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Nuclear Theory Group

Progress Report
RESEARCH IN THEORETICAL NUCLEAR PHYSICS

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I. INTRODUCTION

Program and Principal Achievements of the Stony Brook Nuclear Theory Group During 1988–89

We shall organize the description of our many activities under the following broad headings:

A. Strong Interaction Physics:

- The physics of hadrons.
- QCD and the nucleus.
- QCD at finite temperature and high density.

B. Nuclear Astrophysics.

C. Nuclear Structure and Many–body Theory.

D. Heavy Ion Physics

While these are the main areas of activity of the Stony Brook group, they do not cover all activities. Progress in other fields will be described in the detailed description of work performed to be found below.

Strong Interaction Physics — The Physics of Hadrons

The Stony Brook "little bag" (or topological chiral bag) continues to provide a good description of the many phenomena which depend on nuclear substructure. Since the quark content of the nucleon has a small spatial extent (R roughly 0.5 fm), this models reproduces the kinds of cutoffs needed in semi–phenomenological models of the nucleon–nucleon interaction such as the Bonn potential.

In a deep sense, the chiral bag model has shown us that low–energy properties of baryons and their interactions are remarkably insensitive to the choice of R. This notion has been canonized as the "Cheshire Cat Principle".[1] Although there are no rigorous arguments that these properties are strictly independent of R, evidence continues to mount that the Cheshire Cat Principle is respected at the level of reliability of current calculation skills. However, in the spirit of R–matrix theory, some radii are more convenient to work with than others. In the case of the chiral bag model it is conventional (i) to treat the external meson fields classically and (ii) to neglect gluon effects or treat them perturbatively. The former approximation is valid when mesonic field gradients are small and the bag radius is large; the latter, in view of the running coupling constant of QCD, is valid when the bag radius is small. The best compromise seems to be $R \sim 0.5$ fm. (Although many low–energy properties show only "few percent" sensitivity over the range $0 < R < 1$ fm, some properties — such as the electrodisintegration of the deuteron [2] — are more easily described by $R \sim 0.5$ fm.) This radius corresponds to a chiral angle, $\theta(R)$, of $\pi/2$ which is particularly convenient since the baryon fractionates 50/50 with half lodged in the quark sector and the other half in the meson cloud. The topology guarantees that the total baryon number is, of course, 1.

For $\theta(R) = \pi/2$, the positive and negative energy quark spectra are CP symmetric which often simplifies the treatment of Casimir effects. More importantly, without gluonic corrections (which, as noted, should be small for small bags), g_A has its empirical value of 1.25. In our picture, the axial vector current plays an essential role. Continuity of this current at the bag boundary dictates how the meson cloud is joined (smoothly) to the quark core. The resulting shift of all quark levels in the Dirac sea leads a rich variety of Casimir effects which are essential in realizing the Cheshire Cat Principle (including its most basic result that the baryon number of the nucleon should be 1 independent of R.) Pion–nucleon coupling is also controlled by g_A. Evidently, it is essential to get g_A and the axial vector current right.

While Casimir effects are essential to a complete implementation of the chiral bag model, their evaluation leads to both technical and conceptual complications. The necessary mode sums are usually ultraviolet divergent. Previously, we adopted *ad hoc* prescriptions for obtaining finite results. While they had an appealing connection to the rigorous results of $(1+1)$–dimensional theories, justification was required. During the past year we have seen [3] that the inclusion of the effects of high–energy quark states outside the bag rigorously removes these divergences (as it does in QED) and leads to precisely the prescriptions adopted previously. We have also seen that the usual 'heat kernel' regulation of mode sums sometimes leads to unphysical results: Ward identities, valid term–by–term, are violated by the full sums. This difficulty can be avoided with the replacement of the energy–dependent heat kernel regulators by non-local 'point split' regulators.[3] These developments, together with our earlier realization that convergence rates can be improved dramatically (*i.e.*, by a factor of 10^3) with the introduction of 'Strutinsky' smearing procedures, have made Casimir calculations a far more practical and convenient element in chiral bag model calculations.

There has been a lot of excitement during the past year regarding the EMC experiments [4] which seem to show that very little of the spin of the proton is actually lodged in the quarks. Indeed, making the assumption that the polarization of the strange quark sea is small, Ashman *et al.* [4] found that

$$< S_z >_{u+d} = 0.068 \pm 0.047 \pm 0.103.$$

Under this assumption only $(14 \pm 9 \pm 21)\%$ of the proton spin is carried by the spin of the quarks. In the chiral bag model, the spin fractionates with the moment of inertia. The fraction of spin associated with the quarks is thus

$$\frac{< S_z >_{\text{quarks}}}{< S_z >_{\text{total}}} \sim \frac{\mathcal{I}_{\text{quarks}}}{\mathcal{I}_{\text{total}}}$$

where $\mathcal{I}$ is the moment of inertia. For chiral angle $\theta(R) = \pi/2$, it was earlier found [5] that this ratio is $\sim 1/7$ in remarkable agreement with experiment. On the basis of a similar analysis Dreiner, Ellis and Flores [6] have been led to claim that "recent EMC data on the quark spin content of the proton constrain R to be less than 0.5 fm."

We find, however, that the bag radius, like the Cheshire Cat, fades as we improve the implementation of the chiral bag model with the inclusion of gluonic effects in the bag interior. Contributions from the $E^a \cdot H^a$ term in the interior — essentially the axial anomaly — cancel most of the spin contribution to the singlet axial current (the quantity actually measured in the EMC experiments) as the bag radius grows.[7,8]

In work reported previously we stated our belief that larger bag radius (*e.g.*, $R \sim 1$ fm) would emerge naturally from the study of strange baryons. This is due to the weaker coupling of the meson cloud and the consequently smaller pressure on the bag. A reasonable phenomenology is found with this larger radius. Attempts to achieve a purely solitonic description of strange baryons through the straightforward extension of the $SU(2) \times SU(2)$ skyrmion to $SU(3) \times SU(3)$ were not successful. This is due to the large symmetry breaking caused by the substantial mass of the strange quark

$$m_s{}^{(0)} = 150 - 200 \text{ MeV}.$$

However, the suggestion of Callan and Klebanov [9] that strange baryons can be described by binding a kaon to the $SU(2) \times SU(2)$ skyrmion does provide an attractive and successful description.

In this scheme, strangeness is 'vibrational' and not 'rotational' (like isospin) and arises when a kaon binds to the $SU(2) \times SU(2)$ soliton. There is an associated transmutation of isospin into spin, generic in all topological systems, and the bound kaon behaves (at low energies) like a "bosonic" s quark (since the soliton core with $J = I$ integer or half integer must be quantized as a fermion).[10] An intriguing feature of this picture is that the apparent change of statistics of the kaon depends on the kinematics: It is bosonic at long wavelength and fermionic at short wavelength (*i.e.*, the s

quark in perturbative QCD.) This feature is expected to have interesting consequences on low-energy properties of strange matter. The description of the Λ magnetic moment, for instance, differs drastically from the naive quark model. Implications of this structure on hypernuclear systems have not been investigated. Such investigations are planned for the future.

