GUIDED NOTES

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.

a. 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.

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.

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.

GUIDED NOTES

NOTES:

I. Temperature and Heat

   A. Temperature vs. Heat

      1. Heat and temperature are not the same.

         a. _____: the _____ inside of an object _____of the atoms and molecules

            1.) Symbol:

            2.) SI unit:

         b. <u>Temperature</u>: A _____ measure of _____[1]; measurable by many scales

            1.) Symbol:

            2.) SI unit:

	Conversion to C then to F	Conversion to Celsius	Conversion to Kelvin
F	x	(5/9)(F - 32)	Convert to C then to K
C	(9/5)C + 32	x	**C+273**
K	Convert to C then to F	**K - 273**	x

        • *Memorize 273!*

         c. _____: Energy is _____ spontaneously from a higher temperature system to a lower temperature system. This _____ is called heating. The _____is called _____. (This seems similar to work. See 2, below.)

            1.) Symbol:

            2.) SI unit of heat:

            3.) Traditional unit of heat: _____ where 1.0 kcal of heat transferred into water raises the temperature of 1kg of water $1^\circ C$

---

[1] For example, something that has more internal energy will have a higher temperature than something with less internal energy. BECAUSE temperature is measured relative to something, our three different temperature scales have the flexibility to name "zero" at different levels. For example, "Calling water's freezing point zero degrees, your body has a temperature that is above zero. You have more internal energy than something whose temperature is water's freezing point."

2. Mechanical equivalent of heat: Heat can be considered equivalent to mechanical work.

1kcal = 4186 Joules

in that

4186 Joules of work can transfer 1kcal of heat.

3. Example 1: When a 3.0g bullet, traveling with a speed of 400m/s, passes through a tree its speed is reduced to 200m/s. (a) How much heat is produced and shared by the bullet and the tree? (b) How many kcal is that?

B. _____[2]

1. Most substances expand when heated and contract when cooled.

2. _____: The change in any one dimension (length, width, or height) of a solid during heat transfer

    a. Formula[3]:

        where…

- Δl is the change in length
- α is the coefficient of linear expansion
  - Each substance has a unique coefficient.
  - Units: $°C^{-1}$ or, less commonly, K^{-1} (depends on scale being used)
- l_0 is the initial length (change in length is proportional to original length because a longer object has more substance to expand.)
- ΔT is the temperature change

---

[2] Thermal expansion is not explicitly mentioned in the curriculum.
[3] This is not on the formula sheet.

b. Examples:

1.) Conceptual example: The coefficient for glass is almost 3x bigger than for Pyrex. Pouring boiling water into a cool glass cup expands the interior surface 3x more than it would a Pyrex cup…Glass is not as heat safe.

2.) Conceptual example: There is a bimetalic strip in a thermostat. Room air heats up the strip, and one side strip bends more than the other, curving it outward, tipping mercury over two wires to close the electric circuit and begin electric current flow to furnace

3.) Example 2: When engineering, we need to allow for expansion by leaving gaps. Steel railroad tracks are laid a day when the temperature is 5°C. What size expansion gaps are needed between 12m long rail sections if the temperature range in that region is -10°C to 55°C? The coefficient of expansion for steel is 12E-6°C^{-1}.

3. _____

a. Formula[4]:

where…

- β is the coefficient of volume expansion in °C^{-1} (or K^{-1})
  - $\beta = 3\alpha$ (not α^3…units wouldn't work, and can be found algebraically.)
  - $See\ page\ 365\ for\ examples\ of\ \alpha\ and\ \beta.$

---

[4] This is also not on the formula sheet.

b. Examples

1.) <u>Example 3</u>: The 70-L steel gas tank of a car is filled to the top with gasoline at 20°C. The car is then left to sit in the sun, and the tank reaches a temperature of 40°C. How much gasoline do you expect to overflow from the tank? The coefficients of volume expansion for gasoline and steel are, respectively, 950E-6 $^{\circ}$C^{-1} and 36E-6°C^{-1}.

2.) Conceptual example: A slab of metal with a hole cut in it is heated. Does the hole expand or contract?

3.) Conceptual example: When a metal jar lid is stuck on a glass jar, how could you use thermal expansion to loosen the lid?

4.) Conceptual example: Why is a blow torch standard equipment for a plumber?

GUIDED NOTES

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.

C. _____[5]:

    1. _____ can be _____ by thermal processes involving _____ _____. The _____ in this process of transfer is called _____.

