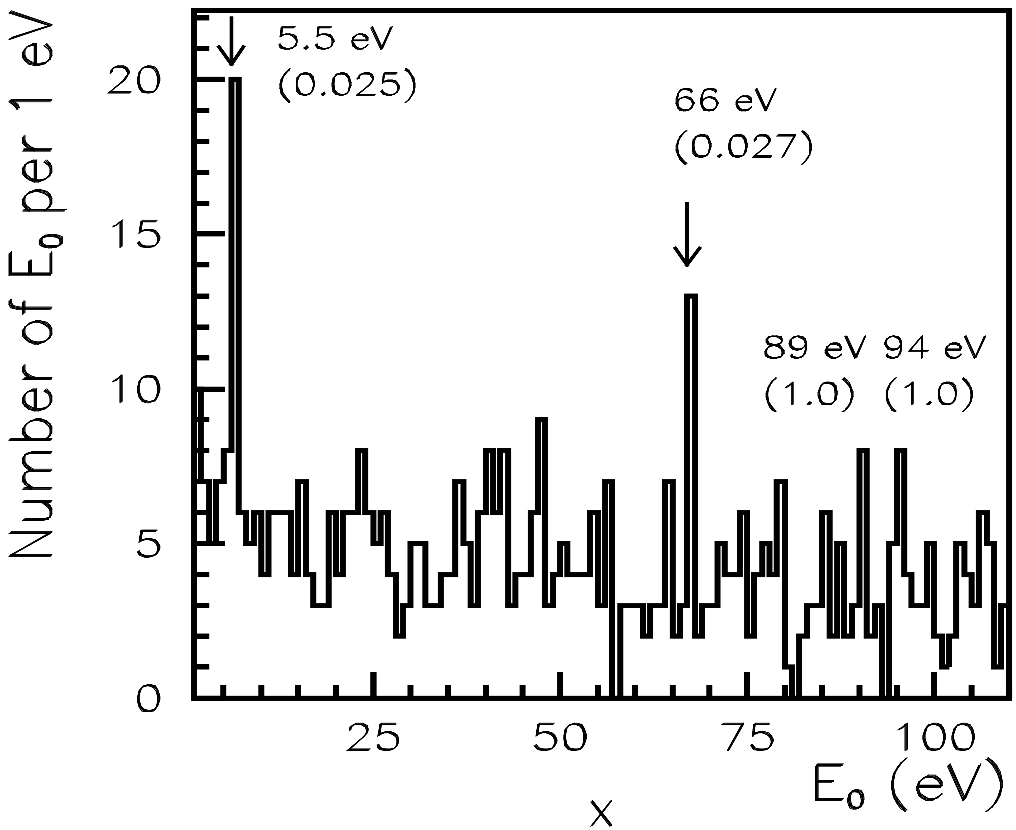


Fig. 1. Distribution of resonance positions known in the 1966.
The selection of one strongest resonance in the interval 10\,eV was used (in parentheses is a random probability).

Coinsidence of positions of neutron resonances in light nuclei

was reported in JINR, Dubna, 12-14 june 1964, at the

Meeting on Interaction of Neutrons with Nuclei

in the energy region 1 eV — 100 keV.

Grouping of neutron resonance positions in heavy nuclei at

5.5 eV was reported at the conference on Nuclear Data —

Microscopic cross-sections and other data basic for reactors

held by the International Atomic Energy Agency in Paris,

17-21 October 1966 (see Fig. 1).

The maximum at 5.5 eV=4ε''(where ε''=1.34 eV) is a stable interval in ^{237}Np spectrum.

In Np (Fig. 2), positions of the doublet of resonances at 1.32 eV and 1.48 eV are close to the maximum (at 1.1 eV) in the spacing distribution (top), while in the distributions for more strong resonances maxima are observed at 5.6 eV=4ε'' and 16.4 eV=12ε'', as well as at 54.8 eV=5δ''=40ε'' and 87.8 eV, close to 88 eV=8δ''=64ε'' (δ''=11 eV=2·5.5 eV).