One clear prediction of the model [11] is that the $\bar{s}s$ content of the proton is small, typically less than 2%. The reason is very simple. The kaon binds to the soliton *via* a topological term known as the Wess–Zumino term and not through an attractive potential. Therefore, there is very little 'ground state correlation' of the type familiar from nuclear physics. As a consequence, the proton remains a remarkably pure up– and down–quark system. A natural consequence is that

$$< p|\bar{s}\gamma_\mu\gamma_5 s|p >\sim 0,$$

so that strange quarks are found to play no significant role in the "proton spin puzzle." This leads naturally to the chiral bag model resolution mentioned above.

The bound kaon–skyrmion description also makes an important prediction for hadronic matter at high density. The topological binding responsible for the kaon interaction implies that at high density, most probably at the chiral phase transition point, parity doubling occurs. (*I.e.*, the $\Lambda^*(1405)$ becomes degenerate with the Λ.) This also implies that, within the context of the chiral bag model, strangeness physics should not depend on the confinement radius once it is formulated with the Callan–Klebanov skyrmion. The Cheshire Cat strikes again!

Strong Interaction Physics — QCD and the Nucleus

Most of nuclear physics is carried out at momenta less than the chiral symmetry breaking scale, $\Lambda_{\chi SB} \sim 1$ GeV. Therefore, we work in the Nambu–Goldstone or broken symmetry mode. Nucleons and mesons are the variables appropriate for this mode. Of course, it is interesting to try to find specific evidence for the presence of quarks. (For example, in last year's report, we pointed out that the large tensor coupling of the ρ–meson to the nucleon, roughly twice the vector dominance value, can be understood in a chiral bag model in which roughly half of the baryon number is in the quark sector.) Nonetheless, such specific indications of quark presence in nucleons or nuclei at low momenta are difficult to find. Very possibly, in accord with the Cheshire Cat Principle, even these can probably be explained or described in the language of mesons and nucleons.

Chiral symmetry, in the absence of current quark masses, is a symmetry of the underlying Yang–Mills equations. The primary nuclear consequences of QCD come from chiral symmetry as expressed in meson and nucleon variables. For example, the $\vec{\pi}$ and σ fields form a four–vector. With increasing density, nuclear systems restore chiral symmetry, the σ and $\vec{\pi}$ fields becoming equivalent, and their masses must be the same, at least in the limit of zero current quark masses. Our assumption was that, with increasing density, the σ mass decreased smoothly towards the pion mass. In fact, it need not do so,[12] although ultimately, with chiral symmetry restoration, it must become equal to the pion mass.

The effective scalar attraction in nuclear physics comes from correlated two–pion exchange and not directly from the exchange of the fundamental scalar meson of the σ–model. The latter does play an important role in that scattering of pions through the elementary σ serves to correlate them. It is well–known that g_A is a function of density changing from $g_A = 1.26$ at zero density to 1 when chiral symmetry is restored. For many years it has been common [13,14] to explain this change with specific medium-dependent effects. For example, g_A can couple through virtual Δ–isobars. We have been using similar medium dependence for the mesons, clothing virtual pions with isobar–hole configurations.

In last year's report we described this medium dependence which leads to a decrease (with increasing density) of the mass of the low-energy effective scalar particle, made up of correlated two pion systems. Although chiral symmetry can be incorporated for long-wavelength phenomena through the Nambu–Jona–Lasinio, this formalism requires a momentum cutoff which is not much higher than the vector meson mass. Unfortunately, results for phenomena involving vector mesons often depended quadratically on this cutoff. As a result, calculations with the Nambu–Jona–Lasinio model are not satisfactory.

Vector mesons have been incorporated as gauge particles of a hidden symmetry [15] which is found in the implementation of Weinberg's program of realizing chiral symmetry locally in the Nambu–Goldstone sector. This gives a satisfactory description of vector mesons, well-suited for nuclear physics. It describes vector mesons as being primarily pion cloud. The resonance necessary for actual vector meson formation results from attraction at a higher mass scale (which has been integrated out). Through these developments, the long-wavelength description in terms of pions is boosted to the mass scale of the vector mesons (and beyond) in a chirally invariant manner. Inclusion of vector mesons [16] may give a description which, even at scales well above $\Lambda_{\chi SB}$, is nearly complete, *i.e.*, has very little correction from high energy perturbative processes. In any case, the procedure of joining perturbative and non-perturbative descriptions is greatly smoothed.

In practice, this description of the ρ–meson is an improved version of the old dispersion theoretic one of Amati, Leader and Vitale,[17] in which the meson cloud aspect was primary, the core (now understood as a quark core) simply serving to rescatter the pions. The extension of this argument to the ω–meson is more complicated, but we believe that the ω can also be considered chiefly as meson cloud for the purposes of nuclear physics.

If the (changed) properties of pions in medium change the mass of the σ–meson, they should also change the mass of ρ– and ω–mesons. We argue that, at least to rough approximation,

$$\lambda(\rho) = \frac{m_N^*(\rho)}{m_N} \sim \frac{m_\sigma^*(\rho)}{m_\sigma} \sim \frac{m_\rho^*(\rho)}{m_\rho} \sim \frac{m_\omega^*(\rho)}{m_\omega}.$$

In other words, there is only one scale, $\lambda(\rho)$.

In the abstracts of this year's report and last year's report, these density-dependent meson masses are seen to explain many nuclear phenomena. Perhaps most surprising is that the $\sim 50\%$ correction they give in the scalar and vector mean fields near the equilibrium density of nuclear matter is easily accommodated by phenomenology. (See Brown, Sethi and Hintz below.)

If all masses scale like $\lambda(\rho)$, the Hamiltonian can be transformed to

$$H(m_i^*, r) = \lambda(\rho) H(m_i, x)$$

where $x = \lambda r$ and m_i^* are the effective nucleon and meson masses and m_i the corresponding bare masses. To the extent this is so, it will be useful in converting the theory in terms of nucleons and mesons into an effective theory of QCD.

We have also considered modifications of the properties of baryons in dense matter using the Skyrme model. There are a number of indications that this model also leads to the restoration of chiral symmetry at sufficiently high baryon densities. Using current algebra results, one can show that the pion decay constant in medium is the average value of the scalar field, $<\sigma>$. The Skyrme model indicates that this order parameter, which has the expected value of f_π at zero density, vanishes rigorously above some critical density. A vanishing pion decay constant is, of course, a hallmark of chiral symmetry restoration. Other evidence is consistent. At this same density both the strange and non-strange spectra of baryon resonances indicate a parity doubling. Below this density, a triplet of Goldstone bosons (*i.e.*, pions) emerge as chiral symmetry is broken spontaneously. The ability of the Skyrme model to mimic (if not model) chiral symmetry restoration represents another extension of the Cheshire Cat Principle, and provides another indication that it may be very difficult to find unambiguous signatures of a quark/gluon plasma in relativistic heavy ion collisions.

Strong Interaction Physics —
QCD at Finite Temperature and High Density

An important problem in strong interaction physics at finite temperatures is to find a first–principles understanding of chiral symmetry breaking. Lattice regularization of QCD based on Monte–Carlo simulations provides an important non–perturbative framework for understanding this question. However, analytic methods are also necessary to understand the physical mechanisms behind these non–perturbative effects. Almost all analytic approaches have been based on the assumption that the perturbative vacuum is unstable in the infrared. The Savvidy–Copenhagen vacuum,[18,19] the monopole vacuum,[20] the glueball condensate vacuum,[21] and the instanton vacuum [22] are such examples.

A qualitative description of the instanton vacuum based on the dilute gas approximation yields most of the nonperturbative aspects of strong interaction physics.[22] Quantitatively, however, the dilute gas approximation is known to be plagued with infrared divergences. Instantons tend to inflate causing most observables to diverge in the infrared.

