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FINAL REPORT

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During the past year, the group has been involved in a wide range of activities. The following is a brief sketch of accomplishments, plus publications and invited talks during this period.

Technical Progress

1. ϵ EXPANSION ANALYSIS OF WEAK FIRST-ORDER TRANSITIONS IN THE CUBIC ANISOTROPY MODEL (P. Arnold and L. Yaffe and Y. Zhang) The reliability of the ϵ expansion for very weak first order phase transitions has been tested by appliying it to the cubic anisotropy model. Various ratios of physical quantities across the transition (specific heat, susceptibility, correlation length) have been computed at next-to-leading and next-to-next-to-leading order in the ϵ expansion. The series are reasonably well behaved, and suggest that next-to-leading order ϵ expansion calculations are accurate to within about 30%.

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2. THE NON-ABELIAN DEBYE SCREENING LENGTH BEYOND LEADING ORDER (P. Arnold and L. Yaffe) An exact relation between the next-to-leading order correction to the Debye screening mass in high temperature non-Abelian gauge theories and the perimeter law coefficient of adjoint Wilson loops in three dimensional pure gauge theories was derived. Consequently the non-perturbative $O(g^2T)$ contribution to the Debye mass may be determined using a relatively simple 3d lattice gauge theory simulation.

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3. ELECTRIC-MAGNETIC DUALITY AND THE HEAVY QUARK POTENTIAL (M. Baker; N. Brambilla and M. Polikarpov, Dipartimento di Fisica dell'Universita-Milano, Milan; F. Zachariasen, Caltech; J. S. Ball, University of Utah) We have obtained an expression for the velocity dependent, spin dependent heavy quark potential in QCD based on a duality assumption that the long distance physics of Yang Mills theory depending on strongly coupled potentials A_μ is the same as the long distance physics of a dual theory describing the interactions of weakly coupled dual potentials and monopole fields. This work supercedes a previous treatment where the quark motion was treated semiclassically and where the dual theory was considered only at the classical level. The dual potentials couple to quarks via a Dirac string connecting the $q\bar{q}$ pair and the potential is determined by an effective Wilson loop, which is a functional integral over the variables of the dual theory. Because the dual theory is weakly coupled at large distances, the quantum fluctuations do not dominate in that domain and the potential can be evaluated by a semiclassical expansion. The classical approximation gives the leading contribution and yields a potential that for large R becomes linear in R and which for small R approaches lowest order perturbative QCD. This latter fact means that these results should remain applicable down

to distances where radiative corrections giving rise to a running coupling constant become important. The spin dependence of the potential at long range as well as at short range reflects the vector coupling of quarks in QCD combined with the dual treatment of long distance Yang Mills theory. The methods developed here should be applicable to any realization of the dual superconductor mechanism. They give an expression determining $W_{\text{eff}}(\Gamma)$ independent of the classical approximation, but semiclassical corrections due to fluctuations of the flux tube were not worked out in this project. Taking these into account should lead to an effective string theory free from the conformal anomaly.

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4. ICE WATER VAPOR INTERFACE (M. Baker and M. B. Baker) In order to understand the mechanism of the growth of ice crystals in clouds, we have constructed a model for the structure of the interface between ice crystals and water vapor at temperatures between 250 and 270 °K. It describes the interface by a mean field lattice gas model with parameters fixed by laboratory data and molecular dynamics calculations. It predicts the existence of a layer of admolecules at the ice surface, which is a few molecules thick. Sharp transitions in the layer thickness occur at well defined temperatures on each crystal face.

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5. GROUPS IN COLD DARK MATTER SIMULATIONS I: GROUP IDENTIFICATION AND SMOOTHING FUNCTIONS (Z. H. Fan and J. M. Bardeen) We develop a method to identify groups in numerical simulations of large-scale structure in the universe. The technique used in smoothed particle hydrodynamics (SPH) is applied to get the smoothed density field from the particle distribution. Centers of particle groups are found as peaks of the smoothed density field. A density contrast threshold d_c is set so that particles with smoothed density contrast above d_c are referred to as collapsed particles. One *ad hoc* factor involved is the smoothing kernel. Concerning smoothed density field and density peaks, conditions on smoothing kernels are discussed. Different smoothing functions are compared from various points of view. We find that in some cases both the height and the site of a peak can vary substantially with the kernel.

