3.2 Nuclear Structure

3.2.1 Complete spectroscopy of ^{90}Y via the ^{89}Y(n,γ) and ^{89}Y($\vec{d}$,p) reactions

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The γ-ray spectrum emitted after thermal neutron capture in ^{89}Y was studied at the TLL high flux reactor using a pair and Compton suppressed germanium detector. A total of 893 transitions were assigned to the decay of ^{90}Y, 392 of which, representing more than 90% of the obtained flux, were placed in a level scheme of sixty states. The neutron binding energy of ^{90}Y was determined as 6857.02(17) keV. The reaction $^{89}Y(\vec{d},p)$ was studied using a 22 MeV vector-polarized deuteron beam and the Munich Q3D spectrometer. Angular distributions of the vector-analyzing power and differential cross sections for nearly all states up to 5 MeV excitation were taken and analyzed within the DWBA formalism. For some eighty states the transferred total and orbital angular momenta, spectroscopic factors and spins were deduced. The results of both measurements are compared and discussed in the frame work of the statistical model, the shell model and the quasiparticle RPA model.

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3.2.2 Solution of the ^{10}Li-Puzzle: Mass and excited states

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The mass of ^{10}Li has been measured with two different reactions: $^{9}Be(^{13}C,^{12}N)^{10}Li, E_{lab} = 336\ MeV$, and $^{13}C(^{14}C,^{17}F)^{10}Li, E_{lab} = 337\ MeV$. The mass excess of 33.445(50) MeV is deduced from the Q-value measurement. ^{10}Li is found to be particle-unstable with respect to one-neutron emission by 0.42(5) MeV. In the analysis of the first reaction a low lying excited state is found at 0.38(8) MeV. This state and the ground state can be most probably identified as the $1^+/2^+$-doublet coupled from the $[\pi 1p3/2 \otimes v1p1/2]$ configuration, the 1^+-state being the ground state. The $(^{13}C,^{12}N)$-reaction populates the 1^+-state strongly due to a spin-isospin-flip character of the dominant part of the transition amplitude. The 2^+-member corresponds to the mass given by Wilcox et al [1]. A second excited state is observed at 4.05(10) MeV with a width of 0.7(2) MeV, it can be associated with the $v1d5/2$-strength. The second reaction is fully supporting the interpretation of the ground state doublet. The excited state at 4.05 MeV is not observed in this reaction and indeed it should not, because the reaction does not populate in first order excited neutron configurations. The levels are well described by mean field calculations including pairing correlations. The lowest resonance in the calculations is the $v1/2^-$-configuration, whereas the $v1/2^+$-configuration shows at the neutron threshold a strong non-resonant contribution.

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[1] K.H. Wilcox, et al., Phys. Lett **B59** (1975) 142

3.2.3 Mass spectroscopy of ^{13}Be

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The mass of ^{13}Be has been measured with the reaction $^{13}C(^{14}C,^{14}O)^{13}Be$ at $E_{lab} = 337\ MeV$. A Q-value of $Q_o = -3702(5)\ MeV$ was obtained and the mass excess is $M.E. = 35.16(5)\ MeV$. If the observed line corresponds to the ground state, ^{13}Be is particle unstable with respect to the one-neutron emission by 2.01 MeV. The observed line width of 0.3(2) MeV supports an assignment of $J^\pi = 5/2^+$ or $1/2^-$, but excludes $J^\pi = 1/2^+$. An excited state is seen at 3.12(7) MeV; there are indications of a second excited state at 6.5(2) MeV. A $5/2^+$ state is also obtained at about the same energy in a calculation with a density dependent pairing interaction. This calculation, however, predicts a $1/2^+$ ground state, and we give reasons, why it is perhaps not seen in the experiment.

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3.2.4 Neutron and proton density distributions in halo nuclei from pion elastic scattering

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We treat Be-isotopes in (i) a mean-field approximation including pairing correlations as well as in (ii) a fully self-consistent Hartree-Fock approach using Skyrme forces plus BCS. Binding energies and density distributions were calculated for the drip line nuclei ^{10}Be, ^{12}Be and ^{14}Be.

