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STUDIES IN THEORETICAL HIGH ENERGY PARTICLE PHYSICS

Technical Progress Report

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ABSTRACT

This is a technical progress report for grant no. DE-FG02-84ER40173 describing research carried out in 1990-1991.

TECHNICAL PROGRESS REPORT (Grant No. DE-FG02-84ER40173)

In this report, we describe technical progress achieved in various areas of research in 1990-1991. A detailed account of our work can be found in the following articles, which have either been published or circulated in preprint form. The publications are labeled by the names of physicists in our group [A ≡ Aratyn, B ≡ Brekke, K ≡ Keung, S ≡ Sukhatme].

A1. BRS Cohomology in String Theory; Geometry of Abelization and the Quartet Mechanism
Aratyn
Journal of Mathematical Physics **31**, 1240-1252 (1990)

A2. Superspace Actions on Coadjoint Orbits of Graded Infinite-Dimensional Groups
Aratyn, E. Nissimov, S. Pacheva and S. Solomon
Phys. Lett. **234B**, 307-314 (1990)

A3. Symplectic Actions on Coadjoint Orbits
Aratyn, E. Nissimov, S. Pacheva and A. H. Zimerman
Phys. Lett. **240B**, 127-132 (1990)

A4. Noether Theorem for Geometric Actions and the Area Preserving Diffeomorphisms on Torus
Aratyn, E. Nissimov, S. Pacheva and A.H. Zimerman
Phys. Lett. **242B**, 377-382 (1990)

A5. The Hidden Kac-Moody Symmetry of the Geometric Actions
Aratyn, E. Nissimov and S. Pacheva
Mod. Phys. Lett. **A5**, 2503-2513 (1990)

A6. Coset Construction of Superstrings via the Coadjoint Orbit Method
Aratyn, E. Nissimov and S. Pacheva
Mod. Phys. Lett. **A5**, 2615-2624 (1990)

A7. On the Group Theoretical Meaning of the Conformal Field Theories in the Framework of Coadjoint Orbits
Aratyn, E. Nissimov and S. Pacheva
Phys. Lett. **251B**, 401-405 (1990)

A8. Kac-Moody Construction of Toda Type Field Theories
Aratyn, L.A. Ferreia, J.F. Gomes and A.H. Zimerman
Phys. Lett. **254B**, 372-380 (1991)

A9. Infinite-Dimensional Noether Symmetry Groups and Quantum Effective Actions from Geometry
Aratyn, E. Nissimov and S. Pacheva
Phys. Lett. **255B**, 359-366 (1991)

A10. Conformal Theories, Integrable Models and Coadjoint Orbits
Aratyn, L.A. Ferreia, J.F. Gomes and A.H. Zimerman
In Proceedings of the VI J A. Swieca Summer School, Section: Particles and Fields, Campos do Jordão, Brazil, 16 pp. (1991)

A11. Symplectic Geometry and Infinite-Dimensional Symmetry Groups
Aratyn, E. Nissimov and S. Pacheva
Talk at the XXth International Conference on Differential Geometric Methods in Theoretical Physics, June 1991, New York

A12. Higher Spin Symmetries of the Conformal Affine Toda Model
Aratyn, C.P. Constantinidis, L.A. Ferreira, J.F. Gomes and A.H. Zimerman
July 1991, 10 pp., submitted for publication

A13. Classical r-matrices and Poisson Bracket Structures on Infinite Dimensional Groups
Aratyn, E. Nissimov and S. Pacheva
July 1991, 12 pp., submitted for publication

A14. A New Deformation of W-Infinity and Applications to the Two-loop WZNW and Conformal Affine Toda Models
Aratyn, L.A. Ferreira, J.F. Gomes and A.H. Zimerman
January 1992, 8 pp., submitted for publication

B1. Statistics of 2D Solitons
Brekke and T. Imbo
To be published in Int. J. Mod. Phys. A