    2. At a _____ the _____is the _____. During average collisions between molecules, _____.

    3. There are _____ (i.e., transferring energy from one object to another.)

        a. _____:

            1.) Heat transfer by the _____within a fluid over relatively _____

          2.) Examples:

            a.) Forced convection: Furnaces blowing hot air through air ducts

            b.) Natural examples: hot air rising, Gulf stream, weather, boiling water

        b. _____:

          1.) Heat transfer directly _____ with a temperature differential from one end to the other; molecules at the hot end vibrate more readily, colliding with molecules at the cooler end and transferring energy to them.

          2.) Conductivity depends on _____ and _____.

            a.) _____. The thermal conductivity is the measure of a material's _____ and is measured in $\frac{J}{s \cdot m \cdot °C}$.

---

[5] Now we're back to things that *definitely ARE* in the curriculum.

b.) Formula for the rate of heat flow:

- Q is the rate of heat (amount of energy transferred)
- Δt is the time interval
- k is the thermal conductivity of the material
- A is the cross-sectional area
- ΔT is the temperature difference on each side
- l is the thickness (length from end-to-end)

b.) Units:

3.) <u>Example 4</u>: A major source of heat loss from a house is through the windows.

(a) Calculate the rate of heat flow through a glass window 2.0m x 1.5m in area and 3.2mm thick if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C respectively. The thermal conductivity of glass is 2.0E-4 $\frac{kcal}{s\cdot m\cdot °C}$ or 0.84 $\frac{J}{s\cdot m\cdot °C}$. (b) If you were a window designer, what modifications would you make to this window to reduce conduction?

c. _____:

1.) Heat transfer _____by means of

_____

2.) Radiation depends on _____ (ability to emit/absorb electromagnetic

radiation) and _____.

a.) Objects _____radiation _____, and

the net in/out determines whether the object heats up or cools off.

b.) Dark objects have high emissivity…a _____ is an object that

absorbs all the electromagnetic radiation falling on it.

3.) Generate an example of something that heats via radiation.

TIMEOUT! Let's talk about probability…

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.**

Probability

- Microstate vs. macrostate

  o The microstate is considered when examining the behavior of every particle.

  o The macrostate is considered when examining the properties (such as pressure and temperature) of the entire system.

- Probability: Many different microstates can create a same macrostate, and each microstate is equally probable. The greater number of microstates that will create the same macrostate, the better the probability is for that macrostate to occur. In this context, it is not impossible for a system to have a decrease in entropy. It is simply highly improbable.

  o *Simple example: If you flip a handful of four coins and get three heads and one tail, one possible microstate is that you got, in order: HHHT. How many other microstates could have created this?*

  o *Continuing the simple example: Is three heads and one tail a more or less probable macrostate than two heads and two tails? What about compared to four tails?*

3 of a kind	Add Total Of All Dice	
4 of a kind	Add Total Of All Dice	
Full House	SCORE 25	
Sm Straight (Sequence) of 4	SCORE 30	
Lg. Straight (Sequence) of 5	SCORE 40	
YAHTZEE 5 of a kind	SCORE 50	

II. _____

    A. _____

        1. Characteristics:

            a. There are a _____that _____

            _____ with a _____ until

            they collide with each other or the container walls.

            b. The _____of molecules is _____ of

            each molecule.

            c. The molecules _____, and they interact

            only when they   collide. (There are no attractive forces between the molecules.)

            d. Faking it to be ideal: For an "ideal" gas, all _____

            and therefore do not transfer momentum or kinetic energy to container walls.

            e. All molecules are alike (_____).

        2. Pressure of ideal gases

            a. *The properties of an ideal gas in its macrostate can be explained in terms of macroscopic*

            variables including temperature and pressure.

            b. The _____…

                1.) determines the force that the system exerts on the walls of its container and…

                2.) is a _____the _____ change in the momentum

                (the _____) of the molecules colliding with the walls of the container.

            c. The _____, not just on the walls of

            the container.

3. _____

    a. Relates pressure, Kelvin temperature, volume, and number of moles of gas

    b. Formula:

    where...

-   P is pressure in Pa

-   V is volume in m^3 (NOTE: 1 liter = 0.001 m^3)

-   n is the number of moles present

-   N is the number of molecules = n x 6.022E^{23} molecules/mol   [6]

-   R is the universal gas constant =8.31 $J/_{mol \cdot K}$ [7]

-   k_B is Boltzmann's constant = $R/_{N_0}$ = 1.38E-23 J/K   [8]

-   T is temperature in Kelvin

4. _____[9] during expansion/compression:

---

[6] Avogadro's # is N_0.

