Abstract

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Table of Contents

Chapter 1

Introduction, with a citation

1.1 Background

This is the introduction. Quisque finibus aliquet cursus. Integer in pellentesque tellus. Duis eu dignissim nulla, a porttitor enim. Quisque vehicula leo non ultrices finibus. Duis vehicula quis sem sit amet sollicitudin. Integer neque est, pharetra et auctor vel, iaculis interdum lectus.

1.2 Summary of chapters

This is a brief outline of what went into each chapter. **Chapter 1** gives a background on duis tempus justo quis arcu consectetur sollicitudin. **Chapter 2** discusses morbi sollicitudin gravida tellus in maximus. **Chapter 3** discusses vestibulum eleifend turpis id turpis sollicitudin aliquet. **Chapter 4** shows how phasellus gravida non ex id aliquet. Proin faucibus nibh sit amet augue blandit varius.

Chapter 2

First research study, with code

2.1 Introduction

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2.2 Method

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2.2.1 Subsection 1 with example code block

This is the first part of the methodology. Cras porta dui a dolor tincidunt placerat. Cras scelerisque sem et malesuada vestibulum. Vivamus faucibus ligula ac sodales consectetur. Aliquam vel tristique nisl. Aliquam erat volutpat. Pellentesque iaculis enim sit amet posuere facilisis. Integer egestas quam sit amet nunc maximus, id bibendum ex blandit.

For syntax highlighting in code blocks, add three "'" characters before and after a code block:

```
mood = 'happy'
if mood == 'happy':
    print("I am a happy robot")
```

2.2.2 Subsection 2

This is the second part of the methodology. Proin tincidunt odio non sem mollis tristique. Fusce pharetra accumsan volutpat. In nec mauris vel orci rutrum dapibus nec ac nibh. Praesent malesuada sagittis nulla, eget commodo mauris ultricies eget. Suspendisse iaculis finibus ligula.

2.3 Results

These are the results. Ut accumsan tempus aliquam. Sed massa ex, egestas non libero id, imperdiet scelerisque augue. Duis rutrum ultrices arcu et ultricies. Proin vel elit eu magna mattis vehicula. Sed ex erat, fringilla vel feugiat ut, fringilla non diam.

2.4 Discussion

This is the discussion. Duis ultrices tempor sem vitae convallis. Pellentesque lobortis risus ac nisi varius bibendum. Phasellus volutpat aliquam varius. Mauris vitae neque quis libero volutpat finibus. Nunc diam metus, imperdiet vitae leo sed, varius posuere orci.

2.5 Conclusion

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Here will be some nice teaser with a picture of our gas or so.

2.6 Superfluidity in strongly interacting 2D Bose gases.

This work focusses on the study of ultra cold strongly correlated 2D gases, their phase coherence properties and the possibility of superfluidity. Unfortunately, for the most prominent phase of superfluidity, a Bose Einstein condensate (BEC), higher dimensions are necessary and 2D is the marginal dimension for its existence (xx). Hence, it is instructive to consider ultra cold 3D gases first, where the concepts of condensation and superfluidity are much easier understood. The line of reasoning will loosely follow the excellent review of Hadzibabic and Dalibard (Dalibard n.d.)

In this chapter, we will consider an infinite homogenous 3D Bose gas at low temperatures and show that the gas will undergo a phase transition where the ground state will be macroscopically populated below a critical Temperature $T_{crit} > 0$. This is due to the rapid decrease of the density of states (DOS) towards low energies (DOS(E) $\rightarrow 0$ for E $\rightarrow 0$) and thus an insufficient number of excited states for the particles to inhabit. Hence, they will condense into the ground state, this phase is called a Bose Einstein condensate.

Since the particles inhabit the same state, the phases of their wave functions – in fact the complete order parameters – are identical. Looking at the coherence or the two-point phase correlation function $g_1(r)$ of the phase over a distance yields thus a constant result. The gas exhibits *long range order* (LRO).

If the particles of the 3D Bose gas are interacting with each other, this condensate will display *superfluidity.* That means that flow below a critical velocity $v_c > 0$ will be frictionless. This velocity is given by the minimal slope of the Bogoluibov dispersion relation (i.e the group velocity of the lowest excitation). The Landau criterion (Landau 1941) states that below this velocity the gas is energetically stable under small perturbations. Here, the onset of condensation and superfluidity coincide.

In contrast, in an infinite homogenous 2D gas at low temperatures, a macroscopic population of the ground state for all temperatures except T=0 is notably absent. The gas does not condense. This is due to a constant DOS even for E $\rightarrow$ 0, allowing a distribution of the particles to the excited states at any temperature T>0. Hence, there exists *no BEC* in a homogenous 2D system for any finite temperature.

Again, investigating the phase of the order parameter, one can show that in an infinite 2D system a continuous symmetry can not be spontaneously broken. This means that for any distance r $\rightarrow \infty$, the correlation function g_1(r)   exp(-r/l_c) vanishes exponentially for any correlation length l_c(T 0). This has been shown for the 2D Heisenberg model by Mermin and Wagner (Mermin & Wagner 1966), applied to 2D quantum field theory (Coleman 1973) and rigorously proven for any 2D system by Hohenberg (Hohenberg 1967). Thus, this gas does exhibit *no long range order*.

A qualitatively different behavior occurs if the particles of the 2D Bose gas are interacting with each other. Now, the correlation function g_1 does not decay exponentially but only algebraically g_1(r)   (/r)

References

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