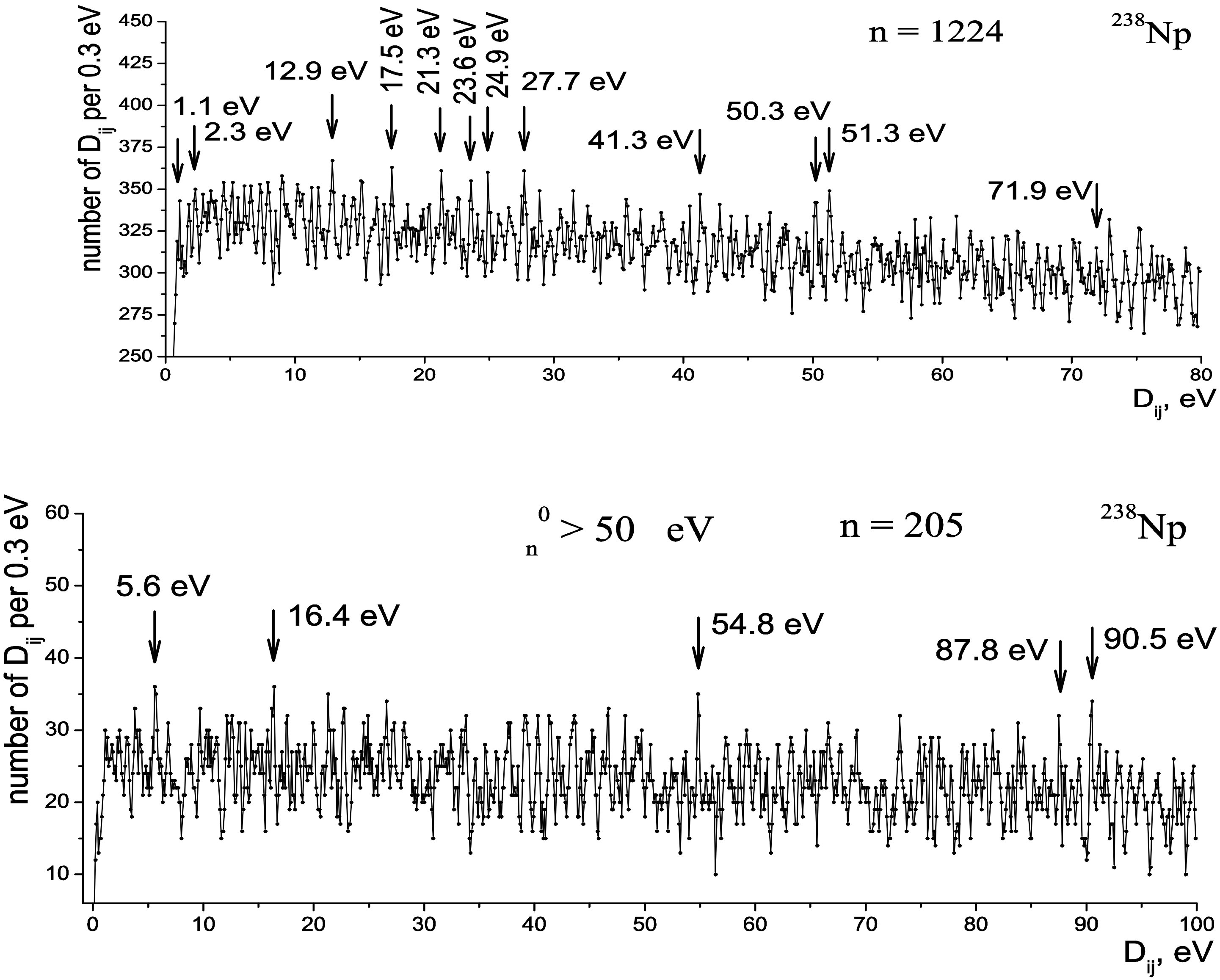

n = 1224
238Np
number of Dij per 0.3 eV
1.1 eV
2.3 eV
12.9 eV
17.5 eV
21.3 eV
23.6 eV
24.9 eV
27.7 eV
41.3 eV
50.3 eV
51.3 eV
71.9 eV
Dij, eV
n0 > 50 eV
n = 205
238Np
number of Dij per 0.3 eV
5.6 eV
16.4 eV
54.8 eV
87.8 eV
90.5 eV
Dij, eV

Fig. 2.

Recent analysis of ^{236}U compound nucleus demonstrate absence of stable interval around 0.3 eV and presence of stable interval multiple to 5.5 eV.

The spectrum of highly excited states ^{236}U contains 3164 states with spacing distribution shown in Figure 3a (all states have L=0).

Neutron resonances were selected according to spin *J* (n=1438 for J=3 and n=1734 for J=4), and respective spacing distributions are given in Figure 3b,c.

