Missing Matter in the Physics Majors' Curriculum

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Caveats

- I’ll be talking about upper-level courses, yet I’ve only taught the calculus-based intro course.
  - But I’ve participated in general curriculum discussions in several physics departments.
- While the typical majors’ curriculum has structural problems, skilled instructors may of course try to address and overcome these problems.
  - But their job would be easier if the structure were improved.

Matter in the curriculum

- The undergraduate curriculum in most physics departments (over)emphasizes mathematical physics, with anonymous 3 kg masses and 5 microcoulomb charges.
- But a block of aluminum is different from a block of lead, and these differences are an important part of physics.

Physical modeling

Lack of physical modeling contributes to the missing matter in the curriculum. Students are rarely asked to construct a physical model themselves, making idealizations, approximations, estimates, etc. As a result, the real world is not well represented, and the real matter of the real world.

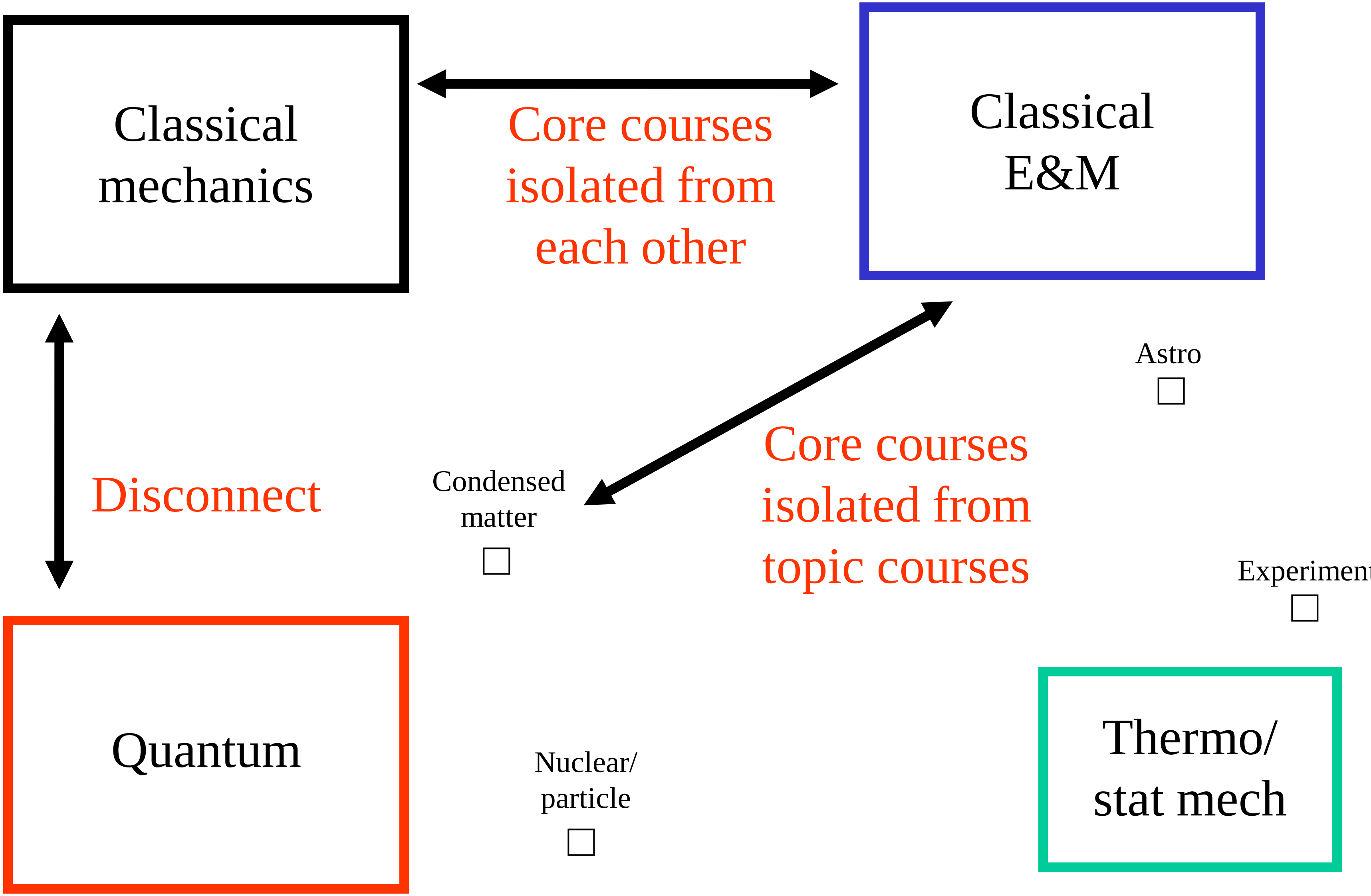
Atomic nature of matter

Ignoring the atomic nature of matter contributes to the missing matter in the curriculum. The introductory physics course, the intermediate mechanics course, and the intermediate E&M course rarely consider atoms, even when basic physics principles could be applied (e.g. energy conservation). Opportunities are missed to make macro-micro connections.