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6. GROUPS IN COLD DARK MATTER SIMULATIONS II: GROUP MASS FUNCTIONS (Z. H. Fan and J. M. Bardeen) A group-finding method based on the techniques of smoothed particle hydrodynamics (SPH) is used to analyze clustering of particles in numerical simulations of large-scale structure in the universe. Our method is compared with the other group-finding algorithms. The group mass functions are studied, and are compared with Press-Schechter theory. We find that on relatively large scales where nonlocal effects are not important, Press-Schechter theory agrees well with our results.

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7. GROUPS IN COLD DARK MATTER SIMULATIONS III: CORRESPONDENCE BETWEEN NONLINEAR GROUPS AND LINEAR DENSITY PEAKS (Z. H. Fan and J. M. Bardeen) The association between nonlinear final groups and linear density peaks is investigated with a cold dark matter simulation of large-scale structure of the universe. We tag all the particles initially within one smoothing radius of a linear peak as peak particles, and follow them to the final epoch. Particles from one linear peak will generally end up associated with several final groups, but if more than half of the peak particles are associated with one final group, the linear peak is said to belong to that group. The correlation between linear peaks and groups is explored both as to how particles from one linear peak are split up among groups and as to how the particles making up a given final group are located with respect to linear peaks. Some linear peaks will not belong to any single group and some final groups may not contain any linear peaks, but at least for the high linear peaks, the overall correspondence of linear peaks with groups is quite good. We investigate how the correlation is affected by the height of the linear peak, the shear of the velocity field, and the ratio of the average infall velocity to the bulk velocity in the neighborhood of the linear peak. Particular cases are studied in detail to gain physical understanding of how the correspondence may break down. The correspondence is quite sensitive to the mass scale of the smoothing used to find linear peaks and final groups, both because at smaller masses groups may arise from statistical fluctuations of the particle distribution within larger clusters, and because on smaller mass scales formation of groups by top-down fragmentation of pancakes and filaments is not negligible.

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8. COMPTON SCATTERING ON BLACK BODY PHOTONS (L. S. Brown and R. S. Steinke) We consider Compton scattering of electrons on black body photons in the case where the electrons are highly relativistic, but the center of mass energy is small in comparison with the electron mass. We derive a value for the partial lifetime of electrons in the LEP accelerator due to this form of scattering in the vacuum beam pipe and compare it with previous results.

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9. NUCLEAR REACTOR RATES IN A PLASMA (L. Brown and R. Sawyer [University of California-Santa Barbara]) The problem of determining the effects of the surrounding plasma on nuclear reaction rates in stars is formulated *ab initio*, using the techniques of quantum statistical mechanics. Subject to the condition that the nuclear reactions ensue only at very close approach of the fusing ions and the condition that the reaction be slow, we derive a result that expresses the complete effects of Coulomb barrier penetration and of the influence of the surrounding plasma in terms of matrix elements of well defined operators. The corrections do not separate into the product of initial state and final state effects. When the energy release in the reaction is much greater than thermal energies, the corrections reduce, as expected, to evaluation of the equilibrium probability of one ion being very near to the position

of another ion. We address the calculation of this probability in an approach that is based on perturbation theory in the couplings of the plasma particles to the two fusing particles, with the Coulomb force between the fusing particles treated non-perturbatively, and interactions among the plasma particles treated in the one-loop approximation. We recapture standard screening effects, find a correction term that depends on the quantum mechanical nature of the plasma, and put an upper bound on the magnitude of the further correction terms for the case of a weakly coupled plasma. We find that possible "dynamical screening" effects that have been discussed in the literature are absent. The form of our results suggests that an approach that relies on numerical calculations of the correlation functions in a classical Coulomb gas, followed by construction of an effective two body potential and a quantum barrier penetration calculation, will miss physics that is as important as the physics that it includes.

