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4th INTERNATIONAL SYMPOSIUM

on

NEUTRON INDUCED REACTIONS

THE ABSTRACTS

of

CONTRIBUTED PAPERS

SMOLENICE, 17-21 JUNE 85

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NEUTRON REACTIONS ON Ti ISOTOPES FROM NEAR THRESHOLD TO 20 MeV

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Abstract

The cross sections of all the more important reaction channels for neutrons on Ti isotopes are calculated and the results are compared with the existing experimental data. The optical model is used to obtain the elastic scattering, total and reaction cross sections, and the Weisskopf-Ewing theory with the precompound correction for the particle energy spectra and excitation functions calculations from near threshold to 20 MeV.

Gamma - ... competition in continuum

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Recently Stengl et al. (1) shown that a statistical cascade model with realistic description of the strength functions for particle and gamma-ray channels can not ... for gamma-ray competition in the continuum of ^{56}Fe. In this work we have shown that inclusion of the unequal distribution of continuum states according to their parity gives the qualitative agreement with the experimental data. The parity distribution function used have been calculated in frame of a thermodynamical model of independent quasiparticles (2) with a realistic Woods-Saxon single particle basis.

(1) Stengl, et al., Nucl. Phys. A 290 (1977) 109

(2) R. Antalik, in Proc. of the Europhys. Top. Conf. on Neutron Induced Reactions, Smolenice 1982, p. 357, Ed. by P. Obložinský, Inst. of Phys., Bratislava 1982

Exciton Model and Multistep-Compound Reactions

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A connection between the Exciton Model (EM) and a microscopic theory (continuum shell-model) is given for the case of neglected continuum-continuum interaction V_{pp}. Starting from S-matrix with $V_{pp}=0$, and making statistical assumptions on the Hamiltonian, Agassi et al. /1/ arrived at the energy-averaged fluctuation cross section

$$\sigma_{cc'} \propto \sum_{n,m} T_n^c \, (\Gamma^{-1})_{nm} \, \Gamma_m^{c'} / 2\pi \varrho_m^b \, . \qquad (1)$$

(T_k^c is the transmission coefficient from channel c to exciton class k). After transformation of the dynamical matrix Γ_{nm} into an EM-like form we get the familiar EM-formula

$$\sigma(\varepsilon)d\varepsilon = \sigma^{abs} \sum_n \tau_n \lambda_n(\varepsilon) \, d\varepsilon \, . \qquad (2)$$

The obtained EM is a pure multistep compound model where the exciton state densities are replaced by "bound" exciton state densities ϱ_n^b. Relations between EM-quantities (transition and emission rates) and the Hamiltonian are explicitly given. In such a way the principle of detailed balance and the Golden Rule are not used. The modified emission-rate formula of Kalbach /2/ can not be justified. The free EM-parameters will be discussed.

Correlations between S-matrix elements pertaining to different values of J and π could arise from:

i) violation of the statistical assumptions in the first few stages of the reaction /1/ and/or
ii) inclusion of the continuum-continuum interactions.

They are necessary for the understanding of the "leading particle model" /3/.

/1/ D. Agassi et al. Phys. Rep. C 22 (1975) 145
/2/ C. Kalbach, Phys. Rev. C 23 (1981) 124
/3/ G. Mantzouranis et al., Phys. Lett. 56 B (1975) 220.

[illegible] model rel [illegible] lys[illegible]

H. [illegible]

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Th[illegible] are many indications that th[illegible] 14.[illegible] MeV - (n,xn) - [illegible] consist almost only of di[illegible]ct scattering contribu- [illegible] by comparing th[illegible] [illegible] reactions with th[illegible] of th[illegible] [illegible] [illegible] because th[illegible] can be [illegible] much higher [illegible] than th[illegible] [illegible] ^{56}[illegible] [illegible] results of [illegible] energy resolution. This thus [illegible] states c[illegible] be [illegible] [illegible] neutron chan[illegible] [illegible] calculatio[illegible] of [illegible] [illegible] differential (n,n')-cross-section yi[illegible] energy - and angular-dependant neutron-emission cross sections of the same high resolution as shown by the measured (p,p')-results. By comparison with these highly resolved (n,n') - results we can show that the results measured as usual in the neutron channel represent a certain avarage of the highly resolved results and this is also true for angle-integrated results of most of the precompound models which provide only fits on the measured results in most cases. Only the results from the geometry-dependent hybrid model are predictions and it is very instructive to see how the results from its surface-dependent n_0=3-component coincide with the results obtained from averaging the highly resolved (n,n')-results calculated on the DWBA basis of the highly resolved results measured for the first 15-26 excited states in the (p,p')-channel. The geometry-dependent hybrid model property of providing predictions is also demonstrated by corresponding results for the ^{93}Nb(n,nx)-cross-sections obtained without any fit-parameters was the basis for the ^{56}Fe(n,xn)-cross section-calculations.

NEUTRON-GAMMA COINCIDENCE CALCULATIONS WITHIN THE PRE-EQUILIBRIUM MODEL

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The gamma emission has been incorporated into the pre-equilibrium model less than a decade ago. Though seriously handicapped by the absence of spin in the formalism used, rather reasonable results were obtained for continuous energy spectra and relative gamma widths, as well as for the exclusive nucleon spectra.