[7] This is different from the one you've seen in chemistry because it is different units.

[8] Note that R = Avogadro's number x Boltzmann's constant: (6.022E^{23}/mol)(1.38E^{-23} J/k) = 8.31 $J/_{mol \cdot K}$

[9] In AP Physics B, W is defined as "work done ON a system" and is (+). That makes sense since energy is literally "added" to the system. Therefore when work is done BY a system (like an expanding gas moving the walls of its container), then W should bear a (−) sign. In the case of an expanding gas the "work" term is simply PΔV, so it bears a (−) sign. THIS IS DIFFERENT FROM YOUR BOOK'S CONVENTIONS.

5. Examples:
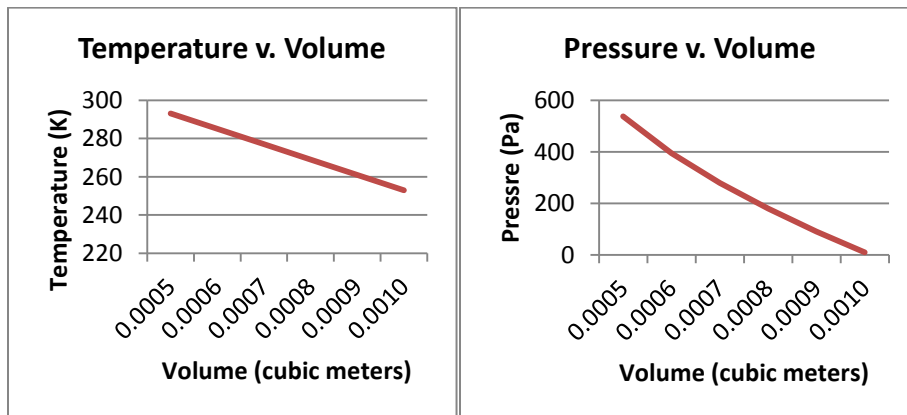
a. <u>Example 5</u>: An ideal gas initially at 20°C under 1 atm of pressure has a volume of 3L in a container with a piston on top. The piston is pushed downward, compressing the gas to a volume of 1L as the temperature rises to 40°C. (a) What is the pressure of the gas when the piston is compressed? (b) If the piston has a surface area of 0.02m² and has a negligible mass, what is the absolute pressure on the piston? (c) How much force is required to hold the piston in place? (d) Was positive or negative work done on the gas? Why? (e) What do you think this did to the kinetic energy of the particles? The average velocity? The internal energy? The temperature?

b. <u>Example 6</u>: A tire is filled to a gauge pressure of 300kPa at 5°C. The temperature goes up to 40°C. What portion of the air must be let out to reduce the pressure back to the original level?

c. <u>Example 7</u>: Student A completes an investigation of a gas contained inside of a syringe and obtains the following data. (a) What conclusions related to the ideal gas law could you make from this data? (b) Refine a scientific question concerning the relationships shown so that you can investigate further.

Volume (m3)	Pressure (Pa)	Temperature (K)
0.0005	537	293
0.0006	395	285
0.0007	279	277
0.0008	179	269
0.0009	91	261
0.0010	10	253

Temperature v. Volume

Temperature (K)

300
280
260
240
220

0.0005 0.0006 0.0007 0.0008 0.0009 0.0010

Volume (cubic meters)

Pressure v. Volume

Pressre (Pa)

600
400
200
0

0.0005 0.0006 0.0007 0.0008 0.0009 0.0010

Volume (cubic meters)

***   d. <u>Example 8</u>: In what way does the ideal gas law relate to probability?   ***

B. _____

     1. *Gas behavior can be viewed macroscopically (macrostate) by investigating the average*

     behavior of the microscopic molecules (microstate) that make up the system.

     2. The _____in an ideal gas follows this formula:

         Note: Only the first part of this equation is on the formula sheet.

         The second part ($\frac{1}{2}mv_{rms}^2$) you can remember conceptually.

     where...

     a. v_{rms} is the square root of the means of the squares of the velocities[10] of all the particles

     "root mean squared" = $\sqrt{\dfrac{v_1^2 + v_2^2 + \ldots + v_n^2}{n}}$ (The benefit is it finds the average velocity without

     regard to the direction of each particle's velocity.)

     b. The $\frac{3}{2}$ is really $\frac{1}{2}$ in three dimensions, because the particles move randomly in any of the 3

     dimensions.

---

[10] translational (straight-line) velocity, not rotational or vibrational...This course looks only at translational velocity when examining kinetic theory of gasses.

