Year

Your Name as it appears in the title page

Title of Your PhD Thesis

by

Your Full Name

A dissertation submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy (Ph.D.)

Aristotle University of Thessaloniki
Month Year

Reading Committee:
Name of reading committee chair, Chair
Name of reading committee member
Name of reading committee member

Program Authorized to Offer Degree: School of Physics

May 26, 2025

Aristotle University of Thessaloniki

Abstract

Title of Your Thesis

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Academic title and name of committee chair

Chair's Department

Please place the abstract of the dissertation here. The abstract should be double-spaced and left-aligned. The abstract section does not go into the table of contents. An **English** and a **Greek** abstract in a single paragraph (no other paragraphs), up to 500 words each, typed in lowercase letters (except for sentence starters and proper nouns) and without mathematical formulas or polyphonic characters is needed.

Εδώ η περίληψη στα ελληνικά.

Acknowledgments

The acknowledgement section goes here. The acknowledge section does not go into the table of contents.

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Chapter 1

Introduction

The introduction of the PhD dissertation. It should contain the relevant aspects of the topic and the main structure of the PhD thesis. It may be separated in sections. References should be included and they should be listed in the Bibliography.

Citations should be included either separated, for example [1], [2] and [3], or in groups as [1, 2, 3] in the case that many references are related to a specific topic.

If tables or figures appear in the introduction, they should be of general purpose. Below two examples of a table and a figure.

1.1 My Section

Optional sections.

Table 1.1: Description of the table. For instance: Series of hydrogen atom.

n_1	n_2	Series Name	Radiation Type
1	$2, 3, 4, \cdots, \infty$	Lyman	
2	$3, 4, 5, \cdots, \infty$	Balmer	
3	$4, 5, 6, \cdots, \infty$	Paschen	
4	$5, 6, 7, \cdots, \infty$	Brackett	
5	$6, 7, 8, \cdots, \infty$	Pfund	
6	$7, 8, 9, \cdots, \infty$	Humphreys	

Figure 1.1: Description of the figure.

Chapter 2

Basic/known framework

This chapter should contain in detail the basic theoretical or experimental frameworks. It can be divided into as many sections as necessary.

2.1 My Section

Basic theoretical/experimental frameworks/methods.

Table 2.1: Series of hydrogen atom

n_1	n_2	Series Name	Radiation Type
1	$2, 3, 4, \cdots, \infty$	Lyman	
2	$3, 4, 5, \cdots, \infty$	Balmer	
3	$4, 5, 6, \cdots, \infty$	Paschen	
4	$5, 6, 7, \cdots, \infty$	Brackett	
5	$6, 7, 8, \cdots, \infty$	Pfund	
6	$7, 8, 9, \cdots, \infty$	Humphreys	

Figure 2.1: Description of the figure.

Chapter 3

My framework

This chapter should contain in detail the new theoretical or experimental frameworks developed/investigated by the PhD candidate. It can be divided into as many sections as necessary.

3.1 My Section

New theoretical/experimental frameworks/methods.

Table 3.1: Series of hydrogen atom

n_1	n_2	Series Name	Radiation Type
1	$2, 3, 4, \cdots, \infty$	Lyman	
2	$3, 4, 5, \cdots, \infty$	Balmer	
3	$4, 5, 6, \cdots, \infty$	Paschen	
4	$5, 6, 7, \cdots, \infty$	Brackett	
5	$6, 7, 8, \cdots, \infty$	Pfund	
6	$7, 8, 9, \cdots, \infty$	Humphreys	

Figure 3.1: Description of the figure.

Chapter 4

My framework: more chapters

You should include as many chapters as necessary for the presentation of your work. For instance, a chapter dedicated to testing applications in comparison to other reference works, a chapter dedicated to the presentation of your results, a chapter dedicated to comparison of your own results with other studies . These chapters can be divided into as many sections as necessary too.

4.1 My Section

Start the text of your work.