In approaching the neutron drip line an increasing neutron skin is found. As a new method to investigate the existence of a neutron "halo" in such nuclei π^+ and π^- elastic scattering calculations were performed using the theoretical density distributions. These exploratory calculations display a remarkable difference for the theoretical cross sections for π^+ and π^- scattering. We predict from our calculations that π-scattering on Be isotopes should be able to reveal the neutron halo.

3.2.5 Pion inelastic scattering and the neutron density in ^{152}Sm

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We apply a microscopic coupled-channel theory of pion elastic and inelastic scattering to study the neutron and proton densities of deformed ^{152}Sm obtained from a Hartree-Fock + BCS calculation with the Skyrme SkM* interaction. The approach utilizes a second-order pion-nucleus optical potential which has been determined from a previous phenomenological study of elastic and charge-exchange data on spherical nuclei. We obtain an excellent representation of the 180 MeV π^+ data. The π^- data are not quite as well reproduced, suggesting that the radius of the neutrons in ^{152}Sm is smaller than the one predicted by our SkM* Hartree-Fock theory. However, we find the deformation of the neutrons and protons as given by the Hartree-Fock theory ($\beta_{2n} = 0.263, \beta_{2p} = 0.287$) to be consistent with the experimental data.

published in Physics Letters **B296** (1992) 5.

3.2.6 Is there a high energy counterpart to the giant angle dipole?

R.R. Hilton, W. Höhenberger

We have pursued the question of potential collective modes of excitation of heavy well deformed nuclei. In the case of fermions within an oscillator one-body container well interacting via Q.Q forces a collective state representing a high energy counterpart to the Giant Angle Dipole, may be described. Such a High Energy Angle Dipole, (HEAD), represents a $K = 1^+$, $\Delta N = 2$ quadrupole excitation in which the relative collective proton-neutron motion is of predominantly isovector shear plus pure contra-rotational structure, together with some weak isoscalar shear admixture. The pure contra-rotational component action acting in a counter sense to that of the isovector shear deformation. The High Energy Angle Dipole represents the complimentary mode to the GAD, in which the role of the shear and contra-rotational components of the motion associated with GAD have been interchanged. The energy of this state is anticipated to lie in the region of 24 MeV.

Preliminary studies of the High Energy Angle Dipole within the QRPA framework using Skyrme III forces with an extended q.p. basis show rather weak B(M1) strength for the isotopes $^{160-164}Dy$ in the energy region 25-28 MeV, in line with the self-cancelling character of the HEAD motion gained from our model description. The B(E2) spectrum shows fragmented strength in the region 23-27 MeV with some components reaching values of 93-118 $e^2 fm^4$ for these nuclei.

3.2.7 Microscopic description of low energy 1^- states in rare earth nuclei

R.R.Hilton,W.Höhenberger

We report preliminary results of an investigation of very low energy 1^- states within the framework of a self-consistent QRPA formalism using Skyrme forces. These studies represent the first fully self-consistent microscopic studies of these states using realistic effective interactions which have been undertaken. Our objective has been to establish whether or not it is possible to describe very weak 1^- states within the QRPA framework using Skyrme III plus pairing interactions.

These early studies have been directed towards ^{156}Gd and ^{162}Dy in which recent observations [1] indicate the existence of such low-lying 1^- states lying in the 1.5-3.0 MeV energy region and possessing B(E1) strengths between $3 - 18.10^{-3}\ e^2fm^2$.

A feature of our initial investigations is that no such low energy states appear in the QRPA solutions when restricting the calculation to a small quasi-particle basis (2.10^4 q.p.). Only on enlarging the basis to include some (2.10^6 q.p.) do weak strength 1^- states emerge having energies lying in the energy region 1.8-3 MeV with B(E1) strengths of the same order of magnitude as those observed.

[1] A.Zilges et al., Z. Phys. **A340** (1991) 155

3.2.8 On the nature of collectivity associated with low energy $K = 1^+$ states

R.R. Hilton, W. Höhenberger, P. Ring

Since its original experimental identification well over 300 studies of the Giant Angle Dipole have been undertaken to date, testifying to the continuing interest in this state by the nuclear physics community.

