Irreversible Thermodynamics and Hydrodynamics of Biological Membranes

by

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Abstract

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This thesis is concerned with developing a wholistic description of biological membranes: fascinating materials that make up the boundary of the cell, as well as many of the cell's internal organelles. Our formulation of the theory of such materials relies on two well-known concepts: differential geometry and irreversible thermodynamics. The setting of differential geometry allows us to describe curves and surfaces, which in this case are embedded in the three-dimensional Euclidean space, while irreversible thermodynamics provides a theoretical framework to develop constitutive relations between the various thermodynamic forces and fluxes in a system. Both concepts are well-known, and are reviewed in Part . . .

Acknowledgments

I acknowledge . . .

{*Dedication . . .* }

Contents

Chapter I

Introduction

This is a PhD thesis template, which satisfied all of the UC Berkeley requirements in Summer 2022. The majority of the style formatting can be found in `thesis-ucb.sty`; some parts of the front matter styling are located in the main TEX file: `thesis-ucb.tex`. Make sure you change the `pdfauthor`, `pdftitle`, and `pdfsubject` in the style file. If you desire, you can split your thesis into “parts” with the `\part{}` command.

Part A

Theory

Chapter II

Important Chapter

> *Classical thermodynamics has solved the problem of the competition between randomness and organization for equilibrium situations. How then is it possible to extend these results to dissipative systems? What part of the energy flow may be used to create and maintain some structure in such systems?*
>
> —Ilya R. Prigogine, 1955 [‡]

I like to begin thesis chapters with a quote. Note that if you use the `\footcite{}` command, then the citation will appear as a footnote, and will also be reported *at the end of each chapter.* For this reason, the file `bib.tex` should be included after every chapter in the file `thesis-ucb.tex` with the command `\input{content/common/bib}`. You can also use the `\footnote{}` command, and then the `\cite{}` command within the footnote, as in the following example which produces the footnote below: [†]

```
\footnote{Consider the scaling analysis by \cite{sahu-mandadapu-pre-2020}.}
```

Note that you can include arXiv links in your citations! The bibliography is compiled by running the command `biber thesis-ucb.bcf` in the command line.

1. The equation environment

Some custom commands are provided in the `content/common/custom-commands.tex` file. The following equation was obtained by writing `\bmnabla \bmcdot \bmv \, = \, 0 ~.`

$$\boldsymbol{\nabla} \cdot \boldsymbol{v} \, = \, 0 ~. \tag{1}$$

In general, I recommend adding additional spaces in math mode, to create a more aesthetic result. The command `\` creates a large space, the command `\,` creates a medium space, and the custom command `\mke` (equivalently `\mkern1mu`) makes a small space. Additionally, the command `~` creates a very large space.

[‡] I. Prigogine. *Introduction to Thermodynamics of Irreversible Processes.* 3rd ed. New York: Interscience Publishers, 1967.

[†] Consider the scaling analysis by A. Sahu, A. Glisman, J. Tchoufag, and K.K. Mandadapu. "Geometry and dynamics of lipid membranes: The Scriven–Love number". *Phys. Rev. E* **101** (2020), 052401. arXiv: 1910.10693.

2. The additional environments

Here, we show two additional features. You can construct an 'Example' environment (currently, this can handle page breaks, but does not maintain nice spacing):

EXAMPLE 1: AN EXAMPLE ENVIRONMENT

Consider an example, which you would like to present to the reader. I like the following equation:

$$e^{i\pi} + 1 = 0 \; .$$

Also, you can display algorithms as follows:

Algorithm II.1: `C++` pseudocode of an algorithm

```
// mesh and basis function calculations
generate_mesh(); generate_basis_functions();

for (time_index = 0; time_index < num_time_steps; ++time_index) {

   initialize_u_vector(); initialize_delta_u();

   while (norm(delta_u) > newton_tolerance) {
      // initialize global residual vector and stiffness matrix
      initialize_r_vector(); initialize_K_matrix();

      assemble_K_matrix();
      assemble_r_vector();

      // apply boundary conditions
      apply_boundary_conditions(K_matrix, r_vector);

      solve_delta_u(delta_u, K_matrix, r_vector);
      u_vector += delta_u;
   }

   output_u_vector();
}
```

Both the example and algorithm environments can be modified in the `thesis-ucb.sty` file.

References

[1] I. Prigogine. *Introduction to Thermodynamics of Irreversible Processes*. 3rd ed. New York: Interscience Publishers, 1967

[2] A. Sahu et al. "Geometry and dynamics of lipid membranes: The Scriven–Love number". *Phys. Rev. E* **101** (2020), 052401. arXiv: 1910.10693