In the present paper we aim to test the ability of the model to give a more refined correlation quantity, namely the differential gamma multiplicities (those associated with the emission of nucleon with given energy). To do that, two of the pre-equilibrium approaches to the gamma emission are used /1,2/, which differ by the interpretation of the Brink-Axel hypothesis.

The calculations were performed using somewhat modified PEQGM code /3/. The comparison to the data was done for 14 MeV neutron induced reactions. Results obtained within both the approaches to the pre-equilibrium gamma emission do not contradict to the data. However, the lack of spin and parity in the present theoretical description disables to extract more information and calls for further development of the model.

References:

/1/ E. Běták, J. Dobeš, Phys. Lett. 84B (1979), 368.
/2/ J.M. Akkermans, H. Gruppelaar, manuscript (1985).
/3/ E. Běták, J. Dobeš, Report IP EPRC SAS No. 43/1983 (Bratislava, 1983).

A METHOD TO DETERMINE THE PAIRING ENERGY FOR EXCITED NUCLEI

G. Rohr

The Bethe level density formula is applied at neutron separation energy with constraints for the level density parameter "a" and the energy shift δ.
The experimental values a_{ex} for odd-odd nuclei as a function of the mass number are calculated with [illegible] the level density and δ = 0. These values are used to define the base line for the level density parameter for nuclei which have a minimum pairing energy (Δ = 0). The a_{ex} for even nuclei are calculated with ρ_0 and δ = Δ, where Δ is the pairing energy for the ground state of the nucleus and is obtained from differences of even and odd neighbouring nuclei. Deviations from the base line indicate a change of pairing energy at high excitation compared to the ground state value.
The following observations can be made and are discussed in this contribution: The a_{ex} for even nuclei (A<200) far off from closed shells are larger than the value given by the base line and the larger values correspond to a reduction of the pairing energy by 30-40%. This effect is known theoretically as the blocking effect and is for the first time measurable. Values for the blocking effect are given in the mass region A ~ 75. The largest deviation from the base line is observed for some nuclei in mass regions A ≈ 107 and 155<A<185 and corresponds to a breakdown of the pairing correlation. The shell properties of these nuclei and the indication of an increase in the deformation for some of these nuclei have led to the interpretation that this breakdown may be caused by the neutron-proton interaction, which counteracts the pairing force[1]. A systematic study of the nuclei in the mass region 155<A< 185 revealed a correlation of the breakdown in the pairing correlation with backbending, indicating that both effects are induced by neutron-proton interaction. In the actinide mass region there are even nuclei with a_{ex}-values which are smaller than those determined by the base line indicating an increase of the pairing energy. The reason for the increase may be the α-clustering in nuclei with a large number of nucleons.

1. G. Rohr, Z. Phys. A 318 (1984), 299

S.P.

Isospin mixing during the decay of the Giant Dipole Resonance.

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For not too light nuclei, the collective 1p-1h structure of the GDR is damped mainly by coupling to more complicated states, eventually leading to the compound nucleus in thermal equilibrium. Isospin mixing between overlapping $T_>$ and $T_<$ compound states in this energy region has been investigated in the past and a mean isospin mixing coefficient of about 4% was found. On the other hand, for self-conjugate nuclei it is possible to deduce the amount of isospin impurity in the GDR itself on the basis of the Barker-Mann formalism. Both approaches have been applied to our [illegible] and [illegible] existing (γ,n) results for ^{28}Si. The isospin mixing in the doorway state is found to be 0.1%, while the mixing between the underlying compound states equals about 15%. This order of magnitude difference stems from the vastly different lifetimes of the states involved ($\Gamma_{GDR} \approx 4$ MeV ; $\Gamma_{com} \approx 40$ keV), so that the weak Coulomb interaction is much more effective in mixing the compound states. From the mixing coefficients a mixing width is deduced and found to be : $\Gamma^{mix}_{GDR} \approx 4.5$ keV ; $\Gamma^{mix}_{com} \approx 7.5$ keV. This supports a recent presumption of constant mixing widths[1]. A simple model for the equilibration of the Giant Dipole Resonance (based on exciton model transition rates) is proposed, taking into account a constant isospin mixing width of 5 keV between states of equal complexity. In this model the pre-equilibrium and equilibrium parts of the decay are treated on a strictly equivalent footing. The amounts of isospin mixing found for ^{28}Si can be fairly reproduced.

1) E.Kuhlmann, and K.Glasner, preprint (Bochum).

Particle-hole state densities for statistical multi-step compound reactions

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Analytical relation is derived for densities of particle-hole bound states employing the equidistant-spacing approximation and using the Darwin-Fowler statistical method. The Pauli exclusion principle as well as the finite depth of the potential well are taken into account.

The set of densities needed for calculations of multi-step compound reactions is completed by deriving densities of accessible final states for escape and damping.

Particle-hole level densities in the approximation of homogeneous spectrum of single particle levels

[illegible]. Obložinsky

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Analytical relation for particle-hole level densities was derived assuming homogeneous spectrum of single particle levels (equi-spaced, twice degenerated according to the sign of the magnetic quantum number).