We have now undertaken an exhaustive study of the Giant Angle Dipole for nuclei in the rare earth region using a self-consistent QRPA formalism employing various Skyrme forces. One of our aims during these extensive calculations has been to gain an understanding of the nature and extent of the collectivity to be expected from such a state. Some general aspects which emerged are of interest.

Investigation of states having the strongest M1 transition strengths in the $2 - 4$ MeV region revealed their B(M1) strength to be a sensitive function of the number of qp pairs, at first growing sharply with respect to the initial number of qp components allowed in the QRPA solution. However, on further increasing the number of qp pairs it was found that the strength fell substantially. Thus, restricting the QRPA solution in effect to a few qp structure, resulted in an artificially increased transition strength over the true value. In ^{156}Gd for example maximum strengths of over $3.3\mu_n^2$ were attained after as few as 8 qp pairs were allowed to contribute, finally settling to $1.7\mu_n^2$ for the full collective solution containing some 50 components. Overlaps with respect to both a contra-rotational as well as a GAD picture follow analagous patterns, with artificial high overlaps being attained for the few qp structure states. Invariably, the GAD overlap exceeded that of the scissors. The associated orbital to spin ratio varied markedly also.

We conclude that, contrary to a widely held belief, few qp states may indeed build up considerable transition strength enhancement due to favourable although fortuitous phase relationships amongst a few qp components. The true collective states, however, may show substantially less strength due to the coherent action of many small components which comprise the full QRPA solution and take on B(M1) values that appear, superficially, little greater than individual qp strengths.

3.2.9 On the coexistence of collective and single particle aspects of the giant angle dipole

R.R.Hilton

Collective vibrational modes of a deformed nucleus which appear naturally within a single particle model framework, rewritten so as to expose such coherent behaviour, are studied. A low energy collective excitation which may be identified with the Giant Angle Dipole (GAD) is investigated. Necessary and sufficient conditions for the model used to describe this state are given and shown to hold for a deformed oscillator system corresponding to a well-deformed heavy even-even nucleus. The inertial parameter, restoring force, and energy appropriate to this mode are obtained and the effects of long range correlations on the on these quantities are investigated. The consequences of using a picture of pure contra rotation for this state are discussed [1].

[1] Annals of Physics **214** (1992) 258

3.2.10 Shape coexistence and extreme deformations near A=80

J.P. Maharana, Y.K. Gambhir, J.A. Sheikh, and P. Ring

The neutron deficient Sr and Zr nuclei are sudied in the relativistic mean-field approach. Large deformations and shape coexistence are predicted for these nuclei in the vicinity of the proton drip line. The charge radii are found to increase with the removal of neutrons form the semimagic ^{88}Sr and ^{90}Zr, in close agreement with the recent isotopic shift measurements [1].

[1] Phys. Rev. **C46** (1992) R1163

3.2.11 Apparent quadratic deformation scaling of transition strengths in samarium isotopes

R.R.Hilton, W.Höhenberger and H.J.Mang

Recent experimental investigations of a sequence of Samarium isotopes report an apparent quadratic deformation dependence of the total B(M1) strength of low-lying 1^+ states. Considering these states as the fragmented distribution of a collective state, the angular analogue to the giant dipole, it is demonstrated that such a deformation dependence arises quite naturally when short range correlations and surface effects are taken into account. The role of such additional parameters in determining the variation of the total transition strength is discussed and a comparison with the picture of pure contra-rotation is made [1].

[1] Phys. Rev. **47** (1993) 602

3.2.12 Application of the angular momentum projection method to some even mass nuclei

K. Hara

Angular momentum projection method is an efficient way of carrying out shell model configuration mixing calculations for deformed nuclei. It has a great advantage over the standard (spherical) shell model: The dimension of the configuration space can be reduced drastically, so that shell model calculations become feasible even for heavy systems. We take an appropriate deformed basis (Nilsson) and upon it build a quasi-particle representation (BCS). The hierarchy of the (intrinsic) states is thus characterized by the energy and the number of quasi-particles. We project out thus obtained (multi-) quasi-particle states onto good angular momenta. This procedure corresponds to the transformation from the body-fixed system to a space-fixed system. The Hamiltonian is then diagonalized in this (many-body) basis for each spin. Interpretation of the results can be done by looking at a diagram in which the rotational energies (i.e. expectation values of the Hamiltonian) of various bands are plotted against spin. Band crossing is often observed in such a diagram. It is a purely quantum mechanical theory and provides us with reliable nuclear wavefunctions.

