

LUDWIG-MAXIMILIANS-UNIVERSITÄT  
MÜNCHEN

Bachelors Thesis

# The role of excited atomic states in multiphoton ionization

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## **Abstract**

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# 1. Introduction

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## 2. Theory

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$$\partial_t u = \mathcal{H}(t)\lambda \quad (2.1)$$

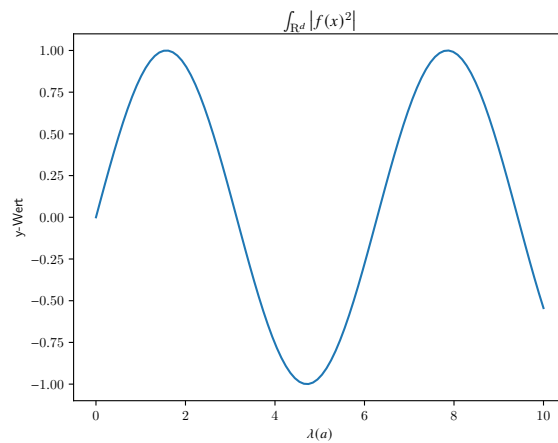


Figure 2.1: Sine function

## 2.1 Basic Formalism

Basic Definitions of schrödinger eq, light dyson series, and sotrong field s matrix

Starting with schrödinger equation and a general hamiltonian

$$i\hbar \frac{\partial}{\partial t} |\Psi(t)\rangle = \hat{H}(t) |\Psi(t)\rangle. \quad (2.2)$$

The formal solution depends on the time dependence of the hamiltonian and the physical setting. In the following we assume (IMPORTANT) that  $[\hat{H}(t), \hat{H}(t')] = 0$  so we assume some sort of quasi static approximation to the Hamiltons time evolution. The solution is then given by

$$|\Psi(t)\rangle = e^{-\frac{i}{\hbar} \int_0^t \hat{H}(t') dt'} |\Psi(t=0)\rangle \quad (2.3)$$

## 2.2 Strong Field Approximation

clear definition of the strong field approximation, and the assumptions that are made.



## 2.3 Strong Field Ionization

Derivation of

$$\lim_{t \rightarrow \infty} |\Psi(t)\rangle = -i \int d^3p |\mathbf{p}\rangle \int_{-\infty}^{\infty} dt' e^{-\frac{i}{2} \int_{t'}^{\infty} [\mathbf{p} + \mathbf{A}(t')]^2 dt'} e^{iI_{\mathbf{p}} t'} \langle \mathbf{p} + \mathbf{A}(t') | \hat{\mathbf{d}} \cdot \mathbf{E}(t') | \Psi_0 \rangle \quad (2.4)$$

## 2.4 Multiphoton Ionization

Different types of Ionization, tunneling Ionization, multiphoton

### 3. Conclusion

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$$\partial \mathbf{A} = \mathfrak{B}$$

$$\int_{\mathbb{R}^d} |f(x)|^2 \, dx = \int_{\mathbb{R}^d} |\mathcal{F}f(\xi)|^2 \, d\xi \tag{3.1}$$

$$\mathrm{i}\partial_t u = \mathcal{H}(t) \, |a\rangle \, \lambda \tag{3.2}$$

for this calculation [1] was used

# A. Appendix A

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## B. Appendix B

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# Bibliography

- [1] Seung Beom Park, Kyungseung Kim, Wosik Cho, Sung In Hwang, Igor Ivanov, Chang Hee Nam, and Kyung Taec Kim. Direct sampling of a light wave in air. *Optica*, 5(4):402–408, Apr 2018.