We started from rather general expression for level density generating function, which accounted for possible constraints put on single particle as well as single hole excitation energies and it naturally involved the Pauli blocking.

We arrived at the level density relation of the form suitable for applications in the preequilibrium models of nuclear reactions as well as in the statistical multi-step compound model.

New results obtained by the number theoretical description of the level densities of nuclei

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The number theoretical method has been developed towards a detailed application to realistic nuclei. By evaluation of the Dirichlet series occurring in the partition function, temperature dependent shell and pairing-effects are obtained as results of the straight-forward development of the formalism. For nuclear temperatures small againts the Fermi energy an analytic closed form level density expression has been rigorously derived. It differs significantly from the Gilbert-Cameron as well as from the back-shifted Fermi gas formula. In particular the description of the case of small excitation energies especially in the neighbourhood of closed shells has been substantially improved.

+ on leave from UNAM, Mexico-City

WALKERS, SLAVES, OR BOTH ?

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Recently a comparison of random walks and Markovian master equations for heavy-ion reactions was given /1/. The correspondence of both the formalisms is somewhat ambiguous, as neither the reaction time t (for the master equation), nor the number of steps q in random walk is directly measurable. However, relating reasonably the values of these quantities, some comparison can be done. Applying the procedure to the N (Z) transfers in one dimension, the results of both approaches essentially agree. In contrary to that, authors of /1/ have found significant discrepancies in the two-dimensional case. Following the approach of /2/, we state that the abovementioned conclusion of /1/ is caused just by the oversimplification of [illegible] assumptions, and that both the descriptions produce similar results also in the two-dimensional case.

References:

/1/ B. Hiller et al., Nucl. Phys. A424 (1984), 335.
/2/ J.M. Akkermans, PhD Thesis (= Report ECN-121), Petten, 1982.

NEUTRON CAPTURE MECHANISM

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Abstract

This paper reviews the radiative neutron capture mechanisms, which are classified according to the hierarchy of the quasiparticle number in the excited configurations. The physics significance and schematic representation, calculation formula, characteristics and test (comparison of theory with data), as well as problem left over are discussed for each mechanism. The contents are following:

1. Transitions from one quasiparticle configurations: channel radiative capture
   - 1-1, Potential capture
   - 1-2. Valence capture
   - 1-3. Interference between potential and valence captures
   - 1-4. Resonance averaged channel radiative capture-- radiative capture in the compound elastic scattering channel
2. Transitions from three quasi-particle configurations(3q): doorway states
   - 2-1. Semidirect capture
   - 2-2 Transition between simple configurations of 3q to 1q
   - 2-3. Inelastic valence capture -- quasiparticle transition in a phonon field
   - 2-4. Radiative capture in the compound inelasic channel
   - 2-5. Transition between simple configurations of 3q to 3q
3. Transitions from five or more quasiparticle configurations; statistical model

THE NEUTRON EMISSION FROM LEAD BOMBARDED WITH 14 MeV NEUTRONS

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Double-differential neutron emission cross section of Pb were measured with the pulsed-beam time-of-flight spectrometer at the TUD TG-generator using a flight path of about 5m. The cross sections were determined in the emission energy range between 2 MeV and 14 MeV and for an angular range from 15° to 165° in steps of 15°. The experimental arrangement and the data reduction procedure used were presented at Gaussig / 1 /.
An interpretation of the experimental data bases on calculations taking into account both preequilibrium and equilibrium statistical contributions by the code AMAPRE / 2 / as wellas direct collective excitations by the Distorted-Wave-Born-Approximation / 3 /.
Comparing the experimentally obtained date with the calculations, the angle-integrated emission spectrum and angular dependences of the neutron emission at some energies are discussed.

/ 1 / T. Elfruth et al., XIII Int. Symposium on Nuclear Physics and CRP-Meeting on 14 MeV Neutron Nuclear Data, Gaussig (GDR) Nov. 1983. Proceedings to be published by the IAEA

/ 2 / H. Kalka. Diplomarbeit, TU Dresden, 1983.

/ 3 / A. I. Ignatyuk, V. P. Lunev, priv. comm. 1984.

NEUTRON SCATTERING OF LIGHT EVEN-EVEN NUCLEI

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The aim of this work was the experimental measurement and theoretical analysis of neutron scattering on ^{24}Mg, ^{28}Si and ^{32}S in the energy range between 7 and 14 MeV. Despite of the quite different structure of these three even-even nuclei there are some similarities concerning the shape of corresponding angular distributions as well as the theoretical interpretation. The analyses should include a number of excited states as high as possible experimentally within a consistent interpretation. In the incident energy range cited above, compound reaction mechanism as well as direct reaction contributions occur. Therefore, we studied the quantitative amount of these two components depending on the incident energy.