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10. COMPARISON OF JETS FROM e^+e^- AND HADRONIC COLLISIONS (J. Chay and S. D. Ellis) The structure of hadronic jets depends not only on the dynamics of QCD but also on the details of the jet finding algorithm and the physical environment in which the jet is produced. To study these effects in more detail we have calculated the jet cross section and the internal jet structure in e^+e^- annihilations and compared them to the results found in hadronic collisions using the *same* jet definition. The different structures of the events in the two cases are evident in the comparison. For a given cone size and jet energy, the distribution of energy inside the cone is more concentrated near the center for jets from e^+e^- collisions than for jets from hadronic collisions. The first set of theoretical results have been submitted for publication. We are proceeding with a more detailed comparison to the data from both the $p\bar{p}$ experiments (CDF and D0) and the e^+e^- experiments (especially the OPAL Collaboration at LEP).

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11. THE ENERGY-ENERGY CORRELATION IN PERTURBATION THEORY (K. Clay and S. D. Ellis) The energy-energy correlation, or EEC, is one of the most widely employed measures of perturbative structure in e^+e^- hadronic final states. As the experimental analysis of this quantity (first defined by members of the University of Washington theory group) has improved in recent years, the disagreement between the various next-to-leading-order perturbative evaluations of the EEC has come to represent a relevant uncertainty (*e.g.*, as a major contribution to the resulting error bar on the derived value of α_s). In a recent recalculation we attempted to remove this uncertainty with a new analysis employing Mathematica to perform essentially all bookkeeping and most numerical tasks. Our results for the $O(\alpha_s^2)$ contribution to the energy-energy correlation function (EEC) of $e^+e^- \rightarrow$ *hadrons* were calculated to high numerical precision and were found to be larger than previously reported by other groups. On the other hand, unlike the previous work where this point was not

checked, we found very good agreement with the leading logarithm approximation at the edges of phase space. Also the accurate cancellation of infrared singularities exhibited by the new calculation suggests that it is reliable. We are working to explore a subtle issue concerning the regulation of double singularities that could the source of the disagreement with other recent calculations.

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12. CPT VIOLATION SEARCH IN THE KAON SYSTEM (P. Huet) There is an ongoing search for CPT violation in the kaon system. This particular system currently offers the best hope to detect violation of CPT symmetry. Even though there is little theoretical motivation for the violation of CPT, there is also no sacrosanct principle that guarantees its conservation: It is an experimental question. There are currently four parameters whose non-zero value would signal CPT violation in the kaon system. The only existing four-parameter fit to the data was made by Huet and Peskin in 1994. A new analysis with more modern data is presented.

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13. REGULARIZATION OF CHIRAL GAUGE THEORIES (R. Narayanan) During the past several years, a series of papers with H. Neuberger (Rutgers) have been published on the non-perturbative regularization of chiral gauge theories. Our solution is based on a regularization of the chiral fermion determinant as an overlap of two manybody states, and it correctly reproduces both instanton physics and perturbation theory. Recent work has focused on testing the validity of our formalism in two dimensions. There are many models in two dimensions that share the features of chiral fermions in four dimensions. We have directly computed the chiral condensate in the Schwinger model, and we have also studied a chiral Schwinger model.

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14. DYNAMICAL SUPERSYMMETRY BREAKING (A. E. Nelson, M. Dine [UCSC], and Y. Shirman [UCSC] and Y. Nir [Weizmann]) A paper has been published with new results, including many new examples of dynamical supersymmetry breaking, a guide to construction of predictive low energy models, and a discussion of the main phenomenological features. Since then, Nelson has found many more examples. One example, recently published, can serve as a viable hidden sector model, in which supergravity serves to communicate supersymmetry breaking. Contrary to a "no-go" result of Affleck, Dine and Seiberg, the gaugino masses need not vanish in this approach. Contrary to another "no-go" result of Banks, Kaplan and Nelson, the "moduli" (gravitationally coupled scalars) are not cosmologically dangerous in this model.

