Unit 9: Thermodynamics

OBJECTIVES

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

Essential Knowledge 1.E.3: Matter has a property called thermal conductivity. The thermal conductivity is the measure of a material's ability to transfer thermal energy.

Learning Objective 1.E.3.1: The student is able to **design an experiment** and analyze data from it to examine thermal conductivity.

Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding 4.C: Interactions with other objects or systems can change the total energy of a system.

Essential Knowledge 4.C.3: Energy is transferred spontaneously from a higher temperature system to a lower temperature system. This process of transferring energy is called heating. The amount of energy transferred is called heat.

a. Conduction, convection, and radiation are mechanisms for this energy transfer.

b. At a microscopic scale the mechanism of conduction is the transfer of kinetic energy between particles.

c. During average collisions between molecules, kinetic energy is transferred from faster molecules to slower molecules.

Learning Objective 4.C.3.1: The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.B: The energy of a system is conserved.

Essential Knowledge 5.B.5: Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed is treated in Physics 2 as a part of thermodynamics.]

Learning Objective 5.B.5.6: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a pressure-volume curve are needed to determine the work done on or by the object or system.

Essential Knowledge 5.B.6: Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer is called heat.

Learning Objective 5.B.6.1: The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation.

Essential Knowledge 5.B.7: The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams – isovolumetric processes, isothermal processes, isobaric processes, and adiabatic processes. No calculations of internal energy change from temperature change are required; in this course, examples of these relationships are qualitative and/or semiquantitative.

Learning Objective 5.B.7.1: The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles.

Learning Objective 5.B.7.2: The student is able to create a plot of pressure versus volume for a thermodynamic process from given data.

Learning Objective 5.B.7.3: The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics.)

Big Idea 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

Enduring Understanding 7.A: The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.

Essential Knowledge 7.A.1: The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum, the impulse, of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.

Learning Objective 7.A.1.1: The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system.

Learning Objective 7.A.1.2: Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure and at thermal equilibrium to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables.

Essential Knowledge 7.A.2: The temperature of a system characterizes the average kinetic energy of its molecules.

a. The average kinetic energy of the system is an average over the many different speeds of the molecules in the system that can be described by a distribution curve.

b. The root mean square speed corresponding to the average kinetic energy for a specific gas at a given temperature can be obtained from this distribution.

Learning Objective 7.A.2.1: The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system.

Learning Objective 7.A.2.2: The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes.

Essential Knowledge 7.A.3: In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V) are related by the equation $PV = nRT$.

Learning Objective 7.A.3.1: The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero.

Learning Objective 7.A.3.2: The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables.

Learning Objective 7.A.3.3: The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law.

Enduring Understanding 7.B: The tendency of isolated systems to move toward states with higher disorder is described by probability.

Essential Knowledge 7.B.1: The approach to thermal equilibrium is a probability process.

a. The amount of thermal energy needed to change the temperature of a system of particles depends both on the mass of the system and on the temperature change of the system.

b. The details of the energy transfer depend upon interactions at the molecular level.

c. Since higher momentum particles will be involved in more collisions, energy is most likely to be transferred from higher to lower energy particles. The most likely state after many collisions is that both systems of particles have the same temperature.

Learning Objective 7.B.1.1: The student is able to construct an explanation, based on atomic-scale interactions and probability, of how a system approaches thermal equilibrium when energy is transferred to it or from it in a thermal process.

Essential Knowledge 7.B.2: The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.

a. Entropy, like temperature, pressure, and internal energy, is a state function whose value depends only on the configuration of the system at a particular instant and not on how the system arrived at that configuration.

b. Entropy can be described as a measure of the disorder of a system or of the unavailability of some system energy to do work.

c. The entropy of a closed system never decreases, i.e., it can stay the same or increase.

d. The total entropy of the universe is always increasing.

Learning Objective 7.B.2.1: The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes.

PROCEDURE:

1. Phase 1: Temperature, Heat, Thermal Expansion, and Thermal Transfer
   - Notes: Roman numeral I
   - Homework 1: *Please note that thermal conductivity coefficients are available on page 400 of your textbook.* Do these in order. Chapter 13 Conceptual Questions 1, 2, 3, 8, 13 and Problems 1 and 2 and Chapter 12 Problem 9
2. Phase 2: Kinetic Theory of an Ideal Gas
   - Notes: Roman numeral II
   - Lab: Behavior of Gases
   - Homework 2: Chapter 14 Conceptual Question 3 and Problems 9, 16, 17, 34
3. Phase 3: First Law of Thermodynamics and Pressure-Volume Diagrams
   - Notes: Roman numeral III A-C
   - Lab: Analysis of P-V Diagrams
   - Homework 3: Chapter 15 Conceptual Questions 1, 2, 4, 5 and Problems 1, 7, 10, 13
     * #7 – Work is done by the gas on the environment. That means the gas expanded, so work on the gas is negative in each step.
4. Phase 4: Second Law of Thermodynamics, Entropy, and Heat Engines
   - Notes: Roman numeral III D-end
   - Homework 4: Chapter 15 Conceptual Questions 11, 22, 23, 24, 25 and Problem 71