B2. Anyons from Bosons
Brekke, A. Falk, S. Hughes and T. Imbo
Phys. Lett. **B271**, 73 (1991)

B3. Alice Strings, Magnetic Monopoles and Charge Quantization
Brekke, W. Fischler and T. Imbo
Phys. Rev. Lett. **67**, 3643 (1991)

B4. Spinning Particles, Braid Groups and Solitons
Brekke, M.J. Dugan and T. Imbo
Univ. of Illinois at Chicago preprint UICHEP-TH/91-7 (1991)

K1. Gauge Hierachy and Attractive Feeble Long-Range Force
Keung, D. Chang and P. Palash
Phys. Rev. **D42**, 630-635 (1990)

K2. Neutrino Magnetic Moment and Nonabelian Discrete Symmetry
Keung, D. Chang and G. Senjanovic
Phys. Rev. **D42**, 1599-1603 (1990)

K3. Neutrino Magnetic Moment and the Dicyclic Group
Keung, D. Chang, S. Lipovaca and G. Senjanovic
Phys. Rev. Lett. **67**, 953-956 (1991)

K4. Two Loop Bosonic Contribution to the Electron Electric Dipole Moment
Keung, D. Chang and T.C. Yuan
Phys. Rev. **D43**, R14-R16 (1990)

K5. The Electric Dipole Moment of W Boson
Keung, D. Chang, J. Liu
Nucl. Phys. **B355**, 295-304 (1991)

K6. Chromoelectric Dipole Moment of Light Quarks Through Two Loop Mechanism
Keung, D. Chang and T.C. Yuan
Phys. Lett. **B251**, 608-612 (1991)

K7. Induced-θ Contribution to the Neutron Electric Dipole Moment
Keung, D. Chang and K. Choi
Phys. Rev. **D44**, 2196-2199 (1991)

K8. The Chromo-Electric Dipole Moment of the Heavy Quark and Purely Gluonioc CP Viloting Operators
Keung, D. Chang, T. Kephart and T.C. Yuan
Phys. Rev. Lett. **68**, (1992)

S1. Solitons from Supersymmetry
Sukhatme, Q. M. Wang, W.-Y. Keung and T. Imbo
Mod. Phys. Lett. **A5**, 525 (1990)

S2. Supersymmetry Inspired WKB Approximation in Quantum Mechanics
Sukhatme, R. Dutt and A. Khare
Amer. Jour. Phys. **59**, 723 (1991)

S3. Analog of the EMC Effect in Neutrino-Nucleus Interactions
Sukhatme and K. Lassila
Int. Jour. Mod. Phys. **A6**, 613 (1991)

S4. Dilepton Production by Protons on Nuclei and the Partonic Origin of Depletion at Small Momentum Fraction
Sukhatme, K. Lassila, A. Harindranath and J. Vary
Phys. Rev. **C44**, 1188 (1991)

S5. Gluon Structure Functions in Nuclei from the Quark Cluster Model
Sukhatme and K. Lassila
Zeit. Phys. **C** (1992)

S6. Backward Hadrons from Deep Inelastic Lepton Scattering on Nuclei
Sukhatme, C.E Carlson and K. Lassila
Phys. Lett. **B263**, 277 (1991)

S7. Finite Eigenfunctions in the WKB Approximation
Sukhatme and A. Pagnamenta
Amer. Jour. Phys. **59**, 944 (1991)

S8. Non-Divergent Semiclassical Wave Functions in Supersymmetric Quantum Mechanics
Sukhatme and A. Pagnamenta
Phys. Lett. **A151**, 7 (1990)

S9. Alternative Approach to Nonrelativistic Perturbation Theory
Sukhatme and Il Woo Kim
Univ. of Illinois at Chicago preprint UICHEP-TH/91-12 (1991)

S10. Mapping of Shape Invariant Potentials Under Point Canonical Transformations
Sukhatme, R. De and R. Dutt
Univ. of Illinois at Chicago preprint UICHEP-TH/92-4 (1992)

S11. Charge Distributions in the Dual Parton Model, Proc. XIII Warsaw Symposium on Elementary Particle Physics, Kazimierz, Poland, ed. Z. Ajduk (World Scientific, Singapore 1990)

We give below a brief description of the main areas in which new physics results were obtained.