3. Maxwell-Boltzman distributions are graphs that show how the velocities of molecules in a gas are distributed. (In other words: How many particles are going at each speed?) The peaks show the average velocity for all of the particles and represent the most probable velocity of any molecule. This average velocity peak varies with temperature, as shown below in the Maxwell-Boltzman distribution for nitrogen gas.

- Example 9: For the distribution below, narrate four conclusions. Include a discussion of probability.
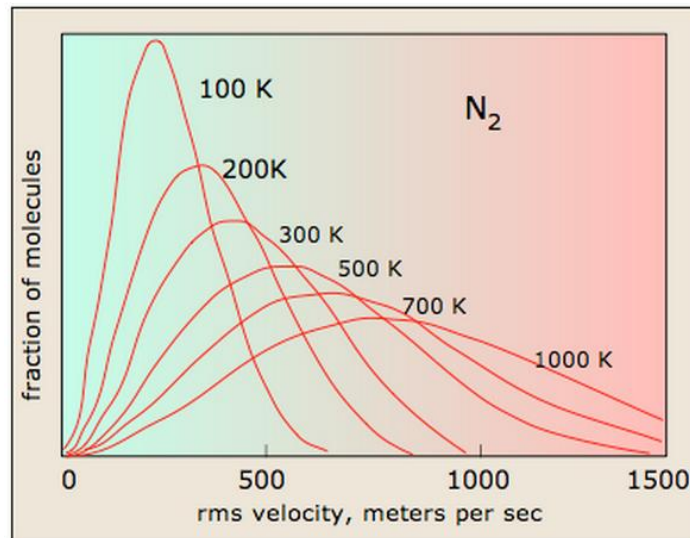
P.S. Look at how fast these are!

5. Additional examples:

    a. <u>Example 10</u>: 0.2 mol of oxygen at 300 kPa take up a volume of 5 L. (a) What is the temperature of the gas? (b) What is the average translational kinetic energy per molecule? (c) How many molecules are present? (d) What is the total translational kinetic energy of the gas?

    b. <u>Homework</u>: Write a narrative response to this free response question: Student A says that the kinetic model explains gas pressure in terms of collisions with container walls. Student B says, "Whhaaa?!?" Write what Student A says to explain this to Student B. Later on, Student B, enlightened, then suggests that this must mean that pressure is proportional to temperature. Write what Student B says.

GUIDED NOTES

III. _____and _____

    A. _____of Thermodynamics: If system A & system B are in thermal equilibrium with system C,

A and B are also in thermal equilibrium with each other.

        1. _____.

        2. _____.

        3. Example: The two containers in (a) with insulating walls have the same temperature. When

connected by a heat conducting wall in (b) heat does not flow.
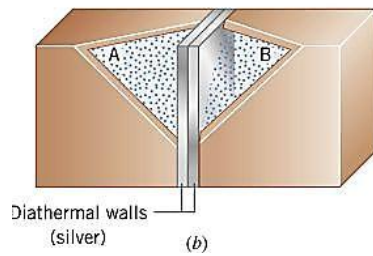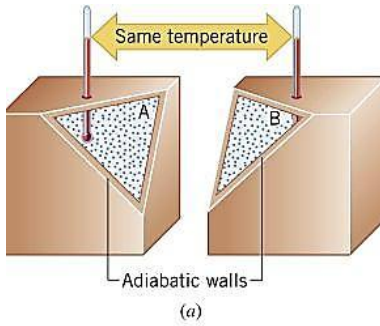
B. _____ of Thermodynamics: When heat flows to or from a system and/or work is done on or by the system, the internal energy of the system changes according to the following relationship:

$$\Delta U = Q + W$$

where…

- Q is the heat flow into or out of the system

- W is the work done ON the system by the environment.

    o _____ is _____. (System does _____.)

    o _____ is _____. (System does _____.)

- Example 11: 500 J of heat is added to system while the system does 200 J of work on the environment. (a) What is the system's change in internal energy? (b) Draw a picture of any system you can imagine that could describe this scenario.

