

## Functional Integrals and Collective Excitations in Boson–Fermion Model\*

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**Abstract** In this paper, collective excitations in the boson-fermion model are investigated by means of functional integration method. The equations of energy gap and excitation spectrum are derived. Moreover, the Bose energy spectrum of zero wave vector Fermi fields is also calculated.

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**Key words:** functional integrals, excitation spectrum, boson–fermion model

### 1. Introduction

In recent years functional integration method has been widely applied in quantum statistical physics, especially in superfluidity and superconductivity.<sup>[1–6]</sup> Functional integrals are very useful for the description of collective excitations in high-temperature superconductivity (HTSC). A 2-D functional integrals method of *d*-pairing model was developed by Brusov and Brusova.<sup>[7–8]</sup> In this model, they calculated the entire collective excitation spectrum for all superconductive states of CuO<sub>2</sub> planes. The complete excitation spectrum for superconductive states arising in symmetry classification of HTSC under triplet *p*-pairing was also investigated in 2-D model. Moreover, the functional integration and temperature Green function methods were used to discuss the nonphonon superconductive mechanism in two-band model.<sup>[9]</sup>

Based on the fact that all high-temperature supercon-

ductors have very small coherent lengths, therefore, a pair state of electrons is localized in the coordinate space and it can be represented phenomenologically by a local boson field  $\phi$ . A possible mechanism for HTSC is assumed through *s*-channel reaction  $2e \rightarrow \phi \rightarrow 2e$ , which leads to a mixed boson–fermion (*b-f*) model. In Refs. [10] and [11], Friedberg and Lee examined the long-range order, gap energy, and Meissner effect in such a model. Moreover, Dicke model describes the one-modes Bose field interacting with Fermi field of atoms, the equations for the phase transition temperature and collective excitations have been derived by means of functional integration method.<sup>[12,13]</sup> The common feature of boson–fermion model and Dicke model is the existing of boson–fermion interacting term, thus two models have similar structure and it is possible to calculate excitation energy spectrum of *b-f* model by using functional integration method.

### 2. Functional Integrals and Excitation Energy Spectrum

The Hamiltonian of the boson–fermion model is<sup>[10]</sup>

$$H = \int d^3x \left[ \hat{\phi}(x, \tau) \left( 2\gamma_0 - \frac{\nabla^2}{2M} \right) \phi(x, \tau) + \sum_{\sigma} \bar{\psi}_{\sigma}(x, \tau) \left( -\frac{\nabla^2}{2m} \right) \psi_{\sigma}(x, \tau) \right] \\ + g \int d^3x \left[ \hat{\phi}(x, \tau) \psi_1(x, \tau) \psi_2(x, \tau) + \bar{\psi}_2(x, \tau) \hat{\phi}_1(x, \tau) \phi(x, \tau) \right], \quad (1)$$

where  $\phi$  is a spin-0 boson field,  $\psi$  is a spin-1/2 fermion of helicity  $\sigma = 1, 2$  in a three-dimensional volume  $V$ .  $g$  is a coupling constant,  $2\gamma_0$  is the bare excitation energy of  $\phi$ .  $M = 2m$  is boson mass,  $m$  is fermion mass. The total particle number is defined to be

$$N = \int d^3x \left[ 2\hat{\phi}(x, \tau) \phi(x, \tau) + \sum_{\sigma} \bar{\psi}_{\sigma}(x, \tau) \psi_{\sigma}(x, \tau) \right]. \quad (2)$$

We can rewrite the Hamiltonian (1) as

$$\hat{H}(\tau) = H - \mu N = \int d^3x \left[ \hat{\phi}(x, \tau) \left( 2\gamma_0 - \frac{\nabla^2}{2M} - 2\mu \right) \phi(x, \tau) + \sum_{\sigma} \bar{\psi}_{\sigma}(x, \tau) \left( -\frac{\nabla^2}{2m} - \mu \right) \psi_{\sigma}(x, \tau) \right] \\ + g \int d^3x \left[ \hat{\phi}(x, \tau) \psi_1(x, \tau) \psi_2(x, \tau) + \bar{\psi}_2(x, \tau) \hat{\phi}_1(x, \tau) \phi(x, \tau) \right], \quad (3)$$

where  $\mu$  is the chemical potential.

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# Functional Integrals And Collective Excitations

