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NUCLEAR ENERGY LEVEL SPACING DISTRIBUTIONS IN EVEN IRON ISOTOPES

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Abstract: Nearest level spacing distributions of s-wave neutron resonances in ^{54,56} and ^{58}Fe have been studied. It is found that for ^{54}Fe and ^{58}Fe the distribution of the observed individual level spacings deviates from a Wigner distribution. For ^{56}Fe such a deviation could not be verified in an unambigous way. The reason for this may be that in ^{54}Fe and ^{58}Fe we are dealing with doorway resonances whereas in ^{56}Fe a mixing of 3p-2h energy levels belonging to neighbouring doorway state resonances is already effective.

(Neutron resonances, level spacing distributions, even Fe-isotopes)

Introduction

Level spacing distributions of resonances in light and closed-shell target nuclei with 4n nucleons up to ^{52}Cr and also ^{96}Zr showed deviations from a Wigner frequency distribution[1]. In these nuclei the spreading widths of the doorway states are small compared to their level spacing and the branching into 3p-2h states is only a fraction of the total width of the doorway state resonances[2]. With increasing number of nucleons in the nucleus the spreading width of the resonance structure increases and if its width becomes comparable to the spacing, neighbouring doorway states may give rise to overlapping. Other nuclei with a number of nucleons different from 4n are characterized by a large spreading width of the doorway state so that for these nuclei such an analysis can be performed when only doorway resonances occur. Good candidates for the detection of such resonances are medium light nuclei with A<38 and also closed shell nuclei[3]. However, in this mass region the experimental data are rather scarce. An investigation extended to higher mass values but restricted to closed shell nuclei offers good quality data near N=28. For this number of neutrons the ^{54}Fe-nucleus is most representative. In this contribution we report the results of the study of nearest-level spacing distributions of neutron s-wave resonances found for the even-even mono-isotopic target nuclei of ^{54,56} and ^{58}Fe.

Level Spacing Systematics

The spacings derived by measuring the intervals between experimentally observed neutron resonances of the same spin and parity are distributed about their mean according to Wigner's hypothesis represented by eq.1.

$$P(x)dx = \frac{\pi}{2} x e^{-\frac{\pi x^2}{4}} dx \qquad (1)$$

where x = D/<D> represents the relative spacing expressed in units of the mean local spacing <D>. This statistical prediction for the level spacing systematics is characterized by the so-called level-repulsion effect, resulting in a few to zero levels with small level spacing D.The applicability of eq. 1 has been shown to work well for high A-value nuclei[4]. However, deviations[1] as well as fluctuations[5,6] from this Wigner type distribution have been found, suggesting non-statistical effects in neutron resonance fenomena.

In view of the new perspectives on the level density of compound resonances and the shape of the step-like structure of the base line representing the level density parameters as a function of the nuclear mass[3], the reaction mechanism of an incoming neutron is now understood as a succession of collisions of two nucleons in the target nucleus resulting in the creation of a doorway state in the first part of the excitation process of the compound state. Calculations of the doorway states agree with experimental level spacings for nuclei A<38 and for closed shell nuclei. Starting with 2 particle-1 hole states for nuclei with A<38, the next generations of 3p-2h and 4p-3h states correspond to A=38 and 69 respectively. For the Fe nuclei under investigation, the question arises whether an extension towards two-step collisions and the subsequent fragmentation into 3p-2h states with a small spreading width of the doorway states compared to their level spacing can still be certified for an unambiguous study of the nearest level spacing distribution in other than 4n target nuclei with closed shells. In the case of ^{54}Fe, doorway resonances are expected to occur because of the closed shell. However, for the other even Fe isotopes, according to the value of their level density parameters, the observed resonances could correspond more likely to 3p-2h configuratons.

Analysis of the Resonance Data

Total neutron cross-section measurements in the resolved resonance region provide useful information to investigate the distributions of the individual level spacings of compound resonances which are of special interest here. The s-wave resonance parameters of the three mono-isotopic target nuclei ^{54,56} and ^{58}Fe are plotted versus their resonance energy in respectively fig. 1, 2 and 3. Resonance energies and their corresponding reduced neutron widths Γ_n° have been taken from ref.7 for ^{54}Fe and ^{56}Fe.