The experimental results contain angular distributions to the $0^+_{gs} - 2^+_1$ (^{32}S), $0^+_{gs} - 2^+_1 - 3^+_1 - 4^+_2 - 4^+_1/2^+_2$ (^{24}Mg) and $0^+_{gs} - 2^+_1 - 4^+_1 - 3^+_1 - 0^+_2 - 3^-_1/4^+_2 - 2^+_2/2^+_3$ (^{28}Si) states and level groups, respectively, in the incident energy region 7 to 12 MeV. In order to fix the optical model parameters as well as deformation parameters, the following steps were necessary: selection of suitable optical model parameters in comparison with the elastic scattering, selection of known (from literature) or determination of unknown deformation parameters by comparison with corresponding angular distributions and determination of the energy dependence of the surface absorption term $W_s(E)$. The coupling schemes were modified with respect to the underlying structure model and also to the coupled-channel code used. In the case of ^{28}Si, different structure models had been tested by our neutron scattering experiments.

S P.

The $^{52}Cr(n,xn\gamma)$ reactions at 14.6 MeV studied by coincident in-beam techniques

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Reactions $(n,xn\gamma)$ were studied by bombarding highly enriched ^{52}Cr sample with 14.6 MeV neutrons using coincident in-beam technique.

Measurements were carried out with the multidetector setup developed for [illegible] spectroscopy employing the associated particle technique. The system included Ø 16 cm x 10cm NaI(Tl) as well as 70cm^3 Ge(Li) γ spectrometers and Ø 12cm x 4cm NE 213 neutron tof spectrometer.

Bulk of new experimental data includes average γ multiplicities related to 8 discrete transitions, average γ multiplicities following emission of 1.3 - 11.6 MeV neutrons, average energies of these γ rays and exclusive neutron spectrum containing solely inelastic component.

Preliminary analysis indicates that γ competition is higher than should be expected by GDR γ ray strength function and standard statistical nuclear reaction model calculations.

THE NUCLEAR LEVEL DENSITY FROM ANALYSIS OF NEUTRON SPECTRA FROM (n, n') AND (p, n) REACTIONS

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(Contributed paper to the 4 th International Symposium on neutron induced reactions, Smolenice, 17-21 June, CSSR)

Abstract

In the present paper the absolute level density and its energy and spin dependences are determined from analysis of energy and angular distributions of neutrons emitted from (p, n) and (n, n') reactions on 23 nuclei measured by authors over a wide excitation energy range.

The method of determination is founded on the following procedure. The spectra, calculated with Hauser-Fechbach and back-shifted Fermi gas formalism with different levels density parameters, are fitted to the equilibrium potions of the experimental spectra in the range overlapping and discrete levels.

The results of such procedure are in good agreements with resonance data (in these rare cases when ones are Known for nuclei investigated). The parameters for ^{113}In, obtained from (p, n) and (n, n') reactions, are consistent. The results of comparison are present in the table.

Residal nucleis	Reaction	a, MeV^{-1}	Δ MeV	D_0(eV) present work	D_0(eV) /1/
^{94}Nb	(p, n)	11.39	-0.70	110	90
^{113}In	(p, n)	18.25	+0.70		
^{113}In	(n, n')	17.90	+0.80		
^{115}Sn	(p, n)	14.0	+0.47	355	320±80
^{122}Sb	(p, n)	16.3	-0.54	11.96	10.30±1
^{181}W	(p, n)	20.3	-0.25	17.75	18.4±4

Reference

1. Mucgrove A.R., Allen B. , et al. Proceedinge of on International Conferens, Harwell, 1978, p.449.

ANALOG GIANT DIPOL EXCITATION IN $^{58}Ni(n,p)^{58}Co$ REACTION AT 17.3 MeV NEUTRON ENERGY.

J.Rondio, S.Mariański, K.Czerski, A.Korman, L.Zemło.

Abstract.

The energy and angular distributions of protons emitted in the $^{58}Ni(n,p)^{58}Co$ reaction have been measured at 17.3 MeV neutron energy to obtain informations on excitation mechanism of parent analog states of GDR. The previeus results at 18.5 MeV have not been in full agrement with expectations based on direct mechanism of the reaction. That suggests that another mechanism must play an important role at these energies. It seems to be most reasonable to suppose that the mechanism is a multistep one in which GDR is a doorway state. The excitation energy is divided between the collective GDR excitation and another modes of the excitation. Some protons emitted from the nucleus before the GDR deexcitation would have energy dependent on that of GDR excitation what means that their energy would be independent of incident neutron energy. The peak at 9.8 MeV seen in the proton spectrum at 18.5 MeV neutron energy is expected to be connected with the deexcitation of a strength of GDR at about 19.3 MeV. The peak at 9.8 MeV is also seen in the proton spectrum measured at 17.3 MeV as it was expected.

INELASTIC SCATTERING CROSS-SECTION OF FAST NEUTRONS ON 160,162,164, DY

T. Al-Janabi, A.B. Kadhim, et al.

The inelastic scattering of reactor fast neutrons has been measured as a function of E_n in the region 0.5-3.5 MeV with an energy resolution of 200 KeV on highly enriched even-mass dysprosuim isotopes , using time-of flight technique[1] . The excitation function for five lwo lying states in each isotope has been measured relative to the first 2^+ (847) KeV level of Fe^{56} . Corrections for flux attenuation and multiple scattering were applied using Monte-Carlo method . The influence of cascade radiation from higher levels (up to 2MeV) on the cross-section measurements has been estimmated as small contribution < 2% . The experimental data were compared with the deduced values based on the Hauser-Feshbach Moldauer statistical model[3] and with the available ENDF evaluation[4] . It has been found that the angular distribution of inelastic scattering appears isotopic within the uncertainties of the experiment . This would indicate that inelastic scattering goes entirely through compound nucleus formation .

