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TRIBUTE TO JOHN WALTER CLARK ON HIS 60TH BIRTHDAY

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One of the highlights of the XIXth International Workshop on Condensed Matter Theories was the special session on Saturday, June 17, 1995, dedicated to honor John Walter Clark on the occasion of his 60th birthday.

This workshop series owes a great deal to John Clark for the leadership, enthusiasm, and perseverance he has shown in the organization of these scientific events. In fact, his participation as a member of the International Advisory Board, the Editorial Board, and the Workshop Trust Fund Committee has been fundamental in maintaining the continuity and the high scientific standards of these workshops. For this reason, the organizing committee of the XIXth International Workshop on Condensed Matter Theories saw it fit to render this well-deserved tribute to John Clark by dedicating one of the sessions to him.

But in addition, there are two other aspects that we considered when making this decision. The first was the wish to express our respect and admiration to John Clark as an outstanding scientist. The second, our desire to pay our tribute to John Clark as an enlightened and generous human being.

This workshop afforded the participants the opportunity to honor John Clark. The workshop was felt to be a particularly appropriate setting for this celebration, since Clark has been instrumental in developing and organizing this workshop series from its inception. Many collaborations which have fostered the advancement of condensed matter theories and the sustenance of state of the art research in developing countries have been a direct result of Clark's tireless efforts in these directions.

As a scientist, John Clark has left his mark of high productivity and originality in diverse areas of physics such as quantum mechanics of many-body systems, quantum fluids, nuclear structure and dynamics, dense matter astrophysics, quantum control theory, and theoretical biophysics. He has authored over 180 articles published in professional journals, books, and conference proceedings.

John Walter Clark was born in Lockhart, Texas, USA, on April 7, 1935. He did his undergraduate work at the University of Texas at Austin, where he obtained his B.S. degree in 1955 and his M.A. degree in 1957. From there he moved to Washington University in St. Louis, where he received his Ph.D. degree in physics in 1959. In the course of his academic career he was a research associate in physics at Washington University in 1959, a NSF postdoctoral fellow at Princeton University from 1959 to 1962, an associate research scientist at the Martin Company, Denver, in the summer and fall of 1961, a NATO postdoctoral fellow at the University of Birmingham and at CENS, Saclay, France, from 1962 to 1963, assistant and later associate professor of physics at Washington University, from 1963 to 1972, and full professor of physics at Washington University since 1972.

His professional honors and awards include an Alfred P. Sloan Foundation fellowship from 1965 to 1967, a NATO senior fellowship in the Laboratorio di Cibernetica, Naples, Italy, in 1972, and the Eugene Feenberg medal for many-body physics in 1987. He is a Fellow of the American Physical Society.

Of the committees on which he has served, we would like to list the International Advisory Committee for the International Workshops on Condensed Matter Theories, the Program Committee for the Conference on Computer Simulation in Brain Science, the International Advisory Board and Program Committee for the Conferences on Recent Progress in Many-Body Theories, the Program Committee for the Conference on Models of Brain Function, and the Program Committee of the Danish Royal Academy's Symposium on Brain and Mind. He has also acted as co-director of the Workshop on Complex Dynamics of Neural Networks.

John Clark arrived in St. Louis in 1957 to do his Ph.D. at Washington University. He became Eugene Feenberg's first student in the essentially new field of many-body physics and much of what Clark has achieved subsequently in this field can be seen to have its origins in this initial period of interaction with Feenberg.

Clark's research on microscopic many-body theory of strongly correlated quantum systems was recognized by the award of the prestigious Eugene Feenberg Memorial Medal in Many-Body Physics to him at the Fifth International Conference on Recent Progress in Many-Body Theories, in Oulu, Finland, in August 1987. A comprehensive overview of this part of Clark's work was presented by one of us (RFB) at that meeting, and is printed in the proceedings (*Recent Progress in Many-Body Theories*, Vol. 1, A. J. Kallio, E. Pajanne, and R. F. Bishop, eds., Plenum, New York, 1988). We have directly excerpted parts of that article for our overview of this phase of his work. In addition, we present an overview of Clark's work on neural networks and related areas.

