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Title

Tesi di Laurea Magistrale in
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Author: **Name Surname**

Student ID: 000000
Advisor: Prof. Name Surname
Co-advisors: Name Surname, Name Surname
Academic Year: 20XX-XX

Abstract

Here goes the Abstract in English of your thesis followed by a list of keywords. The Abstract is a concise summary of the content of the thesis (single page of text) and a guide to the most important contributions included in your thesis. The Abstract is the very last thing you write. It should be a self-contained text and should be clear to someone who hasn't (yet) read the whole manuscript. The Abstract should contain the answers to the main scientific questions that have been addressed in your thesis. It needs to summarize the adopted motivations and the adopted methodological approach as well as the findings of your work and their relevance and impact. The Abstract is the part appearing in the record of your thesis inside POLITesi, the Digital Archive of PhD and Master Theses (Laurea Magistrale) of Politecnico di Milano. The Abstract will be followed by a list of four to six keywords. Keywords are a tool to help indexers and search engines to find relevant documents. To be relevant and effective, keywords must be chosen carefully. They should represent the content of your work and be specific to your field or sub-field. Keywords may be a single word or two to four words.

Keywords: here, the keywords, of your thesis

Abstract in lingua italiana

Qui va l'Abstract in lingua italiana della tesi seguito dalla lista di parole chiave.

Parole chiave: qui, vanno, le parole chiave, della tesi

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1 | Energy functional

Now that the theoretical and numerical framework is clear, we can investigate a plausible nucleonic interaction, which in the present work, takes the form of the Skyrme interaction. It was first proposed by Tony Skyrme in 1958 [8] as a zero range force between nucleons, and has been used successfully as the building block of nuclear structure.
Nowadays, the standard form is slightly enriched to be more general [1]. It comprises a two-body interaction, which reads

$$\begin{aligned} v^{(2)}(\mathbf{r}_1,\mathbf{r}_2) &= t_0\left(1+x_0P_\sigma\right)\delta(\mathbf{r}) && (1.1)\\ &+\frac{1}{2}t_1\left(1+x_1P_\sigma\right)\left[\mathbf{P}'^2\delta(\mathbf{r})+\delta(\mathbf{r})\mathbf{P}^2\right] && (1.2)\\ &+t_2\left(1+x_2P_\sigma\right)\mathbf{P}'\cdot\delta(\mathbf{r})\mathbf{P} && (1.3)\\ &+\frac{1}{6}t_3\left(1+x_3P_\sigma\right)\left[\rho(\mathbf{R})\right]^\sigma\delta(\mathbf{r}) && (1.4)\\ &+iW_0\boldsymbol{\sigma}\cdot\left[\mathbf{P}'\times\delta(\mathbf{r})\mathbf{P}\right] && (1.5)\end{aligned}$$

And a three body interaction, that is

$$v^{(3)}(\mathbf{r}_1,\mathbf{r}_2) = \frac{1}{6}t_3\left(1+x_3P_\sigma\right)\left[\rho(\mathbf{R})\right]^\sigma\delta(\mathbf{r}) \tag{1.6}$$

Where

$$\begin{aligned} \mathbf{r} &= \mathbf{r}_1-\mathbf{r}_2\\ \mathbf{R} &= \frac{\mathbf{r}_1+\mathbf{r}_2}{2}\\ \mathbf{P} &= \frac{-i(\nabla_1-\nabla_2)}{2}\\ \boldsymbol{\sigma} &= \boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2\\ \mathbf{P}_\sigma &= \frac{(1+\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)}{2}\end{aligned}$$

Primed operators refer to the complex conjugate acting on the bra space.
This formulation respects all symmetries required of a non relativistic nuclear interaction (Galilean boost, particle exchange, translation, rotation, parity, time reversal and trans-

lation).
Taking the expectation value of the many body hamiltonian, in the Hilbert space of Slater determinants, yields

$$\langle H \rangle = \langle \Psi | \, H \, | \Psi \rangle = \int \mathcal{H}(\mathbf{r}) d\mathbf{r} = \mathcal{E}_{\text{Skyrme}} \tag{1.7}$$