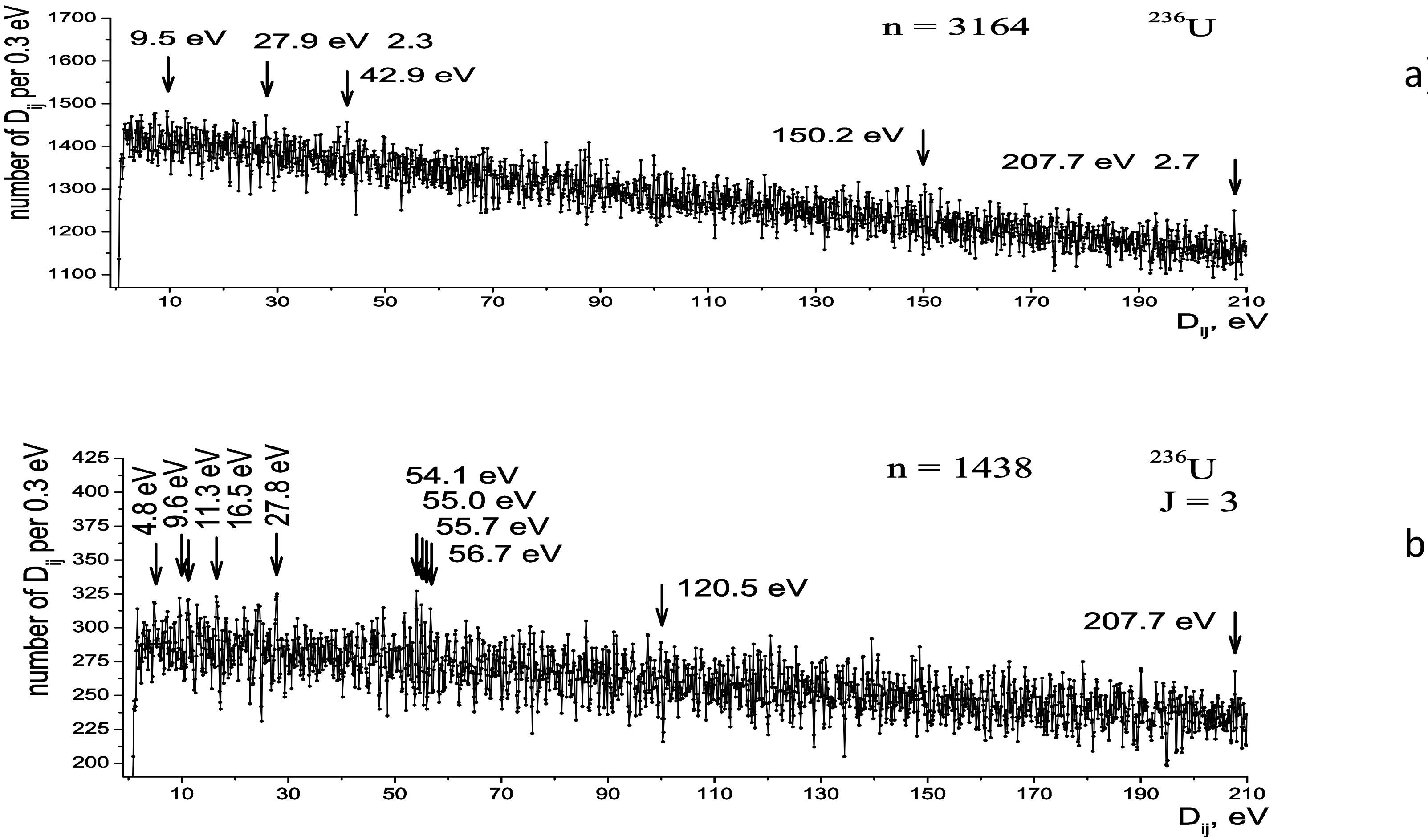


Figure 3. a) Total spacing distribution in all ^{236}U resonances. b) The same for resonances with *J*=3.