Table 4.1: Series of hydrogen atom

n_1	n_2	Series Name	Radiation Type
1	$2, 3, 4, \cdots, \infty$	Lyman	
2	$3, 4, 5, \cdots, \infty$	Balmer	
3	$4, 5, 6, \cdots, \infty$	Paschen	
4	$5, 6, 7, \cdots, \infty$	Brackett	
5	$6, 7, 8, \cdots, \infty$	Pfund	
6	$7, 8, 9, \cdots, \infty$	Humphreys	

Figure 4.1: Description of the figure.

Chapter 5

Summary and Conclusions

You should include a final chapter with a detailed summary and conclusions of your PhD work. This chapter can be divided into as many sections as necessary too.

You may include future perspectives too, either in this chapter or in a separated chapter after the Summary and Conclusions.

5.1 My Section

Start the text of your summary, conclusions, and other similar topics.

Bibliography

[1] P. Demorest, T. Pennucci, S. Ransom, M. Roberts and J. Hessels, ``Shapiro Delay Measurement of A Two Solar Mass Neutron Star," Nature **467**, 1081 (2010).

[2] J. Antoniadis, P. C. C. Freire, N. Wex, T. M. Tauris, R. S. Lynch, M. H. van Kerkwijk, M. Kramer, C. Bassa, V. S. Dhillon and T. Driebe, *et al.*, ``A Massive Pulsar in a Compact Relativistic Binary," Science **340**, 6131 (2013).

[3] N. K. Glendenning, ``Compact stars: Nuclear physics, particle physics, and general relativity,", 2012, Springer, New York, ISBN:9781468404913, 1468404911.

Appendix A

My appendix A

If necessary, you may include appendices. The appendices should then contain detailed derivations. You may include as many appendices as needed.

A.1 My appendix A section

Start the text for the appendix.

A.1.1 Properties of the δ-function

The δ-function is defined as

$$\delta(x) = \lim_{\varepsilon \to 0} \delta^{(\varepsilon)}(x), \tag{A.1}$$

with

$$\delta^{(\varepsilon)}(x) = \begin{cases} 1/\varepsilon, & -\varepsilon/2 < x < \varepsilon/2, \\ 0, & |x| > \varepsilon/2. \end{cases} \tag{A.2}$$

Vita

A short bio of the author is required for a Ph.D. dissertation at the Aristotle University of Thessaloniki. The vita section does not go into the Table of Contents. The formatting style follows the text of the dissertation.

Physical Constants

You may include the values of physical quantities/expressions. For example:

