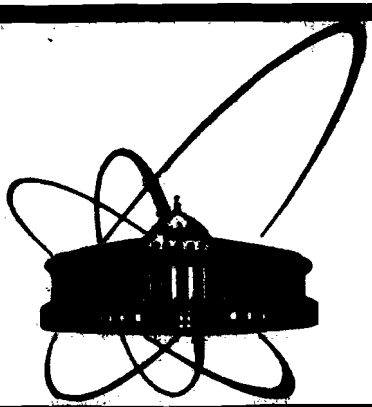

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SELF-ORGANISATION AND ATOMIC NUCLEI

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1. Introduction

The formation of order out of chaos is one of the most interesting problems in present time[1]. Although it is a general problem it should be discussed carefully in some special cases which are proved experimentally in detail. Such a case might be the atomic nucleus the properties of which are investigated for more than fifty years.

The nucleus is a physical system consisting of particles which are all of the same type. Every nucleus appears in different states which can be excited and investigated by means of different nuclear reactions. Two types of nuclear reactions induced by, e.g., low-energy nucleons are very well known for a long time: the fast direct reaction process and the slow resonance reaction process. While in the first case, information on the target nucleus can be obtained, the resonance process contains information on the compound nucleus. For both processes, mathematical methods are worked out the results of which are in good agreement with the experimental data. Although the methods used in both cases are completely different from each other, a regular motion of the nucleons inside the nucleus is proposed in both cases. Nevertheless, nuclear physicists hold often the idea that nucleons in nuclei move chaotically[2,3].

It is the aim of the present paper to discuss this problem on the basis of numerical results obtained from microscopic calculations.

2. Bound and isolated nuclear states

The basis of the microscopic nuclear structure calculations is the shell model in which a regular motion of the nucleons is assumed to take place in a conservative field of force. The basic equation is the Schrödinger equation in a function space (Q space) in which all nucleons occupy bound and quasibound single-particle states,

$$(H_{QQ} - E_R^{SM})\,\Phi_R^{SM} = 0 \qquad (1)$$

with the Hamilton operator

$$H = H_0 + V \qquad (2)$$

and $H_{QQ} \equiv QHQ$. Here, Q is the projection operator onto the Q space which is the total function space in nuclear structure calculations ($Q = 1$). The wavefunctions of the many-particle nuclear states are identified with the eigenfunctions ϕ_R^{SM} while the real eigenvalues E_R^{SM} are assumed to be the energies of the states. The Hamilton operator is proposed to be Hermitean since the system is considered to be limited to the Q space. The wavefunctions

$$\phi_R^{SM} = \sum_i a_{Ri}\, \varphi_i \qquad (3)$$

are mixed in the basic wavefunctions φ_i, the energies E_R^{SM} are real.

The results of the microscopic nuclear structure calculations describe successfully the low-lying bound nuclear states as well as the states at higher excitation energy which are isolated due to their small decay widths or (and) their large distance from other states with the same spin and parity. The results of the nuclear structure calculations represent the real nuclear theory proved by many experimental data, sometimes in a "revolutionary" manner[4] as, e.g., by the discovery of isobaric analogue resonances and of Gamow-Teller resonances. It must be concluded, therefore, that the nucleons move inside the nucleus with some regularity which is, obviously, dictated by the Pauli exclusion principle.

It is, however, very well known that the wavefunctions ϕ_R^{SM} of the nuclear structure calculations do not have the true asymptotic behaviour and that the finite lifetime of the nuclear states cannot be calculated within the model. The point is that the nucleus is treated as a closed system ($Q = 1$) in nuclear structure calculations although most of the nuclear states can decay by particle emission since they lie above particle decay thresholds. The system, included in the Q space, is, in reality, coupled to the continuum (P space) and must be treated as an open system: The nuclear states are "quasibound states embedded in the continuum" (QBSEC)[5].