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15. ELECTROWEAK BARYOGENESIS (P. Huet and A. Nelson) Two papers have been published on a new method for baryogenesis computations during the weak phase transition. Previous weak scale baryogenesis computations were divided into two classes: "Thin wall" calculations where the effects particle interactions with the phase boundary were computed while neglecting incoherent thermal particle scattering, and "thick wall" computations consider the effects on local particle distributions within the phase boundary from local CP violating interactions, assuming that the thermal scattering mean free path is much shorter than the width of the phase boundary, and much longer than typical particle wavelengths.

    Our basic idea is to divide the phase boundary into layers with thickness equal to inverse quasiparticle damping rates (approximately the particle mean free path), and compute the transmission probabilities for particles and antiparticles to propagate from one layer to the next, assuming quantum coherence is maintained within each layer. The realistic case where the phase boundary is neither thick nor thin, may be treated on the same footing as the limiting cases considered previously. The attained accuracy, yet to be challenged, confers a character of falsifiability to electroweak baryogenesis not present in previous calculations.

    The method was applied to a complete calculation of the possible baryon asymmetry produced during the weak phase transition in the supersymmetric extension of the standard model and in models with additional Higgs bosons, and it was found that the magnitude of the CP violating phases required was compatible with quoted upper bounds obtained from electric dipole moment measurements provided that the top squarks and the charginos or neutralinos have a mass in a range that does not extend far beyond the reach of LEP II. Baryogenesis in general multi-Higgs models is also quite feasible.

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16. QUENCHED CHIRAL PERTURBATION THEORY FOR HEAVY-LIGHT MESONS (S. R. Sharpe and Y. Zhang) We formulate quenched chiral perturbation theory for heavy-light mesons coupled to pions, and calculate the one-loop chiral logarithmic corrections to f_B, f_{B_s}, B_B and B_{B_s}. We also calculate these corrections for "partially quenched" theories. In both theories, the chiral logarithms diverge in the chiral limit, indicating that (partially) quenched theories should not be used to study this limit. Comparing the chiral logarithms to those in QCD, we estimate the errors caused by (partial) quenching. By forming suitable ratios, we can reduce the uncertainties in our estimates.

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17. TESTING THE CHIRAL BEHAVIOR OF THE HADRON SPECTRUM (T. Bhattacharya [Los Alamos], R. Gupta [Los Alamos] and S. R. Sharpe) We analyze the chiral behavior of the hadron spectrum obtained with quenched Wilson fermions on 170 $32^3 \times 64$ lattices at $\beta = 6.0$. We calculate masses of hadrons composed of

both degenerate and non-degenerate quarks. We reduce the statistical errors in mass splittings by directly fitting to the ratio of correlation functions. We find significant deviations from a linear dependence on the quark mass, deviations that are consistent with the higher order terms predicted by quenched chiral perturbation theory. Including these corrections yields splittings in the baryon octet that agree with those observed experimentally. Smaller higher order terms are also present in m_ρ and m_N. By contrast, the decuplet baryons are well described by a linear mass term. We find the decuplet splittings to be 30% smaller than experiment. We extrapolate our data to $a \to 0$ by combining with the GF11 results, and the best fit suggests that the quenched approximation is only good to 10–15%

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18. HADRON SPECTRUM WITH WILSON FERMIONS (T. Bhattacharya [Los Alamos], R. Gupta [Los Alamos], G. Kilcup [Ohio State] and S. R. Sharpe) We present results of a high statistics study of the quenched spectrum using Wilson fermions at $\beta = 6.0$ on $32^3 \times 64$ lattices. We calculate the masses of mesons and baryons composed of both degenerate and non-degenerate quarks. Using non-degenerate quark combinations allows us to study baryon mass splittings in detail. We find significant deviations from the lowest order chiral expansion, deviations that are consistent with the expectations of quenched chiral perturbation theory. We find that there is a $\sim 20\%$ systematic error in the extracted value of m_s, depending on the meson mass ratio used to set its value. Using the largest estimate of m_s, we find that the extrapolated octet mass-splittings are in agreement with the experimental values, as is $M_\Delta - M_N$, while the decuplet splittings are 30% smaller than experiment. Combining our results with data from the GF11 collaboration we find considerable ambiguity in the extrapolation to the continuum limit. Our preferred values are $M_N/M_\rho = 1.38(7)$ and $M_\Delta/M_\rho = 1.73(10)$, suggesting that the quenched approximation is good to only $\sim$ 10–15%. We also analyze the $O(ma)$ discretization errors in heavy quark masses.