I. H. Aratyn

A. BRS Operator and Physical States of the String Model (A1)

We found the abelian representation of the string BRS cohomology in terms of basic operators forming naturally two dual Kugo-Ojima quartets. Furthermore, using our gauge-fixing scheme, we constructed a method providing the explicit realizations of both the physical and unphysical subspaces for the string theory.

The passage between abelian and nonabelian quantities was realized geometrically through the use of the moments of the vertex operator, which acted as vielbeins between infinite-dimensional algebras. We have clarified the connection between the Virasoro and the spectrum-generating algebra and uncovered the algebraic duality relation between them.

B. Construction of the Invariant Actions by the Method of Coadjoint Orbits (A2-A3)

Recently we have extended the method of coadjoint orbits of infinite-dimensional Lie groups for derivation of geometric D = 2 field theory actions to the super-Kac-Moody and super-Virasoro groups in a manifestly supersymmetric form. In this way we derive the explicit expressions for the actions of the supersymmetric chiral Wess-Zumino-Novikov-Witten (WZNW) model and of the induced supergravity (the super-gravitational Polyakov action).

We have also derived a new formula to produce general actions in this framework only in terms of the basic group theoretical objects. The method was illustrated in the number of examples including extended superconformal models.

C. Noether Theorem for Geometric Actions and the Area Preserving Diffeomorphisms on Torus (A4)

We found that within the formalism of coadjoint orbits of the infinite dimensional Lie group the Noether procedure leads, for a special class of transformations, to the constant of motion given by the fundamental group one-cocyle **S**. Use is made of the simplified formula giving the symplectic action in terms of **S** and the Maurer-Cartan one-form.

The area preserving diffeomorphisms on the torus $T^2 = S^1 (x) S^1$ constitute an algebra with central extension, given by the Floratos-Iliopoulos cocycle. We applied our general treatment based on the symplectic analysis of coadjoint orbits of Lie groups to write the symplectic action for this model and study its invariance. We found an interesting abelian symmetry structure of this non-linear problem.

D. On the Group Theoretical Meaning of the Conformal Field Theories in the Framework of Coadjoint Orbits (A7)

We presented an unifying approach to conformal field theories and other geometric models within the formalism of coadjoint orbits of infinite dimensional Lie groups with central extensions. Starting from the previously obtained general formula for the symplectic action in terms of two fundamental group one-cocyles, we derived the most general form of the Polyakov-Wiegmann composition laws for any geometric model. These composition laws are succinct expressions for all pertinent Noether symmetries. As a basic consequence we obtain Ward identities allowing for making further progress in determining the quantum properties of the geometric models.

E. Hidden Kac-Moody of the Geometric Models (A5)

A general formalism was proposed to study infinite-dimensional Noether symmetries in arbitrary field theories on group coadjoint orbits as well as in their gauged versions (coset geometric models). The basic tools are generalized group composition laws valid for any geometric action. As a main application, we presented a general scheme for constructing the "hidden" Kac-Moody currents.

F. Coset Construction of Superstrings via the Coadjoint Orbit Method (A6)

The previously proposed general construction of geometric actions on infinite-dimensional group coadjoint orbits in terms of fundamental group one-cocycles was applied to provide an alternative formulation of the Green-Schwarz superstring. It was shown that the latter model can be consistently constructed as geometric action on a certain infinite-dimensional coset space of the semidirect product of left- and right-handed Virasoro groups with a Kac-Moody group based on an appropriate modification of the super-Heisenberg-Weyl group.