Much of Clark's research in many-body physics has been concerned with methods for the quantitative prediction of the ground states and elementary excitations of strongly interacting quantum many-body systems from a completely microscopic starting point. The systems of interest to him have ranged from the helium liquids to finite nuclei, nuclear matter, and neutron star matter. These systems are characterized by having the basic interactions between their constituents so strong that an accurate description in terms of independent-particle models or by means of ordinary perturbation theory is precluded from the outset. Clark is especially known for his contributions over many years to the development and application of the method of correlated basis functions (CBF), which has proven itself to be one of the most effective and viable procedures for dealing with this most important class of quantum many-body systems.

Feenberg and Clark proposed in Clark's first, and their only joint, publication [1] a theory which later became known as the CBF method. Clark's Ph.D. thesis (1959) contains a more detailed development of the method, which includes the first formulation of correlated-basis perturbation theory as a means for the systematic improvement on such single-pass variational treatments as that of Jastrow. At this early date formal prescriptions were also presented for the construction of both off-diagonal and diagonal CBF matrix elements.

The essential steps that paved the way for later practical realizations of the CBF approach to many-fermion systems were outlined in an important early work with Westhaus [6]. Procedures were given there both for the evaluation of off-diagonal CBF matrix elements by cluster expansion techniques and for the transformation to an orthonormal correlated basis. It was also in this paper that the by now familiar Clark-Westhaus form for matrix elements of the kinetic energy operator made its first appearance. The relationship of the CBF method to the quasiparticle picture of Landau was also first explored at this time. With the passage of time one can now see very clearly that many of the key ingredients in the CBF program that is still being carried out today were identified in the early paper by Clark and Westhaus [6]. The collaboration with Westhaus continued and soon led them to consider the formal development of cluster-expansion techniques [4,6], including factorized, or multiplicative, versions of the Iwamoto-Yamada and Aviles-Hartogh-Tolhoek expansions. These techniques have proven to be extremely useful for the subsequent treatment of non-uniform systems such as finite nuclei. Clark returned several years later to work on formal cluster theory, this time in collaboration with Ristig. This work, discussed in more detail below, may nowadays be seen to have provided a firm basis for the later development of the highly important techniques of the Fermi hypernetted chain (FHNC) method, which have been so successful in a wide variety of applications to strongly correlated many-body systems and which have played a vital role in a full implementation of the CBF program.

While others largely worked with such quantum fluids as the helium liquids and Coulombic systems, Clark originally concentrated on applications in nuclear physics. In a subsequent publication [9], which was to be both the first application of CBF perturbation theory to a Fermi system and the first CBF application to a nuclear problem, it was demonstrated, that the tensor force also produces a strong enhancement in the dipole sum rule.

With the benefit of hindsight however, there is no doubt, that the most important contribution of Clark in this early work on nuclear physics was a seminal paper in 1969 with Bäckman and Chakalakal [12], which initiated a quantitative comparison of the Brueckner and Jastrow approaches for quasi-realistic models of nuclear matter. Taken together with later work on the same subject by Clark and his collaborators this avenue of research clearly pointed to the inadequacy of Brueckner theory for nuclear physics applications as it was then commonly practiced.

One can clearly see now however, that it was the early 1969 paper [12] that set the stage for what was only considerably later to become recognized as the by now well-known "crisis in nuclear matter theory." Briefly stated, the results of Clark and his collaborators showed that the expectation value of the Hamiltonian in a trial wavefunction of Jastrow form could be appreciably lower than the corresponding result using Brueckner theory (or, more precisely, what would nowadays be called lowest-order Brueckner theory, LOBT) and the same quasi-realistic Hamiltonian. The energy variational principle then led inexorably to the conclusion that the Brueckner estimate had to be badly wrong, provided that it was accepted that the variational expectation value in the trial Jastrow state had been accurately evaluated by the cluster expansion techniques then employed by Clark and his coworkers.

At that time however, the nuclear theory community was not yet ready to be convinced by these results. This crisis was widely seen to have become settled by about three years later in favor of the variation and CBF treatments and against the LOBT as performed up to the time of the Bethe review. Looking back, it can be seen, that the 1969 paper of Clark et al. [12] had already sounded the death-knell for LOBT, although few recognized it then.

