Introduction: Thermodynamics

Unit: Thermodynamics

Topics covered in this chapter:

This chapter is about heat as a form of energy and the ways in which heat affects objects, including how it is stored and how it is transferred from one object to another.

- *Kinetic-Molecular Theory* explains the implications of the theory that gases are made of large numbers of independently moving particles.
- *Gas Laws* and *The Ideal Gas Law* describe and explain relationships between pressure, volume, temperature and the number of particles in a sample of gas.
- *Energy Conversion* describes conversion between heat and other forms of energy.
- *Thermodynamics* describes the transfer of energy into or out of a sample of gas.
- *Pressure-Volume (PV) Diagrams* and *Heat Engines* describe the relationship between changes in pressure and volume, heat, and work done on or by a gas.
- *Efficiency* describes the relationship between the work obtained from changes to a sample of gas and the maximum amount of energy that is theoretically available.

New challenges specific to this chapter include looking up and working with constants that are different for different substances.

Standards addressed in this chapter:

Next Generation Science Standards (NGSS):

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles or energy stored in fields.

HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

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AP® Physics 2 Learning Objectives/Essential Knowledge (2024):

9.1.A: Describe the pressure a gas exerts on its container in terms of atomic motion within that gas.

9.1.A.1: Atoms in a gas collide with and exert forces on other atoms in the gas and with the container in which the gas is contained.

9.1.A.1.i: Collisions involving pairs of atoms or an atom and a fixed object can be described and analyzed using conservation of momentum principles.

9.1.A.1.ii: The pressure exerted by a gas on a surface is the ratio of the sum of the magnitudes of the perpendicular components of the forces exerted by the gas's atoms on the surface to the area of the surface.

9.1.A.1.iii: Pressure exists throughout the gas itself, not just at the boundary between the gas and the container.

9.2.A: Describe the properties of an ideal gas.

9.2.A.1: The classical model of an ideal gas assumes that the instantaneous velocities of atoms are random, the volumes of the atoms are negligible compared to the total volume occupied by the gas, the atoms collide elastically, and the only appreciable forces on the atoms are those that occur during collisions.

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9.2.A.2: An ideal gas is one in which the relationships between pressure, volume, the number of moles or number of atoms, and temperature of a gas can be modeled using the equation $PV = nRT = Nk_BT$

9.2.A.3: Graphs modeling the pressure, temperature, and volume of gases can be used to describe or determine properties of that gas.

9.2.A.4: A temperature at which an ideal gas has zero pressure can be extrapolated from a graph of pressure as a function of temperature.

9.3.A: Describe the transfer of energy between two systems in thermal contact due to temperature differences of those two systems.

9.3.A.1: Two systems are in thermal contact if the systems may transfer energy by thermal processes.

9.3.A.1.i: Heating is the transfer of energy into a system by thermal processes.

9.3.A.1.ii: Cooling is the transfer of energy out of a system by thermal processes.

9.3.A.3: Energy is transferred through thermal processes spontaneously from a higher-temperature system to a lower-temperature system.

9.3.A.3.i: In collisions between atoms from different systems, energy is most likely to be transferred from higher-energy atoms to lower-energy atoms.

9.3.A.3.ii: After many collisions of atoms from different systems, the most probable state is one in which both systems have the same temperature.

9.3.A.4: Thermal equilibrium results when no net energy is transferred by thermal processes between two systems in thermal contact with each other.

9.4.A: Describe the internal energy of a system.

9.4.A.1: The internal energy of a system is the sum of the kinetic energy of the objects that make up the system and the potential energy of the configuration of those objects.

9.4.A.1.i: The atoms in an ideal gas do not interact with each other via conservative forces, and the internal structure is not considered. Therefore, an ideal gas does not have internal potential energy.

9.4.A.1.ii: The internal energy of an ideal monatomic gas is the sum of the kinetic energies of the constituent atoms in the gas.

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9.4.A.2: Changes to a system's internal energy can result in changes to the internal structure and internal behavior of that system without changing the motion of the system's center of mass.

9.4.B: Describe the behavior of a system using thermodynamic processes.

9.4.B.1: The first law of thermodynamics is a restatement of conservation of energy that accounts for energy transferred into or out of a system by work, heating, or cooling.

9.4.B.1.i: For an isolated system, the total energy is constant.

9.4.B.1.ii: For a closed system, the change in internal energy is the sum of energy transferred to or from the system by heating, or work done on the system.

9.4.B.1.iii: The work done on a system by a constant or average external pressure that changes the volume of that system (for example, a piston compressing a gas in a container) is defined as $W = -P\Delta V$.

9.4.B.2: Pressure-volume graphs (also known as PV diagrams) are representations used to represent thermodynamic processes.

9.4.B.2.i: Lines of constant temperature on a PV diagram are called isotherms.

9.4.B.2.ii: The absolute value of the work done on a gas when the gas expands or compresses is equal to the area underneath the curve of a plot of pressure vs. volume for the gas.

9.4.B.3: Special cases of thermal processes depend on the relationship between the configuration of the system, the nature of the work done on the system, and the system's surroundings. These include constant volume (isovolumetric), constant temperature (isothermal), and constant pressure (isobaric), as well as processes where no energy is transferred to or from the system through thermal processes (adiabatic).

9.6.A: Describe the change in entropy for a given system over time.

9.6.A.1: The second law of thermodynamics states that the total entropy of an isolated system can never decrease and is constant only when all processes the system undergoes are reversible.

9.6.A.2: Entropy can be qualitatively described as the tendency of energy to spread or the unavailability of some of the system's energy to do work.

9.6.A.2.i: Localized energy will tend to disperse and spread out.

9.6.A.2.ii: Entropy is a state function and therefore only depends on the current state or configuration of a system, not how the system reached that state.

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9.6.A.2.iii: Maximum entropy occurs when a system is in thermodynamic equilibrium.

9.6.A.3: The change in a system's entropy is determined by the system's interactions with its surroundings.

9.6.A.3.i: Closed systems spontaneously move toward thermodynamic equilibrium.

9.6.A.3.ii: The entropy of a closed system never decreases, but the entropy of an open system can decrease because energy can be transferred into or out of the system.

Skills learned & applied in this chapter:

- Working with material-specific constants from a table.
- Working with more than one instance of the same quantity in a problem.
- Combining equations and graphs.