

Lecturer

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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

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 & interiorize 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) further 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 (CM)

- **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 $\frac{1}{2}k_B T$.

$$\boxed{k_B = 1.38 \times 10^{-23} \text{ J/K}} \rightarrow \text{(the Boltzmann constant)} \quad (1-1)$$

Each electromagnetic “mode” constitutes a degree of freedom. In a container with perfectly

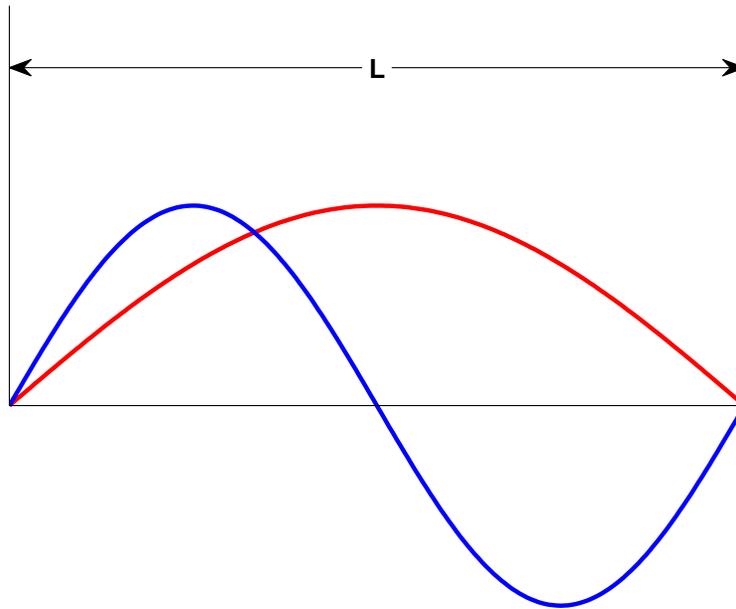


Figure I: Metal container with discrete electromagnetic modes due to boundary conditions on the walls.

conducting walls the modes satisfy $\lambda_n = \frac{2L}{n}$, $n \geq 1$ integer. There are infinitely many short-wavelength modes inside the container. If each contains average energy $k_B T$, then the energy stored inside the container must be infinite.

QM. The mode frequency $\nu_n = \frac{c}{\lambda_n}$ sets a natural energy scale (photon energy) $E_n = h\nu_n$, ($h = 6.6 \times 10^{-34}$ J·s is Planck's constant), modes whose natural energy scale E_n is much larger than $k_B T$ are not thermally populated, they remain empty and carry no thermal energy. High-energy modes with $E_n \gg k_B T$ are “frozen out”. They do not carry thermal energy.

→ Energy inside box remains finite, spectrum and energy per mode agree with experiments. (Planck formula: 8.044).

Heat capacity of diatomic gas

Monatomic gas of N atoms has heat capacity (energy stored at temperature T) given by $C_V = \frac{3}{2}Nk_B$, in agreement with measurements. There are three translational degrees of freedom per atom, each degree of freedom stores kinetic energy $\frac{1}{2}k_B T$.

For a gas of N diatomic molecules, we expect $C_V = \frac{7}{2}Nk_B$, $2N$ atoms with translational degrees of freedom, or 3 center-of-mass translational degrees of freedom, 2 rotational degrees of freedom, 2 vibrational degrees of freedom (one kinetic energy, one potential energy). However, observation at room temperature is $C_V = \frac{5}{2}Nk_B$.

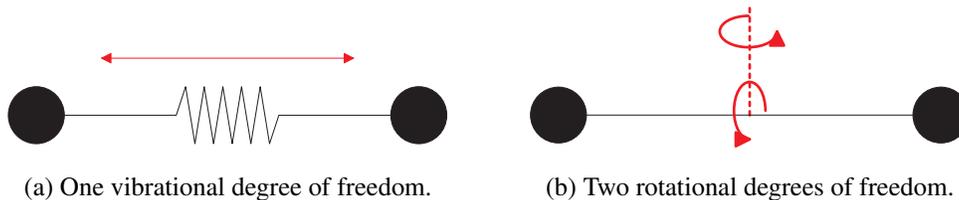


Figure II: Degrees of freedom of a diatomic molecule.

Explanation. Vibrational mode with frequency ν has natural energy scale $E = h\nu \gg k_B T$, is “frozen out,” does not contribute to heat capacity at room temperature. At high temperature $k_B T \gg h\nu$: $C_V \rightarrow \frac{7}{2}Nk_B$.

What about electronic degrees of freedom inside atom?

Also frozen out. $E_n \sim 1$ eV $\gg k_B T = \frac{1}{40}$ eV at room temperature.