C. _____ are a tool to analyze thermodynamic relationships.

1. These show pressure v. volume for a _____ (_____).

2. With n and R constant, T α PV, so we get:
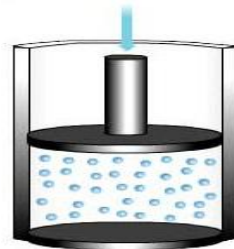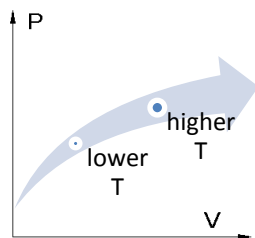
3. The _____ is the _____

_____.

$$W = Fd$$

$$W = (PA)d$$

$$W = P(Ad)$$

(If volume increases, W is negative because the gas did work on the environment, and F and d are in opposite directions with regard to the environment acting on the gas, so we add the negative sign to the equation.)

which is the negative of the area under the curve of a PV diagram.

(This *is* on the formula sheet.)

There are four key thermodynamic "processes" a gas can undergo.

The following describe these and relate them to temperature.

In all processes, consider a closed system in which the number of moles of gas is constant.
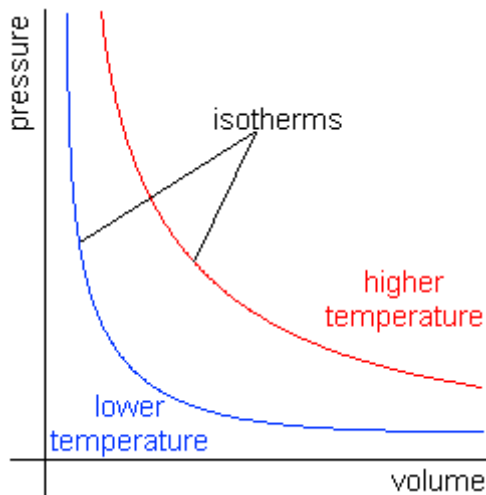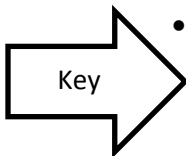
4. PV diagram for an _____ : _____ ,
changing pressure and volume

    a. If $PV = nRT$ and n, R, and _____ are _____ in an isothermal process,

    then…

    b. <u>Example 12</u>: For an isothermal expansion, (a) sketch a PV diagram starting from

    P = 4 Pa and V = 1m^3, changing the volume first to 2m^3 and then to 4m^3. (b) Find the change

    in K and U. (c) Is the work positive or negative? (d) What can you conclude about the role of

    heat in an isothermal compression? Describe how you could create this heat flow.

    (e) Speculate about the role of heat in an isothermal expansion and how you could create it.

- Important: _____
- Therefore _____…Thus the

    Key _____ , keeping the temperature

    constant…Heat or cool the gas as needed to offset the work.

- The curved line is called an isotherm.

This shows the pressure-volume changes for a closed system at two different temperatures.

5. PV diagram for an _____: _____, changing volume

due to change in temperature and work done

    a. Conceptual example: A container with a piston on top is heated (ΔT), pushing the piston

    upward (-W on gas) to maintain constant pressure within the container. (In this

    case, $P_{gas} = P_{atm}$).
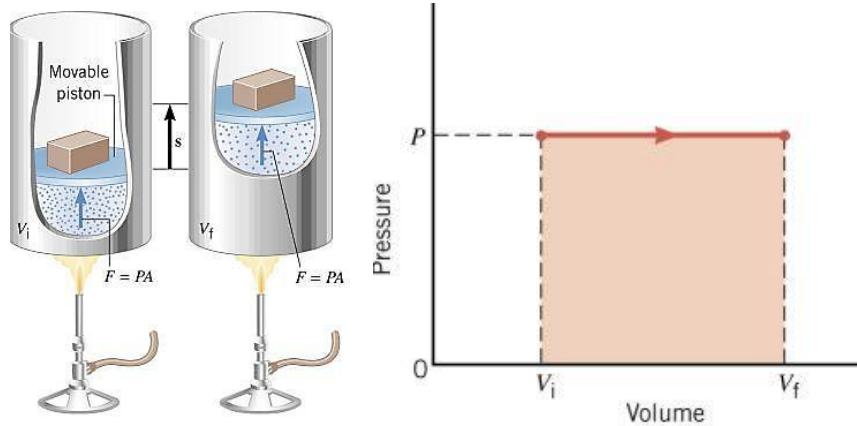
    b. <u>Example 13</u>: (a) Sketch an accurate PV diagram when a gas is slowly compressed at a

    constant pressure of 2.0atm from 3.0L to 1.0L. (b) Find the work done on the gas. (c) Does

    the temperature increase or decrease? (d) In this process, 1400 J of heat flows. Does it flow

    in or out? (e) Find the change in the gas' internal energy. (f) Conceptually: We did positive

    work to compress the gas. To keep the pressure from going sky high, we cooled the gas

    (heat flow out.) This lowered the temperature.