Clearly the crisis in nuclear matter theory has been resolved. Clark himself gave an update [71] on that crisis in 1978 as a summary of the First International Conference on Recent Progress in Many-Body Theories held in Trieste, that still essentially holds today. The major part of the credit for bringing the results of the confrontation between perturbative (LOBT) and variational (CBF) theories applied to nuclear matter to this resolution undoubtedly belongs to Clark. Both the perturbative and variational schools owe him much for drawing the crisis to their attention and also for playing a large role in its resolution. A very beneficial outcome of the confrontation between CBF and LOBT was the subsequent wide appreciation of the enormous power of the variational and CBF techniques. The subsequent emphasis placed on the complementary roles played by the variational and perturbative approaches has also played a vital role in many later developments. Indeed, the exploration of interconnections between the two approaches is nowadays seen to be at least as important as separate advances in either of the methods.

To return to the CBF method and its development, Clark and his collaborators were instrumental in two particular advances that have proven to be essential for later applications of the method to strongly correlated systems of physical interest. Firstly, for realistic nuclear systems for example, it is crucial to incorporate the large state-dependence of the correlations that arises in great part from such strong non-central components in the interaction as the tensor force. There are two distinct ways of including the effects of such correlations in the CBF framework, and both have been developed by Clark and his coworkers. The first alternative is to incorporate the state-dependence into the ground-state trial wavefunction by suitably generalizing the Jastrow form, so that the correlation operator generating the trial states includes state-dependent, especially tensor, terms. Clark, together with Ristig and Ter Louw, gave both the first such systematic procedure for incorporating state-dependent correlations in many-fermion systems and did also the first calculations of nuclear matter with such correlations included [22,28]. The second alternative is to work with CBF perturbation theory on top of the usual Jastrow-Slater (non-state-dependent) correlated basis and to include the effects of the state-dependence by going to higher (i.e., at least to second-order) corrections in this perturbative basis. Clark and his collaborators also pursued this approach, although initially only for central potentials. Both of these alternative approaches were later combined, again with the essential collaboration of Ristig, into a powerful and versatile tool for systems such as realistic nuclear matter, to which it was applied. These CBF approaches have later been further developed and refined by others, particularly by the group of Pandharipande, but the groundwork was done in each case by the Clark-Ristig group.

The second fundamental advance in the CBF method that was vital for its adaptation into such a powerful tool concerns the practical evaluation of such CBF matrix elements as the energy expectation value. We have already noted how Clark was involved in the development of cluster-expansion techniques and cluster formalisms suited to this task [4,6]. The later work with Ristig along these lines also revealed some of the inter-connections between the variational and Brueckner techniques. Most importantly however, this formal cluster theory work provided a basis for much of the later diagrammatic analyses of expectation values in the CBF correlated basis [19,35,37-39] and particularly for the extremely important equations of the FHNC type, which perform a resummation of certain classes of cluster contributions to all orders. The development of the FHNC and related cluster resummation techniques was the second crucial step that was necessary for a full quantitative implementation of the CBF program to such strongly correlated systems as the helium liquids, where it has proven so successful. Clark was not directly involved in the invention of FHNC techniques for the evaluation of expectation values, but he recognized their importance immediately and himself has used them and contributed to their further development ever since. He also published in 1979 what must be considered to be the standard review [64] on the variational theory of nuclear matter. This review surveyed in depth both the formal and practical aspects of FHNC methods and established the notation and terminology used thereafter by the practitioners in this field.

Another area in which Clark has made important contributions is the extension and application of the variational and CBF schemes to deal with superfluid systems. One particular system of continued interest has been neutron star matter, whose period of interest to the nuclear many-body community dates from the discovery around 1968-69 that pulsars are neutron stars. Clark first showed, with Chao, that despite some earlier speculations to the contrary, neutron star matter could not be ferromagnetic, but was likely to be superfluid at certain densities [15]. He continued this work with his students, carrying out the first serious microscopic investigations of the energy gap and isotropic pairing in neutron star matter within correlated BCS theory and considering both proton superconductivity and neutron matter superfluidity. These results have been used repeatedly ever since as input data for models of glitch phenomena and cooling in neutron stars. Clark has also contributed on both sides in the rather heated debate about the possibility of solidification (crystallization) of the cores of neutron stars. His interest in neutron star matter remains strong; he recently published [161] a realistic CBF investigation of neutron pairing, which has quantitatively verified the earlier prediction that the polarization of the medium produces a substantial suppression of the superfluid gap.