In the case of even-even nuclei, time-odd components of the functional reduce to zero, leaving [9]

$$\mathcal{E}_{\text{Skyrme}} = \int \sum_{t=0,1} \left\{ C_t^{\rho}[\rho_0]\rho_t^2 + C_t^{\Delta\rho}\rho_t\nabla^2\rho_t + C_t^{\nabla\cdot J}\rho_t\nabla\cdot\mathbf{J}_t + C_t^{\tau}\rho_t\tau_t \right\} d\mathbf{r} \tag{1.8}$$

Here, $t = 0, 1$ refers to the isoscalar and isovector components of the densities, e.g.

$$\rho_0 = \rho_p - \rho_n$$
$$\rho_1 = \rho_p + \rho_n$$

Where

$$C_0^{\rho} = +\frac{3}{8}t_0 + \frac{3}{48}t_3\rho_0^{\sigma} \tag{1.9}$$
$$C_1^{\rho} = -\frac{1}{8}t_0(1+2x_0) - \frac{1}{48}t_3(1+x_3)\rho_0^{\sigma} \tag{1.10}$$
$$C_0^{\tau} = +\frac{3}{16}t_1 + \frac{1}{16}t_2(5+4x_2) \tag{1.11}$$
$$C_1^{\tau} = -\frac{1}{16}t_1(1+2x_1) + \frac{1}{16}t_2(1+2x_2) \tag{1.12}$$
$$C_0^{\Delta\rho} = -\frac{9}{64}t_1 + \frac{1}{64}t_2(5+4x_2) \tag{1.13}$$
$$C_1^{\Delta\rho} = +\frac{3}{64}t_1(1+2x_1) + \frac{1}{64}t_2(1+2x_2) \tag{1.14}$$
$$C_0^{\nabla\cdot J} = -\frac{3}{4}W_0 \tag{1.15}$$
$$C_1^{\nabla\cdot J} = -\frac{1}{4}W_0 \tag{1.16}$$

As outlined in previous chapters (REF), we can now derive the Kohn-Sham equations, by constraining orthonormality and enforcing the variation of the functional to be zero. What we end up with is

$$\left[-\nabla\left(\frac{\hbar^2}{2m_q^*(\mathbf{r})}\nabla\right) + U_q(\mathbf{r}) + \delta_{\text{q,proton}}U_C(\mathbf{r}) - i\mathbf{B}_q(\mathbf{r})\cdot(\nabla\times\boldsymbol{\sigma}) \right]\varphi_\alpha = \varepsilon_\alpha\varphi_\alpha \tag{1.17}$$

The index $q = n, p$ refers respectively to the neutron and proton quantites.
Each term is here detailed

$$\frac{\hbar^2}{2m_q^*(\mathbf{r})} = \frac{\hbar^2}{2m} + \frac{\delta\mathcal{H}}{\delta\tau_q} \tag{1.18}$$

$$U_q(\mathbf{r}) = \frac{\delta\mathcal{H}}{\delta\rho_q} \tag{1.19}$$

$$\mathbf{B}_q(\mathbf{r}) = \frac{\delta\mathcal{H}}{\delta\mathbf{J}_q} \tag{1.20}$$

The coulomb field U_C, which is present only in the single particle equation for protons, will be properly developed in section (REF).
Following the rules for functional derivatives, outlined in the appendix (REF) for our particular case, we have