REFERENCES :-

1- J.D. JAFAR , T.J. AL-JANABI , S.J. AL-MOUSAWI , A.B. KADHIM , A.F. HUSSEIN , A. SHAKER (Asymmetry Measurement in the Inelastic Scattering of Fast Neutrons on ^{56}Fe). To be published in Nucl. Instr. and Methods .

2- J.B.. PARKER, J.H. TOWLE, D. SAMS, W.B. GILBOY, A.D. PURNELL. and M.J. STEVENS, Nucl. Instr and Methods, 30 (1964) 77-87.

3- E. SHELDON and C.C. ROGERS, Comp. Phys. comm. 6 (1973) 99.

4- CL DUNFORD, AI - AEC - 12931 (JULY 1970) .

DIFFERENTIAL STUDY OF ^{252}CF(SF) NEUTRON EMISSION.

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The double-differential probability $N(E,\theta)$ of 252-Cf(sf) neutron emission (E - is neutron energy, θ - is angle of neutron emission with reference to light-fragment direction) was measured by the use of two parallel-plate avalanche counters (one position-sensitive) for fragment detection (time of flight, direction) as well as two NE213 scintillators for neutron detection (time of flight, scintillator response).
The angular resolution amounts to 3 deg. The $N(E,\theta)$ data cover the full angle range from 0 to 180 deg by steps of 1.5 deg.
Preliminary results are compared with calculations performed in the framework of the complex cascade evaporation model, i.e. evaporation from fully accelerated fragments is considered as alone emission mechanism. A $N(E,\theta)$ valley appearing at $\theta \rightarrow 0$ deg and E close to E_f (fragment kinetic energy per nucleon) is explained as a kinematic effect which was reproduced in the calculations.
The problem of scission neutron emission is discussed. In particular, false interpretations of $N(E,\theta)$ measurements are unavoidable if using rough models of fission neutron emission for comparisons.

THEORETICAL STUDY OF THE ^{252}CF(SF) NEUTRON SPECTRUM.

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The 252-Cf(sf) neutron spectrum was calculated in the framework of both the complex cascade evaporation model (CEM) and the generalized Madland-Nix model (GMNM). The GMNM which was refined with reference to the original Madland-Nix model (MNM) takes into account the fragment mass number (A) dependence of the MNM input parameters. The CEM is based on initial distributions in fragment excitation energy depending on both A and fragment kinetic energy. A semiempirical level density description includes shell and pairing effects both depending on excitation energy. The CMS anisotropy of fission neutron emission appearing due to fragment spin is taken into account roughly.
Calculated spectra are compared with recent experimental data as well as results of two other calculations performed in the framework of the Hauser-Feshbach formalism (RI Leningrad) and the MNM (Los Alamos SL). The CEM yields a spectrum which is in quite good agreement with experimental data between 1 keV and 20 MeV, whereas other calculations underestimate the low-energy region as well as the high-energy spectrum tail (with exception of GMNM).

$^{235}U(n,f)$ fragment mass, kinetic energy and angular distributions at energies below 6 MeV - results and interpretation.

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Extended Abstract

The data were measured with a double ionisation chamber with Frisch grids developed at CBNM, Geel. The detector gives for each fission fragment the kinetic energy and the emission angle.

The present experimental angular distributions for the different fragment masses showed no fragment mass dependence. The measured mass distributions showed a small peak to valley ratio for thermal neutron induced fission. This indicates together with the cold fragmentation data a good mass resolution ≈ 2 amu. The expontential increase of symmetric fissions with increasing excitation energy was confirmed. Clear fine structure ascribed to pairing was still seen for E_n = 6.0 MeV in the mass distribution. The parameters for the fit to the measured mass distributions show sudden changes in their dependence of excitation energy for 1.5 MeV $\leq E_n \leq$ 2.0 MeV. This could indicate the onset of pairbreaking at this energy. No previous mention of this sudden change in the mass distribution was found in the literature.

The mass-kinetic energy data confirm the predictions that can be made from the static scission point model of ref. WIL+ 76. The data yield new experimental information about the potential energy surface as function of excitation energy and mass split. The data reveal the total deformation of the fragments at the scission point as function of excitation energy. The measurements show clearly the shell and pairing effects. Fragments with even proton number showed locally relative smaller deformations than the other fragments for E_n = thermal. The deformations of the fragments with even proton number also showed less changes with excitation energy for $E_n \leq$ 1.5 - 2.0 MeV and indicated that these fragments are stiffer than the fragments with odd proton number until pair-breaking sets on.

The cold fragmentations have been investigated and the data agree well with other recent measurements for thermal neutron induced fission. The cold fragmentation of higher excited compound nuclei were also investigated.