Recently, a method has been worked out[5,6] for treating the nucleus as an open quantum mechanical system. The basic Schrödinger equation $H\psi = E\psi$ is linear in the whole $P + Q$ function space ($P + Q = 1$), but nonlinear for the system confined in the Q space:

$$(H_{QQ} - E)\,\psi = -H_{QP}\,\psi \qquad (4a)$$

or[5,6]

$$(H_{QQ} - E)\,\phi_R^{SM} = -H_{QP}\, G_P^{(+)}\, H_{PQ}\, \phi_R^{SM} \,. \qquad (4b)$$

As a consequence, correction terms to the Hamilton operator

$$H_{QQ}^{eff} = H_{QQ} + H_{QP}\, G_P^{(+)}\, H_{PQ} \qquad (5)$$

as well as to the wavefunction

$$\tilde{\Omega}_R = (1 + G_P^{(+)}\, H_{PQ})\, \tilde{\phi}_R \qquad (6)$$

appear by which the coupling of the Q subspace to the P subspace is taken into account. The wavefunctions

$$\tilde{\phi}_R = \sum_{R'} b_{RR'}\, \phi_{R'}^{SM} \qquad (7)$$

are expanded in terms of the shell model wavefunctions ϕ_R^{SM}. The wavefunction $\tilde{\Omega}_R$ has the true asymptotic behaviour. The Hamilton operator H_{QQ}^{eff} is non-Hermitean. Its eigenvalues are complex,

$$H_{QQ}^{eff}\, \tilde{\phi}_R = (\tilde{E}_R - \tfrac{1}{2}\, \tilde{\Gamma}_R)\, \tilde{\phi}_R \qquad (8)$$

describing the positions $\tilde{E}_R$ as well as the widths $\tilde{\Gamma}_R$ of the nuclear states. The widths $\tilde{\Gamma}_R$ are inverse proportional to the lifetimes $\tilde{T}_R$ of the resonance states.

It has been shown[6,7] on the basis of this model that the spectroscopic properties of the different nuclear states can be described by the standard nuclear structure methods to a good approximation as long as the nuclear states are either bound or well isolated. In such a case, the additional forces via the continuum, which appear in the open system, are small. As a consequence, the nuclear states may be considered as conservative structures, to a good approximation. The coefficients $b_{RR'}$, in the expansion (7) fulfill approximately the condition $b_{RR'} \approx \delta_{RR'}$. The energy shifts $E_R^{SM} - \tilde{E}_R$ are small but nonvanishing even for bound states. The finite lifetime $\tilde{T}_R$ of the resonance states follows immediately from the non-Hermitean part $H_{QQ}^{eff} - H_{QQ}$ of the Hamilton operator.

The equations of the open quantum mechanical nuclear system in the Q space are nonlinear, eqs. (4). Further, strong cooperative effects are known for a long time[2] to exist in the nuclear system. Self-organisation is expected therefore, from a mathematical point of view, to take place in the nuclear system.

The regular motion of the nucleons supposed in all nuclear structure calculations can be, indeed, understood[8] as a consequence of the strong cooperative effects existing between the individual nucleons. A common potential U_o is formed by the nucleons themselves. The residual interaction V_{ik} between the nucleons is relatively small. The different many-particle states of a nucleus differ by the different occupation of the single-particle states with nucleons in the common potential. Only in the ground state, all the nucleons occupy the lowest single-particle

states. In the excited states, some of the nucleons occupy higher-lying single-particle states, which are still bound, by leaving holes in the low single-particle states. If these states of the many-particle system lie above particle decay thresholds, they have a finite lifetime against decay into the open channels.

Thus, the regular motion of the nucleons in bound and isolated nuclear states is not in contradiction to the existence of strong cooperative effects between the nucleons, as proposed in ref.[2], but is caused by them. The description of the nuclear structure by restricting to the Q space is a good approximation according to the slaving principle which is universal in synergetics[9]. Further, the different nuclear states should be considered as dissipative structures formed by self-organisation far from equilibrium in accordance with the definition of dissipative structures in open systems[1,10].

3. The transition from isolated to overlapping resonance states

In contrast to the success of nuclear structure calculations at low level density, the experimental results at higher level density are not described satisfactorily. They raise a number of questions which are on the interface of reaction theory and nuclear structure and force us to rethink our assumptions in dealing with nuclear reactions on several points.

In standard nuclear reaction theory, the motion of the nucleons is assumed to be a chaotic one[3]. The nuclear states are proposed to be statistically independent although this assumption could not be proven experimentally, e.g.[11], and all the nuclear structure studies point to strong cooperative effects.

In order to clarify this problem, microscopic calculations in an open nuclear system have been performed in dependence on the degree of coupling between the system (Q subspace) and the environment (P subspace). The method used is the Rossendorf continuum shell model (CSM) sketched by eqs. (1) to (8), for details see refs.[5,6]. The degree of coupling between the two subspaces has been varied by hand. The calculations are performed in the following manner.