Quantity	Symbol, relation	Value
Speed of light	c	$2.9979 \times 10^8\ \mathrm{m\,s^{-1}}$
Electron charge	e	$1.602 \times 10^{-19}\ \mathrm{C}$
Planck constant	h	$6.626 \times 10^{-34}\ \mathrm{J\,s} = 4.136 \times 10^{-15}\ \mathrm{eV\,s}$
Reduced Planck constant	$\hbar = h/2\pi$	$1.055 \times 10^{-34}\ \mathrm{J\,s} = 6.582 \times 10^{-16}\ \mathrm{eV\,s}$
Conversion constant	$\hbar c$	$197.327\ \mathrm{MeV\,fm} = 197.327\ \mathrm{eV\,nm}$
Electron mass	m_e	$9.109 \times 10^{-31}\ \mathrm{kg} = 0.511\ \mathrm{MeV/c^2}$
Proton mass	m_p	$1.673 \times 10^{-27}\ \mathrm{kg} = 938.272\ \mathrm{MeV/c^2}$
Neutron mass	m_n	$1.675 \times 10^{-27}\ \mathrm{kg} = 939.566\ \mathrm{MeV/c^2}$
Fine structure constant	$\alpha = e^2/(4\pi\varepsilon_0\hbar c)$	$1/137.036$
Classical electron radius	$r_e = e^2/(4\pi\varepsilon_0 m_e c^2)$	$2.818 \times 10^{-15}\ \mathrm{m}$
Electron Compton wavelength	$\lambda_e = h/m_e c = r_e/\alpha$	$2.426 \times 10^{-12}\ \mathrm{m}$
Proton Compton wavelength	$\lambda_p = h/m_p c$	$1.321 \times 10^{-15}\ \mathrm{m}$
Bohr radius	$a_0 = r_e/\alpha^2$	$0.529 \times 10^{-10}\ \mathrm{m}$
Rydberg energy	$\mathcal{R} = m_e c^2 \alpha^2/2$	$13.606\ \mathrm{eV}$
Electron speed in the first Bohr orbit	$v_1 = \alpha c$	$2.1876913 \times 10^6\ \mathrm{m/s}$
Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788 \times 10^{-11}\ \mathrm{MeV\,T^{-1}}$
Nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152 \times 10^{-14}\ \mathrm{MeV\,T^{-1}}$
Avogadro number	N_A	$6.022 \times 10^{23}\ \mathrm{mol^{-1}}$
Boltzmann constant	k	$1.381 \times 10^{-23}\ \mathrm{J\,K^{-1}} = 8.617 \times 10^{-5}\ \mathrm{eV\,K^{-1}}$
Stefan--Boltzmann constant	$2\pi^5 k^4/(15h^3c^2)$	$5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$
Gas constant	$R = N_A k$	$8.31\ \mathrm{J\,mol^{-1}\,K^{-1}}$
Gravitational constant	G	$6.673 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$
Permittivity of free space	$\varepsilon_0 = 1/\mu_0 c^2$	$8.854 \times 10^{-12}\ \mathrm{C^2\,N^{-1}\,m^{-2}}$
Useful quantity	$e^2/(4\pi\varepsilon_0)$	$1.440\ \mathrm{MeV\,fm}$

Conversion of some useful units

$1\ \mathrm{fm} = 10^{-15}\ \mathrm{m}$, $1\ \mathrm{barn} = 10^{-28}\ \mathrm{m^2} = 100\ \mathrm{fm^2}$, $1\ \mathrm{G} = 10^{-4}\ \mathrm{T}$

$1\ \mathrm{atmosphere} = 101\,325\ \mathrm{Pa}$ Thermal energy at $T = 300\ \mathrm{K}$: $kT = [38.682]^{-1}\ \mathrm{eV}$

$0\ {}^\circ\mathrm{C} = 273.15\ \mathrm{K}$, $1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$, $1\ \mathrm{eV/c^2} = 1.783 \times 10^{-36}\ \mathrm{kg}$

Essential Relations

Planck's Distribution: $u(\nu, T) = (8\pi\nu^2/c^3)\left(h\nu/\left(e^{h\nu/kT} - 1\right)\right)$, **de Broglie Relation:** $\lambda = h/p$

Compton wavelength shift: $\Delta\lambda = h\,(1 - \cos\theta)\,/m_e c$, **Fine structure constant:** $\alpha = \left(\frac{e^2}{4\pi\varepsilon_0}\right)\frac{1}{\hbar c}$

Bohr model: $a_0 = \left(\frac{4\pi\varepsilon_0}{e^2}\right)\frac{\hbar^2}{m_e}$, $r_n = n^2 a_0$, $v_n = \frac{\alpha}{n}c$, $E_n = -\left(\frac{e^2}{4\pi\varepsilon_0}\right)\frac{1}{2n^2 a_0} \equiv -\frac{1}{2n^2}\alpha^2 m_e c^2$

General relations:

$$e^{\hat{A}}e^{\hat{B}} = e^{\hat{A}+\hat{B}}e^{[\hat{A},\ \hat{B}]/2},$$

$$e^{\hat{A}}\hat{B}e^{-\hat{A}} = \hat{B} + [\hat{A},\ \hat{B}] + \frac{1}{2!}[\hat{A},\ [\hat{A},\ \hat{B}]] + \frac{1}{3!}[\hat{A},\ [\hat{A},\ [\hat{A},\ \hat{B}]]] + \cdots$$