SHELL EFFECTS IN THE SPONTANEOUS AND THERMAL NEUTRON INDUCED FISSION OF THE PLUTONIUM ISOTOPES

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Abstract

In the frame of a systematic study of the fission fragment mass and energy distributions and their correlations, the spontaneous fission of ^{238}Pu, ^{240}Pu, ^{242}Pu and ^{244}Pu and the thermal neutron induced fission of ^{239}Pu and ^{241}Pu has been studied. These series of measurements make it possible to investigate the influence of the shell effects for even-even fissioning systems with the same number of protons ($Z = 94$) but with different mass and in some cases also with different excitation energy. In particular the present results can be interpreted in terms of the nuclear shell effects presented in the scission point model of Wilkins et al. (Phys. Rev. C14, 1832 (1976)) and Moreau and Heyde (Phys. Mag. 5, 91 (1983)).

Comparing the mass distributions of the spontaneously fissioning Pu-isotopes, one can notice the almost constant position of the heavy fragment peak, so that the increase of the mass of the compound nucleus results in an upwards shift of the light fragment peak. This is a result of the preferential formation of fragments with neutron number $N = 82$ and $N = 88$, due to the combined influence of the corresponding neutron shells. A second observation is a difference in fine structure, mostly caused by the influence of neutron shells ($N = 53$ and $N = 64$) on the light fragment. For ^{238}Pu(s.f.) even the influence of the proton shell $Z = 38$ is observed. Studying the energy characteristics of the different spontaneously fissioning systems, the influence of the spherical neutron shell $N = 82$ and the spherical proton shell $Z = 50$ is obvious. The influence of these spherical shells should increase with increasing mass of the compound nucleus, taking into account that the charge/mass ratio of the fragment pairs tends to be equal to Z/A of the compound nucleus. This is in complete agreement with our experimental results, since the total kinetic energy in the mass region, influenced by these nuclear shells, increases with increasing mass of the compound nucleus. However, considering only the Coulomb repulsion, without the shell effects, one would expect the opposite behaviour.

A comparison of the mass distribution of ^{240}Pu(s.f.) and ^{242}Pu(s.f.) with ^{239}Pu(n_{th},f) and ^{241}Pu(n_{th},f) shows a narrower mass distribution, a more pronounced fine structure and a much higher peak yield for the spontaneous fission as compared to the neutron induced fission.
For the above mentioned fissioning systems the difference in excitation energy does not show up, the kinetic energy being even higher for the spontaneous fission. All these observations can be explained by a decrease of the shell corrections with increasing excitation energy.

One concludes that the energy and mass characteristics of the fission fragments are very much influenced by the shell effects, influence that however decreases with increasing excitation energy of the fissioning system.

ENERGY DEPENDENCE PECULIARITIES OF FRAGMENT MEAN KINETIC ENERGY AT NUCLEI FISSION BY NEUTRONS

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ABSTRACT

THE 4-th INTERNATIONAL CONFERENCE ON NEUTRON-INDUCED REACTIONS , SMOLENICE, 17-21 JUNE, CSSR .

The measurements of the fragment total kinetic energy value (TKE) and fission cross-section have been made in the $^{234}U(n,f)$ reaction at $E_n < 2$ MeV.

In the TKE energy dependence the variations reaching 0.6 MeV can be observed, they are localized in the energy range of compound nucleus excitation, where resonance fission cross-section behaviour due to β-oscillation of a nucleus in the second potential barrier well manifests itself. The differences in the TKE value of fragments scattered in the direction of target colliding neutrons and normal to it (which are observed in the test) indicate the connection between these oscillations and the fragment kinetic energy value.

Thermal neutron fission cross-sections of ^{236}Np isomers

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Thermal neutron fission cross-section and fission resonance integral of long-lived ^{236}Np isomer were measured: $\sigma_{n,f}(l) = 2760 \pm 170$ barns and $I_f(l) = 1030 \pm 100$ barns, respectively. The obtained values $\sigma_{n,f}(l)$ and $I_f(l)$ are compared with measured by us $\sigma_{n,f}(s) = 2740 + 140$ barns and $I_f(s) = 700 \pm 400$ barns of the short-lived ^{236}Np isomer. The dependance of the thermal neutron fission cross-section on the target spin is discussed.

The experimental study of γ-ray emission from neutron resonance fission of ^{235}U

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The emission of prompt γ-rays from fission fragments was studied for several neutron resonances of ^{235}U nucleus. The average characteristics of γ-ray spectra (e.g. energy per photon $\bar{\varepsilon}_{\gamma}$) of the resonances with $J^{\pi} = 3^-$ and 4^- have been determined. The difference (+13,1 ± 9.5) keV has been observed at $\bar{\varepsilon}_{\gamma}$ between resonances with 3^- and 4^-.

S. P.

CHEMICALLY SHIFTS OF URANIUM NEUTRON RESONANCES

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Transmission spectra were measured with a time-of-flight spectrometer at the Dubna pulsed reactor IBR-30 operated in booster mode with the linac LUE-40. As targets, metallic U, UO_2, UF_4, UO_3, and $UO_2(NO_3)_2 \cdot 6H_2O$ in natural isotopic composition were used as well as samples of metallic U, UO_2, U_3O_8, and UO_3 enriched in ^{235}U.
The spectra were compared in the regions of ten low-energy resonances of ^{234}U, ^{235}U, and ^{238}U to observe chemically induced shifts. After elimination of contributions caused by different Doppler broadenings, the resonance shifts are interpreted as effect of mean-square charge radius changes of nuclei capturing neutrons / 1,2 /. The $\langle r^2 \rangle$ of the compound nucleus states show on the average a weak diminution compared with the ground state values. They are also discussed with the fission widths of the resonances.