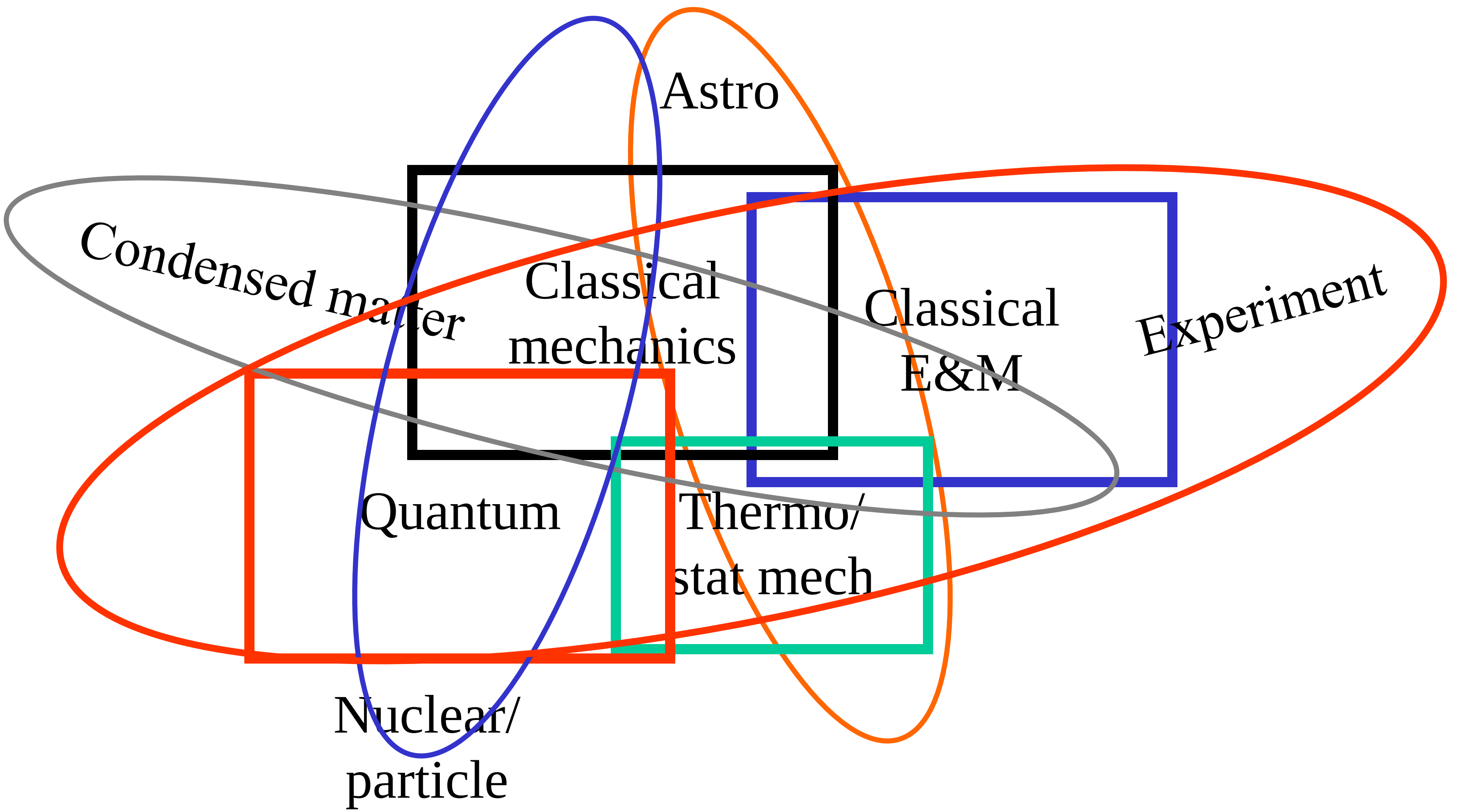
Unification

Lack of unification contributes to the missing matter in the curriculum. The intermediate mechanics course rarely invokes electric or magnetic forces, or quantum mechanics, or thermal issues. Similarly, the intermediate E&M course rarely invokes mechanics or statistical issues.

What it looks like to the student



What it looks like to us



Matter that matters in physics

- Particles: quarks, hadrons, leptons
- Nuclei, atoms, molecules, nanoparticles
- Solids, liquids, gases
- Planets, stars, solar system, galaxies, dark matter…

Matter is considered in topic courses, but typically not in the big core courses, which loom very large to students.

Types of problems involving real matter

One way to break down the barriers, and to provide better balance, is to introduce homework problems that deal with real matter, and that integrate different areas of physics.