Recently Dyakonov and Petrov [22,23] pointed out that the infrared problem is inherent to the dilute gas approximation. They suggested that instanton–anti-instanton interactions in the vacuum provide an overall repulsion which stabilizes the vacuum in a phase resembling a quantum liquid of instantons and anti–instantons. Using qualitative arguments, they showed that the random character of the instantons in the vacuum leads to a delocalization of the 't Hooft zero modes and the spontaneous breakdown of chiral symmetry.

More recently Shuryak [24,25] and a group at Stony Brook [26] have carried out detailed numerical simulations in the instanton liquid approximation to assess quantitatively the relevance of instantons to the spontaneous breakdown of chiral symmetry in the QCD ground state. At high instanton density the vacuum state exhibits the characteristics of a liquid phase of instantons and anti–instantons in which chiral symmetry is spontaneously broken. At low instanton densities, the QCD ground state is composed of a molecular gas of instantons and anti–instantons. This phase lacks flavour coherence, and chiral symmetry is restored. The spontaneous breakdown of chiral symmetry in the instanton liquid phase is reminiscent of the metal–insulator transition (*i.e.*, the Mott transition) in solids.

We have investigated the effects of the large strange quark mass on the up and down constituent quark masses at high and low instanton densities. Our results indicate a weak strangeness mixing due to instantons in the liquid phase. This result implies no strangeness admixture *via* instantons in the nucleon state at zero momentum transfer. (See above.)

In the long–wavelength approximation and with suitable coarse graining, the instanton liquid can be described by an effective Lagrangian that is consistent with the generic effective Lagrangians derived from large N_c arguments (see for example refs.[27,28]). To leading order, the long–wavelength pseudoscalar mesons decouple from the heavier (scalar and pseudoscalar) glueballs. The role of the scalar glueballs is played by the density of instantons in the liquid phase, and the the role of the pseudoscalar glueballs by the variance of the topological charge. Our effective Lagrangian satisfies both the chiral anomaly and the scale anomaly. The latter is directly related to the compressibility of the instanton liquid.

Using generalized bosonization techniques we have investigated the bulk properties of pseudoscalar mesons in the instanton liquid phase. In particular, we have shown that in the chiral limit π's, K's, and η's are Goldstone modes, while the η' is heavy due to the explicit breaking of the $U_A(1)$ anomaly *via* instantons. In the presence of current quark masses, the bulk parameters of the liquid state yield a pseudoscalar nonet in good agreement with the data.

We are currently investigating baryon–baryon correlators in real time. Our purpose is to study the properties of baryons in the instanton liquid state.

Motivated by the 'phase transitions' seen in systems of cold skyrmions, we are involved in a number of projects using a variety of techniques aimed at describing the properties (particularly, phase transitions) of hot skyrmions. These include the determination of temperature–dependent coupling constants in the Skyrme model through the evaluation of (temperature dependent) one–loop quantum corrections. (See Adami and Zahed below.) The recent conjecture by Atiyah and Manton [29] that skyrmion field configurations can be derived from instanton configurations in four–dimensional Euclidean space suggests another approach to this problem through the construction of temperature–dependent instantons (calorons) and their skyrmion analogues. Results of Nowak and Zahed (see below) indicate a generic 'swelling' of nucleons which is a precursor to chiral symmetry restoration. Finally, we are considering this problem at the semiclassical (mean field) level by constructing the skyrmion configuration and its normal modes as a function of the order parameter, $< \sigma >$, and minimizing the free energy with respect to this parameter. (See Jackson and Weiss below.) As the temperature is increased (at fixed baryon density), $< \sigma >$ is reduced and vanishes above some critical temperature. As noted above, this can be regarded as an indicator of chiral symmetry restoration.

As always, skyrmion (*i.e.*, pure effective Lagrangian) results can be regarded as indicative of more general chiral bag model results for the special case of a bag of radius zero. While it can be argued that lattice gauge calculations are more 'fundamental', progress in this direction is extremely slow and we are many years away from reliable calculations which will have anything useful to say about RHIC physics. Chiral bag model calculations are far easier to perform. As we have taken pains to indicate, the chiral bag model embodies much of the content of QCD relevant for nuclear physics (even at high temperatures and densities). We anticipate that this model will have considerable utility in applications to RHIC physics, and we continue to make progress in this direction.

Nuclear Astrophysics

The supernova SN 1987A on 23 February 1987 has been the major astronomical event of this century. Coming, as it did, after a decade of our work on the theory of supernovae, it fell nicely into our program! Although SN 1987A followed the general scenario laid out by astrophysicists (see the article by Brown and Bethe, *Scientific American* May 1985), it produced lots of surprises. The presupernova star first evolved to a red giant and then to the blue before exploding. This happens in the evolution only when semiconvection — which we earlier argued should not be put in — is turned off.

In earlier work we found that energetic explosions can be produced only if the nuclear equation of state is soft at supranuclear densities, thus facilitating the infall of the collapsing core to high densities. With improved neutrino transport, inclusion of μ and τ neutrinos, and, especially, neutrino–electron down–scattering, which degrades energies of neutrinos allowing them to escape, we no longer produce prompt explosions — our previous pride and joy.

Work by Bethe and Pizzochero (described below) shows in a nearly model–independent way that the energy of the SN 1987A explosion was greater than 1 foe (1 foe equals 10^{51} ergs). Woosley,[30] in fitting the empirical light curve, obtains 1.4 foe. At the moment, no mechanism other than our prompt mechanism can produce such a large energy.

Since we believe the physics that we have included in the collapse calculation is correct, we are looking into the evolution of presupernova cores. We believe that the cores obtained by Weaver and Woosley (as a result of burning large stars numerically) may be too big. At the moment they are some $1.35M_\odot$ for the $18M_\odot$ star suggested as the progenitor of SN 1987A. Bruenn [31] has shown that if the core mass is brought below $\sim 1.10M_\odot$ and if the entropy in the core is low, it may be possible to explode it by the prompt mechanism.

We are engaged in a study to determine how small the core can be. With the (again) smaller $^{12}C(\alpha,\gamma)^{16}O$ capture rate determined by Cal Tech coincidence experiments, silicon core burning proceeds out to substantially larger mass points than with the fat capture rate used for some years. (See below.) It may be possible that the core collapses after silicon core burning rather than adding additional mass through shell burning. This will cut down the mass of the core.

Our chief discovery in studying the evolution of the star is that the electron capture employed is inadequate. Fuller and collaborators [32] furnished Weaver, Pinto and Woosley [32A] with electron capture matrix elements only up to $A = 60$. Yet, when the core goes neutron rich, the average atomic weight moves higher than this. In the evolutionary calculations, the electron capture essentially runs out when Z/A reaches 0.43–0.42, which is sufficiently neutron rich that the abundance of ^{60}Co (with $Z/A = 0.45$) runs out. For $Z/A \sim 0.43$ the reaction $^{60}\text{Co} + e^- \rightarrow {}^{60}\text{Fe}$ gives more than half of the total capture.