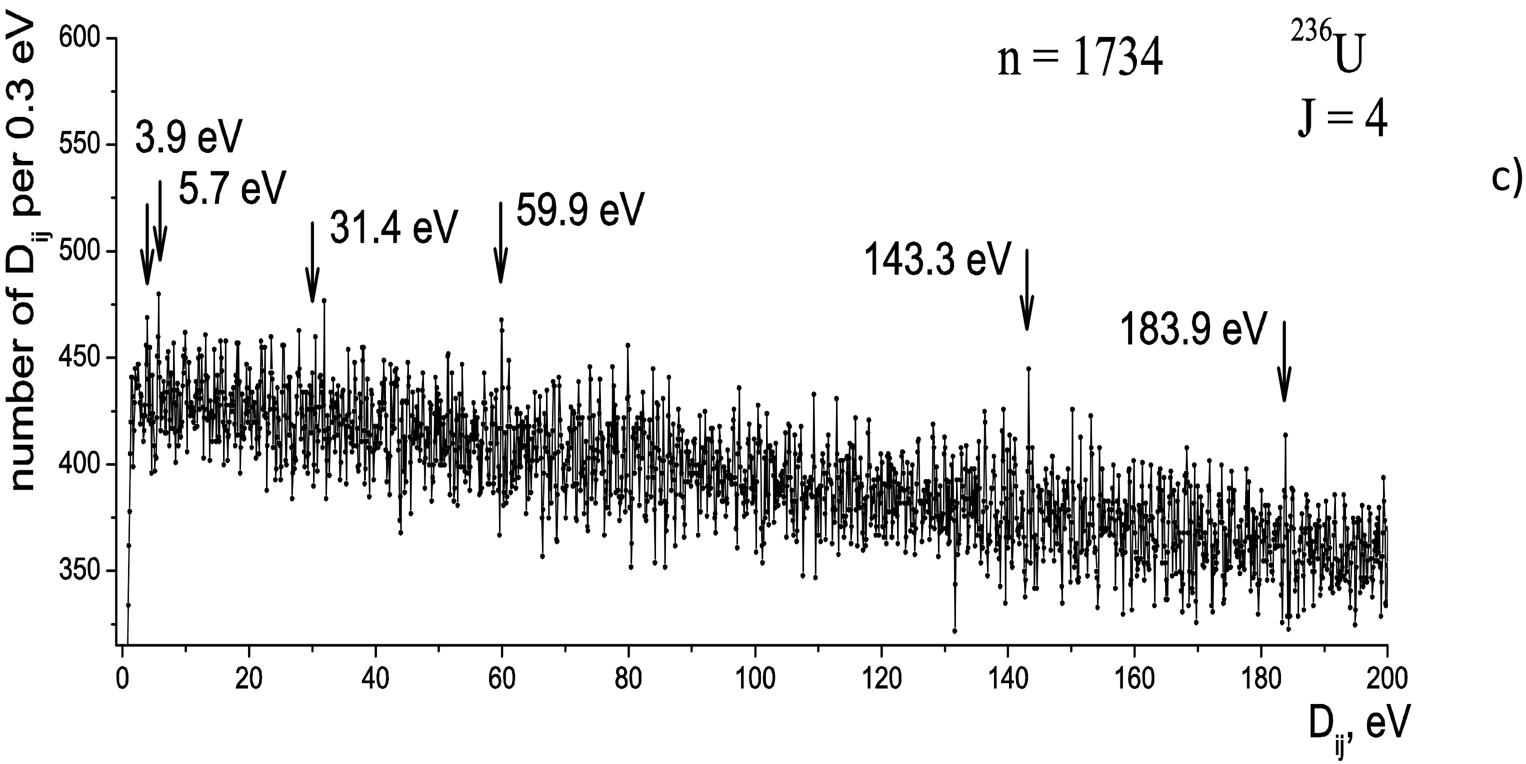


Figure 3c. Spacing distribution of all ^{236}U resonances, *J*=4.