Generalized uncertainty principle: $\Delta A\Delta B \geq \frac{1}{2}\left|\langle[\hat{A},\ \hat{B}]\rangle\right|$, where $\Delta A = \sqrt{\langle\hat{A}^2\rangle - \langle\hat{A}\rangle^2}$

Canonical commutator: $[\hat{x},\ \hat{p}] = i\hbar$

Heisenberg uncertainty principle: $\Delta x\Delta p \geq \hbar/2$, $\Delta E\Delta t \geq \hbar/2$

Measurement probability: $\hat{A}|\psi_n\rangle = a_n|\psi_n\rangle$, $P_n(a_n) = \frac{|\langle\psi_n|\psi\rangle|^2}{\langle\psi|\psi\rangle}$

Expectation value: $\langle\hat{A}\rangle = \frac{\langle\psi|\hat{A}|\psi\rangle}{\langle\psi|\psi\rangle} = \sum_n a_n P_n(a_n)$

Time evolution of expectation values: $\frac{d}{dt}\langle\hat{A}\rangle = \frac{1}{i\hbar}\langle[\hat{A},\hat{H}]\rangle + \langle\frac{\partial\hat{A}}{\partial t}\rangle$

Commutators and Poisson brackets: $\frac{1}{i\hbar}[\hat{A},\hat{B}] \longrightarrow \{A,B\}_{classical}$

Time-dependent Schrödinger equation: $i\hbar\frac{\partial|\Psi(t)\rangle}{\partial t} = \hat{H}|\Psi(t)\rangle$

Probability density: $\rho(\vec{r},t) = \Psi^*(\vec{r},t)\Psi(\vec{r},t)$

Probability current density: $\vec{J}(\vec{r},t) = \frac{i\hbar}{2m}(\Psi\vec{\nabla}\Psi^* - \Psi^*\vec{\nabla}\Psi)$

Conservation of probability: $\frac{\partial\rho(\vec{r},t)}{\partial t} + \vec{\nabla}\cdot\vec{J} = 0$

Angular momentum:

$$[\hat{J}_x,\hat{J}_y] = i\hbar\hat{J}_z, \qquad [\hat{J}_y,\hat{J}_z] = i\hbar\hat{J}_x, \qquad [\hat{J}_z,\hat{J}_x] = i\hbar\hat{J}_y$$

$$\hat{\vec{J}}^2 \mid j,\ m\rangle = \hbar^2 j(j+1) \mid j,\ m\rangle, \qquad \hat{J}_z \mid j,\ m\rangle = \hbar m \mid j,\ m\rangle$$

$$\hat{J}_\pm \mid j,\ m\rangle = \hbar\sqrt{j(j+1) - m(m\pm 1)}\ \mid j,\ m\pm 1\rangle$$

$$\langle j,\ m \mid \hat{J}_x^2 \mid j,\ m\rangle = \langle j,\ m \mid \hat{J}_y^2 \mid j,\ m\rangle = \frac{\hbar^2}{2}\left[j(j+1) - m^2\right]$$

For $j = \frac{1}{2}$: $J_k = \frac{\hbar}{2}\sigma_k$ (with $k = x, y, z$), where σ_x, σ_y, and σ_z are the Pauli matrices:

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \qquad \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \qquad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

For $j = 1$: the matrices of J_x, J_y, and J_z are

$$\hat{J}_x = \frac{\hbar}{\sqrt{2}}\begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \quad \hat{J}_y = \frac{\hbar}{\sqrt{2}}\begin{pmatrix} 0 & -i & 0 \\ i & 0 & -i \\ 0 & i & 0 \end{pmatrix}, \quad \hat{J}_z = \hbar\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$