

**Two-Component Bose-Einstein Condensation**

by

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This thesis entitled:  
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has been approved for the Department of Physics

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Date \_\_\_\_\_

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Matthews, Michael Robin (Ph.D., Physics)

Two-Component Bose-Einstein Condensation

Thesis directed by Prof. Eric Cornell

Bose-Einstein condensates in dilute atomic gases have been around for almost 5 years now. The first experiments dealt with density related properties of the condensate – things like internal energy, collective excitations, and density profiles. All of these aspects are well described by a non-linear Schrodinger equation, in which the non-linearity arises from repulsive potentials between  $^{87}\text{Rb}$  atoms that make up the condensate. While interesting in their own right, these experiments had little to do with the “strangeness” of a condensate as a macroscopic quantum object.

In this work the new era of condensate physics is described. These are experiments mainly concerned with the quantum phase and coherence properties. We have constructed a robust system for creating internal-state superpositions, with the ability to image the interference between them. Our first observations show how condensates, initially created with a well-defined phase, remain coherent, unlike a sample of thermal atoms. We have devised schemes to spatially manipulate the relative phase between two condensates in unique ways which brings about very unexpected behavior. By choosing a very specific scheme we were able to create a vortex state and measure the unique  $2\pi$  phase winding, making this a very simple system for utilizing quantum control.

## Dedication

I dedicate this work to my wife Melanie, and my parents Ann and Robin. Melanie has really given up a lot so that I could follow physics. To her it meant living apart for many years, and always having to cut short our time together. She has been incredibly patient and supportive, and understanding when sometimes physics came first. I hope I can make it up to her.

Sometimes people ask my parents where I got my talent at physics. For some reason people assume that it could not have been from a kindergarten teacher and a highschool geography teacher. Well, it was. From as early as I can remember, they motivated in me an interest in everything. They indulged me when ever they could afford to – things from archery to cadaver frogs. One of the first times I remember thinking about the world was when I asked my dad why the Battlestar Gallactica ships seemed to have so many parts that weren't aerodynamic. He answered "That's smart thinking, but remember, there is no air in space". To this I replied, "Then why do all the movies have ships that look so much like airplanes?". Eventually my scientific knowledge outgrew theirs, but their love and support continued. Both my sister and I owe them everything for our talent and confidence to pursue the most difficult paths.

## Acknowledgements

Given the stereotype of physicists as introverted and antisocial, it seems amazing that I have not had to work with a single one. The Wieman, Cornell and Jin groups have known some truly dedicated, bright, and fun people.

First, I need to acknowledge Eric Cornell for the opportunity and guidance. He knew when to lend advice, and when to let me go off on my own. His grasp of physics inspired me to understand things from new perspectives. It's been a privilege to work with him. Carl Wieman is another great physicist who led me through my graduate career. His technical intuition always motivated me to seek out new methods and find simple but useful techniques. Even though their status is among the elite, and the Nobel Prize may well come to JILA, they always treated the grad students as respectable, intelligent scientists in their own right. It's part of what made JILA a stimulating environment.

There have been other great scientists who shared equally in this work. Mike Anderson who pushed me into the experiment head first, and was responsible for most of the work leading to the original BEC. Jason Ensher was a co-grad student for most of my time here. He and I worked very well together with complimentary styles. The second post-doc I had the privilege of working with was Deborah Jin. Coming from a condensed matter background, she had little atomic physics training, and yet always seems to stay a step ahead of everything. She, Jason and I made a great team, and did some of the best early condensate studies in the

world. After feeling a personal responsibility for the success of our experiment, David Hall came to our group as a post-doc. He was very well trained in the art of precision measurement, which led to numerous arguments between us concerning nearly every detail of the apparatus. Because of this, the experiment was taken to another level. We ferreted out some of the last bugs and made the experiment extremely robust, making the best compromises between making things work and making things right. It was a great experience working with David (except when *he* suggested to Carl that we find some cots for the lab so we could sleep there too). Paul Haljan recently entered the group, and has contributed a lot to this work. He and the newest post-doc Brian Anderson have been instrumental in the recent vortex studies. The experiment is in good hands.

On another front, much of this work was based on and/or motivated by the work of theorists at JILA. Jinx Cooper, Chris Greene, Murray Holland, and John “Weird” Bohn have given a lot of support and ideas. Jim Burke, Brett Esry, and Jamie Williams have devoted much of their efforts to understanding and providing new directions for our experiment.