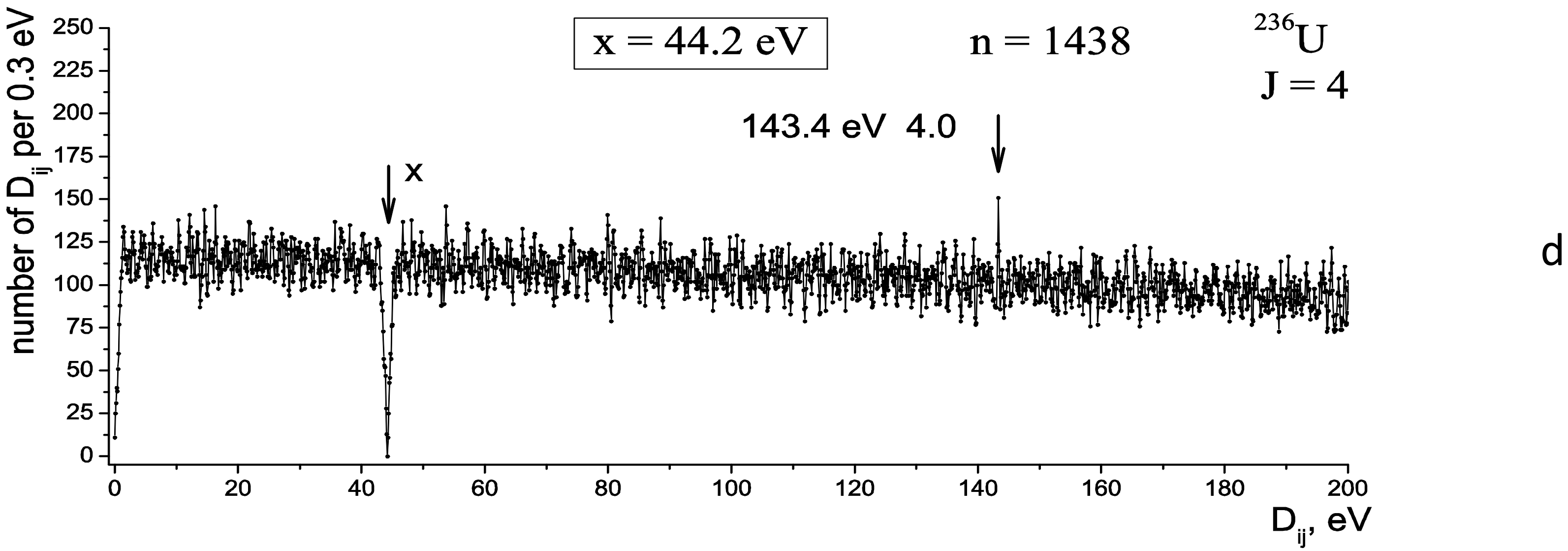
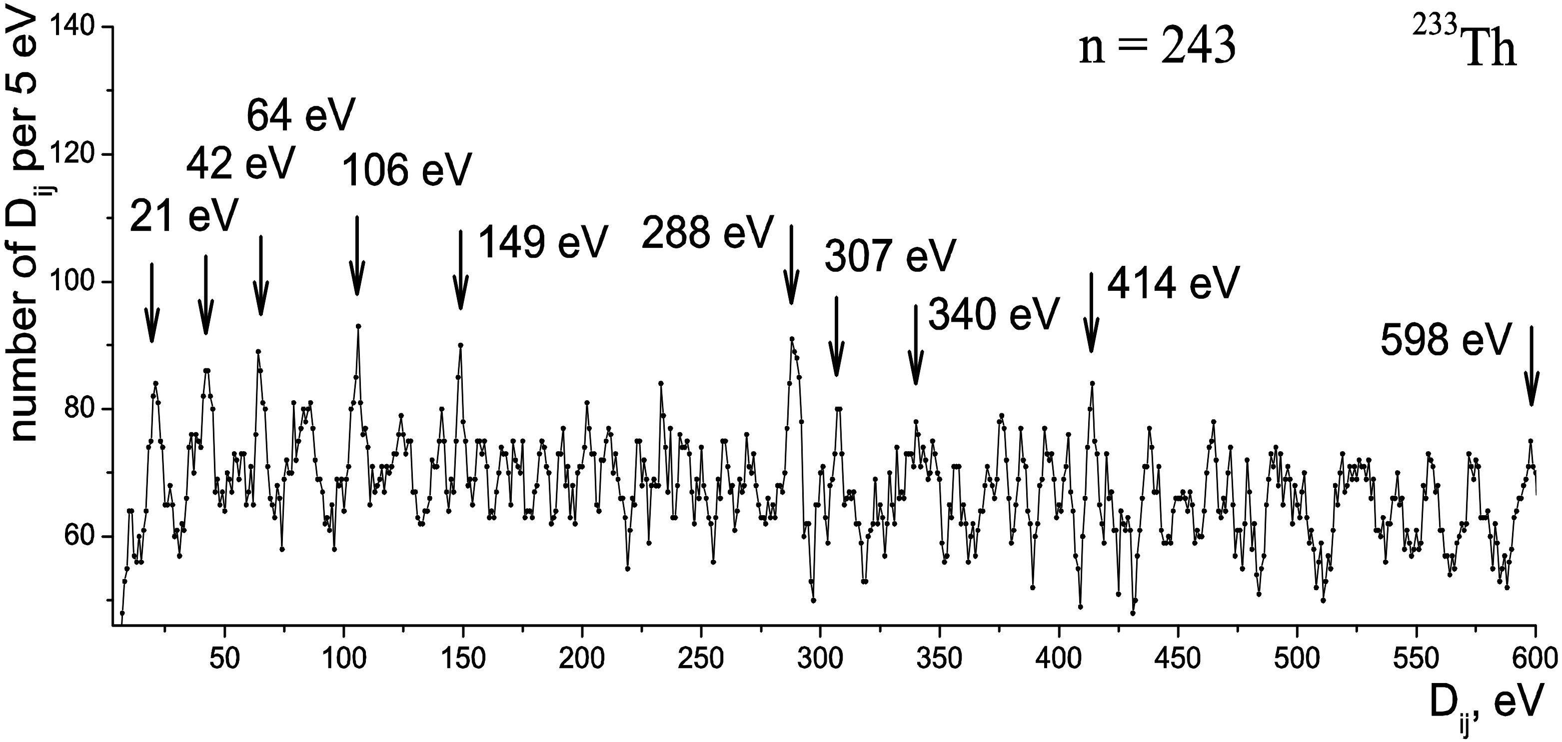


Figure 3d. Adjacent interval distribution in *J*=4 ^{236}U resonances, fixed interval *x*=44.2 eV. Deviation 4.0σ in maximum at 143.4 eV is marked. An exact ratio 13:4 is between intervals under consideration (143.4 eV and 44.2 eV).