6. PV diagram for an _____: _____,

changing pressure due to heat flow, resulting in ΔU

    a. _____ done in an isochoric process is _____ because there is _____

    _____ if the volume doesn't change. However, _____

    _____ because _____ in or out.

    b. Example 14: (a) Sketch a PV diagram for an isochoric process and show that the work is

    zero. (b) Identify where the temperature is high or low and (c) whether heat flows in or out

    for compression and expansion.

7. PV diagram for an _____

    a. _____ is exchanged with the environment in an adiabatic process so that

    _____.

    b. Done by either...

        1.) Putting the gas in a very well-insulated container or...

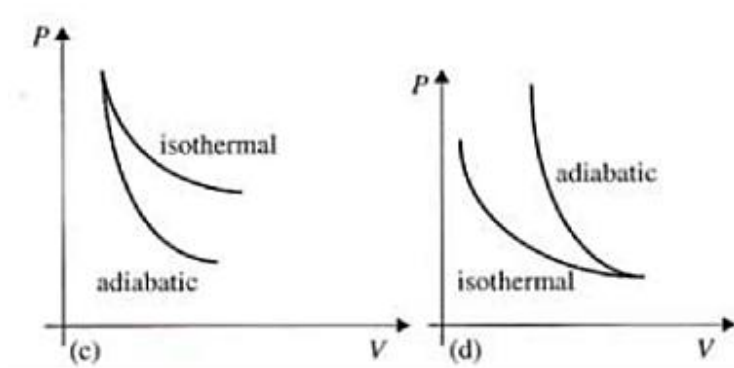   2.) Making the change very quickly so that there is not enough time for heat exchange.

    c. _____, so _____; therefore

    _____, and therefore _____.

    d. _____:

        1.) _____because...

    _____ → _____ → _____.

        2.) On the left side of the graph below, the _____

    _____.

    e. _____:

        1.) _____because...

    _____ → _____ → _____.

        2.) On the right side of the graph above, the _____

    _____.

GUIDED NOTES

Organizing thoughts for understanding the next law:

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

Introductory thought: The first law of thermodynamics recognizes that energy is conserved. Consider a situation in which something warm heats up a cooler object, such as when you put a pot of cool water on a hot stove burner to make delicious macaroni & cheese. Heat flows from the hot burner to the cold pot of water. This conserves energy. BUT…wouldn't it also conserve energy if the scenario happened in reverse so that the cool pan gave heat to the hot burner, making the pan of water colder and the burner hotter? This obeys the first law of thermodynamics, but it never happens. As another example, the heat exiting your body into a cold room will never return to your body. In addition to hot and cold interactions, there are many processes that occur in nature in one direction but never in reverse. Drop an egg, and it will break into pieces (and goo.) The egg will never rise back up and reassemble itself. When your three-ring binder falls and pops open, spilling the papers in a distressing heap of haphazard misery, they will never on their own accord reassemble themselves into their former order. (And monkeys will never type a Shakespearean sonnet no matter how long you let them type.) Keep these things in mind as we move forward…

…and here we go!

D. _____ of Thermodynamics: _____

_____

_____

1. Taking the first part first…

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

a. The _____ (given by _____) _____

_____ (reflected in _____) of a system of particles _____

the _____ of the system and on the _____of the system.

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

c. _____,

_____

_____.

Taking the second part…

2. _____: A measure of the _____ of a system

a. Entropy, like temperature, pressure, and internal energy, is a _____
whose value depends only on the configuration of the system at a particular instant and not
on how the system arrived at that configuration. [11]

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.

_____

_____. It is _____within a system.

     ○ The _____is _____.

e. Increase in entropy ΔS can be calculated as a change in the amount of order by $\Delta S = \frac{Q}{T}$.
However, you are only expected to understand this qualitatively. An example is included
here, though, to help you understand: *A 3 E-3 kg ice cube melts when 2400 calories are
transferred to it as heat. When a solid melts, its temperature stays the same, so the increase
in entropy for the ice cube is* $\Delta S = \frac{2400\ cal}{273\ K} = 8.8\ cal/K.$

---

[11] In contrast, heat and work are process functions, and their values depend on how the system undergoes a
change.

- <u>Example 15</u>: If we include the air and the surface that the ice cube sits on as part of a system, speculate about the change in entropy of the air and surface when the ice cube increases its entropy. Then speculate about the net change in entropy of the system.

