

## Computational Physics

Physics 711/811 has the task of both giving a solid treatment of basic methods, tools, and techniques of computational physics used in modern physics, and developing skills for practical solving computational problems in physics.

This is not a course in computing science, or in programming. It focuses specifically on practical methods for solving physics problems. The course is therefore designed such that a significant fraction of the students' time is spent actually programming specific physical problems. In this course the students **learn by doing**. Students will practice writing, compiling, and running computer programs, together with analysis of results, and presentation of their results as scientific reports.

<b>University Catalog</b>	PHYS 711/811. Computational Physics. 3 Credits. Studies of high-level computer languages. Computational techniques used in physics. Numerical techniques for differential and integral problems. Algebraic processing languages. Introduction to scientific visualization techniques.
<b>Course structure</b>	This course is conducted <b>asynchronously</b> , allowing students to complete the modules and assignments at their own pace within the weekly schedule. Each week consists, on average, of the following components: 1) Two video lectures accompanied by lecture notes (as reading material), 2) An assignment (either as exercises or a project), 3) Office hours as Zoom meetings. At the beginning of each week students will have a detailed schedule for the week.
<b>Course materials</b>	Video lectures, lecture notes, assignments and other class materials will be published on Canvas's class page.
<b>Instructor</b>	Dr. Alexander Godunov Office: OCNPS 0219 (Oceanography and Physics) Phone: 683-5805 email: <a href="mailto:agodunov@odu.edu">agodunov@odu.edu</a> Web: <a href="http://www.odu.edu/~agodunov">www.odu.edu/~agodunov</a>
<b>Textbooks</b>	There is no book that could serve as a sole book for the course. However, there are many excellent books (see page 5 of the syllabus).
<b>Requisites</b>	<i>Hardware and software essential for this class:</i> a computer with a language/software of your choice (C, C++, Python, MatLab, Fortran).
<b>Support resources</b>	<i>Office hours:</i> Mondays: Time (preliminary) 14:30-15:30 (subject to change after consulting with the class) (Zoom: <a href="https://odu.zoom.us/j/93780386433">https://odu.zoom.us/j/93780386433</a> or Meeting ID: 937 8038 6433, Passcode: CPhys811 and by appointment (the same Zoom meeting info). <i>E-mail:</i> <a href="mailto:agodunov@odu.edu">agodunov@odu.edu</a> (have "Physics 811" in the subject line).
<b>Homework</b>	Homework assignments will be set as we progress through the course. All assignments should be submitted electronically as pdf files. Program listings should be attached as well. Doing the homework problems is one of the best



ways to learn the material. You should start homework early and get help if needed before the due date.

No individual extensions of assignment submission dates will be given.

**Filename standard:** LastName\_HXX.pdf where XX in a homework assignment.

### Projects

There will be midterm computational projects and one final project. The projects will aim to solve specific problems in physics. You will be required to submit a report on each project. All reports should have the following sections: title, description of the problem, equations and computational model, testing, example of input parameters, results (figures, tables, analysis), and conclusion.

The report together with your computer program should be submitted electronically by the due date and time (as an attachment, including an example with input/output files). This will enable the assessors to check and run your program if necessary. Please, remember that “no submitted program = no credit for the assignment”. Recommended format for reports is PDF, with all figures embedded in the body of the document. Each assignment will be graded for completeness and correctness. Clarity of your presentation may affect your grade. No make-up projects will be given.

**Filename standard:** LastName\_PXX.pdf where XX in an assigned project.

### Final Exam/Project

Since this is a “learn by doing” course, there will be no traditional final exam but a final project. The final project should be written as a short research paper based on your calculations.

### Course grades

The final grade is calculated on an absolute scale. There are 100 points possible for this course of which  
40 points are for homework assignments,  
40 points for midterm projects,  
20 points for the final project.

A letter grade is determined only at the end of the term.

Grade Requirements

$92 \leq A < 100$     $88 \leq A- < 92$     $83 \leq B+ < 88$

$75 \leq B < 83$     $70 \leq B- < 75$     $65 \leq C+ < 70$

$60 \leq C < 65$     $55 \leq C- < 60$     $50 \leq D < 55$     $F < 50$

### Keys to success

Right motivation, working diligently, effectively and efficiently is the key to success. If you work regularly and allocate enough time each day to practice and complete the assignments on time and keep up with the course, you will get the most out of the course both intellectually and grade-wise.

You should invest about 6-9 hours per week outside of class to succeed in this course. This is consistent with university guidelines (i.e. two to three hours of outside preparation time for every credit hour). Students with little or no programming experience (or those who love the subject and wish to do extremely well in it) may want to put in more hours. Please, let me know as soon as possible if you have difficulties and may need extra help.

You are recommended to start your assignments well before the last night when your assignments are due. It is a general experience that a computer program usually does not work correctly (if works at all) at the beginning. A search for a problem, or a computer bug, may take much more time that you expect.

**Collaboration**

Collaboration is strongly encouraged. Because the course is graded on an absolute scale, you will never reduce your grade by helping others — on the contrary, by doing so you will reinforce your own knowledge and improve your performance. Although, before working together or consulting others on any assignments, it is helpful to first tackle the work alone.

Activities for which collaboration is encouraged: group projects, understanding issues discussed in class, using compilers and other software, using numerical libraries.