The realization that pulsars are neutron stars, which dates the origin of interest of the many-body community in neutron star matter, occurred almost simultaneously with the appearance of the first signals from Clark's works of the impending "crisis in nuclear matter theory." It is perhaps worth recalling that the excitement and diversion caused by the surge of interest in neutron star matter enabled such many-body theorists as Clark to test and hone their methods on a new problem. Upon subsequently returning to the nuclear matter problem, the crisis found a speedy resolution.

Another noteworthy contribution with Ristig concerns the formulation of a variational theory of the momentum distribution and one-body density matrix for quantum fluids [50,52,55,60]. Fundamental structural relations in terms of classes of cluster diagrams were discovered during this development of a cluster theory for the momentum distribution corresponding to a Jastrow trial wavefunction. These relations were later exploited by Fantoni in a derivation of FHNC equations for this function. The Clark-Ristig group subsequently applied their techniques to helium liquids and nuclear matter. Their helium results are well known by the inelastic neutron scattering community, particularly by those involved in the experimental determination of momentum distributions.

The period since about 1979 has seen the further extension of the CBF approach towards providing a comprehensive description of the dynamics and statics of strongly correlated quantum many-body systems. Two formal advances that Clark has achieved with his students and with Krotscheck as his primary collaborator are particularly noteworthy. These are the so-called FHNC' theory and the correlated random-phase approximation (CRPA). In the context of the former problem setting, Krotscheck and Clark extended the FHNC theory for the evaluation of diagonal CBF matrix elements in a Jastrow-Slater correlated basis to the corresponding FHNC' theory for off-diagonal elements. This work led to the definition of the CBF effective interaction and to many illuminating connections with conventional diagrammatic many-body perturbation theory. Exploration of these connections has allowed powerful techniques from ordinary many-body theory, as developed for weakly interacting systems, to be taken over for comparable application to strongly interacting systems within the CBF program. Such familiar quantities as self-energies and quasiparticle interactions have thus been brought under the CBF mantle.

The second major advance has seen the use of CBF theory by Clark and his collaborators to extend the random-phase approximation to the microscopic description of linear response and elementary excitations in strongly interacting systems [84]. This has been achieved by a generalization of time-dependent Hartree-Fock theory to a correlated basis. It permitted a genuine microscopic treatment of the elementary excitations in such systems to be made for the first time. Numerous successful applications of this CRPA method have already been made to various systems. Examples include normal unpolarized liquid ^{3}He, polarized liquid ^{3}He, the electron gas, and closed-shell nuclei.

While Clark and his collaborators have continued the formal development of CBF methods, they have also been at the forefront of applications to real physical systems. A major theme of more recent work has been the application of both CBF perturbation theory and other variational approaches to the quantitative description of the ground states of unpolarized and polarized liquid ^{3}He and of several species of electron-spin-aligned bulk atomic deuterium. Particularly worthy of mention are the variational Monte Carlo calculations with Panoff and others on the ground-state phases of polarized deuterium species. Looking finally to nuclear applications, Mead and Clark [75] gave the first non-trivial application of CBF theory, in the form of a correlated Tamm-Dancoff approximation, to a finite nucleus.

In addition to his mainstream work in many-body theory, Clark has devoted substantial research efforts to quantum control theory (see, e.g., Ref. 183) and to the theory of neural networks. He has made such substantial contributions to both areas that one feels it is only a matter of time before a full CBF-like program flowers to envelop these new enterprises as well. Indeed, particularly in the latter case of theoretical neurobiology, Clark may well be in at the birth of another new field of vast future importance – in much the same way as his own career began nearly forty years ago under his friend and mentor Feenberg, who was then similarly turning his attention to assist at the birth of quantum many-body theory. The wheel then will have turned full circle, and in so doing will surely provide a fitting tribute to the lasting power of the example and guiding light provided by Eugene Feenberg.

Clark's work in the area of neural networks covers an impressive variety of different topics ranging from modeling real, living nervous systems in physiological contexts to applications of artificial neural networks as novel computing devices to fundamental problems in basic science. In addition to his numerous original contributions to this exciting field at the forefront of contemporary science Clark authored several major review articles, providing not only comprehensive accounts of the present state of neural networks research but also excellent introductory reading for the uninitiated.