We have made shell model calculations of the beta decay of ^{62}Co and ^{64}Co. The matrix element of the former can be determined by detailed balance from the β–decay of ^{62}Fe. We find the rate to be two to three orders of magnitude larger than used in the Weaver–Woosley evolutionary program. We also find large matrix elements in the Cu isotopes not included by Weaver and Woosley. There are many large β–decays which are not included in present evolutionary programs. The β–decay of ^{64}Co has a 0.3 second half-life, extremely short compared to the $\sim 10^6$ second Kelvin–Helmholtz contraction time of the core following silicon burning. The Q value of this β–decay is 7.3 MeV, essentially the entire thermal energy of a typical nucleus. Consequently, when Z/A comes down to ~ 0.45 where there begin to be significant abundances of ^{64}Co, this β–decay will cool the central core to about half the temperature in the cores of present evolutionary calculations. (The β–decays of ^{70}Cu and ^{62}Co are also fast and energetic. These should be included.) This will shut down the abundances of odd–odd nuclei favorable for electron capture, so it is not likely that Y_e will drop further. However, thermal effects increase the Chandrasekkar mass, essentially the core mass, by about 20%, so that with half of the temperature this may be only about 5%.

M. Aufderheide will put these new electron capture and beta decay rates into the Weaver–Woosley evolutionary code which is presently being rewritten since the machine it was written for has been dismantled. We will not be able to see quantitatively until autumn or winter what the new rates do, but it is clear that they will have a major effect.

Astronomers have used the black–body curve to make bolometric corrections to the light curve of SN 1987A, necessary to determine the total energy of the explosion. The empirical light curve is significantly blue–shifted from blackbody, because long wavelength light is more strongly absorbed. Working out the radiative transport in detail corrects the early–time light curve by about one–half magnitude, bringing it into much better agreement with Woosley's [30] model 10H. Using similar techniques, R. Wagoner of Stanford brings the distance to SN 1987A from 50 kpc down to 43 kpc, giving a 30% lowering of the luminosity of the progenitor. The latter may be closer to $15M_\odot$ than to $18M_\odot$, which would somewhat reduce the mass of the core.

The developments sketched above will lead to smaller cores, but it is not clear that they will be small enough for us to explode with sufficient energy. In any case, the physics entering into stellar evolution can be greatly improved, and we are strongly involved in this task.

Many of the observed properties of neutron stars are determined by the equation of state (EOS) of dense matter. The relationship between the maximum neutron–star mass, M_{max}, and observable parameters of the EOS has bearing on other issues as well. The EOS must be consistent with those inferred from the analysis of giant resonances in laboratory nuclei. It must also correspond to what is obtained in the studies of particle multiplicities and the matter, momentum and energy flows in heavy–ion collisions.

Prakash, Lattimer and Ainsworth [33] explored the roles of the nuclear incompressibility K_0 and the symmetry energy on the maximum neutron-star mass. For realistic symmetry energies, the relationship of M_{max} to K_0 is extremely model–dependent. The compression modulus of symmetric nuclear matter by itself does not provide a model–independent basis for constraining the structure of neutron stars. This is because the high–density EOS is uncertain and there is no unique way to link the high–density EOS to properties of matter around the empirical saturation density.

The study of compact stellar objects in rapid rotation offers some promise in this direction. The recent report [34] of a 0.5 ms pulsar in SN 1987A is particularly interesting. Including effects of general relativity, the maximum rotational frequency of a neutron star (*i.e.*, approximately the Keplerian frequency) is well approximated by [35]

$$\Omega_{max} \cong 7.7 \cdot 10^3 \left(\frac{M_{max}}{M_\odot}\right)^{1/3} \left(\frac{10\,\mathrm{km}}{R_{max}}\right)^{2/3} \mathrm{s}^{-1}$$

where M_{max} and R_{max} are the maximum mass and the radius of the maximum mass star in the non–rotating configuration, respectively. To be consistent with the $12.36 \cdot 10^3$ s^{-1} of the recent observation, a $1.4M_\odot$ star needs a radius of 8.16 km.

Calculations of Lattimer, Masak and Prakash (see below) suggest that sub–millisecond pulsation can be a result of uniform rotation only if the EOS is very soft close to nuclear densities (this assures rapid enough rotation) but very stiff–approaching the causal limit–for supra–nuclear densities (to have sufficient mass, say 1.4 $M_\odot$). Possible phase transitions from nucleonic degrees of freedom to those of quarks, strange matter *et cetera* soften the EOS for high densities and therefore are inconsistent with sub–millisecond rotational periods. Phase transitions to parity doublet matter [36] soften the EOS around nuclear densities but retain the causal behavior at very high densities.

Work on modelling stellar collapse continues to be an important activity of our group. In the last year, the three major groups studying the prompt explosion mechanism have reached detailed agreement on the simulations. This has been achieved to a great extent by the incorporation of the equation of state developed by Cooperstein and Baron by the two other groups (S. Bruenn, and E. Myra and S. Bludman). This equation of state is in analytic form and is numerically very fast while incorporating the major physics of the problem and allowing for uncertain input parameters to be varied.

With the incorporation of full neutrino transport of all flavors and neutrino–electron scattering, current initial models do not explode. In an effort to define the boundaries of what size core with proper structure can explode we have again taken to manufacturing our own cores. With the most conservative input physics even cores as small as $1.1M_\odot$ do not explode. It is important to study whether smaller cores are possible and the extent that the input physics must be altered in order to explode such cores.

One of the main reasons that make Type II supernovae interesting objects of study is that they are the major production site for most of the heavy elements in the universe. We have begun a program to study the nucleosynthesis of heavy elements in Type II's. Lacking realistic explosion models, it is necessary to parameterize the shock wave as it leaves the iron core and traverses the mantle and envelope of the star. It is crucial to examine the effects of different shock parametrizations upon the nucleosynthetic yields. We are also interested to study whether the R-process is active at the edge of the iron core. This is the leading candidate for the R–process site.

Observations of SN 1987A will continue to provide us with new and fascinating data for decades. Not the least of this will be the early cooling curve of a newly born neutron star. We have developed a stellar evolution code in order to study neutron star cooling. In particular we are able to study "exotic" cooling methods such as quark cores, kaon condensation, and strange stars. We have used a variety of equations of state and have compared to the four well-observed neutron stars. It seems clear that in order to fit the data, superfluidity is required. The three hot, young neutron stars do not appear to have any exotica in their cores. In order to fit the Vela pulsar, however, it seems necessary to include an exotic coolant, which one depending on the details of the superfluid gap. The difference between Vela and the young pulsars is then presumably one of total mass, Vela having a higher density core where condensation occurs.

Nuclear Structure and the Nuclear Many–Body Problem

We remain convinced of the inadequacy of the traditional (*i.e.*, Brueckner–Hartree–Fock) approach to the nuclear many-body problem. While this approach (correctly) recognizes the importance of a careful treatment of short–range correlations in any strongly–interacting quantum fluid, it seriously underestimates the importance of a correct treatment of the long–wavelength, low–energy excitations of the system crucial for a correct estimate of either ground state properties or the effective interaction so important for the calculation of the properties of low–energy excitations. Such conventional treatments often provide results which are even qualitatively incorrect. Thus, we have a long–standing interest in the development of a more satisfactory formulation of the many–body problem. These efforts include the 'parquet approach' (of Jackson and co–workers [37]) and the 'generalized ring diagram' approach developed by Kuo. (Differences between these approaches are more of language than of content; each emphasizes the importance of a non–perturbative approach to long–wavelength excitations.)

