

## 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  $\text{CuO}_2$  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-model 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>

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

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

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

where  $\mu$  is the chemical potential.

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# Functional Integrals And Collective Excitations

**Daniel Baumann, Liam McAllister**



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## **Table of Contents Functional Integrals And Collective Excitations**

1. Understanding the eBook Functional Integrals And Collective Excitations
  - The Rise of Digital Reading Functional Integrals And Collective Excitations
  - Advantages of eBooks Over Traditional Books
2. Identifying Functional Integrals And Collective Excitations
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Functional Integrals And Collective Excitations
  - User-Friendly Interface
4. Exploring eBook Recommendations from Functional Integrals And Collective Excitations
  - Personalized Recommendations
  - Functional Integrals And Collective Excitations User Reviews and Ratings
  - Functional Integrals And Collective Excitations and Bestseller Lists

5. Accessing Functional Integrals And Collective Excitations Free and Paid eBooks
  - Functional Integrals And Collective Excitations Public Domain eBooks
  - Functional Integrals And Collective Excitations eBook Subscription Services
  - Functional Integrals And Collective Excitations Budget-Friendly Options
6. Navigating Functional Integrals And Collective Excitations eBook Formats
  - ePub, PDF, MOBI, and More
  - Functional Integrals And Collective Excitations Compatibility with Devices
  - Functional Integrals And Collective Excitations Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Functional Integrals And Collective Excitations
  - Highlighting and Note-Taking Functional Integrals And Collective Excitations
  - Interactive Elements Functional Integrals And Collective Excitations
8. Staying Engaged with Functional Integrals And Collective Excitations
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Functional Integrals And Collective Excitations
9. Balancing eBooks and Physical Books Functional Integrals And Collective Excitations
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Functional Integrals And Collective Excitations
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Functional Integrals And Collective Excitations
  - Setting Reading Goals Functional Integrals And Collective Excitations
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Functional Integrals And Collective Excitations
  - Fact-Checking eBook Content of Functional Integrals And Collective Excitations
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning



- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

### 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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