$$\frac{\hbar^2}{2m_q^*(\mathbf{r})} = + \frac{\hbar^2}{2m} \tag{1.21}$$

$$+ \frac{1}{8}[t_1(2 + x_1) + t_2(2 + x_2)]\rho(\mathbf{r}) \tag{1.22}$$

$$- \frac{1}{8}[t_1(1 + 2x_1) + t_2(1 + 2x_2)]\rho_q(\mathbf{r}) \tag{1.23}$$

$$\tag{1.24}$$

$$U_q(\mathbf{r}) = + \frac{1}{8}[t_1(2 + x_1) + t_2(2 + x_2)]\rho \tag{1.25}$$

$$+ \frac{1}{8}[t_2(1 + 2x_2) - t_1(1 + 2x_1)]\rho_q \tag{1.26}$$

$$+ \frac{1}{8}[t_1(2 + x_1) + t_2(2 + x_2)]\tau \tag{1.27}$$

$$+ \frac{1}{8}[t_2(1 + 2x_2) - t_1(1 + 2x_1)]\tau_q \tag{1.28}$$

$$+ \frac{1}{16}[t_2(2 + x_2) - 3t_1(2 + x_1)]\nabla^2\rho \tag{1.29}$$

$$+ \frac{1}{16}[3t_1(2x_1 + 1) + t_2(2x_2 + 1)]\nabla^2\rho_q \tag{1.30}$$

$$\tag{1.31}$$

$$\mathbf{W}_q(\mathbf{r}) = + \frac{1}{2}W_0[\nabla\rho + \nabla\rho_q] \tag{1.32}$$

$$- \frac{1}{8}(t_1x_1 + t_2x_2)\mathbf{J} + \frac{1}{8}(t_1 - t_2)\mathbf{J}_q \tag{1.33}$$

For ease of notation and implementation, unindexed densities refer to isovector quantites.

Introduction

This document is intended to be both an example of the Polimi LaTeX template for Master Theses, as well as a short introduction to its use. It is not intended to be a general introduction to LaTeX itself, and the reader is assumed to be familiar with the basics of creating and compiling LaTeX documents (see [5, 7]).
The cover page of the thesis must contain all the relevant information: title of the thesis, name of the Study Programme and School, name of the author, student ID number, name of the supervisor, name(s) of the co-supervisor(s) (if any), academic year. The above information are provided by filling all the entries in the command `\puttitle{}` in the title page section of this template.
Be sure to select a title that is meaningful. It should contain important keywords to be identified by indexer. Keep the title as concise as possible and comprehensible even to people who are not experts in your field. The title has to be chosen at the end of your work so that it accurately captures the main subject of the manuscript.
Since a thesis might be a substantial document, it is convenient to break it into chapters. You can create a new chapter as done in this template by simply using the following command

```
\chapter{Title of the chapter}
```

followed by the body text.
Especially for long manuscripts, it is recommended to give each chapter its own file. In this case, you write your chapter in a separated `chapter_n.tex` file and then include it in the main file with the following command

```
\input{chapter_n.tex}
```

It is recommended to give a label to each chapter by using the command

```
\label{ch:chapter_name}%
```

where the argument is just a text string that you'll use to reference that part as follows: *Chapter 2 contains* AN INTRODUCTION TO . . . .
If necessary, an unnumbered chapter can be created by

```
\chapter*{Title of the unnumbered chapter}
```

2 | Chapter one

In this chapter additional useful information are reported.

2.1. Sections and subsections

Chapters are typically subdivided into sections and subsections, and, optionally, subsubsections, paragraphs and subparagraphs. All can have a title, but only sections and subsections are numbered. A new section is created by the command

```
\section{Title of the section}
```

The numbering can be turned off by using `\section*{}`.
A new subsection is created by the command

```
\subsection{Title of the subsection}
```

and, similarly, the numbering can be turned off by adding an asterisk as follows

```
\subsection*{}
```

2.2. Equations

This section gives some examples of writing mathematical equations in your thesis.

Maxwell's equations read:

$$\begin{cases} \nabla \cdot \boldsymbol{D} = \rho, & \text{(2.1a)} \\ \nabla \times \boldsymbol{E} + \dfrac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{0}, & \text{(2.1b)} \\ \nabla \cdot \boldsymbol{B} = 0, & \text{(2.1c)} \\ \nabla \times \boldsymbol{H} - \dfrac{\partial \boldsymbol{D}}{\partial t} = \boldsymbol{J}. & \text{(2.1d)} \end{cases}$$

Equation (2.1) is automatically labeled by `cleveref`, as well as Equation (2.1a) and Equation (2.1c). Thanks to the `cleveref` package, there is no need to use `\eqref`.