During the past year we have performed some finite–temperature nuclear structure calculations. Using realistic G–matrix interactions derived from the Paris and Bonn potentials, we have calculated the effects of RPA ring–diagram correlations on the nuclear lever density parameter. A relatively convenient formalism has been derived to carry out this calculation in which the thermal energy is calculated using finite–temperature RPA eigenvalues and the corresponding Bose–Einstein distribution functions. Both the particle–particle/hole–hole and the particle–hole ring diagrams have been included; the former seems to be more important. The correlation effect on the level density parameter appears to be important only at low temperatures (approximately $\leq$ 10 MeV). This is consistent with a recent schematic calculation.[38] Our results are being compared with empirical values extracted from heavy–ion reactions.

During the last year we have completed nuclear matter EOS calculations where the particle–particle/hole–hole ring diagrams are included to all orders. Several interesting features have been observed. An intermediate step of such calculations is the solution of a finite–temperature

RPA equation. And this equation is found to have complex eigenvalues in a restricted low–density and low–temperature region. This occurrence of complex eigenvalues appears to be associated with the liquid–gas phase transition in nuclear matter. (This point has been emphasized previously using the parquet theory.) We are carrying out further studies to extend this formalism to calculate the specific heat and critical exponents of nuclear matter. So far we have found that the compression modulus given by our ring–diagram EOS ($\sim$ 150 MeV) is softer than the value usually obtained from BHF calculations. This is consistent with our intuition regarding these long–wavelength modes.

A long–standing difficulty in finite–temperature many–body theory is how to make the approximations "conserving". We have made some progress towards resolving this difficulty. In practice one must calculate various thermodynamic quantities such as the thermodynamic potential, Ω, with some suitable approximations. Unfortunately, such approximate thermodynamic quantities frequently fail to satisfy fundamental thermodynamic relations. For example, the well–known relation

$$pV = -\Omega$$

may no longer hold if the quantities have been calculated with a non–conserving approximation. We have found that this difficulty can be overcome by choosing an appropriately constructed single–particle potential, U. The essential point is that U must be chosen in strict accordance with the approximation used in constructing Ω. We have obtained a prescription for doing this. We have shown that a number of basic thermodynamic relations are rigorously fulfilled when such a U is employed.

Heavy Ion Physics

Extracting information about the nuclear equation of state (EOS) has been a major goal of intermediate energy heavy–ion collisions (below 2 GeV/nucleon lab energy). Of the several observables suggested to obtain limits on the nuclear incompressibility, measurements of transverse momenta [39] have raised much optimism. Other complementary observables are flow angles,[40] and azimuthal distributions about the reaction plane.[41] It is hoped that mass transport properties can be directly related to the nuclear EOS.

Theoretical analyses of heavy–ion experiments in the above energy range currently employ Boltzmann–type kinetic equations that include effects due to both hard collisions and soft interactions at a semiclassical level. In–medium scattering cross–sections and mean fields that depend on both the density and the momentum that a nucleon has with respect to the medium, serve as inputs in such a study. For both of these inputs, simple parametrizations that mimic results of more microscopic calculations are employed in a detailed study. Our work in this area has served to clarify the really significant issues.

Questions concerning the accuracy of the numerical methods used in the simulation of the Boltzmann–type kinetic equation were addressed by Welke, Malfliet, Gregoire, Prakash and Suraud,[42] by choosing a specific form of the collision integral with the intent to provide checks with exact solutions of a "homework" problem (*i.e.*, Krook–Wu model). This work allowed the assessment of the relative merits of various simulation procedures used in the literature.

The issue of magnitudes of transverse momenta and their origin was addressed in the work of Gale, Welke, Prakash, Lee and Das Gupta.[43] A good fraction of the final average transverse momenta is generated quite early in the time history of a collision where thermalization has not been achieved. Thus the traditional EOS variables (*e.g.*, pressure) cannot account for the observed magnitudes of the transverse momenta.

Both mean field and hard collisions cooperate in producing transverse momenta and both are important. The mean field by itself can produce a certain amount of transverse momenta and the sign as well as the magnitude depends on the assumed form of the mean field. A momentum independent mean field that leads to a soft EOS ($K_0 = 215$ MeV) produces small negative transverse momenta while a mean field that gives a hard EOS ($K_0 = 380$ MeV) produces a small but positive transverse momenta. Inclusion of momentum dependence in the mean field, which is required by empirical optical potential data of a nucleon in a medium, leads to positive transverse momenta that are significantly larger than those given by a mean field without momentum dependence. In conjunction with hard collisions a momentum dependent mean field that gives a soft EOS ($K_0 = 215$ MeV) is able to reproduce the Streamer Chamber data. It is satisfying that the mean fields required to explain the data are rather close to those calculated using microscopic theories of nuclear matter.

There is much current interest in heavy–ion collisions at ultra–relativistic energies as the initial high density matter produced in such collisions may be in a quark–gluon phase. It is important to learn whether the resulting hadrons can be used to deduce the original state of the system and whether dense matter, indeed, undergoes a phase transition. Telltale signatures may be hard to find, and it is essential for experiment and theory to work hand in hand.

From the published results of the first round of experiments at CERN (O and S beams of $p_{lab}/A = 200$ Gev/c) and at Brookhaven National Laboratory (O and Si beams of $p_{lab}/A \sim 20$ Gev/c), we now have detailed information on distributions of the transverse energy, the pion rapidity and the transverse momenta of the produced secondaries. Reliable interferometry data are not yet available. Theoretical understanding of these data must include approaches which involve only hadronic degrees of freedom before one can assert that a quark–gluon plasma has been formed. For example, J/ψ suppression has been regarded as a confirmation of quark–gluon formation. Vogt, Prakash, Koch and Hansson have shown that inelastic scatterings of the J/ψ with co–moving secondaries also leads to suppression. The transverse momentum dependence of the suppression from scatterings with the secondaries is weak but, inclusion of initial state scatterings of gluons producing the J/ψ accounts for most of the momentum dependence seen in the experiment. This work also brought to attention the need for a quantitative understanding of the J/ψ–hadron absorption cross sections.

Vogt and Gavin have undertaken a systematic investigation in an effort to place limits on J/ψ–hadron cross sections by studying the transverse energy and mass number dependence of J/ψ's produced in proton and pion induced reactions on nuclei performed at the Fermi lab. They find that the cross sections required to reproduce the proton–nucleus data are significantly larger than given by traditional approaches, a finding which is in line with current ideas about color transparency. They also find that the same cross sections that fit the proton–nucleus data also fit the nucleus–nucleus data.

Using J/ψ production in heavy–ion collisions as a probe of the plasma is beset with ambiguities as this resonance is easily destroyed in such a 'hostile' environment. This point is clearly brought out not only by considering inelastic scatterings with hadrons but also by considering the magnitude of electric fields in the surrounding environment. Charmonium bound states are easily ripped apart by field strengths comparable to the QCD string tension in much the same way as hydrogen atoms in strong electric fields (see the work of Adami, Prakash and Zahed). This and other related work underscores the point that current understanding of J/ψ production is such that many view points are able to claim success.