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/ 2 / S. Mittag et al., Nucl. Phys. A435 (1985) 97.

TEMPERATURE SHIFT OF NEUTRON RESONANCES

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The energy of gamma rays emitted by a solid depends on the sample temperature. This effect found by Pound and Repka / 1 / and by Josephson / 2/ is also called Doppler effect of second order. The energy of neutrons absorbed in a solid should show an analogous variation, so that a neutron resonance is shifted with the temperature by $E_n \sim \Delta\langle E_k\rangle/A$, where A is the mass number of the absorbing atom, and $\Delta\langle E_k\rangle$ is the variation of its mean kinetic energy which is at sufficiently high temperatures proportional to the temperature variation.
Resonances of ^{103}Rh(1.26 eV), ^{109}Ag(5.2 eV), ^{161}Dy(2.7, 3.7, and 4.3 eV), and ^{163}Dy(1.71 eV) were investigated with variation of sample temperatures between 294 and 665 K with a time-of-flight spetrometer at the Dubna pulsed reactor IBR-30 operated in booster mode with the linac LUE-40. The expected shift of the resonances with sample temperature has been observed.

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MEASUREMENT AND EVALUATION OF NUCLEAR DATA FOR NUCLEAR POWER APPLICATION

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(Abstract of report to the 4th International Symposium on Neutron Induced Reactions, Smolenice (CSSR), 17-21 June, 1985

One of the important applications of nuclear data to power engeneering is its use for fast breeder reactors (calculation of parameters, which are important for reactor operation, for out-of-pile fuel cycle, choice of alternative ways). The scientifically substantiated requirements to the accuracies of these data and priorities of measurements and evaluations are given in works /1,2/. The works on nuclear data measurements and evaluations were done in FEI in correspondce with these requirements.

Fissionable nuclei (measurements)

The fission, capture, (n, n') and (n, 2n) reaction cross sections, average number of fission prompt neutrons and its spectra for a number of nuclei, which are important for fast breeder reactors (for example, U-232, U-233, U-235, U-236, U-238, Np-237, Am-241), were measured.

Nuclei of structural materials and fission products (measurements)

The measurements of capture, inelastic scattering and (n, 2n) - reaction cross sections for a number of structural elements and fission products (only capture cross sections) have been done.

Nuclear data evaluation

The work was made on development of evaluation method. The evaluation of radiative capture cross sections for the most important fission products and reevaluation of all the cross sections of neutron interaction with cromium and nikel nuclei have been done.

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PROGRESS IN THE DETECTION OF LOW ENERGY NEUTRONS

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Advances in the study of neutron-induced reactions require the development of improved neutron detectors. Instrumental developments in the detection of neutrons with energies less than 20 MeV are discussed. These include those with fast timing capabilities for use in time-of-flight measurements at both broad spectrum pulsed neutron sources and pulsed monoenergetic facilities. The types of detector discussed include the dual-thin scintillator, the thick plastic scintillator, proton recoil telescope, gas proportional counter, fission ionization chamber, and He-3 gas scintillator. Also included are applications of the time-correlated associated-particle technique, development of position sensitive detectors for two-dimensional analysis, and experience with resonance absorption detectors for use in eV neutron scattering experiments. The uncertainty in the efficiency of most of these detectors is limited by the uncertainties in the neutron reaction cross sections which are dependent upon the standard reaction cross sections. The exceptions to this rule include thick [illegible] associated-particle methods. Experience with the newly developed dual-thin scintillator is highlighted by examples of [illegible] calculations in the 1-20 MeV energy region. Comparisons of this detector with the response of a thick [illegible] are presented for the 1-[illegible] MeV energy region. Neutron fluence measurements throughout the 1-20 MeV interval are demonstrated by a proton recoil telescope. Advances in the development of a He-3 gas scintillator as a neutron monitor in the thermal to 2 MeV interval are given. The successful development of this detector will increase the energy range of the $^3He(n,p)^3H$ neutron standard reaction. The development of position sensitive detctors for applications of two-dimensional analysis for resonance-neutron radiography is also presented. There is intensive development of resonant neutron detectors to exploit the pioneering field of eV neutron scattering which is now possible because of the new intense pulsed sources becoming available. Examples of the progress in this field are described.

INTENSE NEUTRON GENERATOR PROJECT AT THE TECHNICAL UNIVERSITY DRESDEN

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The project of an intense neutron generator is presented. Using the DT-reaction in connection with beam parameters in the order of U=200-300 kV, I=15-20 mA, N≤5 kW, an intensity of 14 MeV neutrons above 10^{12} s^{-1} could be obtained. For this purpose the following components had to be developed:

- duoplasmatron ion source with specified extraction geometry for high ion currents;
- ionoptical elements, as extraction electrode, einzel lens, acceleration tube, focusing lens (quadrupole triplet) and water-cooled diaphragms;
- ionoptical calculations with space charge effect and its compensation for construction and optimization;
- vacuum system for oil-free vacuum ($p \geq 10^{-4}$ Pa, $S \geq 2000$ ls^{-1}) with control; especially development of an orbitron pump which is used on high voltage potential;
- electronic power supply units (limit values U=50 kV, I=50 A, N=1.5 kW), mostly operating in switching mode with high efficiency;
- data acquisition and transfer by opto-electronical glass fibres in connection with sensor elements for pressure, temperature and flow rate; hard and soft ware for a microcomputer and a colour display.