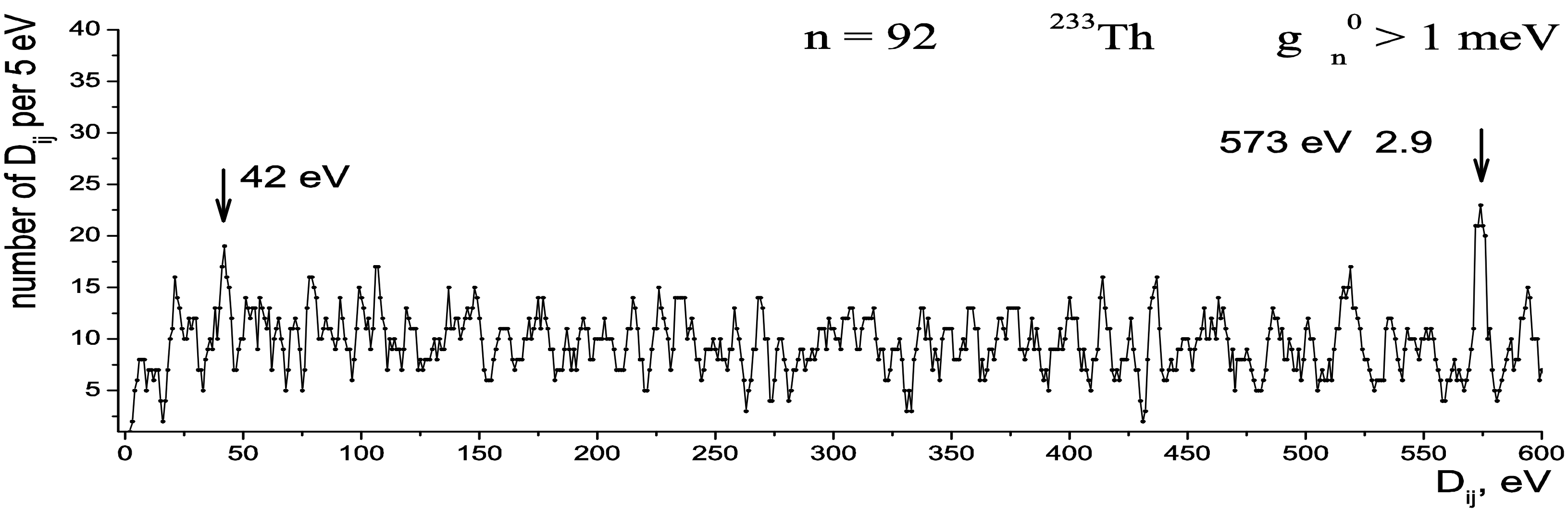
Thorium isotopes have 90 protons corresponding to filled $f_{7/2}$ subshell. It was marked long ago that spacing distribution of its L=0 resonances has a clear nonstatistical character. On the histogram with averaging parameter 5 eV (Fig. 4a) equidistancy of maxima at k=1, 2, 3, 5 of the estimated period 11 eV = 2·5.5 eV corresponds (as k=288/11=26) to the strongest maximum at D=288 eV (marked with arrow).

Figure 4a. Spacing distribution of all L=0 neutron resonances in ^{233}Th.



Fixing all such intervals (*x*=288 eV) in the spectrum of all *s*-wave resonances (Fig. 4b), one obtains maximum at the doubled value 576 eV. Such an interval corresponds to a distance between strong neutron resonances (maximum at 573 eV in Fig. 4c, with a deviation from the random level of ≈3σ, selection of resonances with reduced neutron widths greater than 1 meV).

Figure 4c. Spacing distribution ^{233}Th all L=0 strong neutron resonances ($g\Gamma_n^o \geq 1.1$ meV). Resonance at 570 eV means that neutron separation energy is correlated with a period 573 eV. Small maximum at 42 eV corresponds to a ratio 1:13 between the states with relatively large single-particle component in the wave function.