We have been applying this method for some years to doubly even, doubly odd and odd mass rare-earth nuclei using a Q·Q + Pairing + Quadrupole-Pairing force model[1]. We shall present some new results in this region on the BE2 calculations for doubly even nuclei as well as on the signature inversion in doubly odd nuclei. It will be shown that there are two alternative mechanisms which lead to the latter phenomenon, namely the one due to self-inversion within a given band and the other due to crossing of two bands which have mutually opposite signature dependence.

On the other hand, experimental data are accumulating for nuclei in the mass region A=130–140. It is therefore quite interesting to apply the same model to such systems. We shall report on a recent work done in collaboration with Gamma-Spectroscopy group in São Paulo and discuss their latest data on two (positive and negative parity) bands in the nucleus ^{138}Pr. Oblate deformation ($\epsilon \approx -0.16$) gives consistent results for both bands. A systematic analysis over neighboring doubly odd and odd mass nuclei indicates that transition from prolate to oblate shape takes place across the neutron number 77. Nuclei around this neutron numbber (N = 76, 77, 78) are most likely γ-deformed.

Abstract of an invited talk given at the 21st INS International Symposium on “Rapidly Rotating Nuclei”, Tokyo, October 26–30, 1992

[1] K. Hara, Y. Sun, Nucl. Phys. **A529** (1991) 445 (I. Doubly Even Nuclei);
Nucl. Phys. **A531** (1991) 221, (II. Doubly Odd Nuclei);
Nucl. Phys. **A537** (1992) 77 (III. Odd Mass Nuclei)

3.2.13 Studies of high-spin states in rare-earth nuclei using the angular momentum projection method. (III) Signature splitting in odd mass nuclei

K. Hara and Y. Sun

The problem of signature splitting in odd-mass rare-earth nuclei is investigated by using the angular momentum projection method. According to the present theory, the inversion of signature dependence observed in odd-proton nuclei is due to the crossing between a single-proton band ($h_{11/2}$) and a band consisting of a single-proton state ($\mathrm{h}_{9/2}$) coupled to a neutron broken-pair state ($i^2_{13/2}$). In odd-neutron nuclei, on the other hand, crossing between a single-neutron band ($i_{13/2}$) and a band consisting of a single-neutron state ($i_{13/2}$) coupled to a proton broken-pair state ($h^2_{11/2}$) state occurs at much higher spins because the proton broken-pair ($h^2_{11/2}$) is less decoupled compared to that of neutron ($i^2_{13/2}$). This explains the reason why two isobar nuclei like ^{165}Lu and ^{165}Yb show quite different spectra [1].

[1] Nucl. Phys. **A537** (1992) 77

3.2.14 Relativistic mean-field description of neutron-deficient platinum isotopes

M.M. Sharma and P. Ring

We have studied neutron-deficient even-mass platinum isotopes in the framework of the relativistic mean-field theory. The ground-state properties of nuclei have been calculated in the $\sigma\omega\rho$ model with the nonlinear scalar self-interaction of the σ-mesons. The charge radii, binding energies, and deformation properties have been obtained in the relativistic Hartree approximation with deformed basis. Solutions have been obtained for both the prolate as well as oblate shapes. A comparison of the calculated properties has been made with data from recent measurements on these nuclei performed at the ISOLDE project at CERN. It has been shown that the isotopic shift measurements reveal an oblate shape for all even platinum isotopes, in contrast with some existing theoretical calculations which indicate prolate shape for highly neutron-deficient isotopes [1].

[1] Phys. Rev. **D46** (1992) 1715

3.2.15 Finite temperature projected calculations in the static path approximation

R. Rossignoli, P. Ring, and N. Dang

Particle number projected calculations are examined within the context of the static path approximation. A different evaluation of the thermal average energy is also employed, which is seen to provide the correct behaviour at low temperature and is more appropriate for projected calculations. The evaluation of the energy level density is also discussed. Application to a pairing hamiltonian is made [1].