G. Kac-Moody Construction of Toda Type Field Theories (A8-A10)

Using the coadjoint orbit method we derived a geometric WZWN action based on the extended two-loop Kac-Moody algebra, which we had introduced for the purpose of study models exhibiting both conformal invariance and integrability. We have shown that under a Hamiltonian reduction procedure, which respects conformal invariance, one obtains a hierarchy to Toda type field theories, containing as submodels the Toda molecule and periodic Toda lattice theories. We also discussed the classical r-matrix and the integrability properties of resulting models.

H. Infinite-Dimensional Noether Symmetry Groups and Quantum Effective Actions from Geometry (A9)

We have considered quantum effective actions for arbitrary models possessing an infinite-dimensional group G of Noether symmetries. We observed that the relevant Ward identities yield functional differential equations for the effective action whose exact solution is found to be given by the geometric action on a coadjoint orbit of the (central extended) Noether group $\tilde{G}$. As a particular application we show that the effective action of the light-cone quantized toroidal membrane is explicitly given by the geometric co-orbit action of the group of area-preserving diffeomorphisms on torus.

Starting from the general symplectic manifold's formalism (generalizing the group coadjoint orbit formalism) we discussed arbitrary models (in $D \geq 2$ dimensions) possessing an infinite-dimensional group G of Noether symmetries and consider coupling of the Noether currents to external "sources". We wrote down the Ward Identities for the corresponding quantum effective actions and employed the W-Z consistency relations to uncover the following remarkable property: no matter what is the specific action of the initial classical model, its quantum effective action is always given by the geometric action on a generic coadjoint orbit of the (central extension of the) Noether symmetry group $\tilde{G}$. Given therefore the model with Noether symmetry algebra which admits central extension, the geometric action approach developed by us can then be employed to find its unique quantum effective action.

I. Classical r-matrices and Poisson Bracket Structures on Infinite-Dimensional Groups (A11-A13)

Starting with a canonical symplectic structure defined on the cotangent bundle **T*G** we derived, via Dirac Hamiltonian reduction, Poisson brackets (PB's) on arbitrary infinite-dimensional group **G** (admitting central extension). The PB structures are given in terms of an **r**-operator kernel related to the two-cocycle of the underlying Lie algebra and satisfying a differential classical Yang-Baxter equation. The explicit expressions of the PB's among the group variables for the (N,O) for N = 0,1,...,4 (super-)Virasoro groups and the group of area-preserving diffeomorphisms on torus were presented.

J. A New Deformation of W-Infinity and Applications to the Two-loop WZNW and Conformal Affine Toda Models (A12-A14)

We constructed a centerless W-infinity type of algebra in terms of a generator of a centerless Virasoro algebra and an abelian spin-1 current. This algebra conventionally emerges in the study of pseudo-differential operators on a circle or alternatively within

KP hierarchy with Wantanabe's bracket. Construction we used was based on a special deformation of the algebra w_∞ of area preserving diffeomorphisms of a 2-manifold.

We showed that this deformation technique applies to the two-loop WZNW and conformal affine Toda models, establishing henceforth W_∞ invariance of these models.

II. L. Brekke

A. Statistics of Particles and Solitons (B1, B2 and B4)

We have developed topological techniques for determining the allowed statistics for particles in quantum mechanics and solitons (and other topological objects) in field theories. In particular, we demonstrated that certain field theories living on a spatial circle can have various exotic forms of statistics including ambistatistics, where the superselection rule between bosons and fermions is effectively violated. We also investigated the behavior of composite systems of two or more particle types in quantum mechanics with two spatial dimensions. It was found that there exist quantum systems in which two bosons can form composites of any desired statistical angle. We have extended our topological methods to include particles with spin and the relationship between spin and statistics.

B. Charge Quantization in the Presence of an Alice String

Alice strings are a class of cosmological strings in which electric charge changes sign after circling the string. We showed that charge must be quantized in the presence of such a string. Field theories possessing Alice strings were shown to also contain magnetic monopoles. The charge quantization coming from the presence of Alice strings is consistent with the Dirac quantization condition from the magnetic monopoles.