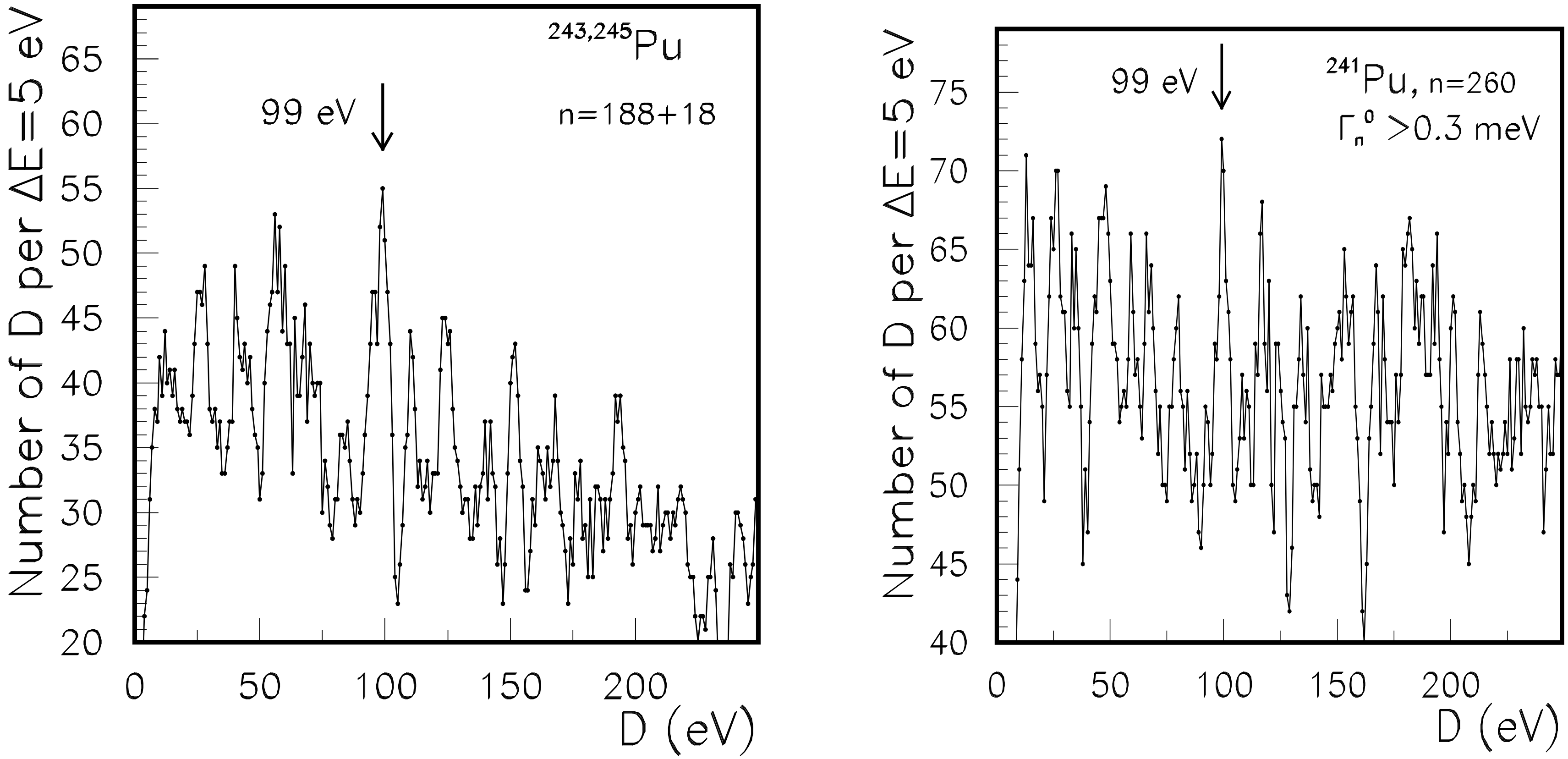


Figure 5. *D* - distributions in neutron resonances of heavy compound nuclei. The doubled period of 99 eV (198 eV) was observed in neighbor ^{239}U (Fig. 6).

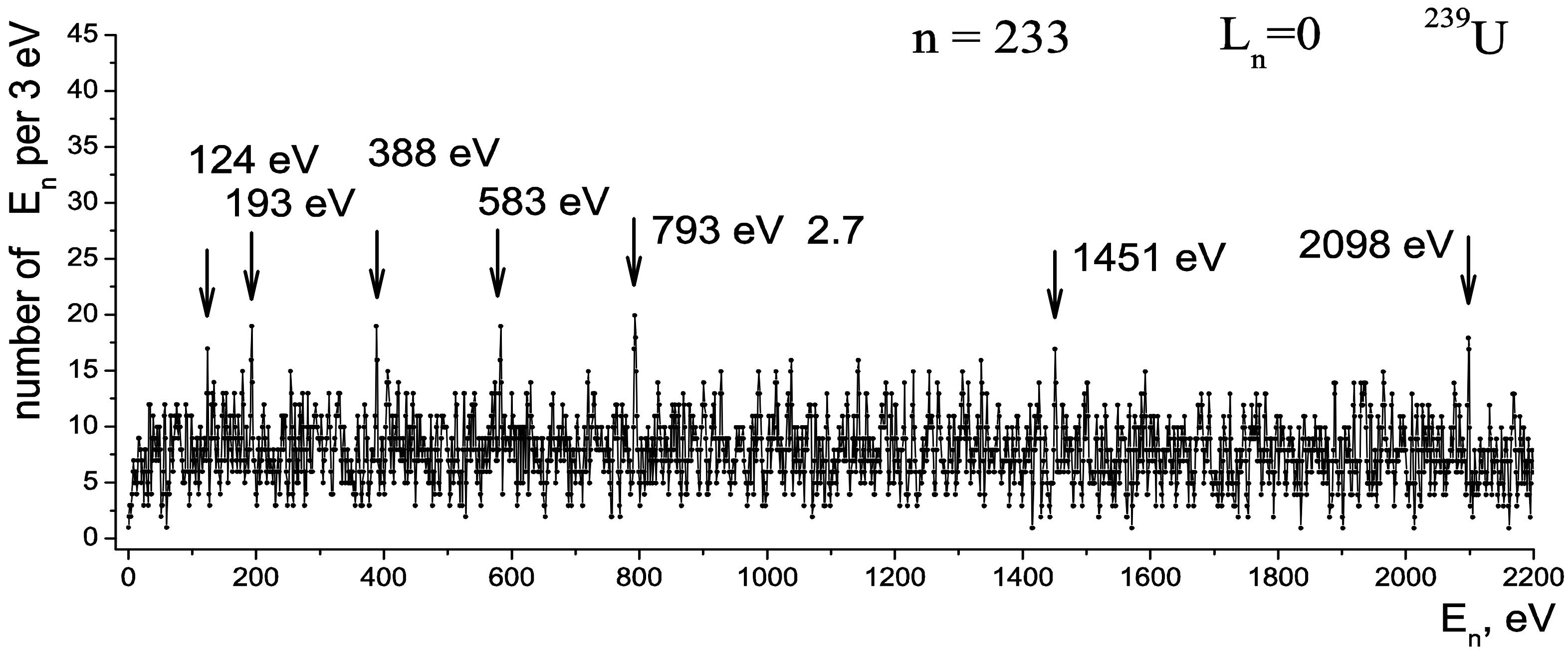


Figure 6. Spacing distribution for 233 L=0 strong neutron resonances ^{239}U with $\Gamma_n^{\ 0} \geq 1$ meV. Equidistant maxima at 193 eV, 388 eV, 583 eV and 793 eV correspond to the doubled period 99 eV (198 eV). Intervals 9×11 eV and 13×11 eV are distinguished in heavy nuclei.