[1] Phys. Lett. **297B** (1992) 9

3.2.16 Recipe for the solution of the Dirac equation in the basis set expansion method.

Y.K. Gambhir and P. Ring

The problems arising due to the use of the finite basis set expansion method for the solution of the Dirac equation in the Relativistic Mean Field theory, are analysed, particularly the appearance of the "Spurious" states. A satisfactory prescription (or remedy) for the avoidance of these "Spurious" states is proposed. Illustrative results for this are presented. The proposesd prescription is critically analysed and it is shown to be consistent with that encountered for the spherical case in the molecular and atomic physics problems.

3.2.17 Projected statistics and level densities

R. Rossignoli, A. Ansari, and P. Ring

General exact projection formulae at finite temperature for one-body statistical operators with broken symmetries are derived and applied to the calculation of angular momentum projected average energies and level densities in the static path approximation. The method is illustrated for ^{20}Ne using a quadrupole interaction and compared with exact shell model results [1].

[1] Phys. Rev. Lett. **70** (1993) 1061

3.2.18 Lipkin-Nogami method at finite temperature in the static path approximation

N. Dinh Dang, P. Ring, and R. Rossignoli

An approximate particle number projection at finite temperature using the Lipkin - Nogami method in the context of the static-path approximation is proposed. The numerical evaluation, performed in a simple degenerate 2Ω-level model, shows that the present approach can improve the standard unprojected static-path approximation and is superior to the usual prescription based on classical thermodynamics [1].

[1] Phys. Rev. **C47** (1993) 606

3.2.19 Exotic nuclei in a relativistic mean field approach.

J.A. Sheikh and P. Ring

The neutron rich Zr-isotopes are studied in a relativistic mean field approach. A transition from spherical to strongly deformed shapes is obtained around $A \simeq 100$ and ground state deformations are found, which are in size close to superdeformed shapes. Furthermore very large radii are predicted in the vicinity of the neutron drip line due to the combined effects of deformation and neutron excess.

3.2.20 Relativistic extended Thomas-Fermi calculation with exchange term contributions

S. Haddad and M.K. Weigel

The selfconsistent relativistic Hartree-Fock nuclear problem is investigated using a standard one-boson-exchange (OBE) Lagrangian density and utilizing the Wigner-Kirkwood $\hbar$-expansion scheme in detail up to the second order. The selfconsistent extended Thomas-Fermi (ETF) and Thomas-Fermi-Fock (ETFF) problems are formulated and solved numerically. The results are discussed and compared with the results of other approximations and with experimental data (see Fig. 1). Furthermore, for the first time we have extracted and solved the integral equation for the tensor part of the density - corresponding to the nondiagonal part of the density matrix. It corresponds to a tensor type self-energy. The contribution of the tensor self-energy is rather small.

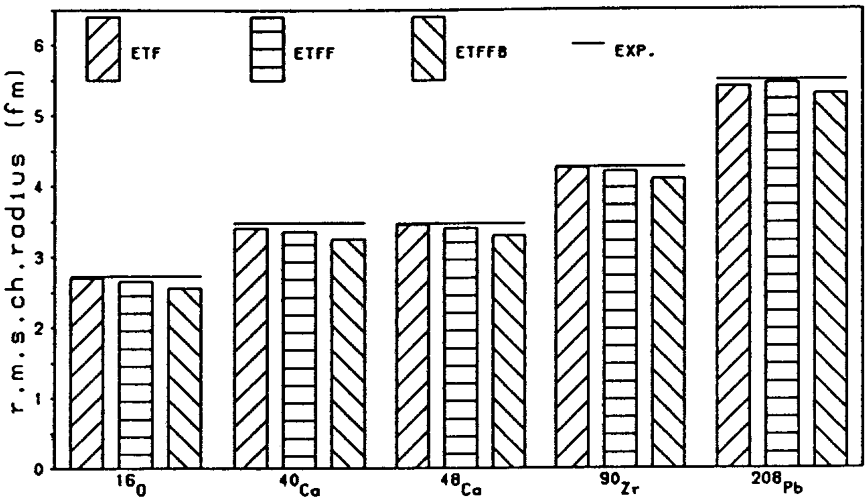

Fig. 1: Charge r.m.s. radii of closed shell nuclei in ETF, (corresponds to Relativistic Hartree), ETFF (corresponds to RHF) and ETFFB (RHF with Boussy approximation and Boussy parametrization) in comparison with experimental data. The other parameter sets are filled to properties of nuclear matter only.