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## Contents

<b>Chapter</b>	
<b>1</b> Introduction	1
1.1 Overview . . . . .	1
1.2 Who cares? . . . . .	8
<b>2</b> Finite Temperature excitations [1]	11
<b>3</b> Two-Photon transition	22
3.1 Introduction . . . . .	22
3.2 Transition for a free atom . . . . .	22
3.3 Transition for a trapped condensate . . . . .	31
3.3.1 Quantum mechanical derivation . . . . .	32
3.3.2 Classical derivation . . . . .	33
3.3.3 Observable effects . . . . .	37
3.4 Rabi frequency gradient across the condensate . . . . .	43
3.4.1 Trap offset . . . . .	43
3.4.2 Intermediate-state detuning . . . . .	44
3.4.3 Drive polarization . . . . .	45
3.5 Density shift . . . . .	46
3.6 Tilted TOP . . . . .	48

<b>4</b>	Imaging	51
4.1	Near resonance - absorption imaging . . . . .	51
4.1.1	Lensing . . . . .	54
4.1.2	Signal-to-noise . . . . .	57
4.1.3	Magnification measurement . . . . .	58
4.1.4	Double condensate imaging . . . . .	60
4.2	Polarization Imaging . . . . .	62
4.2.1	Signal-to-noise . . . . .	69
4.3	Phase-contrast imaging . . . . .	71
4.3.1	Non-destructive imaging techniques . . . . .	74
4.3.2	Signal to noise . . . . .	75
4.4	Comparisons . . . . .	78
<b>5</b>	Double Condensate experiments – density related [2]	81
5.1	Introduction . . . . .	81
5.2	Dynamical response-instantaneous change in scattering length . .	83
5.3	Mixtures of condensates . . . . .	87
<b>6</b>	Double condensate experiments – phase related [3]	98
<b>7</b>	Unique phase patterns [4]	106
7.1	Twisting the phase . . . . .	107
7.2	Dressed states . . . . .	118
<b>8</b>	Vortex creation [5]	122

<b>Bibliography</b>	134
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## **Appendix**

<b>A Phase-contrast imaging</b>	145
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## Figures

### Figure

2.1	Experimental quantities . . . . .	14
2.2	Finite temperature oscillations . . . . .	15
2.3	Excitation spectrum . . . . .	17
2.4	Excitation model . . . . .	18
2.5	Nonlinear response . . . . .	20
2.6	Frequency response and phase shift . . . . .	21
3.1	Energy structure of $^{87}\text{Rb}$ and the two photon drive . . . . .	24
3.2	Energy level splittings of $^{87}\text{Rb}$ . . . . .	26
3.3	Two-photon drive setup . . . . .	27
3.4	Two-photon timing example . . . . .	30
3.5	Two-photon resonance shape . . . . .	30
3.6	Ramsey oscillations . . . . .	31
3.7	Effect of the rotating field . . . . .	35
3.8	TOP trap fields . . . . .	36
3.9	Separation between $ 1, -1\rangle$ and $ 2, 1\rangle$ . . . . .	39
3.10	Two-photon transition frequency II . . . . .	41
3.11	Slope of the two-photon transition . . . . .	42
3.12	Effect of two-photon polarization . . . . .	47

4.1	Optical depth correction . . . . .	53
4.2	Lensing due to a condensate . . . . .	56
4.3	Optimal signal to noise . . . . .	59
4.4	Magnification measurement setup . . . . .	61
4.5	Destructive double condensate image . . . . .	63
4.6	Clebsch-Gordon coefficients for $^{87}\text{Rb}$ . . . . .	64
4.7	Polarization imaging setup . . . . .	67
4.8	Polarization signal and data . . . . .	68
4.9	Polarization signal to noise . . . . .	70
4.10	Phase-contrast imaging setup . . . . .	73
4.11	Discrete, non-destructive images . . . . .	76
4.12	Continuous, non-destructive images . . . . .	77
4.13	Phase contrast signal to noise . . . . .	79
5.1	Oscillations caused by change in $a$ . . . . .	86
5.2	RF systematic . . . . .	88
5.3	Density distributions . . . . .	91
5.4	Radial separation of the double condensate . . . . .	92
5.5	Time-evolution of densities . . . . .	93
5.6	Center-of-mass motion . . . . .	95
5.7	Cross section for different mixtures . . . . .	97
6.1	Condensate interferometer schematic . . . . .	101
6.2	Density profiles . . . . .	103
6.3	Interference as a function of time . . . . .	105
7.1	Continuous Rabi oscillation . . . . .	109
7.2	Schematic of the condensate phase . . . . .	111

7.3	“Nailed down” theory . . . . .	112
7.4	Model and actual experiment . . . . .	113
7.5	Density distribution for phase winding . . . . .	115
7.6	Theory and experiment comparison . . . . .	116
7.7	Recurrence of Rabi oscillations vs two-photon detuning . . . . .	117
7.8	Fraction in the $ 2, 1\rangle$ state . . . . .	120
7.9	Density profile of dressed condensates . . . . .	121
8.1	Vortex creation schematic . . . . .	125
8.2	Build-up of $ 1, -1\rangle$ atoms from vortex drive . . . . .	128
8.3	Vortex density and phase images . . . . .	130
8.4	Ball-and-shell density and phase image . . . . .	131
8.5	Vortex evolution . . . . .	132

## Tables

### Table

3.1	Useful fundamental constants . . . . .	25
4.1	Far off resonance CB coefficients . . . . .	65