Of Clark's research in the area of biological neural nets we would like to highlight his work on the mammalian olfactory bulb [137,149], which is considered to be one of the simplest and thus most fundamental of cortical systems in vertebrates, a sort of "hydrogen-atom" of cortical neuronal assemblies. In this work, analog neural network models operating in continuous time, with the activities of the neuronal units representing firing frequencies, have been adopted to describe the basic six-neuron circuit of the olfactory system. Extensive computer simulations of the dynamical behavior of this system revealed the occurrence of sustained, stable oscillations in response to external stimuli, with periods that are typical of the frequencies found in EEG experiments, thus reproducing theoretically one of the most salient features of observed cortical activity. In these studies similar behavior was found also for physiologically more realistic chains and rings of basic olfactory bulb circuits.

Related to these explorations of the olfactory system are Clark's studies [121,122] of cyclic behavior in quasi-randomly connected networks of binary neurons operating synchronously in discrete time – work motivated by the neuro-physiological significance of cycles of short periods in living nervous systems. In these papers Clark and collaborators performed extensive empirical studies, by computer simulations, of cycling in such deterministic, finite-state, sequential machines of neuronal units. Accessibility of cycles from initial conditions, periods of cycles, stabilities of cyclic solutions of the neuro-dynamical equations with respect to disturbances by single-neuron state flips, and the average number of cyclic modes have been investigated in detail for networks varying in size, density of interneuronal connections, fraction of inhibitory units, and magnitudes of non-zero neuron-neuron couplings.

Clark's work [110,116,123] on deterministic chaos in quasi-random, continuous-time neural network models with continuous activity variables evolved out of these studies of cyclic behavior in discrete-time, binary networks. Clark and his co-investigators examined the occurrence of chaotic solutions of the non-linear neuro-dynamical equations, governing the time-dependence of the analog activities of the neuronal units, in dependence on connectivity, network size, and interneuronal coupling strengths, with the strength of the external stimulus to a net serving as control parameter. For certain ranges of the external input, chaos was found to be quite common in sufficiently large nets, a finding which bears potential biological implications such as the possibility for nervous systems to break out of rigid, stereotyped behavior.

Clark's more recent involvement in neural networks research has focussed mainly on scientific applications of artificial neural networks with an emphasis on problems of current interest in nuclear physics. Layered networks consisting of analog units with feedforward neuron-neuron connections of adjustable strength have been trained with standard backpropagation or backpropagation-like learning algorithms to fit and predict the systematics of the nuclear chart. This work led to remarkably accurate neural-network models of the stability-instability dichotomy of nuclides [154], of nuclidic spins [159], and of proton and neutron binding energies in nuclides [151,152,155] and ultimately culminated in global neural-network models of atomic mass excesses [159] and of branching ratios in decay of unstable nuclides [171]. The latter neural-network models in particular have been found to be superior to conventional, semi-phenomenological, global models of nuclear stability and decay. Apart from the significance of these results for nuclear physics, neural-network modeling of nuclear decay furnished a nice opportunity for exploring, from a more technical point of view, in a real-world application a modified backpropagation algorithm, based on relative entropy [145] as cost function, for teaching networks to predict probabilities [171]. In a similar vein, Gernoth and Clark proposed a modified backpropagation learning scheme designed to train neural networks on data with error bars [175]; this algorithm was tested numerically with success in the context of neural-network modeling of atomic mass excesses.

Clark's reviews on neural networks are notable for their thorough treatment of a vast number of highly relevant aspects of the physics of these non-linear complex systems. His reviews furnish outstanding introductory material to the most common of mathematical models of living nervous systems and their functioning, such as possible biological mechanisms of learning through neural plasticity, and to the basic elements of neuronal anatomy and physiology underlying these models [108,136,149]. Moreover, Clark's review articles cover the equilibrium and non-equilibrium statistical mechanics of deterministic and of probabilistic neural networks [119,128] with deep insight.

We would like to conclude this brief survey of Clark's many activities in the area of neural networks by mentioning, that his reviews also provide a summary of the learning algorithms used in training layered, feedforward artificial neural networks and comprise a discussion of several remarkable applications of neural nets to pressing problems in basic science [160].

Parts of this article have been adapted from the presentation (by R. F. Bishop) of the second Eugene Feenberg Memorial Medal in Many-Body Physics to John Walter Clark at the Fifth International Conference on Recent Progress in Many-Body Theories in Oulu, Finland, in 1987.

JOHN WALTER CLARK
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