(i) The shell model problem (1) is solved for the compound nucleus ^{16}O with basic wavefunctions φ_i out of the configuration space $(1p_{3/2},1p_{1/2})^{-1}_2(2s_{1/2},1d_{5/2})^1$ and $(1s_{1/2})^{-1}(1p_{3/2},1p_{1/2})^{-1}(2s_{1/2},1d_{5/2})^2$. The 76 states with $J^\pi = 1^-$ (mixed isospin) are mixed in the basic states φ_i, eq. (3), six of which are of (1p-1h) type and the remaining ones are of (2p-2h) type. The potential used is of Woods-Saxon type with standard parameters[12].

(ii) The shell model problem (1) is solved for the residual nuclei ^{15}N and ^{15}O within the configuration space $(1p_{3/2})^{-1}$ and $(1p_{1/2})^{-1}$ by using the same parameters as for ^{16}O.

(iii) The Schrödinger equation (8) with the non-Hermitean operator (5) is solved in an energy region where the $d_{3/2}$ single-particle resonance is not important, with 29 or 30 out of the 76 resonance states which are used as basic states in the coupled channel calculations (8). The 29 resonance states have small components of the basic 1p-1h configurations. In some calculations, another resonance state has been added to the 29 ones with the main component $\varphi_i = (1p_{3/2})^{-1}\,1d_{5/2}$, either $T = 0$ or $T = 1$. The number of channels taken into account in the calculations is 1 (corresponding to the ground state $1/2^-$ of ^{15}N), 2 (corresponding to the two states $1/2^-$ and $3/2^-$ of ^{15}N) or 4 (corresponding to the two states $1/2^-$ and $3/2^-$ in both nuclei ^{15}N and ^{15}O).

In figs. 1 to 3, the dependence of the inelastic cross section and of the widths $\tilde{\Gamma}_R$ on the degree of overlapping $\langle\Gamma\rangle / \langle D\rangle$ of the resonance states (where $\langle\Gamma\rangle \equiv \bar{\Gamma}$ is the mean width and $\langle D\rangle \equiv \bar{D}$ the mean distance) is shown. The overlapping has been varied by solving eq. (8) with input values E_R^{SM} obtained as solutions of eq. (1) as well as with other values $E_R'^{SM}$ changed by hand in such a manner that the differences ΔE_R^{SM} between the energies of the different shell model states are reduced. The wavefunctions ϕ_R^{SM} of the shell model states used as input in eq. (8) thereby remain unchanged. Such a procedure to vary the degree of overlapping is justified because the eigenfunctions $\tilde{\Phi}_R$ and eigenvalues $\tilde{E}_R - \frac{i}{2}\tilde{\Gamma}_R$ of the operator (5) depend only weakly on energy. The parameters of the Woods-Saxon potential and of the residual interaction remain unchanged in this procedure (for details see ref. [13]).

The degree of overlapping $\langle\Gamma\rangle/\langle D\rangle$ of the resonances corresponds to the strength of external mixing, involved in eqs. (7) and (8), which is given by the non-diagonal matrix elements

$$\langle\phi_R^{SM}|\, H_{QQ}^{eff} - H_{QQ}\,|\phi_{R'}^{SM}\rangle = \langle\phi_R^{SM}|\, H_{QP}\, G_P^{(+)}\, H_{PQ}\,|\phi_{R'}^{SM}\rangle \,. \quad (9)$$

The more the resonances overlap, the larger are the matrix elements (9). The results shown in figs. 1 to 3 illustrate therefore the behaviour of the nuclear system in dependence on the degree of external mixing of the resonance states via the continuum.

The eigenfunctions ϕ_R^{SM} of H_{QQ}, eq. (3), as well as the eigenfunctions $\tilde{\Phi}_R$ of H_{QQ}^{eff}, eq. (7), are the more mixed in the corresponding basic functions φ_i and ϕ_R^{SM} the stronger the residual interaction V is

