A practical walk through formal scattering theory

Connecting bound states, resonances, and scattering states in exotic nuclei and beyond

Introduction

Sebastian König, NC State University

Code of conduct

We want this summer school to be an enjoyable experience for everyone! To ensure this, everyone should adhere to the **FRIB Theory Alliance Code of Conduct**:

The FRIB Theory Alliance is committed to fostering a safe, diverse, and equitable environment that values mutual respect and personal integrity. [...] FRIB-TA does not tolerate harassment of any kind, including sexual harassment, bullying, intimidation, violence, threats of violence, retaliation, or other disruptive behavior. Discrimination in any guise (verbal, written or physical) based on an individual's race, color, sex, religion, disability, etc. is not acceptable. [...]

- Discrimination is defined as prejudicial treatment of individuals or groups of people based on their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws.
- Sexual harassment is unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature that creates an intimidating, hostile, or offensive environment. Other types of harassment include any verbal or physical conduct directed at individuals or groups of people because of their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws, that creates an intimidating, hostile, or offensive environment.
- Bullying is unwelcome, aggressive behavior involving the use of influence, threat, intimidation, or coercion to dominate others in the professional environment.

About the FRIB Theory Alliance

Facility for Rare Isotope Beams (FRIB)

- established and operated at Michigan State University (MSU)
- funded by the U.S. Department of Energy Office of Science (DOE-SC)

FRIB will enable scientists to make discoveries about the properties of rare isotopes (that is, short-lived nuclei not normally found on Earth), nuclear astrophysics, fundamental interactions, and applications for society, including in medicine, homeland security, and industry. (https://frib.msu.edu)

Theory Alliance (TA)

- initiative funded by the DOE-SC, Office of Nuclear Physics (grant DE-SC0013617)
- broad scientific mission, **including in particular support for this school**

The FRIB Theory Alliance (FRIB-TA) is a coalition of scientists from universities and national laboratories who seek to foster advancements in theory related to diverse areas of FRIB science; optimize the coupling between theory and experiment; and stimulate the field by creating permanent theory positions across the country, attracting young talent through the national FRIB Theory Fellow Program, fostering interdisciplinary collaborations, and shepherding international initiatives. (https://fribtheoryalliance.org)

About your lecturers

Kévin Fossez

- FRIB Theory Fellow at Argonne National Lab
- moving to Florida State University (as FRIB-TA Bridge Faculty)
- open quantum systems, many-body methods, nuclear structure and reactions

Heiko Hergert

- Associate Professor at FRIB / Michigan State University
- nuclear structure and reactions, RG methods, BSM physics

Sebastian König

- Assistant Professor at North Carolina State University (FRIB-TA Bridge Faculty)
- few-body systems, nuclear effective field theories, finite-volume techniques

Virtual setup

While we eagerly await a return to in-person events, this summer school will still be held virtually. **We would like all of you to follow the current set of guidelines and Zoom etiquette.**

1. We are a small class and would like to set up the school to be as interactive and personal as circumstances allow. To foster as much as possible an atmosphere of being together in a room, we encourage all of you to keep your cameras turned on during both lecture and lab sessions.
2. We have decided not to record lectures to make everyone feel comfortable in the protected space of the virtual classroom.
3. While not speaking, please make sure your microphone is muted.
4. You should ask at any time if you have a question. To do so, please try first raising your hand on Zoom, and if that does not catch our attention, feel free to unmute and interrupt. You may also post questions in the Zoom chat.
5. While Zoom is very convenient for online lecturing, the build-in chat is somewhat tedious to use. We have therefore set up a Slack channel where you can communicate with us and with each other.

Structure of this school

The promise

This summer school will offer an introduction to nonrelativistic quantum scattering theory, discussing its fundamental assumptions and techniques guided by concrete applications. Formal aspects, centered around the important concept of the S-matrix, will be covered in detail, complemented at each step by numerical illustrations and hands-on programming exercises. At the end of this three-day course, participants will have a firm understanding of the basic concepts of scattering theory, how they relate to a variety of few- and many-body quantum systems, and how they can be implemented numerically for simple examples.

The implementation

- **lecture sessions** will introduce and/or review key concepts
  - slides will serve as reference
  - Jupyter notebooks will present numerical implementations
- **programming lab sessions** will allow each of you to internalize material from the lecture by implementing applications

Programming labs

- about 40% of the overall course time is allocated for programming labs
- you **work together** on assignments **in groups of five people**
  - programming in Google Colaboratory (Colab)
  - communication via Zoom breakout rooms (and optionally Slack)
- as **lecturers will switch between breakout rooms** to help you
- we will provide pre-prepared Colab notebooks, one per group and assignment
  - Python helper library included via download

Working with Colab

- Google Colab permits parallel editing...
- ...but unlike Google Docs, changes are not visible live
- we therefore suggest you elect one primary editor per group
- to try things in parallel, each of you can create notebook copies in playground mode
  - select "File → Open Notebook in Playground Mode"

Python library

- for convenience, we provide a small **library of Python classes and functions**
- this provides the basic programming infrastructure for examples and labs

Included functionality

- quadrature meshes
- physical system properties (particle mass etc.)
- potentials and operators
- global spline interpolation

Example

```
from lib.system import *
from lib.potential import *

# Set up a two-nucleon system:
sys = System(mass=938.918, scale=197.327)

# Convert momentum of 1.0 MeV to energy:
print(sys.e_from_k(1.0))
```

Recommended literature

Textbooks

- **John R. Taylor, Scattering Theory: The Quantum Theory of Nonrelativistic Collisions**, Dover Publications, 1972/2000
  - excellent introduction to scattering theory
  - covering mathematical details and proofs
  - yet intuitively accessible and readable
- **Roger G. Newton, Scattering Theory of Waves and Particles**, Second Edition, Dover Publications, 1966/1982/2002
  - another excellent discussion, covering more material than Taylor
  - more emphasis on mathematical aspects, but still very readable
- **Walter Glöckle, The Quantum Mechanical Few-Body Problem**, Springer, 1983
  - main emphasis on three-body calculations
  - first chapter contains excellent summary of formal scattering theory
  - second chapter discusses two-nucleon systems