We'll look at several different genres of problems that involve the properties of real matter, and which are under-represented in the typical undergraduate curriculum.

Particle properties

- In the symmetric fission of uranium into two palladium nuclei, how far apart are these nuclei if they start out with zero speed? Compare with twice the palladium radius.
- In a nuclear reactor, which elements make good moderators of fast neutrons? Why?
- In the fusion reaction $p + d \rightarrow \mathrm{He}^3 + \gamma$ what is the approximate input energy required to make nuclear contact, to make the reaction go? What is the resulting photon energy?

Macro-micro connections

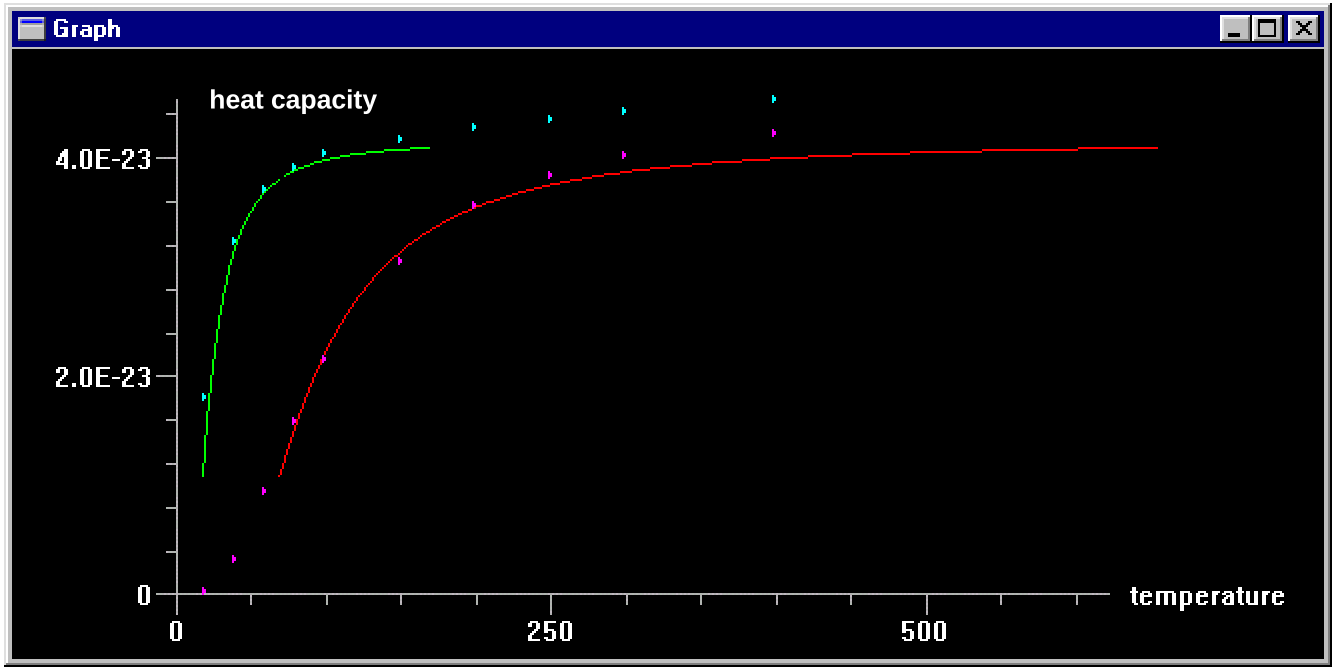
- From the size of an air molecule, estimate the ionization energy of an air molecule.
- From atmospheric density, estimate the mean free path d of an electron.
- Estimate the critical field E_c for triggering a spark in air, given one free electron somewhere.
- Given this model, how should E_c vary with air density? Compare with data.