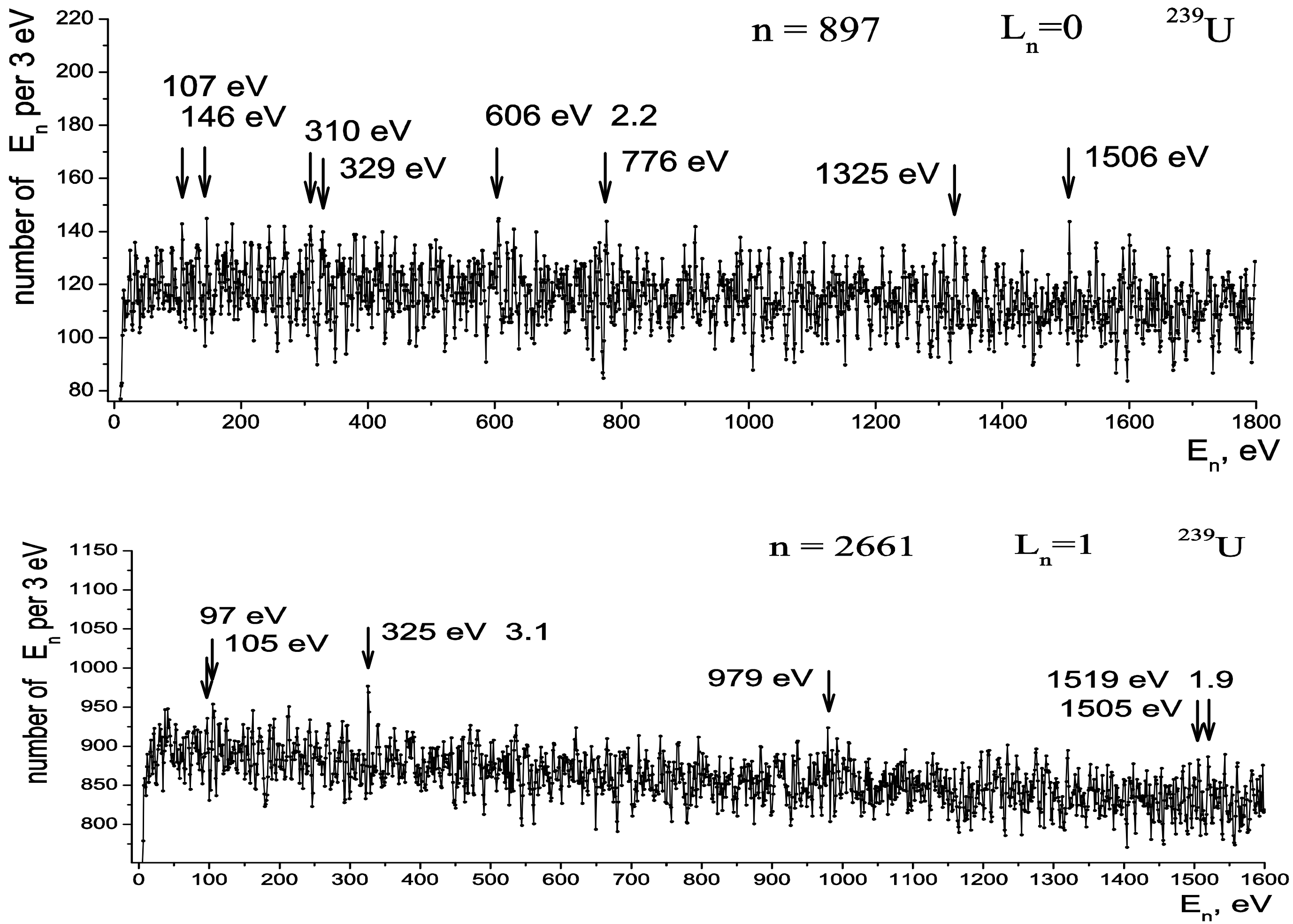


Fig. 7. Top: Spacing distribution in all 897 L=0 neutron resonances of ^{239}U.
Bottom: Spacing distributions in L=1 neutron resonances of ^{239}U.

CONCLUSIONS

Resonance parameters that are investigated within neutron resonance spectroscopy demonstrate the same symmetry motivated relations observed between stable nuclear intervals and in particle masses.