- <u>This leads us to a restatement of the second law of thermodynamics</u>: The entropy of an isolated system can be constant or can increase but can never decrease such that

$$\Delta S = \Delta S_{object} + \Delta S_{env} > 0$$

   Again, we are only dealing with this conceptually.

3. _____ & _____ processes:

a. By the second law of thermodynamics, _____

_____. Thus there can be _____ that can reset

itself after doing work.

b. _____: A device that _____

to _____by _____

_____

(Example: Burning coal to turns water to steam. As the steam flows to cooler regions, it passes

through a turbine, causing the turbine to turn. This turns the generator to create electrical

energy.)

    1.) _____ of heat engines: The engine carries a gas through a cycle in

    which...

        a.) _____creating a region of gas at high temperature (the

        _____.)

        b.) The _____ region of cooler air
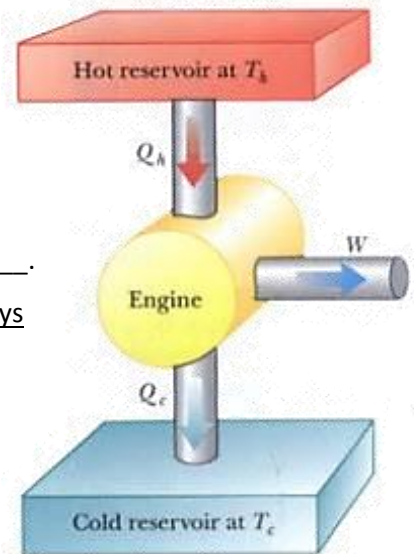
        (_____.)_____

        _____.

        c.) As the gas moves from the heat reservoir to the cold

        reservoir, _____

        _____.

    2.) _____: A more efficient heat engine does
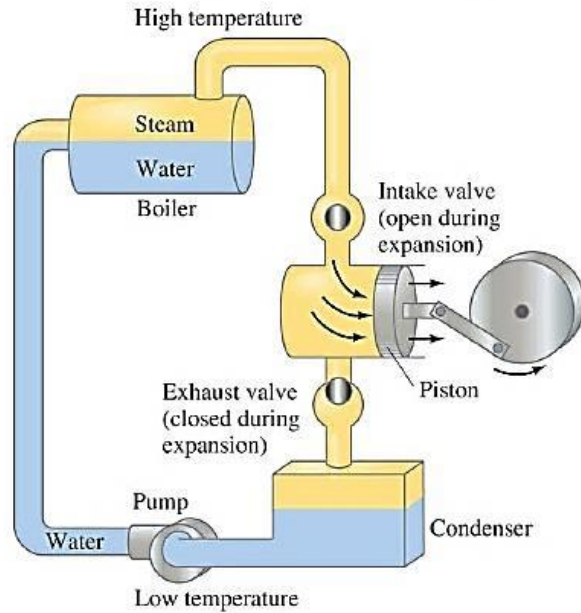
    _____ and _____.

    3.) <u>Heat engines are irreversible processes because they always</u>

    <u>increase entropy.</u>

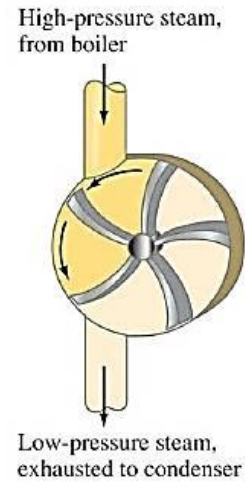Put a little star here.

Put another little star here.

Hot reservoir at T_h

Q_h

W

Engine

Q_c

Cold reservoir at T_c

A steam engine is one type of heat engine.

High temperature

Steam

Water

Boiler

Intake valve
(open during
expansion)

Exhaust valve
(closed during
expansion)