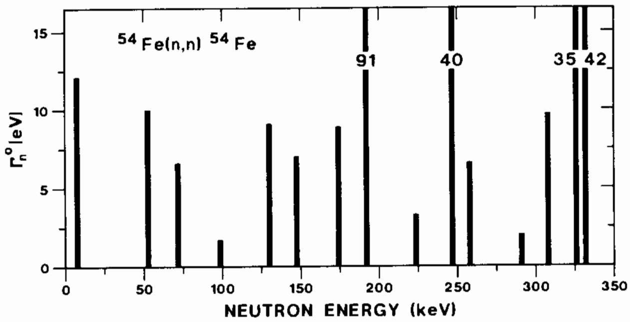

Fig. 1 s-wave resonance energies and reduced neutron widths for ^{54}Fe+n

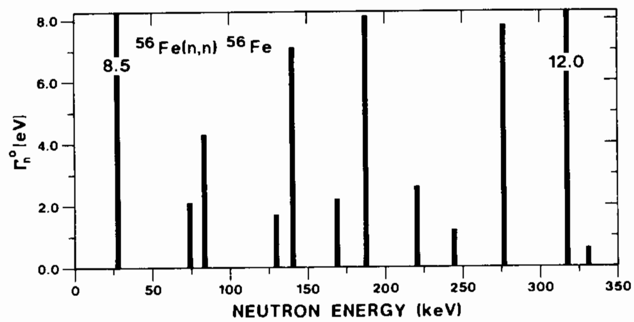

Fig. 2 s-wave resonance energies and reduced neutron widths for ^{56}Fe+n

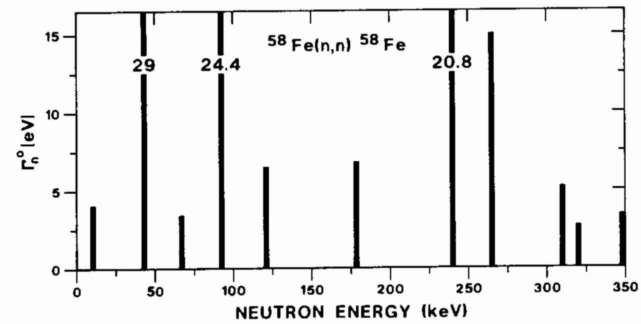

Fig. 3 s-wave resonance energies and reduced neutron widths for ^{58}Fe+n

For the extremely rare isotope ^{58}Fe, we have taken the resonance energies of the ref. 8 data, obtained with a nominal resolution of about 0.07 ns/m. However, they are in agreement with the ref.9 data and both sets do not show an s-wave resonance at 61.7 keV which was tentatively indicated in brackets in ref.7. In table I are given for each isotope the neutron separation energy E_B, the energy range E_{max} for the resonances considered, the number of resonances found in this energy range, the average level spacing <D>, the lower- and upperlimits of the value of D/<D> and P the probability for finding within these limits N°-1 spacings with relative spacing D/<D> obeying the Wigner single-population nearest-neighbour spacing distribution.

Table 1 Characteristic values of resonances in ^{54,56,58}Fe

$^{A}_{26}$Fe	E_B (MeV)	E_{max} (keV)	N°of res.	<D> (keV)	D/<D> min.	D/<D> max.	P %
54	9.30	250	10	26.6	0.65	1.69	1.2
56	7.64	317	11	28.9	0.33	1.68	8.7
58	6.58	310	9	33.9	0.70	1.76	1.5

Fig. 4 and 5 represent plots of the adjacent level spacing histrogrammes for the spacings in ^{54,58}Fe and ^{56}Fe, corresponding to the levels with same spin and parity as experimentally observed in neutron resonance spectroscopy. In the framework of the statistical theory of energy levels, we have compared the experimental results for each isotope with two different theoretical distributions, namely the well-known Wigner function and the Poisson distribution function representing a random distribution sequence in which small spacings predominate. These results are also pictured in the respective histogramme figures.

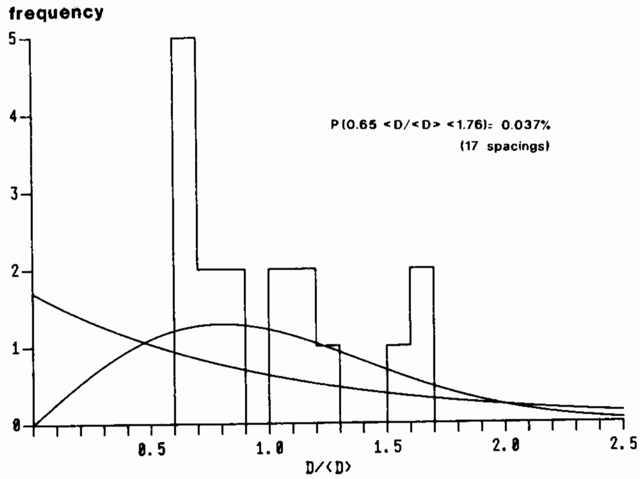

Fig. 4 Histogramme of D/<D> for both ^{54}Fe+n and ^{58}Fe+n compared with Wigner and Poisson (exponential) distributions.

What can we learn from this detailed statistical comparison ?