Additionally we treated the Boussy interaction [1], in which the δ-like short-range part of the πN- and ρN-interaction is dropped in order to take partly two-particle correlations into account, which would suppress these short-range interaction [1]. However for the parameter set of Boussy et al., which needs a small σ-meson mass plus a small ratio $\frac{f_\rho}{g_\rho} = 3.7$ of the tensor vs. vector coupling the agreement with the data gets worse. The comparison with the wave function treatment for the Boussy interaction improves - as expected - with increasing mass number.

[1] A. Boussy et al., Phys. Rev. **C36** (1987) 380

3.2.21 An approach to the relativistic extended Thomas-Fermi expansion for Green's functions, phase-space densities and densities

D. Von-Eiff, S. Haddad and M.K. Weigel

Since the pioneering work of Wigner [1] semiclassical approaches have been applied with great success. Generally the advantage of the semiclassical approach is the avoidance of wave function calculations by utilizing densities, which in many cases makes the calculations easier.

In recent years much interest has been put toward describing the nucleus as a relativistic system [2] In this case one expects several complications due to the Dirac structure of the approach, which make the formalism more difficult than in the standard nonrelativistic theory.

In this contribution we present a pure algebraic method, which resembles the standard nonrelativistic scheme as described, for instance, by Grammaticos and Voros [3] It involves only straightforward but tedious algebraic methods and the residuum calcules.

The basic quantity for the semiclassical expansion is the Wigner transform of the one-particle propagator, defined as:

$$G(R,p) = \int d^4r \big(e^{\frac{ipr}{\hbar}}(-i)\times < N|T(\psi(R+\frac{r}{2})\bar{\psi}(R-\frac{r}{2}))|N >\big)$$

which obeys the Dyson equation in the mixed position-momentum representation. The relevant expansions of the G-functions, phase-space densities and densities are given by the following scheme:

$$G(\vec{R},p) = \hbar^4 \sum_{j=0}^{\infty} \hbar^j G^{(j)}(\vec{R},p),$$

$$n(\vec{R},\vec{p}) = \hbar^3 \sum_{j=0}^{\infty} \hbar^j \int \frac{dp_0}{2\pi i} e^{ip_0\eta} G^{(j)}(\vec{R},p),$$

$$n(\vec{R}) = \sum_{j=0}^{\infty} \hbar^j \int \frac{d^3p}{(2\pi)^3} n^{(j)}(\vec{R},\vec{p}).$$

These expansions are given explicitly up to second order in $\hbar$.

published in Phys. Rev. C **46**, 230 (1992).

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[2] L.S. Celenza and C.M. Shakin, "Relativistic Nuclear Physics", World Scientific, Singapore (1986).
[3] B. Grammaticos and A. Voros, Ann. Phys. (N.Y.) **123** (1979) 359 and **129** (1980) 153

3.2.22 Relativistic Thomas-Fermi calculations of finite nuclei including quantum corrections

D. Von-Eiff and M.K. Weigel

Relativistic Thomas–Fermi calculations including quantum corrections have been performed for a set of spherical nuclei. There are two kinds of quantum corrections up to the second order in $\hbar$. First the WK–corrections, which are supposed to improve the expectation values of one body operators compared with pure Thomas–Fermi calculations [1]. In this case we used a linear σ–ω model which reproduces the nuclear matter saturation point but yields a considerably too large nuclear matter incompressibility. The latter point causes a surface energy, which is too high within Thomas–Fermi calculations. Inclusion of WK–corrections significantly reduces the difference between the RTFA– and experimental value of the surface energy coefficient resulting in more realistic binding energies. This improvement within the RTFA–WK approximation is achieved by a better description of the nuclear surface through the consideration of the spatial dependence of the meson– and the electromagnetic fields and the possibility of a negative kinetic energy density in the surface region which characterizes the physics of the classical forbidden region.