III. W.-Y. Keung

A. Symmetries in Gauge Theories (K1-K3)

(i) We have related the long range of an attractive feeble force to the gauge hierachy in grand unification. (ii) We have studied a mechanism which gives a small mass but a large magnetic moment for the neutrino such that the solar neutrino deficit problem can be explained. The idea is a discrete version of Voloshin's SU(2) mechanism. Examples using the quaterion group and the dicylic group are illustrated.

B. Electric Dipole Moments (K4-K8)

Following the recent works of Weinberg, and Barr and Zee on the electric dipole moments of the neutron and the electron, we have set up the correct QCD evolution equations for the relevant operators, in particular, the chromoelectric dipole moments of quarks which play an important role in the neutron electric dipole moment. For the electron dipole moment, we have performed a general analysis in multi-(>2)-Higgs

models, with technical calculations of the two-loop contribution. For the neutron electric dipole moment, we include the analysis of induced topological θ term. We have also shown the importance of the dimension 8 operator due to the QCD enhancement. We have performed a complete analysis on the W electric dipole moment in various models.

IV. U. Sukhatme

A. Multi-Soliton Solutions and Supersymmetric Quantum Mechanics (S1,S2,S7-S10)

The application of supersymmetry to quantum mechanics has proved to be very fruitful. It has yielded a deeper understanding of analytically solvable potentials as well as improvements of approximation techniques like large N expansions and the WKB method. Recently, we have explicitly mapped all shape invariant potentials into two classes using point canonical transformations. Also, using supersymmetric quantum mechanics we have constructed the most general family of potentials which have the same bound state energies and scattering amplitudes. This family has n parameters, where n is the number of bound states in the potential. Such families solve nonlinear differential equations of physical interest e.g. Korteweg-de Vries equation. By suitably identifying the n parameters in our isospectral families, we have obtained explicit, simple expressions for pure multi-soliton solutions [corresponding to reflectionless potentials].

A long-standing problem and major shortcoming of semiclassical (WKB) bound state wave functions is their divergence at the classical turning points. Presently available regularization schemes are accurate but rather complicated. We show how finite wave functions can be simply obtained by reorganizing the WKB perturbation expansion in powers of $\hbar$ and retaining appropriate higher order terms. This technique has been applied both to the ordinary WKB as well as the supersymmetric WKB approximation. The resulting finite wave functions compare well with numerical results, and provide a useful starting point for the calculation of physically interesting matrix elements.

The method of choice for performing perturbation theory calculations for one dimensional problems is logarithmic perturbation theory, which in its simplest form is only applicable to the ground state wave function since it has no nodes. We have developed an alternative, modified version of logarithmic perturbation theory which is applicable to excited states too.

B. Effects of Quark Clusters in Nuclei (S3-S6,S11)

A successful phenomenological explanation of the EMC effect (for deep inelastic lepton scattering on nuclei) is based on the formation of "quark clusters" in nuclei. It is natural to look at other processes involving nuclei for related phenomena. We have

investigated the consequences of clusters in neutrino and antineutrino charged current events. Although, in principle, discriminating neutrino experiments which emphasize parton structure functions in different momentum fraction regions are possible, unfortunately accurate data will be hard to obtain. The situation is quite different for the Drell-Yan process. The shadowing behavior at small-x predicted by the quark cluster model has recently been confirmed by dimuon production measurements for protons incident on nuclei [experiment E772 at Fermilab]. The model also predicts that gluon and ocean quark structure functions in nuclei are shadowed but the valence quarks are not. We have also calculated the spectrum of hadrons produced in the backward hemisphere from deep inelastic lepton scattering on nuclear targets. One obtains very satisfactory agreement with available data on backscattered protons. Aside from the general quark cluster approach, the only ingredients in our computations are the counting rules for the longitudinal momentum distribution supplemented by a standard exponential parameterization of the transverse momentum distribution.

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