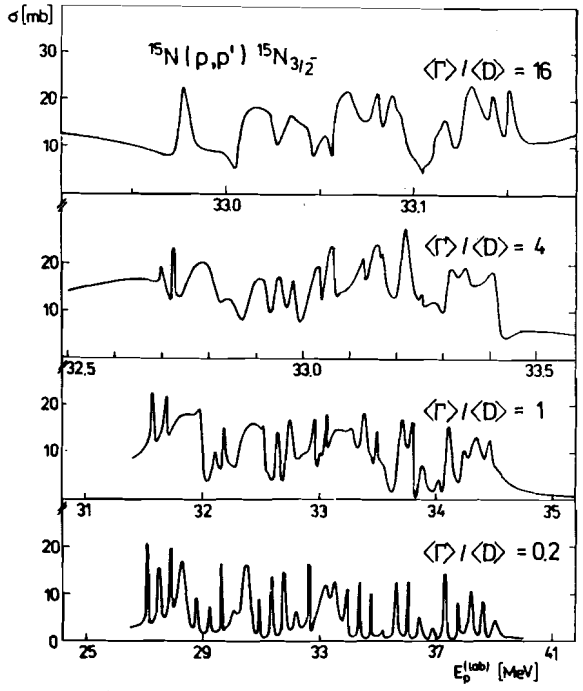

Fig.1.
The inelastic cross section $^{15}N(p,p')$ in dependence on the degree of overlapping $\langle\Gamma\rangle/\langle D\rangle$. The calculation has been performed with two channels and with 30 resonance states, 29 of which have dominant 2p-2h nuclear structure (corresponding to Fig.1 in ref.13) and 1 state has dominant 1p-1h nuclear structure and $T \approx 1$.

in the first case and the non-diagonal matrix elements (9) at fixed residual interaction V in the second case. Strong internal mixing corresponds to large coefficients a_{Ri} with $R \neq i$ in the expansion (3) in the same manner as strong external mixing leads to large coefficients $b_{RR'}$ with $R \neq R'$ in the expansion (7). The coefficients a_{Ri} are real while the coefficients $b_{RR'}$ are complex since the operator H_{QQ} is Hermitean and the operator (5) is non-Hermitean.

The basic wavefunctions φ_i of the shell model problem (1) describe a regular motion of the nucleons in the central potential which is dictated by the Pauli principle. If the eigenfunctions Φ_R^{SM} are mixed strongly in the φ_i, i.e. no main component in the expansion (3) can be found, then the motion of the nucleons is usually considered to be a chaotic one. Another representation, e.g. by taking into account the collective aspects in the interplay between the constituent particles from the very beginning, is more adequate in this case. This fact is very well known from the numerous nuclear structure calculations for heavy nuclei.

In a closed system, a chaotic motion of the nucleons (from the one-body point of view) corresponds to the formation of an equilibrium

state: the different basic states are excited with a probability which is about the same for all φ_i, and the lifetime of the nuclear state is infinite by definition. An equilibrium state of the system will be reached therefore if the system is closed and if the residual interaction is not too small.

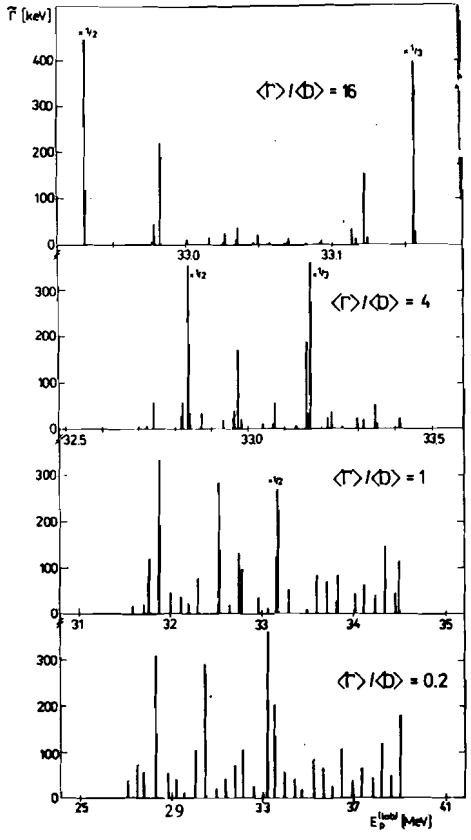

Fig.2.
The widths $\tilde{\Gamma}_R$ of the individual resonance states R in dependence on the degree of overlapping $\langle\Gamma\rangle/\langle D\rangle$. The calculation has been performed with two channels and with the same 30 resonance states as in Fig.1.

In the open system, the external mixing creates also an excitation of the basic states Φ_R^{SM} which is more or less the same for all Φ_R^{SM} if the external mixing is not too small. But in contrast to a closed system, the open system has to organise itself in such a manner that the lifetime of the states reached is as long as possible. Otherwise, the state reached cannot be considered as an equilibrium state.

