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Physics on the Back of the Envelope

Instructor

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Place and Times

Mondays, Wednesdays, and Fridays, 2:05-2:55pm
Room L5, Howey Physics Building

Textbook

None, but there are several good sources of relevant information:

- Dimensional Analysis by J.C. Gibbings
- Scaling by G.I. Barenblatt
- Gases, Liquids and Solids and Other States of Matter by D.N. Tabor
- Understanding the Properties of Matter by M. de Podesta
- On Size and Life by T.A. McMahon and J.T. Bonner

In addition, you should print out a list of useful physical constants and values that come up often in order-of-magnitude calculation.

Course Description

The aim of this course is to enhance your problem solving skills by integrating the knowledge that you have accumulated during your undergraduate (as well as graduate) studies and help you transition from taking classes to doing research. We will mainly discuss the use of approximate calculations as a tool that allows one both to do a preliminary exploration of unfamiliar problems by identifying the important physical phenomena and to check the results of detailed (analytical or numerical) calculations. Dimensional analysis, scaling arguments, and perturbation theory will be used to explore problems in classical and quantum mechanics, thermodynamics and statistical physics, fluid dynamics, biophysics, and astrophysics. However, the main emphasis will be on applications, rather than fundamental physics.

Pre-requisites

You are expected to be familiar with classical and quantum mechanics, electricity and magnetism,

thermodynamics and statistical mechanics at the undergraduate level. It is ok if you are learning relevant material concurrently with this course (or if you already forgot some of it).

Grading

The class will be highly interactive, with all students expected to actively participate in the discussion. The grades will be based on class participation as well as homeworks and a final project.

Course Schedule

1. Counting and Estimation

- A typical Brinks truck and how it is made
- Age distribution of the US population

2. Scaling

- Blood vessels in the lungs, in the brain, somewhere else, and their fractal structure. Base metabolic rate scaling.
- Plants: leaf vessels, tree branches, and tree roots. Branch and root scaling.
- "Life's Universal Scaling Laws," G. B. West and J. H. Brown, *Physics Today* **57**, 36 (2004) [pdf]
- "A General Model for the Origin of Allometric Scaling Laws in Biology," G. B. West, J. H. Brown and B. J. Enquist, *Science* **276**, 122 (1997) [pdf]
- "Re-examination of the "3/4-law" of Metabolism," P. S. Dodds, D. H. Rothman and J. S. Weitz, *J. Theor. Biol.* **209**, 9 (2001) [pdf]

3. Dimensional analysis

- Drag coefficient for a sphere
- Friction coefficient for a pipe
- Water striders walking (and resting) on water: [movie], [movie]
- "Jesus Christ" lizard running on water: [movie], [movie], [movie]
- Sizing animals

4. Differential equations and scales

- Turkey roasting times
- Science of cooking meat

5. Perturbation theory

- Boundary layer of a flat plate

6. Putting the pieces together

- Fastest way to freeze boiling water?
- Shape and size of falling droplets
- "Single-drop fragmentation determines size distribution of raindrops," E. Villermaux and B.

Rossa, *Nature Physics* **5**, 697 (2009) [pdf]
- Shape of the largest bubbles

7. Fundamental principles of physical theories

8. Material properties

Homework Assignments

- **Problem set #1:** assignment
- **Problem set #2:** assignment **Solution:** light bending
- **Problem set #3:** assignment **Solutions (1,3,5/6):** Maple worksheet

Course project

- Due Tuesday, April 30 at 12 noon. If I am not in, please slide under the door.

Course Instructor Opinion Survey

Please fill out the online Course Survey. This is your real opportunity to provide feedback regarding the contents of the course, the style and quality of the presentation, or any other subject related to the course. Tell us what you liked and what you did not like. Your input is very valuable and will benefit students taking this course in subsequent years.