The bulk of the secondaries produced in the CERN experiments is in the form of pions. A theoretical description of the rapidity and the transverse momentum spectra of these charged secondaries allows for an understanding of the dynamics of the collision process. An economical description of these features may be found in the Landau hydrodynamic model which predicts gaussian shaped rapidity distributions as found in experiments. For the model description to be valid one requires the production of a large number of secondaries and significant stopping of the projectile nucleus. The CERN and Brookhaven experiments give considerable support for use of the Landau model. For example, Venugopalan and Prakash find that they can give a good account of the transverse momentum spectra once transverse flow effects are incorporated in the model. They also find a striking anti–correlation between the break–up temperature and the transverse hydrodynamic velocity in fits of the Landau–Milekhin model to the transverse momentum spectra. These fits indicate that one cannot uniquely determine the break–up temperature without a better understanding of transverse flow in ultra–relativistic nuclear collisions. Efforts are under way to devise means that can isolate the transverse flow effects from the break–up temperature.

As noted above, there is increasing evidence that meson masses drop from their free–space values with increasing density and/or temperature. The large entropy mismatch found in naive models of hadron to quark–gluon phase transition is essentially due to fact that, even at the critical temperature, the hadronic phase is usually described as a gas of free pions. If meson masses drop in medium, there will be a corresponding decrease in the entropy mismatch between the two phases. This will have a direct consequence on the nature of the phase transition — making a strong first–order transition weaker or even changing its order. We are currently studying such questions.

At higher energies (200 – 800 Gev/A) we have continued the phenomenological study of transverse energy, E_T production in proton–nucleus and nucleus–nucleus collisions. Our aim is to understand the content of recent data from FERMILAB and from the HELIOS collaboration. Our basic approach is that of ref.[44] which assumes that E_T production involves a sequence of uncorrelated NN collisions and no dramatic new physics. We considered the effects of the correlations implied by the Pauli Principle and by short–range repulsion in the NN interaction and found them to be small.[45] Of greater importance, we have shown that the totality of E_T data in pA collisions — from $A = 1$ to $A = 208$ — can be described simultaneously if one allows for degradation of the primary proton. The resulting 30% fits are impressive since the data spans more than eight decades. This work has re–enforced our conviction that E_T production data does not reveal signs of a quark/gluon plasma.

REFERENCES

[1] For summary and references, G.E. Brown and Mannque Rho, Comments Nucl. Part. Phys. **18** (1988) 1.
[2] J.F. Mathiot, Phys.Rep., **173** (1989) 63.
[3] A.D. Jackson and L. Vepstas, *Justifying the Chiral Bag,* Phys.Rep., to be published.
[4] J. Ashman *et al.*, Phys.Lett. **B20** (1988) 364.
[5] A.D. Jackson, L. Vepstas, E. Wüst and D.E. Kahana, Nucl.Phys., **A462** (1987) 661.
[6] H. Dreiner, J. Ellis and R.A. Flores, Phys.Lett., **B221** (1989) 173.
[7] T. Hatsuda and I. Zahed, Phys.Lett., **B221** (1989) 173.
[8] B.-Y. Park, V. Vento, M. Rho and G.E. Brown, in preparation.
[9] C.G. Callan and I. Klebanov, Nucl.Phys. **B262** (1985) 365.
[10] N.N. Scoccola, D.P. Min, H. Nadeau and M. Rho, Phys. Lett. **B201** (1988) 425.
[11] J.P. Blaizot, M. Rho and N.N. Scoccola, Phys.Lett. **B209** (1988) 27.
[12] D.K. Griegel and T.D. Cohen, Phys.Rev., **39C** (1989) 1032.
[13] M. Rho, Nucl.Phys., **A231** (1974) 493.
[14] K. Ohta and M. Wakamatsu, Nucl.Phys., **A234** (1974) 445.
[15] M. Bando, T. Kugo and K. Yamawaki, Phys.Rep., **164** (1988) 217.
[16] W.A. Bardeen, J. Bignens and J.M. Gerard, Phys.Rev.Lett., **62** (1989) 1343.
[17] D. Amati, E. Leader and B. Vitale, Nuovo Cimento, **17** (1960) 68; **18** (1960) 409.
[18] G.K. Savvidy, Phys.Lett. **71B** (1982) 133.
[19] N.K. Nielsen and P. Olesen, Nucl.Phys. **B144** (1978) 376.
[20] G. 't Hooft, Phys. Scripta **25** (1982) 133.
[21] T.H. Hansson, K. Johnson and C. Peterson, Phys.Rev. **D26** (1982) 2069.
[22] D.I. Dyakonov and V.Y. Petrov, Nucl.Phys. **B245** (1984) 259.
[23] D.I. Dyakonov and V.Y. Petrov, Nucl.Phys. **B272** (1986) 457.
[24] E. Shuryak, Phys.Lett. **193B** (1987) 319.
[25] E. Shuryak, Novosibirsk preprint 87-96 and 87-97 (1987).

[26] M.A. Nowak, J.J.M. Verbaarschot and I. Zahed, Stony Brook preprint (1988) to appear in Nucl.Phys.B.
[27] C. Rosenzweig, J. Schecter and C.G. Trahern, Phys.Rev. **D21** (1980) 3388.
[28] P. DiVecchia and G. Veneziano, Nucl.Phys. **B171** (1980) 253.
[29] Atiyah and N.S. Manton, Cambridge University preprint, (1989).
[30] S.E. Woosley, Ap. J. **330** (1988) 218.
[31] S. Bruenn, Ap. J. **340** (1989) 955.
[32] G.M. Fuller, W.A. Fowler and M.J. Newman, Ap. J. Suppl. **42** (1980) 447; Ap. J. **252** (1985) 715; Ap. J. Suppl. **48** (1982) 279; Ap. J. **293** (1985) 1.
[32A] S.E. Woosley, P.A. Pinto and T.A. Weaver, *Recent Results on SN 1987A*, preprint, (1988).
[33] M. Prakash, J.M. Lattimer and T.L. Ainsworth, Phys.Rev.Lett. **61** (1988) 2518.
[34] J. Middleditch *et al.*, IAU Circular No. 4735 (1989).
[35] P. Haensel and J.L. Zdunik, Nature (1989), submitted.
[36] T. Hatsuda and M. Prakash, Phys.Lett., in press.
[37] See, *e.g.*, A.D. Jackson, A. Lande and R.A. Smith, Phys.Rept., **C86** (1982) 55.
[38] N. Vinh Mau, Nucl.Phys., **A491** (1989) 246.
[39] P. Danielewicz and G. Odyniec, Phys.Lett., **157B** (1985) 146.
[40] H.A. Gustafsson *et al.*, Phys.Rev.Lett., **52** (1984) 1590.
[41] G. Welke *et al.*, Phys.Rev., **C38** (1988) 2101.
[42] G. Welke *et al.*, Phys.Rev., to be published.
[43] C. Gale *et al.*, Phys.Rev., to be published.
[44] A.D. Jackson and H. Bøggild, Nucl.Phys., **A470** (1987) 669.
[45] M. Prakash, A.D. Jackson and S. Das Gupta, Nucl.Phys., **A489** (1988) 714.

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Experience :

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Professor of Physics, University of Birmingham, 1959 - 1960

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Professor of Physics, Princeton, 1964 - 1968

Professor of Physics, State University of New York at Stony Brook, 1968 - 1974

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Editor, Physics Reports (North Holland Publishing Co., Amsterdam), 1971 to present

Editor, Nuclear Physics (North Holland Publishing Co., Amsterdam), 1974 to present

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Visiting Committees :

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IV. RECENT PUBLICATIONS

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839. NTG–88–52 Progress Report, August 1988

840. NTG–88–53 T.T.S. Kuo
Theoretical Foundations of the Nuclear Shell Model
Invited talk at the Second International Spring Seminar on Nuclear Physics, Nuclear Shell Model: Where Do We Stand?, May 16-20, 1988, Capri, Italy (World Scientific), to be published.