Remember that Equations have to be numbered only if they are referenced in the text.

Equations (2.2), (2.3), (2.4), and (2.5) show again Maxwell's equations without brace:

$$\nabla \cdot \boldsymbol{D} = \rho, \tag{2.2}$$

$$\nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = \mathbf{0}, \tag{2.3}$$

$$\nabla \cdot \boldsymbol{B} = 0, \tag{2.4}$$

$$\nabla \times \boldsymbol{H} - \frac{\partial \boldsymbol{D}}{\partial t} = \boldsymbol{J}. \tag{2.5}$$

Equation (2.6) is the same as before, but with just one label:

$$\begin{cases} \nabla \cdot \boldsymbol{D} = \rho, \\ \nabla \times \boldsymbol{E} + \dfrac{\partial \boldsymbol{B}}{\partial t} = \mathbf{0}, \\ \nabla \cdot \boldsymbol{B} = 0, \\ \nabla \times \boldsymbol{H} - \dfrac{\partial \boldsymbol{D}}{\partial t} = \boldsymbol{J}. \end{cases} \tag{2.6}$$

2.3. Figures, Tables and Algorithms

Figures, Tables and Algorithms have to contain a Caption that describe their content, and have to be properly reffered in the text.

2.3.1. Figures

For including pictures in your text you can use `TikZ` for high-quality hand-made figures, or just include them as usual with the command

```
\includegraphics[options]{filename.xxx}
```

Here xxx is the correct format, e.g. `.png`, `.jpg`, `.eps`, ...

Figure 2.1: Caption of the Figure to appear in the List of Figures.

Thanks to the \subfloat command, a single figure, such as Figure 2.1, can contain multiple sub-figures with their own caption and label, e.g. Figure 2.2a and Figure 2.2b.

(a) One PoliMi logo.

(b) Another one PoliMi logo.

Figure 2.2: This is a very long caption you don't want to appear in the List of Figures.

2.3.2. Tables

Within the environments `table` and `tabular` you can create very fancy tables as the one shown in Table 2.1.

Title of Table (optional)

	column 1	**column 2**	**column 3**
row 1	1	2	3
row 2	α	β	γ
row 3	alpha	beta	gamma

Table 2.1: Caption of the Table to appear in the List of Tables.

You can also consider to highlight selected columns or rows in order to make tables more readable. Moreover, with the use of `table*` and the option `bp` it is possible to align them at the bottom of the page. One example is presented in Table 2.2.

	column1	**column2**	**column3**	**column4**	**column5**	**column6**
row1	1	2	3	4	5	6
row2	a	b	c	d	e	f
row3	α	β	γ	δ	ϕ	ω
row4	alpha	beta	gamma	delta	phi	omega

Table 2.2: Highlighting the columns

	column1	**column2**	**column3**	**column4**	**column5**	**column6**
row1	1	2	3	4	5	6
row2	a	b	c	d	e	f
row3	α	β	γ	δ	ϕ	ω
row4	alpha	beta	gamma	delta	phi	omega

Table 2.3: Highlighting the rows

2.3.3. Algorithms

Pseudo-algorithms can be written in LaTeX with the `algorithm` and `algorithmic` packages. An example is shown in Algorithm 2.1.

Algorithm 2.1 Name of the Algorithm

```
Initial instructions
for for − condition do
    Some instructions
    if if − condition then
        Some other instructions
    end if
end for
while while − condition do
    Some further instructions
end while
Final instructions
```

2.4. Theorems, propositions and lists

2.4.1. Theorems

Theorems have to be formatted as:

Theorem 2.1. *Write here your theorem.*

Proof. If useful you can report here the proof.