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19. QUENCHED CHIRAL PERTURBATION THEORY FOR BARYONS (J. Labrenz and S. R. Sharpe) We develop chiral perturbation theory for baryons in quenched QCD. Quenching (the elimination of diagrams containing virtual quark loops) is achieved by extending the Lagrangian method of Bernard and Golterman, and is implemented in a theory where baryons are treated as fixed velocity sources. Our method requires that the octet baryons be represented by a three index tensor rather than by the usual matrix field. We calculate the leading non-analytic corrections to the masses of octet and decuplet baryons. In QCD these are proportional to M_π^3. We find that quenching alters the M_π^3 terms, but does not completely remove them. In addition, we find non-analytic contributions to baryon masses proportional to M_π and $M_\pi^2 \log M_\pi$. These terms, which are artifacts of quenching, dominate over the M_π^3 terms for sufficiently small quark masses. This pattern of corrections is different from that in most mesonic quantities, where the leading non-analytic terms in QCD

(proportional to $M_\pi^4 \log M_\pi$) are removed by quenching. We also point out various peculiarities of the quenched theory, most notably that the Δ baryon can decay (if kinematically allowed), in the sense that its two point function will be dominated at long Euclidean times by a nucleon plus pion intermediate state.

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20. MATRIX ELEMENTS OF 4-FERMION OPERATORS WITH QUENCHED WILSON FERMIONS (R. Gupta [Los Alamos], T. Bhattacharya [Los Alamos] and S. R. Sharpe) We present results of weak matrix elements of four-fermion operators calculated using quenched Wilson fermions. The simulations have been done on 170 $32^3 \times 64$ lattices at $\beta = 6.0$ The small statistical errors allow us to analyze the systematic errors in the calculation of B_K, B_7, B_8. In particular we focus on errors due to the explicit breaking of chiral symmetry inherent in Wilson fermions. Our results, without extrapolation to $a = 0$ and without corrections for the quenched approximation, are $B_K(NDR, 2\text{GeV}) = 0.67(9)$, $B_7^{3/2}(NDR, 2\text{GeV}) = 0.58(2)$ and $B_8^{3/2}(NDR, 2\text{GeV}) = 0.81(1)$.

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21. CLASSICAL PREHEATING AND DECOHERENCE (D. T. Son) We establish the equivalence between the quantum evolution of spatially homogeneous oscillations of a scalar field and that of an analogous classical system with certain random initial conditions. We argue that this observation can be used for numerical simulation of the Universe in the preheating epoch. We also explicitly demonstrate that the phenomenon of parametric resonance that leads to preheating is simultaneously an effective mechanism for generating quantum decoherence of the Universe.

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22. REHEATING AND THERMALIZATION IN A SIMPLE SCALAR MODEL (D. T. Son) We consider a simple model for the Universe reheating, which consists of a single self–interacting scalar field in Minkowskian space–time. Making use of the existence of an additional small parameter proportional to the amplitude of the initial spatially homogeneous field oscillations, we show that the behavior of the field can be found reliably. We describe the evolution of the system from the homogeneous oscillations to the moment when thermalization is completed. We compare our results with the Hartree–Fock approximation and argue that some properties found for this model may be common features of realistic theories.

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23. FROM QUANTUM FIELD THEORY TO HYDRODYNAMICS: TRANSPORT COEFFICIENTS AND EFFECTIVE KINETIC THEORY (S. Jeon and L. Yaffe) A consistent formulation of an effective kinetic theory description for high temperature scalar field theory was constructed and shown to reproduce the correct shear and bulk viscosities at any temperature, including the regime where thermal renormalization becomes significant ($T \sim m/\sqrt{\lambda}$), and at asymptotically large temperatures ($T \gg m/\lambda$) where the quantum trace anomaly generates the dominant contribution to the bulk viscosity. In order to describe correctly the dynamics of low energy quasiparticles (to which the bulk viscosity is sensitive) the effective kinetic theory must include a non-dynamical auxillary field (characterizing the local "index of refraction" for soft excitations) and local-temperature dependent collision terms for both particle number conserving and particle non-conserving scattering processes. Numerical results (and various analytic asymptotic forms) for the resulting shear and bulk viscosity were computed.