The results shown in fig. 3 illustrate this behaviour of the open nuclear system. Instead of the lifetime of the resonance states, their widths are considered. As long as the resonance states do not overlap

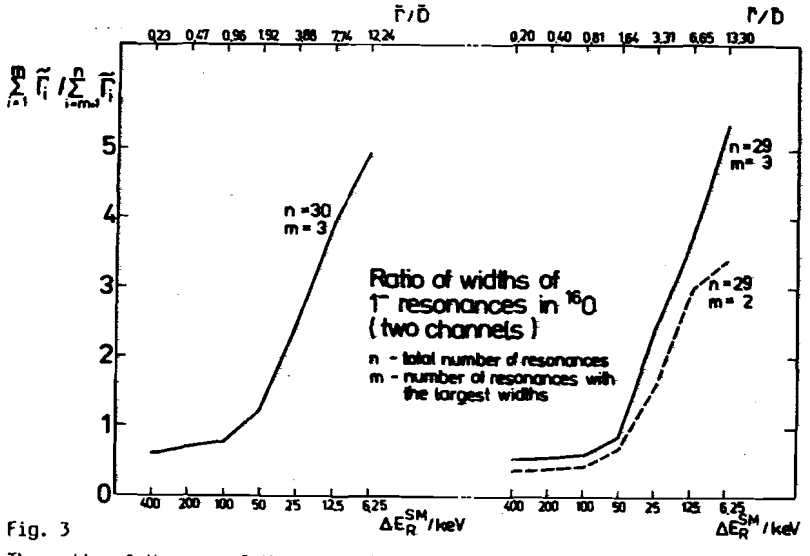

Fig. 3

The ratio of the sum of the two and three, resp., largest widths to the sum of the remaining widths for the 30 resonance states shown in Figs. 1 and 2 and for the 29 resonance states shown in Figs. 1 and 2 of ref.[13] in dependence on the degree of overlapping $\bar{\Gamma}/\bar{D}$.

($\langle\Gamma\rangle/\langle D\rangle < 1$), it holds $b_{RR'} \approx \delta_{RR'}$. The motion of the nucleons in the eigenstates of H_{QQ}^{eff} is therefore of the same regularity as in the corresponding eigenstates of H_{QQ}. As soon as the resonance states begin to overlap, the system tends to reach an equilibrium state by means of the external mixing: The expansion (7) contains many terms the weights $b_{RR'}$ of which are of almost the same magnitude. Additionally, the widths of most resonance states are reduced, i.e. their lifetimes are enlarged. This reduction of the widths must, however, be compensated in the open system due to the condition[6]

$$\sum_R \tilde{\Gamma}_R = \sum_R \Gamma_R \,, \qquad (10)$$

where $\tilde{\Gamma}_R$ are the widths of the resonance states R obtained by taking into account the external mixing (eigenvalues of H_{QQ}^{eff} according eq. (8)) and Γ_R are their widths calculated by neglecting the external mixing (diagonal matrix elements of H_{QQ}^{eff}). The numerical results show that the compensation takes place by an enlargement of the widths of a small number of states. The stronger the external mixing, the larger is the difference between the widths of the many long-living states and those of the few short-living states. The redistribution of the widths starts rather suddenly at $\langle\Gamma\rangle/\langle D\rangle \approx 1$.

The matrix elements $\langle \phi_R^{SM} | H | \xi_E^c \rangle$ of the operator H_{QP} between the wavefunctions ϕ_R^{SM} of the Q space and the scattering wavefunctions ξ_E^c of the P space are involved in both expressions for the width $\tilde{\Gamma}_R$ as well as the excitation probability of the resonance state R in nucleon induced reactions. A long lifetime $\tilde{T}_R$, corresponding to a small width $\tilde{\Gamma}_R$, is correlated therefore with a small excitation probability[8]. Consequently, the equilibrium states with a long lifetime are excited with a small probability in nucleon induced reactions.

The few other states of the system which appear due to the condition (10) in an open system together with the many "equilibrium" states, are far from equilibrium. These states have a large width, corresponding to a short lifetime, and will be excited in nucleon induced reactions with a large probability. They can therefore be simulated by single-particle resonances in relation to the target nucleus, i.e. by changing the central potential. In this representation, the short-living resonance states consist of one unbound nucleon in relative motion to the target nucleus which consists of A - 1 bound nucleons. The motion of these A - 1 nucleons is a regular one in the central potential created by the nucleons themselves.