The second kind of quantum corrections of the order $\hbar^2$ are exchange corrections. Here we also considered π–meson and tensor ϱ–nucleon contributions. This shifts the nuclear matter incompressibility to more reasonable values. In turn, we found the nuclear surface energy lowered by the exchange corrections by $\sim 14\%$, which yields stronger bindings and smaller charge r.m.s. radii compared with the RTFA approach. As a consequence, the bulk values of the charge–, particle– and kinetic energy densities are systematically higher within RTFA–EX calculations.

Within nuclear matter Hartree–Fock calculations, m_σ constitutes an adjustable parameter. We calculated a set of parameters with m_σ adjusted to get the experimental charge r.m.s. radius of ^{16}O and studied its influence on properties of nuclear matter and finite nuclei. While m_σ affects nuclear matter properties only slightly, it has significant influence on those of finite systems. With the σ–meson contribution representing almost the entire attractive part of the nuclear potential, m_σ determines its range. Hence we found that a lower m_σ yields larger r.m.s. radii, weaker bindings and lower bulk values of the various densities. The larger r.m.s. radii go along with a more diffuse fall–off in the surface regions of the densities we investigated.

Finally we calculated the spin–orbit interaction. We found that its strength decreases with both, the inclusion of exchange corrections and decreasing m_σ. The maximum value of the spin–orbit splitting we found within RTFA–EX calculations for a proton in ^{40}Ca is in good agreement with the experiment.

published in Phys. Rev. **C46** (1992) 1797

[1] D. Von-Eiff, S. Haddad and M.K. Weigel, Phys. Rev. **C46** (1992) 230

3.2.23 Relativistic Thomas-Fermi calculations of hot nuclei

D. Von-Eiff and M.K. Weigel

Relativistic thermal Thomas–Fermi equations have been derived on the basis of a quantum hadrodynamical Lagrangian. Beside the coupling of σ–, ω– and ϱ–mesons to the nucleon field, nonlinear σ–selfinteractions and the electromagnetic field were taken into account. To treat the continuum contributions correctly, we presented a subtraction mechanism based on the "equivalent sharp radii" of the density distributions [1].

For our calculations we have chosen a set of parameters from the literature [2] which fits accepted nuclear matter ground state data. We performed calculations for the ground state of ^{208}Pb and compared the results with Thomas–Fermi calculations of other authors, Hartree calculations and experimental data.

We then turned to the description of hot uncharged ^{208}Pb. First, we checked the independence of our results on the size of the box in which the calculations were performed and found them sufficiently reliable. By studying various thermostatic properties of the system we saw them not noticeably affected by the temperature up to T=5$\sim$7.5 MeV. At around T$\approx$13.25 MeV there exists a limiting temperature beyond which the total energy of the nucleus becomes positive. Further increase in temperature leads to systems which still possess a surface until the temperature reaches roughly the value of T_c from nuclear matter calculations. We investigated the various contributions to the binding energy, recovered the cancellation of the terms arising from the exchange of σ– and ω–mesons at different temperatures and found the expected growing importance of the kinetic energy with increasing temperature. In general our results are very similar to those of various nonrelativistic approaches [3].

Special attention was devoted to the level density parameter a. Therefore we performed calculations for a hot uncharged isosymmetric system with mass number A=160. Due to the lack of correlation effects our pure mean field model implies significantly smaller level densities than the experimentally extracted values at temperatures T<4.5 MeV. In the region 4.5 MeV$\leq$T$\leq$6 MeV our results are in good agreement with the available data and further improvement can be expected from the inclusion of the Coulomb field. For the high temperature region T>6 MeV we discussed the impact of the subtraction mechanism on the calculation of the level density and compared the results of our model with a different approach by other authors [4]. It turned out, that the subtraction procedure we used cannot provide an expected decrease of the level density at high temperatures, at which, on the other hand, the physical picture behind our model becomes in general more and more unrealistic.