**Uwe C. Täuber**



## Functional Integrals And Collective Excitations:

**Functional Integrals and Collective Excitations** Victor Nikolaevich Popov, 1987 This book describes the theory and selected applications of one of the most important mathematical tools used in the theoretical investigation of collective excitations in statistical physics such as occur in superfluidity superconductivity plasma dynamics superradiation and in phase transitions *Functional Integrals in Quantum Field Theory and Statistical Physics* V.N. Popov, 2001-11-30 Functional integration is one of the most powerful methods of contemporary theoretical physics enabling us to simplify accelerate and make clearer the process of the theoretician's analytical work Interest in this method and the endeavour to master it creatively grows incessantly This book presents a study of the application of functional integration methods to a wide range of contemporary theoretical physics problems The concept of a functional integral is introduced as a method of quantizing finite dimensional mechanical systems as an alternative to ordinary quantum mechanics The problems of systems quantization with constraints and the manifolds quantization are presented here for the first time in a monograph The application of the functional integration methods to systems with an infinite number of degrees of freedom allows one to uniquely introduce and formulate the diagram perturbation theory in quantum field theory and statistical physics This approach is significantly simpler than the widely accepted method using an operator approach [Recent Progress In Many-body Theories - Proceedings Of The 9th International Conference](#) David Neilson, Raymond F Bishop, 1998-10-20 The Lake Louise Winter Institute is held annually to explore recent trends in physics The proceedings contain pedagogical and review lectures by invited experts and contributed presentations by participants *Critical Dynamics* Uwe C. Täuber, 2014-03-06 A comprehensive and unified introduction to describing and understanding complex interacting systems *Statistical Mechanics* James H. Luscombe, 2021-01-09 This textbook provides a comprehensive yet accessible introduction to statistical mechanics Crafted and class tested over many years of teaching it carefully guides advanced undergraduate and graduate students who are encountering statistical mechanics for the first time through this sometimes intimidating subject The book provides a strong foundation in thermodynamics and the ensemble formalism of statistical mechanics An introductory chapter on probability theory is included Applications include degenerate Fermi systems Bose Einstein condensation cavity radiation phase transitions and critical phenomena The book concludes with a treatment of scaling theories and the renormalization group In addition it provides clear descriptions of how to understand the foundational mathematics and physics involved and includes exciting case studies of modern applications of the subject in physics and wider interdisciplinary areas Key Features Presents the subject in a clear and entertaining style which enables the author to take a sophisticated approach whilst remaining accessible Contains contents that have been carefully reviewed with a substantial panel to ensure that coverage is appropriate for a wide range of courses worldwide Accompanied by volumes on thermodynamics and non equilibrium statistical mechanics which can be used in conjunction with this book on courses which

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**Quantum Fields on a Lattice** Istvan Montvay, Gernot Münster, 1994. Presents a comprehensive and coherent account of the theory of quantum fields on a lattice.

**Affine Lie Algebras and Quantum Groups** Jürgen Fuchs, 1995-03-09. This is an introduction to the theory of affine Lie Algebras, to the theory of quantum groups, and to the interrelationships between these two fields that are encountered in conformal field theory.

**The Interacting Boson-Fermion Model** F. Iachello, P. van Isacker, 1991-08-30. The interacting boson-fermion model has become in recent years the standard model for the description of atomic nuclei with an odd number of protons and/or neutrons. This book describes the mathematical framework on which the interacting boson-fermion model is built and presents applications to a variety of situations encountered in nuclei. The book addresses both the analytical and the numerical aspects of the problem. The analytical aspect requires the introduction of rather complex group theoretic methods, including the use of graded or super Lie algebras. The first and so far only example of supersymmetry occurring in nature is also discussed. The book is the first comprehensive treatment of the subject and will appeal to both theoretical and experimental physicists. The large number of explicit formulas for level energies, electromagnetic transition rates, and intensities of transfer reactions presented in the book provide a simple but detailed way to analyse experimental data. This book can also be used as a textbook for advanced graduate students.

**Causality, Measurement Theory and the Differentiable Structure of Space-Time** R. N. Sen, 2010-02-11. Introducing graduate students and researchers to mathematical physics, this book discusses two recent developments: the demonstration that causality can be defined on discrete space-times and Sewell's measurement theory in which the wave packet is reduced without recourse to the observer's conscious ego, nonlinearities, or interaction with the rest of the universe. The definition of causality on a discrete space-time assumes that space-time is made up of geometrical points. Using Sewell's measurement theory, the author concludes that the notion of geometrical points is as meaningful in quantum mechanics as it is in classical mechanics, and that it is impossible to tell whether the differential calculus is a discovery or an invention. Providing a mathematical discourse on the relation between theoretical and experimental physics, the book gives detailed accounts of the mathematically difficult measurement theories of von Neumann and Sewell.

**Loops, Knots, Gauge Theories and Quantum Gravity** Rodolfo Gambini, Jorge Pullin, 2000-07-03. Now in paperback, this text provides a self-

contained introduction to applications of loop representations and knot theory in particle physics and quantum gravity Loop representations and the related topic of knot theory are of considerable current interest because they provide a unified arena for the study of the gauge invariant quantization of Yang Mills theories and gravity and suggest a promising approach to the eventual unification of the four fundamental forces This text begins with a detailed review of loop representation theory It then goes on to describe loop representations in Maxwell theory Yang Mills theories as well as lattice techniques Applications in quantum gravity are then discussed in detail Following chapters move on to consider knot theories braid theories and extended loop representations in quantum gravity A final chapter assesses the current status of the theory and points out possible directions for future research

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the england women s national lacrosse team represents england at women s lacrosse it is governed by the english lacrosse association they were runners up in the women s lacrosse world cup twice and have also hosted the tournament twice the team came 3rd in the 2017 women s lacrosse world cup which has held in oshawa canada 1

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and competitions our regional and national academies also provide girls with an

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as adopted by world lacrosse and ratified by all world lacrosse members the world lacrosse women's rule book is compiled and published by world lacrosse wl in addition to the rules guidance sections in italics are provided to give clarity and rule interpretations for umpires coaches and players

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jun 10 2022 nlc has made this decision because of timescales related to world lacrosse's publishing of their latest rule book including the new rules instead these latest january 2022 rules will be implemented for the 2023 24 season to view the latest england lacrosse approved women's rules [click here](#)

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national lacrosse committee has voted in favour of implementing the world lacrosse women's field rule changes within the domestic game for the upcoming 2020 21 season the domestic game includes england lacrosse leagues regional school and university pending approval from bucs rules regulations meeting competitions

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in general the official rules of sixes lacrosse apply equally to both the women's and men's game where the official english language version march 2020 1st edition page 6 the game sixes lacrosse is played by two teams of six players each the purpose of each team is to score by causing

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usa lacrosse acknowledgement the ncaa acknowledges usa lacrosse the national governing body of men's and women's lacrosse and the former united states women's lacrosse association for their respective roles in developing and publishing the

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