Macro-micro connections

- Measure Young's modulus *Y* for a metal.
- Use *Y* to determine the effective stiffness k_s of the interatomic spring-like force (5 N/m for Pb, 16 N/m for Al).
- Model propagation of a disturbance along a line of atoms, using k_s and atomic mass; compare with observed speed of sound for Pb and Al.
- Stat mech of Einstein model of a solid using k_s and atomic mass; fit to data for heat capacity as a function of temperature for Pb and Al.

Using ball and spring model of a solid (Einstein model: independent quantized oscillators), students write a computer program to calculate the heat capacity of a solid as a function of temperature.

Students fit curves to actual data for Pb and Al, with one parameter, the interatomic spring constant k_s. Values obtained are consistent with values obtained from Young's modulus.



(Students also measure heat capacity of water in a microwave oven.)

Macro-micro connections

- From the mass of a bar magnet, estimate its magnetic moment on the basis of the magnetic moment expected for one atom. Compare with the magnetic moment determined by measuring the compass deflection produced at a known distance.
- Charge a plastic pen by rubbing. See how close the pen must approach a tiny scrap of paper to pick it up. From this observation, estimate the atomic polarizability of carbon. Compare with published value.

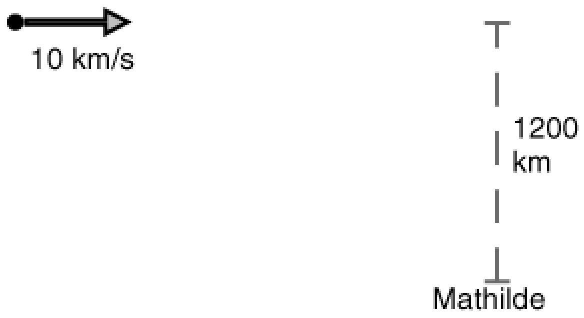
Using published data

- Given the recent data on orbits of stars near the center of our Milky Way galaxy, estimate the mass of the object around which these stars orbit. Express in terms of Solar masses. This unseen object is very compact: it must be a giant black hole.
- In the 1911 Rutherford experiment with 10 MeV alpha particles, what was the distance of closest approach to the gold nucleus? Was there contact, which would have brought the nuclear interaction into play?
- During the 1988 occultation of a star by Pluto, it was observed that the density of Pluto's atmosphere 50 km above the surface was 1/3 that at the surface. Spectroscopic data shows that the atmosphere is mainly N_2. Estimate the temperature of Pluto's atmosphere.

Using published data

In 1997 the NEAR spacecraft passed within 1200 km of the asteroid Mathilde at a speed of 10 km/s relative to the asteroid (http://near.jhuapl.edu). Photos transmitted by the spacecraft show Mathilde's dimensions to be about 70 km by 50 km by 50 km. It is presumably composed of rock; rock on Earth has an average density of about 3000 kg/m^3. The mass of the NEAR spacecraft is 805 kg.

A) Sketch qualitatively the path of the spacecraft:



B) Make a rough estimate of the change in momentum of the spacecraft resulting from the encounter. Explain how you made your estimate.

C) Estimate the deflection (in meters) of the spacecraft's trajectory from its original straight-line path, one day after the encounter.

D) From actual observations of the position of the spacecraft one day after encountering Mathilde, scientists concluded that Mathilde is a loose arrangement of rocks, with lots of empty space inside. What about the observations must have led them to this conclusion?

Numerical results that raise conceptual questions

- What is the drift speed of electrons in the copper wires in a simple circuit? Given this very slow speed, why does the light turn on as soon as you close the switch?
- Measure the voltage-current relationship for a light bulb. Why doesn’t the current double when you double the voltage?