841. NTG–88–54 S.D. Yang, M.F. Jiang, T.T.S. Kuo, and P.J. Ellis
Comparison of Two Methods for Calculating Finite-Temperature Ring Diagrams
Phys. Rev. C (1989), to be published.

842. NTG–88–55 I. Zahed
Excited Baryons in the Syrme Model
Invited talk at the 1988 Conference on Excited Baryons, RPI, New York, (World Scientific, 1989).

843. NTG–88–56 T.T.S. Kuo
Collapse of Ring Diagrams as a Signal of Nuclear Matter Phase Transitions
In *Condensed Matter Theories*, Vol. 4, J. Keller, ed. (Plenum), to be published.

844. NTG–88–57 G.E. Brown, E. Oset, M. Vicente Vacas, and W. Weise
Production of Pionic Modes in Relativistic Heavy Ion Collisions
Submitted to Nucl. Phys. **A**.

845. NTG–88–58 Y. Kohyama, K. Kubodera, and M. Takizawa
Nambu-Jona-Lasinio Model Estimation of Strangeness Content in Nucleons
Phys. Lett. **B208** (1988) 165.

846. NTG–88–59 M. Prakash, T.L. Ainsworth, and J.M. Lattimer
The Equation of State and the Maximum Mass of Neutron Stars
Phys. Rev. Lett. **61** (1988) 2518.

847. NTG–88–60 G.E. Brown
Sizes of Baryon Confinement Regions
Invited talk at the 1988 Conference on Excited Baryons, RPI, New York, (World Scientific, 1989).

848. NTG–88–61 G.E. Brown
Current and Future Trends in Nuclear Physics
Invited talk at XI Reuniao de Trabalho sobre Fisica Nuclear no Brazil

849. NTG–88–62 T. Hatsuda and M. Prakash
Parity Doubling of the Nucleon and First Order Chiral Transition in Dense Matter
Phys. Lett. **B** (1989), in press.

850. NTG–88–63 M. Rho
Topological Structure of Hadronic Matter
Invited talk at the Fifth International Conference on Clustering Aspects in Nuclear and Subnuclear Systems, Kyoto, Japan, July 25-29, 1988, and at SNU Summer Workshop in Nuclear Physics, Seoul, Korea, August 1988.

851. NTG–88–64 M. Rho, G.E. Brown, and B.-Y. Park
Spin of the Proton and the Chiral Bag
Phys. Rev. C **39** (1989) 1173.

852. NTG–88–65 P. Pizzochero
Early Spectrum and Bolometric Corrections for SN1987A
SUNY Preprint, November 1988

853. NTG–88–66 W.D. Heiss and T.T.S. Kuo
A Dyson Equation for the Two-Particle Green Function
Int. J. Mod. Phys. (1989), in press.

854. NTG–88–67 B.-Y. Park and M. Rho
Neutron-Proton Mass Difference in the Chiral Hyperbag
Phys. Lett. **B220** (1989) 7.

855. NTG–88–68 H. Forkel, A.D. Jackson, M. Rho, and N.N. Scoccola
Kaon Condensation in the Bound-State Approach to Strangeness on the Hypersphere
Submitted to Phys. Lett. **B**

856. NTG–88–69 G.E. Brown
High-Density Equation of State
Nature **336** (1988) 519

857. NTG–88–70 G.E. Brown and M. Rho
Missing Strength in Longitudinal Electron Response and y-Scaling
Phys. Lett., to be published.

858. NTG–88–71 J. Cooperstein and E. Baron
Supernovae: The Direct Mechanism and the Equation of State
In *Supernovae*, A. Petschek, ed. (Springer-Verlag, New York), in press.

859. NTG–88–72 G.E. Brown
Heavy Ion Collisions at Bevalac Energies
Comm. Nucl. Part. Phys., to be published.

860. NTG–88–73 M.F. Jiang and T.T.S. Kuo
Rearrangement Potential in Finite Temperature BCS Theory

861. NTG–88–74 G. Bertsch and G.E. Brown
Temporal Development of the Plasma Phase Transition
Submitted as Brief Report to Phys. Rev. C.

862. NTG–88–75 C. Sanchez-Castro and K. Bedell
Spin Polarized Fermi Liquids: Applications to Liquid ^3He
Phys. Rev. B (1989) in press.

863. NTG–88–76 C. Sanchez-Castro and K. Bedell
The Magnetic Field Dependence of the Landau Parameters in Strongly Correlated Fermi Systems
Journal of Low Temp. Phys, (1989) in press.

864. NTG–88–77 C. Sanchez-Castro and K. Bedell
An Induced Interaction Model for a Two Component Fermi Liquid
Preprint, 1988.

865. NTG–88–78 H. Yamagishi
Operator Structure of Lagrangian Field Theory
Int. J. Mod. Phys. **A4** (1989) 2591.

866.	NTG–88–79	H. Yamagishi The Green-Kubo Formula in Gauge Theories Proceedings of the Thermal Physics Workshop Physica, to be published.
867.	NTG–88–80	C.B. Dover and P. Koch Strangeness Production in $\bar{p}$–Nucleus Annihilation Conference on "Hadronic Matter in Collisions", Tucson, Arizona
868.	NTG–88–81	P. Koch H-Dibaryon Production in Nuclear Collisions Proceedings of Quark Matter 88, Lenox, Massachusetts
869.	NTG–88–82	H.C. Chiang, S.T. Hsieh and T.T.S. Kuo $^{182-190}Pt$ and $^{180-188}Os$ Isotopes in the Phenomenological Interacting Boson Model Phys. Rev. C **38** (1988) 2543.
870.	NTG–88–83	C. Greiner, D.-H. Rischke, H. Stöcker, and P. Koch Creation of Strange-Quark-Matter Droplets as a Unique Signature for Quark-Gluon-Plasma Formation in Relativistic Heavy-Ion Collisions Phys. Rev. D **38** (1988) 2797.

1989

871.	NTG–89–1	M.F. Jiang, S.D. Yang, and T.T.S. Kuo Particle-Particle Hole-Hole Ring Diagrams and Softening of Nuclear Matter Equation of State Phys. Lett. **B** (1989), in press.
872.	NTG–89–2	T. Hatsuda and I. Zahed The Spin of the Proton and the Axial Anomaly Phys. Lett. **B221** (1989) 173.
873.	NTG–89–3	B.-Y. Park and M. Rho Comments on "Neutron-Proton Mass Difference in the Chiral Solitonic Bag Model" Submmitted to Phys. Rev. D.

874. NTG–89–4 M.A. Nowak, J.J.M. Verbaarschot, and I. Zahed
Chiral Fermions in the Instanton Vacuum at Finite Temperature
Nucl. Phys. **B**, in press.

875. NTG–89–5 R. Alkofer and H. Reinhardt
Instanton Induced Flavor Mixing in the Presence of Vector Mesons
Z. Phys. C, to be published.

876. NTG–89–6 E. Suraud, C. Grégoire, and B. Tamain
Birth, Life and Death of Hot Nuclei
Prog. of Nucl. Part. Sci., to be published.