In an open system the equilibrium state with a chaotic motion of the nucleons can, therefore, not be reached immediately. On the way to the equilibrium, another state far from equilibrium appears which becomes soon the overwhelming one due to its large and fast probability of excitation. This state can be represented by a regular (and not chaotic) motion of all but one nucleon.

The two extreme cases of reaction mechanism at low and high level density are very well known in nuclear reaction theory. While information on the nuclear structure of the resonances in the A nucleon system can be obtained at low level density, this information is lost at high level density. According to the chaotic motion of the nucleons, the resonance states can be seen at high level density as fluctuations around an average value only. This average value is determined by the fast direct process which contains the information on the environment (motion of a nucleon relative to the target nucleus). The correlation between the system (Q space) and the continuum (P space) is so strong at high level density that the consideration of the nucleus as an open system (in the Q space) looses its sence. The properties of the system at high level density are determined mainly by the P space in which the motion of only A - 1 nucleons is a regular one.

It is worthy of note that irreversibility on a microscopic level[8] exists still at high level density in the long-living states, but is

hidden partly by the fast direct scattering process which is reversible as a whole in the P + Q space. The scattering process is described by a Hamilton operator which is Hermitean in the closed P + Q space.

It can be seen from fig. 3 (see also ref.[16]) that the transition from the resonant process to the direct one takes place at $\langle\Gamma\rangle/\langle D\rangle \approx 1$, independently of the nuclear structure of the resonance states and of the number of channels taken into account in the calculation. The addition of a resonance state with mainly 1p-1h nuclear structure and with isospin T = 0 or T = 1 does not change the final result discussed above. The resonance state with mainly 1p-1h nuclear structure can be identified in the cross section at low level density but not at high level density[14]. The number of channels taken into account in the numerical calculation is correlated with the number of short-living resonance states at high level density as it is to be expected from calculations in a schematic model[15]. The general picture of the transition from one type of regular motion to another one is, however, independent of the number of channels. It is, obviously, the sharper, the larger the continuum is, i.e. the larger the number of channels is (ref.[16]).

4. Summary

The transition from the resonance reaction mechanism at low level density to the direct reaction mechanism at high level density has been investigated in this paper by means of numerical results obtained from microscopic calculations for nucleon induced reactions. In the resonance reaction mechanism, a compound nucleus is formed the properties of which can be described by standard nuclear structure calculations. The nucleons move in an average potential in a regular manner. The second part of the Hamilton operator (5) is small in comparison with the first part. In the direct reaction mechanism, the nucleon is scattered in the field of the target nucleus as a whole. All but one nucleon move in an average potential in a regular manner. The second part of the Hamilton operator (5) plays an important role.

The numerical calculations give the following results

(i) The transition from resonant to direct reaction mechanism takes place rather sharply at $\langle\Gamma\rangle/\langle D\rangle \approx 1$. The transition is the sharper the larger the continuum is, i.e. the more channels are taken into account in the calculation (ref.[16]).

(ii) The second part of the Hamilton operator (5) creates both an information loss on the nuclear structure of the compound nucleus and an information gain on the nuclear structure of the open channels, i.e. on the nuclear structure of the target and residual nuclei.

(iii) At high level density, two types of motion of the nucleons exist simultaneously: a motion in long-living states which are near equilibrium, and a motion in short-living states which are far from equilibrium. The long-living states are excited in nucleon induced reactions with a small probability while the short-living ones are excited with a high probability. Furthermore, the reaction via the short-living states is very fast. Due to their large widths, these states overlap the long-living states, and the nucleus behaves more or less as a whole.

(iv) From the point of view of the compound nucleus, the nucleons move chaotically in long-living states at high level density. These states appear in the cross section as fluctuations around an average value.

(v) From the point of view of the target and residual nuclei, the motion of the nucleons at high level density of the compound nucleus is represented by a regular motion of all but one nucleon in the average field of the target and residual nuclei, resp. The average value of the cross section is determined by the scattering of a nucleon in the field of the target nucleus as a whole.

(vi) The numerical results show that order out of chaos takes place only in the open quantum mechanical nuclear system. In a closed system, there are no forces to introduce a new order. If the equilibrium state is reached in a closed system, it can exist a long time without any distortion.