Publications

Articles Published

P. Arnold and L. Yaffe, "The Non-Abelian Debye Screening Length Beyond Leading Order", *Phys. Rev.* **D52**, 7208 (1995).

P. Arnold and C. Zhai, "The Three-Loop Free Energy for High-Temperature QED and QCD with Fermions", *Phys. Rev.* **D51**, 1906 (1995).

P. Arnold, "The Electroweak Phase Transition, Part 1: Review of Perturbative Methods", in *Proceedings of the Eighth International Seminar Quarks '94*, (World Scientific, Singapore, 1995)

M. Baker, J. S. Ball and F. Zachariasen, "A Constituent Quark Anti-Quark Lagrangian Based on the Dual Superconducting Model of Long Distance QCD", *Int. J. Mod. Phys.* **A 11**, 343 (1996).

M. Baker, "The Dual Description of Long Distance QCD and the Effective Lagrangian for Constituent Quarks", in *Proceedings of the International Workshop on Color Confinement and Hadrons*, (World Scientific, Singapore, 1995).

Z. Fan and J. M. Bardeen, "Distributions of Fourier modes of cosmological density fields", *Phys. Rev.* **D51**, 6714–6721 (1995).

L. S. Brown, "An Important Schwinger Legacy: Theoretical Tools" in *Julian Schwinger: The Physicist, the Teacher, and the Man*, Ed. by Y. Jack Ng, (World Scientific, Singapore, 1996).

S. D. Ellis and D. E. Soper, "Triply Differential Jet Cross-Sections for Hadron Collisions at Order α_s^3 in QCD", *Phys. Rev. Lett.* **74**, 5182 (1995).

P. Huet, A. E. Nelson, "Electroweak Baryogenesis In Supersymmetric Models", *Phys. Rev.* **D53**, 4578–4597 (1996).

P. Huet, A. E. Nelson, "CP Violation And Electroweak Baryogenesis In Extensions Of The Standard Model", *Phys. Lett.* **B355**, 229–235 (1995).

R. Narayanan and H. Neuberger, "Progress in lattice chiral gauge theories", *Nucl. Phys. B (Proc. Suppl.)* **47**, 591 (1996).

R. Narayanan, H. Neuberger and P. Vranas, "Some applications of the overlap formalism", *Nucl. Phys. B (Proc. Suppl.)* **47**, 596 (1996) .

M. Dine, A. E. Nelson, Y. Nir, Y. Shirman, "New Tools For Low-Energy Dynamical Supersymmetry Breaking", *Phys. Rev.* **D53**, 2658–2669 (1996).

A. E. Nelson, "A Viable Model Of Dynamical Supersymmetry Breaking In The Hidden Sector", *Phys. Lett.* **B369**, 277–282 (1996)

S. R. Sharpe, "Introduction to Lattice Field Theory", 5 lectures at the 1993 Uehling Summer School, University of Washington, in *Phenomenology and Lattice QCD*, Eds. G. Kilcup and S. R. Sharpe, (World Scientific, Singapore, 1995).

S. R. Sharpe and Y. Zhang, "Estimating quenching errors in f_B and B_B", *Nucl. Phys.* **B (Proc. Suppl.) 47**, 441 (1996).

T. Bhattacharya, R. Gupta and S. R. Sharpe, "Testing the chiral behavior of the hadron spectrum", *Nucl. Phys.* **B (Proc. Suppl.) 47**, 549 (1996).

S. R. Sharpe and Y. Zhang, "Quenched Chiral Perturbation Theory for Heavy-Light Mesons", *Phys. Rev.* **D53**, 5125 (1996).