877. NTG–89–7 G.E. Brown
Supernovae in Theory and Practise
(World Scientific), to be published.

878. NTG–89–8 G.M. Welke
Momentum Dependent Mean Fields in the BUU Model of Heavy Ion Collisions
In *Nuclear Matter and Heavy Ion Collisions*, M. Soyeur, H. Flocard, M. Porneuf, and B. Tamain, eds. (Plenum Publishing Corp., New York, 1989) to be published.

879. NTG–89–9 Y. Umino and F. Myhrer
Hyperon Resonances in the Chiral Bag Model
Phys. Rev. D **39** (1989) 3391.

880. NTG–89–10 C. Grégoire
Introduction to Non-Relativistic Transport Theories
In *Nuclear Matter and Heavy Ion Collisions*, M. Soyeur, H. Flocard, M. Porneuf, and B. Tamain, eds. (Plenum Publishing Corp., New York, 1989) to be published.

881. NTG–89–11 J. Aichelin, J. Cugnon, Z. Fraenkel, K. Frankel, C. Gale, M. Gyulassy, D. Keane, C. M. Ko, J. Randrup, A. Rosenhauer, H. Stöcker, G. Welke, and J. Q. Wu
Comparison of Nuclear Transport Models with 800A-MeV La+La Data
Phys. Rev. Lett. **62** (1989) 1461

882.	NTG–89–12	G. Welke, R. Malfliet, C. Grégoire, M. Prakash, and E. Suraud Collisional Relaxation in Simulations of Heavy-Ion Collisions using Boltzmann-like Equations Submitted to Phys. Rev. C.
883.	NTG–89–13	N.N. Scoccola, D.P. Min, H. Nadeau, and M. Rho The Strangeness Problem: An SU(3) Skyrmion with Vector Mesons Submitted to Nucl. Phys. **A**.
884.	NTG–89–14	R. Alkofer and I. Zahed The Pseudoscalar Nonet in Generalized NJL Models Submitted to Nucl. Phys. **B**.
885.	NTG–89–15	R. Alkofer and I. Zahed Flavour Mixing and the $U_A(1)$ Anomaly Mod. Phys. Lett. A, in press.
886.	NTG–89–16	G.E. Brown, A. Sethi, and N.M. Hintz Proton-Nucleus Scattering and the Swelling of Nucleons in the Nucleus Submitted to Phys. Rev. C.
887.	NTG–89–17	R. Venugopalan and M. Prakash Flow Effects on Transverse Momentum Spectra in Ultra-Relativistic Nuclear Collisions Submitted to Phys. Lett. **B**.
888.	NTG–89–18	T. Hatsuda The Anomalous Gluon Content of Proton Submitted to Nucl. Phys. **B**.
889.	NTG–89–19	H. Yamagishi and I. Zahed Chiral Perturbation Theory and Effective Lagrangians Submitted to Phys. Rev. Lett.
890.	NTG–89–20	C. Gale, G.M. Welke, M. Prakash, S.J. Lee, and S. DasGupta Transverse Momenta, Nuclear Equation of State and Momentum Dependent Interactions in Heavy-Ion Collisions Submitted to Phys. Rev. C.
891.	NTG–89–21	G.E. Brown QCD Constraints and the Shell Model Nucl. Phys. **A**, to be published.

892. NTG–89–22 M.F. Jiang, T.T.S. Kuo, and H. Müther
Single-Particle Spectrum and Ring-Diagram Nuclear Matter Calculations – A Reply to Mahaux and Sartor's Comment
Submitted to Phys. Rev. C.

893. NTG–89–23 H.A. Bethe and P. Pizzochero
Mass-Energy Relation for SN1987A from Observations

894. NTG–89–24 B.-Y. Park, V. Vento, M. Rho, and G.E. Brown
Proton Spin, Axial Anomaly and the Cheshire Cat Principle
Submitted to Nucl. Phys. **A**.

895. NTG–89–25 H. Forkel, A.D. Jackson, M. Rho, C. Weiss, A. Wirzba, and H. Bang
Chiral Symmetry Restoration and the Skyrme Model
Submitted to Nucl. Phys. **A**.

896. NTG–89–26 A.D. Jackson
A Skyrmion Model of Two-Dimensional Superconductors
Invited talk at the Landau Conference, NORDITA, Copenhagen, June 1988.
Pergamon Press, to be published.

897. NTG–89–27 L. Castillejo, P.S.J. Jones, A.D. Jackson, J.J.M. Verbaarschot, and A. Jackson
Dense Skrymion Systems
Nucl. Phys., to be published.

898. NTG–89–28 L. Vepstas and A.D. Jackson
Justifying the Chiral Bag
Phys. Reports, to be published.

899. NTG–89–29 A.D. Jackson, C. Weiss, A. Wirzba, and A. Lande
Accurate Variational Forms for Multi-Skyrmion Configurations
Nucl. Phys., to be published.

900. NTG–89–30 D. Masak
Quantizing Gauged $SU(3)_v$ Skyrmions
Phys. Rev. D **39** (1989) 305.

901. NTG–89–31 D. Masak and Y. Dothan
The Merits of Gauging
Submitted to Rep. Prog. Phys.

902. NTG–89–32 H. Forkel
Yang-Mills Instantons in Closed Robertson-Walker Space-Time

903. NTG–89–33 P. Koch and C.B. Dover
On $K^{\pm}$, $\bar{p}$, and Ω Production in Relativistic Heavy Ion Collisions
Phys. Rev. C, in press.

904. NTG–89–34 C.B. Dover, P. Koch, and M. May
Production of H-Dibaryon iin Ultrarelativistic Heavy Ion Collisions
Phys. Rev. D, in press.

905. NTG–89–35 P. Koch
Quark Gluon Plasma and Strangeness
In *Quark Gluon Plasma*, R. Hwa, ed. (World Scientific), to be published.

906. NTG–89–36 M. Grabiak, B. Müller, G. Soff, and P. Koch
Electroweak Physics at Ultrarelativistic Heavy Ion Colliders
J. Phys. G **15** (1989) L25.

907. NTG–89–37 D.B. Stout and T.T.S. Kuo
Linked Diagram Expansions for the Nuclear Transition Matrix and the Normalization of Model-Space Wave Functions
Nucl. Phys. **A**, to be published.

908. NTG–89–38 M.F. Jiang, R. Machleidt, D.B. Stout, and T.T.S. Kuo
Strength of Tensor Force and s-d Shell Effective Interactions
SUNY Preprint, 1989.

909. NTG–89–39 M.A. Nowak and I. Zahed
Skyrmions from Instantons in Matter
Submitted to Phys. Lett. **B**.

910. NTG–89–40 M.A. Nowak, J.J.M. Verbaarschot, and I. Zahed
OZI Rule and Instantons
Phys. Lett. **B**, in press.

911. NTG–89–41 M.A. Nowak, J.J.M. Verbaarschot, and I. Zahed
Instantons and Chiral Dynamics
Submitted to Phys. Lett. **B**.

912.	NTG–89–42	Y. Umino and F. Myhrer Excited Chiral Bag with Strangeness In *Excited Baryons 1988*, G. Adams, N. Mukhopadhay, and P. Stoler, eds. (World Scientific, Singapore, 1989), in press.
913.	NTG–89–43	Y. Umino and F. Myhrer Electromagnetic Decays of Hyperons
914.	NTG–89–44	Y. Umino Monopole Color Electric Fields in Bag Models In Proceedings of Hampton University Graduate Studies at CEBAF 1989, to be published.
915.	NTG–89–45	Progress Report, July 1989