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INSTITUTO DE FÍSICA DE SÃO CARLOS

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Investigation of Magneto-Optical Traps using Monte Carlo Simulation

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Dissertation presented to the Graduate Program in Physics at the Instituto de Física de São Carlos da Universidade de São Paulo, to obtain the degree of Master in Science.

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For my family and friends who support me during all my academic life.

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ABSTRACT

Santos, B. N. **Model for thesis and dissertations in LaTeX using the USPSC Package to the IFSC**. 2022. 35p. Dissertation (Master in Science) - Instituto de Física de São Carlos, Universidade de São Paulo, São Carlos, 2022.

This is the english abstract.

Keywords: LaTeX. USPSC class. Thesis. Dissertation. Conclusion course paper.

RESUMO

Santos, B. N. **Modelo para teses e dissertações em LaTeX utilizando o Pacote USPSC para o IFSC**. 2022. 35p. Dissertação (Mestrado em Ciências) - Instituto de Física de São Carlos, Universidade de São Paulo, São Carlos, 2022.

O resumo deve ressaltar o objetivo, o método, os resultados e as conclusões do documento. A ordem e a extensão destes itens dependem do tipo de resumo (informativo ou indicativo) e do tratamento que cada item recebe no documento original. O resumo deve ser precedido da referência do documento, com exceção do resumo inserido no próprio documento. (. . .) Salientamos que algumas Unidades exigem o titulo dos trabalhos acadêmicos em inglês, tornando necessário a inclusão das referências nos resumos e abstracts, o que foi adotado no **Modelo para TCC em LaTeX utilizando a classe USPSC** e no **Modelo para teses e dissertações em LaTeX utilizando a classe USPSC**. As palavras-chave devem figurar logo abaixo do resumo, antecedidas da expressão Palavras-chave:, separadas entre si por ponto e finalizadas também por ponto (**?**).

Palavras-chave: LaTeX. Classe USPSC. Tese. Dissertação. Trabalho de conclusão de curso (TCC).

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LIST OF ABBREVIATIONS AND ACRONYMS

ABNT	Associação Brasileira de Normas Técnicas
abnTeX	ABsurdas Normas para TeX
IBGE	Instituto Brasileiro de Geografia e Estatística
LaTeX	Lamport TeX
USP	Universidade de São Paulo
USPSC	Campus USP de São Carlos

LIST OF SYMBOLS

Γ	Letra grega Gama
Λ	Lambda
ζ	Letra grega minúscula zeta
$\in$	Pertence

CONTENTS

1 INTRODUCTION

1.1 Motivation

The profound understanding of light-matter interaction brought several scientific possibilities like the control of ultracold atoms. The Nobel Prize of Physics in 1997 was awarded jointly to Steven Chu (1), Claude Cohen-Tannoudji(2), and William D. Phillips(3) for developing methods to cool and trap atoms with laser light, also known as laser cooling (4). This achievement has enabled modern technologies, including accurate atomic clocks (5), qubits for quantum computing (6), and quantum sensors (7). Laser cooling also allowed the experimental confirmation of the degenerate quantum gas known as Bose-Einstein condensation (BEC) (8), motivating the Nobel Prize of Physics in 2001 (9, 10).

The workhorse of laser cooling is the magneto-optical trap (MOT) (11): a technique to trap and cool a dilute atomic gas until temperatures in a range of μK. A standard MOT consists of six laser beams on a counter-propagating configuration and a magnetic quadrupole field. Briefly, the atoms scatter photons from the light through electronic transitions, which causes a momentum exchange. From a semiclassical perspective, the average momentum exchange yields a trapping and drag force on the atoms. The spectral linewidth is essential to define how often the momentum exchange will happen, affecting the minimum temperature. MOTs using linewidths closer to the photonic recoil, known as narrow-line magneto-optical traps (nMOTs)(12), can reach lower temperatures at the cost of trapping efficiency.

The current theories for the MOT based upon the Doppler cooling theory (13) give us a challenging task to predict some experimental quantities. The difficulty arises from the complex three-dimensional light in the presence of a magnetic quadrupole field. Furthermore, the analysis of nMOTs is even more delicate since the typical semiclassical approach fails when one scattering event changes considerably the probability of the next one, which demands treating individuals scatterings. Therefore, there is considerable interest in quantitative models capable of predicting MOT properties either to nMOTs or more complex systems like molecular MOTs (14), which involves complicated optical pumping effects. A viable path is to simplify assumptions about the optical transitions and simulate the MOT dynamics (15), which allows the evaluation of usual and unusual MOTs setup considering several parameters.

1.2 The Thesis

In this thesis, we introduce the required elements of light-matter interaction to understand the semiclassical picture of MOTs, analysing the limit for narrow transitions. We also present a model of Monte Carlo simulation, in which the photons scattering is treated as a stochastic process, specifically a Markov chain. Our goal is to study the dynamics of atoms in nMOTs and obtain predictions for experimental quantities. Moreover, we propose few-beams MOT setups presenting a semiclassical analysis and verifying their trapping and cooling efficiency through simulated results.

The thesis is structured as follows. We initially introduce concepts of light-matter interaction in Chapter 2. After, we present the semiclassical picture of MOTs and the nMOT theory in Chapter 3. In Chapter 4, we detail the simulation model and, subsequentially, the results in Chapter 5 and the conclusion in Chapter 6.

4 SIMULATION MODEL

5 RESULTS

6 CONCLUSION

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