The distribution of the nearest level spacings normalized to the local mean value <D> for ^{54}Fe and ^{58}Fe are restricted to the interval limits $0.65 \leq D/\langle D \rangle \leq 1.69$ and $0.7 \leq D/\langle D \rangle \leq 1.76$ respectively, showing the typical mutual repulsion effect. Calculated probabilities for finding 9 respectively 8 spacings belonging to a Wigner's type distribution within these intervals give values of 1.2% for ^{54}Fe and 1.49% for ^{58}Fe. According to this analysis the ^{58}Fe nucleus shows evidence for properties of level systematics similar to those for the closed shell nucleus ^{54}Fe. Indeed, for both nuclei, level spacings are comparable despite the 3 MeV (30%) difference in the neutron separation energy.

However, when taking into account the pairing energy plus shell effects in evaluating the effective excitation energy, one finds within 10% the same values. These results were obtained when assuming that the deviation of the experimental level density parameter value for the base line represents the shift Δ obtained from the Bethe level density formula[3]. For ^{54}Fe, Δ was found to be 3.26 MeV and for ^{58}Fe 1.13 MeV. This gives us confidence for considering also ^{58}Fe a case of doorway resonances like in ^{54}Fe. Indeed, extending the energy range Emax for both nuclei reduces the lower limit of the intervals (smaller spacings), indicating that we are near the threshold of generating 3p-2h resonances.

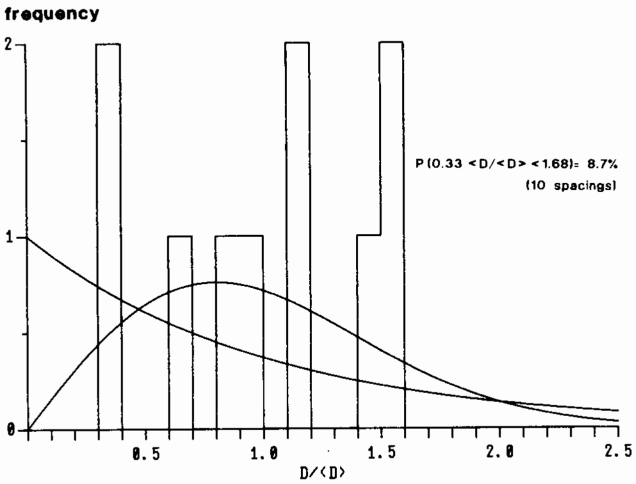

Fig. 5 Histogramme of D/<D> for ^{56}Fe+n compared with Wigner and Poisson (exponential) distributions.

For the ^{56}Fe nucleus, the repulsion effect is found not to be so strong regarding the spacing frequency distribution limited between the values 0.33 and 1.68. The corresponding probability was now found to be 8.7% for 10 spacings. Although the spreading width for 4n nuclei is supposed to be small, this assumption is likely not anymore valid for ^{56}Fe, resulting in a less outspoken departure from a Wigner distribution. Considering the 17 spacings for both ^{54}Fe and ^{58}Fe combined (fig.4), yields a probability P=0.037%, a distinguishing effect showing a tendency that in these two nuclei the resonances are preferentially distributed with roughly equal spacings.

Conclusion

Total neutron cross section measurements with high-resolution have been used to investigate the nearest level spacing distribution for s-wave neutron resonances in even Fe-isotopes. The study shows for ^{54}Fe and ^{58}Fe a deviation from a Wigner type distribution resulting in almost equidistant spacings. Evidence for such a deviation revealing an energy correlation between resonance states, was not so clearly found in the results for the 4n-nucleus ^{56}Fe.

REFERENCES

1. G. Rohr: contribution to this Conference.
2. G. Rohr: Proc. of the 6th Int. Symp. on Capture Gamma-Ray Spectroscopy 1987, Leuven, 643(1988), and to be published in Journ. of. Nucl. Phys.
3. G. Rohr: Z. Phys. A318, 299(1984).
4. H. Liou, H.S. Camarda, S. Wynchank, M. Slagowitz, G. Hacken, F. Rahn and J. Rainwater: Phys. Rev. C, 5, 974(1972) and references cited in there.
5. S. Sukhoruchkin: Proc. of the Int. Conf. on Statistical Properties of Nuclei, Albany, NY, ed. by J. Garg, Plenum Press. p. 215(1971)
6. K. Ideno, M. Ohkubo: Journ. of Phys. Soc. of Japan, 30, nr. 3, 620(1971).
7. S. Mughabghab, M. Divadeenam and N.E. Holden: Neutron Cross Sections, Vol. 1, Part A(1981).
8. J.B. Garg, S. Jain and J. Harvey: Phys. Rev. C, 18, 1141(1978).
9. H. Beer, Ly Di Hong and F. Käppeler: Nucl. Sc. and Eng. 67, 184(1978).