These components are completed by commercially available devices (high voltage power supply, vacuum technique, rotating target). A concept for beam analyzers was elaborated also in order to investigate the intensity as well as profile of the beam. Furthermore, the problem of secondary electron suppression is considered.

[illegible] developments in the multipurpose intense 14 MeV neutron source at Bratislava

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Intense D+T neutron source based on the 20 mA duoplasmatron [illegible] high voltage power supply is under [illegible] Institute of Physics in Bratislava.

[illegible] several components have been developed/completed [illegible] 1) The high voltage power supply together [illegible] all supplementary units such as water [illegible] and high voltage cable [illegible] namely the isolating transformer [illegible] kV/[illegible] for high voltage terminal, the isolating transformer [illegible] for the duoplasmatron and 50 kV dc/3,75 kVA for the extraction power supply source.

Under construction are the high voltage terminal, the diagnostic elements of ion beam as well as the rotating target.

The paper gives a short survey of the present status in the development of the accelerator.

A Time of Flight Spectrometer for the Measurement of Gamma Correlated Neutron Spectra

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Abstract

A time of flight spectrometer for the measurement of gamma correlated neutron spectra from $(n, Xn\gamma)$ reactions is described. The operation and the main parameters are discussed. The resolution in the neutron channel is 2.2 nsec/m at the 150 keV neutron energy threshold. The simultaneously measurement time of flight and amplitude distributions allows to study gamma correlated neutron spectra as well as the prompt gamma spectra in coincidence with selected energy neutrons. In term to test the spectrometer, measurements of the neutron spectrum in coincidence with the 846 keV gamma line of ^{56}Fe were carried out at an incident neutron energy of 14.1 MeV.

S.P.

[illegible] of [illegible] symmetry violation [illegible] at low energies

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[illegible] analysing power as [illegible] differential cross section data on [illegible] (d,n)^{3}He at incident deute[illegible] [illegible] in terms of [illegible] [illegible]. Charge [illegible] symmetry of reduced p-wawe contributions to this reactions seems to result from different values of neutron and proton widths of neighbour [illegible] = 0, ^{4}He excited states.

Consideration of the (n,d) and (p,d) scattering and breakup reactions through singular integral equations

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We choose a proper complete set of base vactors to expande Faddeev equations of the T-matrix form, and consider local two-body interactions, then we obtain a set of the two-variable integral equations. If the energy parameter S is negtive, but it is lager than the two-body binding S_b , or if S = pasitive real+$i\epsilon$, $\epsilon \to o^+$, then the integral equation obtained is the Cauchy singular equation.

In order to solve the equation, we must make it become the standard form of the singular integral equation after the variable transformations. The index K of the singular integral equation is very important, because of the solution *form of the equation is well defined by the index. From the equation coefficient* we can construct the two functions a and b , which are required to satisfy the following conditions

$$0 < a + \lambda_1 < 1 \ ,$$
$$-1 < b + \lambda_2 < 0 \ ,$$

where $\lambda_1, \lambda_2 = 0, \pm 1, \pm 2, \cdots$, then index K of the equation equals

$$K = -(\lambda_1 + \lambda_2) \ .$$

From it we obtained a algebra equation system. What the system is solved isn't difficult.

The forementioned is a problem about the two-body short range force, but it can also be used to discuss the Coulomb problem. We remember that Coulomb force is long range. Therefore L-S equation can not hold. But its Hamiltonian is a unbounded operator. It is the limit operator of the screening Coulomb Hamiltonian. Since the screening Coulomb potential is finite range, It satisfies L-S equation. Thus the equation which is satisfied by the pure screening Coulomb potential is the Fredholm equation. But for the Coulemb modified stong amplitude it *must be studied in the Coulomb modified representation. If there is not* any Coulomb binding state in the two-body T matrix, then the equation shall be Fredholm. It is easy to solve the equation. But when there are Coulomb binding states, the equation is the singular integral equation. We can solve it in terms of the feremention method. Then the results obtained is inserted into the three-body equation, we can finally solve three-body breakup problems in which there are the two charged particles. For on-shell amplitudes and wave functions we can realize the limit transition by renormalization of these quantities.

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[illegible] Be(n,2n)

[illegible]

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[illegible] Be(n,2n) are quite complex. The investigation [illegible] shown, that it is necessary [illegible]

The [illegible] paper [illegible] for following [illegible]:

[illegible] inelastic scattering and statistical decay with neutron [illegible]

[illegible] n_2

[illegible] with [illegible] model,

$n + {}^9Be \longrightarrow {}^8Be + n_1 + n_2$

4-body break-up process [illegible] semiempirical formula)

$n + {}^9Be \longrightarrow 2\alpha + 2n$

The comparision with experiments and discussions are given.

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