Activities for which collaboration is NOT permitted are homework assignments, individual projects (unless stated otherwise), and the final project.

**Professional Integrity**

In Physics 711/811 high professional and ethical standards are promoted. Plagiarism and cheating are serious offenses and may be punished by failure on the exam and failure in the course. The academic integrity code is to be maintained at all times. Using Google, Chegg, and similar resources for getting solutions to homework problems and projects is considered as cheating.

**Accommodation**

Students are encouraged to self-disclose disabilities that have been verified by the Office of Educational Accessibility by providing Accommodation Letters to their instructors early in the semester in order to start receiving accommodations. Accommodations will not be made until the Accommodation Letters are provided to instructors each semester.

**Using AI Tools**

In this course, we encourage the exploration of AI tools to enrich your learning experience. These innovative tools can offer valuable assistance. However, it is important to note that these tools should be used responsibly and ethically. While AI can be a powerful aid, it is crucial to understand that using AI tools to cheat on assignments is strictly prohibited. The purpose of assignments is to assess your understanding and skills; cheating not only undermines this process but also diminishes your own growth. Therefore, we expect all students to use AI tools as a supplement to their learning, but not as a means to cheat or gain an unfair advantage.

**The use of AI tools as automated code generators is strictly forbidden.**

## Course Outline

### Part 1: Introduction to computing

1. Tools of computational physics
2. Numerical and physics libraries
3. Computer languages (C/C++, MatLab, Fortran, Python, ...) and physics
4. \* High-performance computing

### Part 2: Introduction to basic numerical methods with applications to physics

1. Interpolation.
2. Derivatives
3. Numerical integration
4. Solution of non-linear equations
5. Ordinary differential equations: initial and boundary value problems
6. Linear Algebra: systems of linear equations, eigenvalue problems
7. Partial differential equations (elliptic, parabolic, hyperbolic)
8. Data fitting and analysis
9. Optimization: genetic algorithm.

### Part 3: Application to physics, computer simulation methods

1. Monte Carlo simulation
  - 1.1 Monte Carlo integration (including Metropolis sampling)
  - 1.2 Random walk with applications
  - 1.3 Some applications of Monte Carlo simulation to classical and quantum systems
2. Classical mechanics
  - 2.1 Particle motion
  - 2.2 Classical scattering
  - 2.3 \* Molecular dynamics simulation
3. Quantum mechanics
  - 3.1 Time-independent Schrodinger equation
  - 3.2 \* Time-dependent Schrodinger equation
  - 3.3 \*\* Quantum scattering
4. Statistical mechanics
  - 4.1 Heat equation
  - 4.2 \*Thermal systems, Ising model
5. Electromagnetic theory
  - 5.1 \* \*Potentials and fields
6. Additional chapters
  - 6.1 Based on suggestions from students and from students' advisors

Some topics may be added, and some topics omitted at the instructor's discretion, and depending on student's interest and time constraints.

\* *Depending on class preparedness*

\*\* *Indicates "optional" sections (if we get that far)*

## Books

### Computational Physics (recommended for the class)

1. R. Landau et. all
  - a. Computational Physics. Problem solving with computers (Wiley 1997)  
First edition: **C++ and Fortran** based
  - b. Computational Physics. Problem solving with computers (Wiley 2007)  
Second edition: **Java** based
  - c. Computational Physics. Problem solving with computers (Wiley 2015)  
Third edition: **Python** based
  - d. Computational Problems for Physics:  
With Guided Solutions Using **Python** (CRC Press 2018)
2. H. Gould et all, An Introduction to Computer Simulation Methods:  
Applications to Physical Systems, (Addison-Wesley; 3<sup>rd</sup> edition 2006)  
**Java** based
3. Jay Wang, Computational Modeling and Visualization of Physical Systems  
with **Python** (Wiley 2015)
4. Jos Thijssen, Computational Physics (Cambridge University Press; 2<sup>nd</sup> edition 2007)  
Upper-level graduate text with an emphasis on condensed matter applications.  
**Language independent** text

### Numerical methods

1. J.D. Hoffman, Numerical Methods for Engineers and Scientists (CRC Press; 2<sup>nd</sup> edition 2001)  
with **Fortran** examples
2. T. Sauer, Numerical Analysis (Pearson, 3<sup>rd</sup> edition, 2018)  
with **MatLab** examples
3. W.H.Press et all, Numerical Recipes. The Art of Scientific Computing (Cambridge University Press 3<sup>rd</sup>  
edition 2007)  
**C++** based, note that other editions are centered on **Fortran, C, Pascal**
4. J.R.Dormand, Numerical Methods for Differential Equations: A Computational Approach (CRC-Press  
1996) with **Fortran** examples
5. P. Davis and P. Rabinowitz, Methods of Numerical Integration (Academic Press 1984)  
with **Fortran** examples

### Computer languages (many excellent books, here my favorites)

1. P. Deitel and H. Deitel, **C++** How to program (Pearson; 10th edition 2016)
2. B. Hahn and D.T. Valentine, Essential **MATLAB** for Engineers and Scientists  
(Academic Press; 7th edition 2019)
3. M. Lutz, Learning **Python** (O'Reilly, 5th Edition Fifth Edition 2013)
4. S. Chapman, **Fortran** for scientists and engineers (McGraw Hill; 4th edition 2017)