Piston

Pump

Water

Condenser

Low temperature

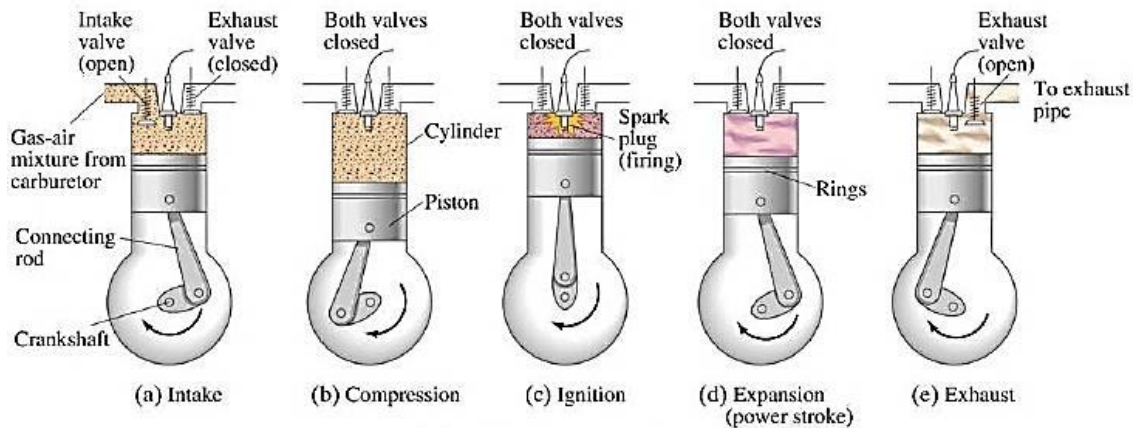(a) Reciprocating type

High-pressure steam,
from boiler

Low-pressure steam,
exhausted to condenser

(b) Turbine (boiler and
condenser not shown)

The internal combustion engine is a type of heat engine as well.

Intake
valve
(open)

Exhaust
valve
(closed)

Gas-air
mixture from
carburetor

Connecting
rod

Crankshaft

(a) Intake

Both valves
closed

Cylinder

Piston

(b) Compression

Both valves
closed

Spark
plug
(firing)

(c) Ignition

Both valves
closed

Rings

(d) Expansion
(power stroke)

Exhaust
valve
(open)

To exhaust
pipe

(e) Exhaust

d. _____: A _____with

_____because the engine operates in a reversible process in which

both system and environment return to their intial states with no increase in entropy

- Carnot cycle steps:

  - Isothermal expansion with temperature T_H where the gas expands, absorbing heat Q_H (A-B on the P-V diagram below)

  - Adiabatic expansion where the gas expands without absorbing heat. This lowers the temperature to T_C. (B-C on the P-V diagram below)

  - Isothermal compression at T_C with constant temperature so that heat flows out. (C-D on the P-V diagram below)

  - Adiabatic compression replenishes the temperature to T_H. (D-A below)

  - Note: The area inside the curve equals the work done.
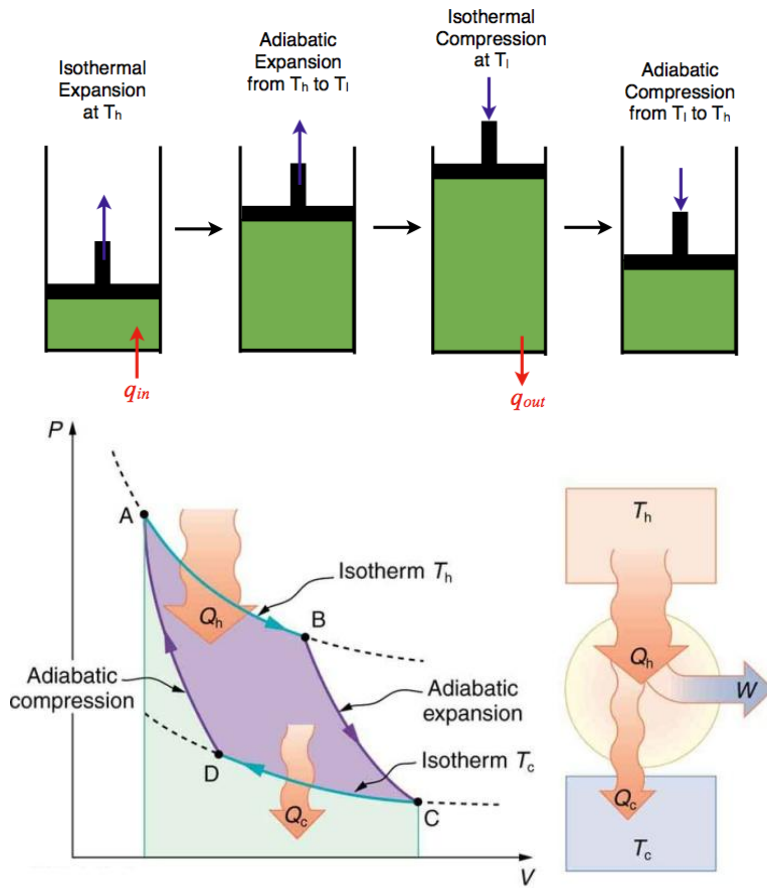
E. Third Law of Thermodynamics: It is impossible to lower the temperature of a system to absolute zero.