Lecturer: Vladimir Vuletec

Available information:
course policies
announcements & suggested reading
problem sets/solutions, practice exams
student grades
Problem sets:
posted by Thursday,
due following Thursday afternoon

Late homework not accepted (solutions are published online)
One lowest homework score will be dropped when calculating grades.

In-class exams 11 am - 12:30 pm

Tuesday, March 14
Tuesday, April 25

Final: week May 22-26

Grading:
Exam 1 20%
Exam 2 20%
Final 40%
problem sets 20%

Collaboration on problem sets encouraged, but everybody has to submit own solution.
Textbooks
Gasiorowicz required
French & Taylor strongly recommended
Feynman, Lectures on Physics, selected chapters
Texts as reference & reading as preparation
Lectures are basis, notes will be posted

Learning goals for 8.04

- boundary between classical and quantum physics;
- understand crucial experiments that paved way for development of quantum mechanics;
- understand & interpret probability amplitude and interference concepts that are at the heart of QM;
- single-particle quantum mechanics for external degrees of freedom (Schrödinger equation)
  (internal degrees of freedom, e.g., spin: 8.05,
   many-body quantum physics: 8.06 and beyond)
- some formal structure of QM
  (operators, expectation values, commutators, Dirac notation)
  Dirac notation development: 8.05
- understand interface between mathematical structure (Schrödinger equation as partial differential equation) and physical interpretation, measurement, uncertainty, correlations and entanglement;

- study important qm systems: harmonic oscillator, hydrogen atom.

At the end of this course you should be able to:

- solve simple qm single-particle problems in one and three dimensions (scattering, tunneling, bound states);

- give a physical interpretation of mathematical entities (operators, wavefunction, state representation in different bases, Fourier transform, Heisenberg uncertainty relation);

- appreciate & understand the all-importance of interference effect (addition of probability amplitudes) in qm.

8.04: only non-relativistic qm
Problems with/ Failures of classical mechanics (CH)

CM fails at microscopic level.
CM cannot explain, e.g.,
- stability of individual atoms,
- emission spectra of atoms,
- molecular bonds,
- chemical properties, chemical reactions,
- properties of solids

Predictions from CM contradict some experimental facts in thermodynamics:
- blackbody spectrum (spectral density of thermal electromagnetic radiation)
- heat capacity of a gas of diatomic molecules

**Blackbody spectrum**

Classical thermodynamics predicts that each "degree of freedom" at absolute temperature \( T \) carries on average an energy \( \frac{1}{2} k_B T \) \( (k_B = 1.38 \times 10^{-23} \text{ J/K}) \) is the Boltzmann constant.)
And electromagnetic "mode" constitutes a degree of freedom.

\[ n = \frac{2 \pi}{\lambda} \quad \text{n is integer} \]

There are infinitely many short wavelength modes inside the container; if each contains average energy \( \hbar \), then the energy stored inside the container must be infinite.

Qm: The mode frequency \( \nu_n = \frac{\xi}{\lambda_n} \) sets a natural energy scale (photon energy) \( E_n = \hbar \nu_n \),

\( \hbar = 6.6 \times 10^{-34} \text{ J s} \) is Planck's constant,

modes whose natural energy scale \( E_n \) is much larger than \( \hbar \nu \) are not thermally populated, they remain empty and carry no thermal energy.

("High-energy modes with \( E_n \gg \hbar \nu \) are frozen out.")

1) Energy inside box remains finite, agrees with measured value. (Planck formula 8.044).
Heat capacity of diatomic gas

Monatomic gas of N atoms has heat capacity (energy stored at temperature T) given by \( C_v = \frac{3}{2} N \nu k_b \), in agreement with measurements.

Three translational degrees of freedom per atom, and degree of freedom stores kinetic energy \( \frac{1}{2} k_b T \).

For a gas of N diatomic molecules we expect \( C_v = 3Nk_b \) if 2N atoms with translational degrees of freedom, 0 of center-of-mass translational degrees of freedom, 2 rotational degrees, 0 vibrating degrees of freedom.

Observation at room temperature \( C_v = \frac{5}{2} N \nu k_b \).

Explanation: Vibrational mode with frequency \( v \) has natural energy scale \( E = h v \gg k_b T \), is "frozen out," does not contribute to heat capacity.

At high temperature \( k_B T \gg h v \) \( C_v \to 3Nk_b \).

What about electron degrees of freedom inside atom? Also frozen out \( E_n \sim 1 eV \gg k_B T = 10 eV \) at room temperature.