2.4.2. Propositions

Propositions have to be formatted as:

Proposition 2.1. *Write here your proposition.*

2.4.3. Lists

How to insert itemized lists:

- first item;
- second item.

How to insert numbered lists:

1. first item;
2. second item.

2.5. Use of copyrighted material

Each student is responsible for obtaining copyright permissions, if necessary, to include published material in the thesis. This applies typically to third-party material published by someone else.

2.6. Plagiarism

You have to be sure to respect the rules on Copyright and avoid an involuntary plagiarism. It is allowed to take other persons' ideas only if the author and his original work are clearly mentioned. As stated in the Code of Ethics and Conduct, Politecnico di Milano *promotes the integrity of research, condemns manipulation and the infringement of* *intellectual property*, and gives opportunity to all those who carry out research activities to have an adequate training on ethical conduct and integrity while doing research. To be sure to respect the copyright rules, read the guides on Copyright legislation and citation styles available at:

`https://www.biblio.polimi.it/en/tools/courses-and-tutorials`

You can also attend the courses which are periodically organized on "Bibliographic citations and bibliography management".

2.7. Bibliography and citations

Your thesis must contain a suitable Bibliography which lists all the sources consulted on developing the work. The list of references is placed at the end of the manuscript after the chapter containing the conclusions. We suggest to use the BibTeX package and save the bibliographic references in the file `Thesis_bibliography.bib`. This is indeed a database containing all the information about the references. To cite in your manuscript, use the `\cite{}` command as follows:
Here is how you cite bibliography entries: [3], or multiple ones at once: [4, 6].
The bibliography and list of references are generated automatically by running BibTeX [2].

3 | Conclusions and future developments

A final chapter containing the main conclusions of your research/study and possible future developments of your work have to be inserted in this chapter.

Bibliography

[1] E. Chabanat, P. Bonche, P. Haensel, J. Meyer, and R. Schaeffer. A skyrme parametrization from subnuclear to neutron star densities. *Nuclear Physics A*, 627(4):710–746, 1997. ISSN 0375-9474. doi: https://doi.org/10.1016/S0375-9474(97)00596-4. URL `https://www.sciencedirect.com/science/article/pii/S0375947497005964`.

[2] CTAN. BiBTeX documentation, 2017. URL `https://ctan.org/topic/bibtex-doc`.

[3] D. E. Knuth. Computer programming as an art. *Commun. ACM*, pages 667–673, 1974.

[4] D. E. Knuth. Two notes on notation. *Amer. Math. Monthly*, 99:403–422, 1992.

[5] S. Kottwitz. *LaTeX Cookbook*. Packt Publishing Ltd, 2015.

[6] L. Lamport. *LaTeX: A Document Preparation System*. Pearson Education India, 1994.

[7] T. Oetiker, H. Partl, I. Hyna, and E. Schlegl. The not so short introduction to latex2ε. *Electronic document available at http://www. tex. ac. uk/tex-archive/info/lshort*, 1995.

[8] T. Skyrme. The effective nuclear potential. *Nuclear Physics*, 9(4):615–634, 1958. ISSN 0029-5582. doi: https://doi.org/10.1016/0029-5582(58)90345-6. URL `https://www.sciencedirect.com/science/article/pii/0029558258903456`.

[9] P. Stevenson and M. Barton. Low-energy heavy-ion reactions and the skyrme effective interaction. *Progress in Particle and Nuclear Physics*, 104:142–164, 2019.

A | Appendix A

If you need to include an appendix to support the research in your thesis, you can place it at the end of the manuscript. An appendix contains supplementary material (figures, tables, data, codes, mathematical proofs, surveys, ...) which supplement the main results contained in the previous chapters.

B | Appendix B

It may be necessary to include another appendix to better organize the presentation of supplementary material.

List of Figures

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List of Symbols

Variable	Description	SI unit
$\boldsymbol{u}$	solid displacement	m
$\boldsymbol{u}_f$	fluid displacement	m

Acknowledgements

Here you might want to acknowledge someone.