(vii) There exists a strong correlation between the finite lifetime of the states near equilibrium in an open system and the formation of states far from equilibrium. In the states far from equilibrium, the target nucleus behaves as a whole, i.e. the many-body aspects play a subordinate role in the P + Q space.

(viii) The finite lifetime of the nuclear states creates an irreversibility on a microscopic level. This irreversibility continues to exist at high level density although the main process (scattering of a nucleon on a target nucleus) is, of course, reversible.

Although most of the discussed results are very well known in nuclear physics for a long time, a direct experimental test has yet to

come (for a detailed discussion see ref.[8]). The most direct way is to investigate the lifetime of the compound nucleus states in dependence on the excitation energy and the correlations between the resonance amplitudes. In both cases, deviations from the assumptions of standard nuclear reaction theory result if the nucleus is considered as an open system.

In this paper, only nucleon channels have been considered. The results hold, however, in an analogous manner also for, e.g., alpha particle channels and for the coupling to the electromagnetic field.

References

1. I. Prigogine, I. Stengers, Order out of chaos (London 1984 and Moscow 1986)
2. N. Bohr, Nature 137 (1936) 344
3. H.A. Weidenmüller, Comments on Nuclear and Particle Physics 16 (1986) 199; Nuclear Structure 1985, ed. by R. Broglia et al. (North-Holland 1985), p. 213; and references therein
4. E. Vogt, Intern. Conf. on Spin Excitations in Nuclei, Telluride, Colorado, 1982, TRI-PP-83-17 (TRIUMF 1983)
5. H.W. Barz, I. Rotter and J. Höhn, Phys. Letters 37B (1971) 4; Nucl. Phys. A275 (1977) 111
6. I. Rotter, Fiz. Elem. Chastits At. Yadra 15 (1984) 762 (translation 15 (1984) 341 and ZfK-500 (1983))
7. I. Rotter, Phys. Rev. C27 (1983) 2261; C29 (1984) 1119; H.R. Kissener, I. Rotter and N.G. Goncharova, Fortschritte der Physik (1987)
8. I. Rotter, J. Phys. G12 (1986) 1407; Fiz. Elem. Chastits At. Yadra (in press; translation ZfK-598 (1986))
9. H. Haken, Synergetics (Springer 1978); Advanced Synergetics (Springer 1983)
10. I. Prigogine, From Being to Becoming (San Francisco 1979 and Moscow 1985)
11. E.P. Kanter et al., Nucl. Phys. A299 (1978) 230; B.H. Chou et al., Phys. Rev. Letters 45 (1980) 1235; W.K. Wells et al., Z. Phys. A297 (1980) 215; J.F.Jr. Shriner et al., Z. Phys. A305 (1982) 307
12. P. Kleinwächter and I. Rotter, Nucl. Phys. A391 (1982) 137
13. P. Kleinwächter and I. Rotter, Phys. Rev. C32 (1985) 1742
14. P. Kleinwächter and I. Rotter, to be published
15. V.V. Sokolov and V.G. Zelevinsky, private communication
16. I. Rotter, to be published

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Роттер И. E4-88-141

Самоорганизация и атомные ядра

При помощи численных результатов, полученных из микроскопических расчетов реакций, вызванных нуклеонами, рассматривается переход от резонансного механизма реакций при низких плотностях к прямому механизму при высоких плотностях. Переход обнаруживается при $\langle\Gamma\rangle \approx \langle D\rangle$, когда существуют одновременно два типа движения нуклонов: долгоживущие состояния, находящиеся почти в равновесии, и короткоживущие состояния, удаленные от равновесия. Появление порядка из хаоса наблюдается только в открытой квантовомеханической ядерной системе. Оно является следствием квантовых флуктуаций через континуум.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1988

Rotter I. E4-88-141

Self-Organisation and Atomic Nuclei

The transition from the resonance reaction mechanism at low level density to the direct reaction mechanism at high level density is investigated by means of numerical results obtained from microscopic calculations for nucleon induced reactions. The transition takes place rather sharply at $\langle\Gamma\rangle \approx \langle D\rangle$. Here, two types of motion of the nucleons exist simultaneously: a motion in long-living states which are near equilibrium and a motion in short-living states which are far from equilibrium. A formation of order out of chaos takes place only in the open quantum mechanical nuclear system. It is caused by the quantum fluctuations via the continuum.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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