T. Bhattacharya, R. Gupta, G. Kilcup and S. R. Sharpe, "Hadron Spectrum with Wilson Fermions", *Phys. Rev.* **D53**, 6486 (1996).

S. Jeon and L. G. Yaffe, "From Quantum Field Theory to Hydrodynamics: Transport Coefficients and Effective Kinetic Theory", *Phys. Rev.* **D53**, 5799 (1996).

L. G. Yaffe, "The Electroweak Phase Transition: A Status Report", in *String Gravity and Physics at the Planck Energy Scale*, N. Sánchez and A. Zichichi, Eds., (Kluwer Academic, Boston, 1996).

L. Yaffe, "The Electroweak Phase Transition, Part 2: ϵ-Expansion Results", in *Proceedings of the Eighth International Seminar Quarks '94*, (World Scientific, Singapore, 1995)

Articles in Process of Publication

M. Baker; N. Brambilla and M. Polikarpov, F. Zachariasen, and J.S. Bell, "Confinement: Understanding the Relation Between the Wilson Loop and Dual Theories of Long Distance Yang Mills Theory", to appear in *Phys.Rev.* **D.**

L. S. Brown, and C.-X. Zhai "Atomic Effects in Tritium Beta Decay", to appear in *Ann. Phys.* (NY).

L. S. Brown and R. S. Steinke "Compton Scattering on Blackbody Radiation", to be published in *Am. J. Phys.*

P. Huet, R. Narayanan and H. Neuberger, "Overlap formulation of Majorana-Weyl fermions", to appear in *Physics Letters* **B**.

P. Huet, *Probing the Planck Scale Physics with Low energy Experiments*, to appear in *Workshop on Kaon Physics* proceedings, Orsay 1996.

Papers Submitted or To Be Submitted

P. Arnold, S. R. Sharpe, L. G. Yaffe, and Y. Zhang, "A Toy Model for the Electroweak Phase Transition: the ϵ Expansion *vs.* Numerical Simulations for Weakly First-order Transitions in the Cubic Anisotropy Model", in preparation.

P. Arnold and L. G. Yaffe, "ϵ Expansion Analysis of Very Weak First-Order Transitions in the Cubic Anisotropy Model, Part I", in preparation.

P. Arnold and Y. Zhang, "ϵ Expansion Analysis of Very Weak First-Order Transistions in the Cubic Anisotropy Model, Part II", in preparation.

M. Baker and M. B. Baker, "A Model for Ice-Vapor at Equilibrium", submitted to *Journal of Crystal Growth.*

Z. H. Fan and J. M. Bardeen, "Groups in Cold Dark Matter Simulations I: Group Identification and Smoothing Functions", submitted to *Astrophys. J.*

Z. H. Fan and J. M. Bardeen, "Groups in Cold Dark Matter Simulations II: Group Mass Functions", submitted to *Astrophys. J.*

Z. H. Fan and J. M. Bardeen, "Groups in Cold Dark Matter Simulations III: Correspondence between Nonlinear Groups and Linear Density Peaks", submitted to *Astrophys. J.*

L. S. Brown and R. F. Sawyer, "Nuclear Reaction Rates in a Plasma", submitted to *Reviews of Modern Physics.*

J. Chay and S. D. Ellis, "Cone Algorithm Jets in e^+e^- Collisions", submitted to *Phys. Rev.* **D**.

R. Narayanan and H. Neuberger, "Anomaly free U(1) chiral gauge theories on a two dimensional torus", submitted to *Nucl. Phys.* **B**.

D. T. Son, "Classical Preheating and Decoherence", submitted to *Phys. Lett.* **B**.

D. T. Son, "Reheating and Thermalization in a Simple Scalar Model", submitted to *Phys. Rev.* **D**.

Talks

P. Arnold, "Non-abelian Debye Screening: Does It Make Any Sense?", Rutgers University, December 1995.

P. Arnold, "The Electroweak Phase Transition", Duke University, February 1996.

P. Arnold, "The Electroweak Phase Transition", University of California at Irvine, February 1996.

M. Baker, "Electric-Magnetic Duality in QCD", *Australian National Center for Theoretical Physics Workshop on Perturbative Methods in Field Theory*, Canberra, Australia, June 1995.

