Chapter 15 Lecture

Chapter 15: Thermal Properties of Matter

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Goals for Chapter 15

• To understand and learn to use the mole and Avogadro's number.
• To see applications for equations of state.
• To study the kinetic theory of an ideal gas.
• To explore heat capacities.
• To learn and apply the first law of thermodynamics.
• To study thermodynamic processes.
• To delineate the properties of an ideal gas.
Avogadro's Number

- A number to describe a set count of atoms, like "dozen" is a standard set for eggs.

- Because atoms are so small, it must be a huge number: $6.022 \times 10^{23}$.

- To put that number in perspective, count all the stars. That number would be approximately 100 billion ($1.0 \times 10^{11}$).

- It would take a trillion ($1.0 \times 10^{12}$) Milky Way galaxies to contain as many stars as there are particles in a mole. Again, because atoms are tiny.
• Because atoms are tiny, we must gather a mole of them to see a "human object size" pile.

• At right, you're looking at a mole of what is likely water (a liquid at 18 g/mol), nitrogen (a gas at 28 g/mol but with molecules much farther apart than in the water or the salt), and table salt (sodium chloride, a solid at 58 g/mol).

• Refer to Example 15.1 on page 460 of your text.
Imagine that we were able to work with the device at right. It would be able to vary temperature, volume, pressure, and the amount of sample. It could do this all at once in selections of our choice while holding the others constant.

It would reveal to us that volume is proportional to the moles of sample, that volume varies inversely with pressure, and that pressure and/or volume vary in proportion to temperature.
Equations of State

• If we combined all the observations from the device on the previous slide regarding pressure, volume, temperature and quantity of material, we could form one equation to describe the overall behavior of an ideal gas.

• \( pV = nRT \) is our ideal gas equation where \( R \) is a constant, 0.08206 (L\( \cdot \)atm)/(mol\( \cdot \)K).

• This equation may also be rearranged and cast in terms of molecular weight of the gas and mass of sample or density and molecular weight. Refer to page 462.

• Refer to Problem Solving Strategy 15.1 on page 463, Example 15.2 on page 464, and Example 15.3 on page 464.

• Example 15.3 is especially germane to underwater diving.
It proves especially useful to plot pressure and volume at constant temperature for a range of temperatures. In this way we can generate a 3-D surface of isothermal lines and make predictions of an ideal gas’s behavior.

Each curve represents pressure as a function of volume for an ideal gas at a single temperature. For each curve, $pV$ is constant and is directly proportional to $T$ (Boyle’s law).

$T_4 > T_3 > T_2 > T_1$

$p > T_4 > T_3 > T_2 > T_1$

Above the critical temperature $T_c$, there is no liquid–vapor phase transition.

Below $T_c$, the material condenses to liquid as it is compressed.
Pressure and Temperature Plotted – Figure 15.5

- This plot is exceptionally useful. We can present freezing and melting, boiling and condensation, regions of permanent gas phase, even a triple point where all phases exist in equilibrium.

At $T$ and $p$ values above the **critical point**, the material properties change smoothly with changing $p$ or $T$, rather than undergoing a phase change.

At the **triple point**, solid, liquid, and vapor coexist.
Kinetic Molecular Theory of an Ideal Gas

• Most solids maintain a constant and organized spacing (like the salt crystal shown below).

• Gases may be treated as point particles undergoing rapid elastic collisions with each other and the container (shown at right).

- Velocity component parallel to the wall (y component) does not change.
- Velocity component perpendicular to the wall (x component) reverses direction.
- Speed $v$ does not change.
Molecular Speed Distributions – Figure 15.10

- Molecules move at a distribution of speeds around a mean velocity for any given temperature.
- Refer to Problem Solving Strategy 2 and Examples 15.5–15.6.
Molecular Heat Capacities

- Molecules can store heat energy in translation, rotation and vibration.
- Refer to Table 15.3 and the text on pages 474 and 475 to guide you through a calculation.

(a) Translational motion

(b) Rotational motion

(c) Vibrational motion

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The First Law of Thermodynamics –

• In simple terms, "the energy added to a system will be distributed between heat and work."

• "Work" is defined differently than we did in earlier chapters. Here, it refers to a $p\Delta V$ (a pressure increasing a volume).

Mount St. Helens in 1980
The Work Done by Volume Change – Figures 15.14 and 15.15

- Incremental, reproducible changes may be summed.
Work as Area Under the Curve – Figures 15.16 and 15.17

The volume *decreases* \((V_2 < V_1)\) and the system does negative work.

![Diagram of constant pressure work](image1)

![Diagram of varying pressure work](image2)

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Expansions and Contractions – Figure 5.20

- Slow, reversible changes in volume can be done isothermally.
- The entire system is isolated from external sources of heat or cold.

(a) System does work on piston; hot plate adds heat to system ($W > 0$ and $Q > 0$).

(b) System does no work; no heat enters or leaves system ($W = 0$ and $Q = 0$).
First Law Calculations – Figures 15.21 and 15.22

- Refer to Examples 15.8, 15.9, and 15.10 on pages 482 and 483 in your text.
Thermodynamic Processes – Figures 5.23 and 5.24

- A process can be adiabatic and have no heat transfer in or out of the system.
- A process can be isochoric and have no volume change.
- A process can be isobaric and have no volume change.
- A process can be isothermal and have no temperature change.

![Diagram showing thermodynamic processes]

This process is isobaric because the pressure remains constant.
Properties of an Ideal Gas – Figures 15.25 and 15.26

• Compare constant volume and pressure processes. $U$ depends only on $T$.

• Observe an adiabatic process for an ideal gas.

Adiabatic process $a \rightarrow b$: $Q = 0$, $\Delta U = -W$

An adiabatic curve at any point is always steeper than the isotherm passing through the same point.