published in Phys. Rev. **C46** (1992) 1288

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[2] M. Centelles et al., Nucl. Phys. **A 537** (1992) 486
[3] P. Bonche et al., Nucl. Phys. **A436** (1985) 265
[4] E. de Lima Medeiros and J. Randrup, Phys. Rev. **C45** (1992) 372

3.2.24 Relativistic mean–field calculations of Λ and Σ hypernuclei

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Relativistic mean–field calculations of Λ and Σ single–particle spectra in hypernuclei were performed. For this purpose an interaction that considers neutron-star masses, the Λ binding in saturated nuclear matter, and experimental Λ single-particle levels has been used. Concerning the Σ couplings we assumed an universal hyperon coupling; i.e. all hyperons in the lowest octet couple to the meson fields as the Λ. We employed the so-called expectation-value method whose reliability was found to be sufficient compared with fully self-consistent relativistic Hartree (RHA) calculations [1]. Analyzing the hypernuclear spectra, the spin-orbit potentials for hyperons and, in the case of Σ hypernuclei, the isospin dependence of the selfenergies were investigated. These two features are of particular interest in the current discussion concerning hyperon potentials in nuclei [2] and are naturally incorporated into the used relativistic quantum hadrodynamical model.

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3.2.25 Baryon chiral perturbation theory

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To understand the non-perturbative aspects of the nucleon is a fundamental challenge in particle physics. The most promising approach to gain insight into these topics is based on effective field theory methods, namely chiral perturbation theory with baryons. It allows to systematically impose the constraints from spontaneously broken chiral symmetry on the interaction of pions, nucleons and external fields, like e.g. the photon.

The scattering of low energy photons off protons and neutrons reveals important information on their electric and magnetic polarizabilities. Chiral perturbation theory to one loop order fixes completely the leading term in the quark mass expansion of these quantities. One finds $\alpha_p = alpha_n = 10\beta_p = 10\beta_n = 5e^2g_A^2/384\pi^2F^2m_\pi$, numbers which are in favorable agreement with experiment. A study of all next to leading order corrections is presently under way. At this order a large paramagnetic contribution from the $\Delta(1232)$ resonance comes in. The empirical information on $\beta_{p,n}$ tells, however, that this term must be largely cancelled by other terms contributing at the same order of the chiral expansion.

An other important process is photoproduction of neutral pions from protons close to threshold. Such experiments are performed at MAMI (Mainz). We have shown, that the so-called low energy theorem for the electric dipole amplitude E_{0+} derived in the seventies was incomplete. The pion loops contribute a new term at order m_pi^2. Its origin is an infrared singular behaviour of the loop diagrams in the chiral limit, which invalidates an assumption made earlier to derive the low energy theorem. Comparison between theory and experiment is, however, still hampered by the fact that next to leading order corrections like isospin breaking effects arising e.g. from the nonequality of the neutral and charged pion mass are quite sizable.

The nucleon as an extended particle possesses an axial root means square radius characterizing the distribution of spin and isospin. Two alternatives to measure this radius are neutrino scattering and pion electroproduction. We have shown that due to the presence of pion loops the axial mean square radii extracted from both reactions must differ by a finite amount of magnitude $3(\pi^2-12)/64\pi^2F^2$. This difference closes the discrepancies between the present neutrino and electroproduction data.

Applications of chiral perturbation theory to the s-wave πN scattering lengths (a^+, a^-), π^0 electroproduction close to threshold and hyperon electromagnetic polarizabilities have been studied.

3.2.26 Nonperturbative solutions to the Dyson-Schwinger equations of pure QCD

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The selfconsistent reproduction of nonperturbative power corrections to vertices was obtained. We used the operator product expansion to obtain an ansatz for the nonperturbative vertices of pure QCD. It could be shown that the Dyson-Schwinger equation for the ghost selfenergy is selfconsistently solved by them if the logarithmic renormalization group improvement is taken into account. We found that Ward-identities are satisfied, but that dimension four operators which are not BRS-invariant contribute to the operator product expansion of the vertices. This result can be interpreted as an indication that Goldstone Modes exist in the unphysical sector of the the theory [1, 2].

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