M. Baker, "Electric-Magnetic Duality in QCD", University of Melbourne, June 1995.

M. Baker, "Electric-Magnetic Duality in QCD", University of Adelaide, June 1995.

D. G. Boulware, "Radiation from a Uniformly Accelerated Charge", Seoul National University, Soeul, Korea, Sept. 1995.

D. G. Boulware, "Space-times with Closed Time-like Curves", Seoul National University, Soeul, Korea, Sept. 1995.

D. G. Boulware, "Space-times with Closed Time-like Curves", Kangwon National University, Kangwon, Korea, Sept. 1995.

L. S. Brown, "Julian Schwinger Remembered", Brown University, Oct. 1995.

S. D. Ellis, "Jet Structure/Algorithms - Theory", *CTEQ Topical Workshop on Collider Physics 1995*, Michigan State University, October,1995.

P. Huet, "Electroweak Baryogenesis and CP Violation: Present Status", DESY, Germany, July 1995.

P. Huet, "CPT Violation in the Kaon System", DESY, Germany, July 1995.

P. Huet, "Electroweak Baryogenesis and Supersymmetric Models", CERN, Switzerland, July 1995.

P. Huet, "Electroweak Baryogenesis and Supersymmetric Models", University of Texas, Austin, September 1995.

P. Huet, "Constraints on Electroweak Baryogenesis from CP Violation", Invited Session – *Topics in Particle Astrophysics*, APS/AAPT meeting, Indianapolis, May 1996.

P. Huet, "Constraints on Electroweak Baryogenesis from CP Violation", Université de Louvain-La-Neuve, Belgium, May 1996.

P. Huet, "Constraints on Electroweak Baryogenesis from CP Violation", Université de Liège, Belgium, May 1996.

P. Huet, "Probing the Planck Scale Physics with Low energy Experiments", *Workshop on Kaon Physics*, Orsay, June 1996.

R. Narayanan, "Overlap formulation of chiral gauge theories", University of California, San Diego, January 8, 1996.

R. Narayanan, "Overlap formulation of chiral gauge theories", SLAC, Palo Alto, January 10, 1996.

R. Narayanan, "Overlap for 2D chiral U(1) models", Lattice 96, St. Louis, June 8.

A. E. Nelson, "Flavor, Compositeness, and Dynamical Breaking of Supersymmetry at Low Energies", *Fourth International Conference on Supersymmetry*, University of Maryland, May 29-June 1, 1996.

A. E. Nelson, "New Issues In Low-Energy Dynamical Supersymmetry Breaking", *Yukawa International Seminar '95: From the Standard Model to Grand Unified Theories*, Kyoto, Japan, 21–25 Aug 1995.

A. E. Nelson, "Cornucopia of New Models for Dynamical Supersymmetry Breaking", *Workshop on Exact Results in Supersymmetric Theories*, Aspen Center for Physics, Aspen, July 18 1995.

A. E. Nelson, "New and Old Issues in Dynamical Supersymmetry Breaking", University of Tokyo, Aug. 26, 1995.

A. E. Nelson, "Dynamical Sypersymmetry Breaking in Chiral Confining Gauge Theories", University of California, Santa Barbara, Feb 8, 1996

S. R. Sharpe, "Estimating quenching errors in f_B and B_B", *Lattice 95*, Melbourne, Australia, July 1995.

S. R. Sharpe, "Review of weak matrix elements and chiral perturbation theory", Plenary talk at *Lattice 96*, St. Louis, June 1996.

D. T. Son, "Reheating in a simple scalar model", *Quarks-96* International Conference, Yaroslavl, Russia. May 1996.

L. G. Yaffe, "The Electroweak Phase Transition: A Status Report", Erice summer school on *String Gravity and Physics at the Planck Energy Scale*, September 1995.

L. G. Yaffe, "Non-Abelian Debye screening", University of Chicago, April 1996.

L. G. Yaffe, "Hydrodynamics and effective kinetic theory in relativistic quantum field theory", Rutgers University, May 1996.