Chapter 7

Temperature, Energy and Heat, Ideal Gas Law & Kinetic Theory, Thermodynamics

Chapter 7 is finished, but is not in camera-ready format. There are no pictures, but here are some text-excerpts, with omissions indicated by .....

Read Section 7.1 first. Then choose one of the following paths, depending on the order your class studies topics:

• You can read 7.2 (moles & atomic weight) to prepare for 7.3 (Ideal Gas Law, PV=nRT) or 7.4 (Kinetic Theory).

• Or go to any of these sections: 7.5 (heat capacity and phase changes), 7.6 (heat transfer by conduction, convection & radiation) or to 7.7 and 7.8 (the first and second laws of thermodynamics).

7.1 Temperature, Kinetic Energy and Heat

Atoms and Molecules

If you could look closely enough, you would see that water is made of tiny *atoms* of hydrogen and oxygen (represented by H and O below) that are connected to form *molecules* of H_2O. ..... [no picture]

Temperature and Kinetic Energy

Theory and experiments show that boiling water, which is "hot" with a high *temperature,* contains fast-moving H_2O molecules that have a large *kinetic energy.* By contrast, ice water is "cold", with a low temperature and relatively slow-moving H_2O molecules that have a smaller kinetic energy.

Heat: the transfer of energy from hot objects to cold objects

Imagine a large room cut in half by a wall. In the left half, 100 blue billiard balls are barely moving. In the right half, 100 red billiard balls move extremely fast, in many different directions. If all collisions are *elastic* (with kinetic energy conserved) and the wall is removed, the red and blue balls eventually reach the same average speed, in-between the blue balls' initial slow speed and red balls' initial fast speed.

The blue balls start out slow and "cool", analogous to molecules with low kinetic energy and low temperature. The red balls begin fast and "hot", like molecules with high kinetic energy and high temperature. When the blue & red balls interact and end up "lukewarm" at a medium-sized kinetic energy, the low temperature balls gain kinetic energy and the high temperature balls lose kinetic energy.

BLUE: slow, cool, low KE, low T	RED: fast, hot, high KE, high T
⇓	⇓
lukewarm, medium KE	lukewarm, medium KE
(their KE has increased)	(their KE has decreased)

Do you see that energy naturally moves from hot objects (like balls or molecules) to cold objects? This process is called *heat transfer* or *heat flow:* ***heat*** is the energy that is transferred from a hot object to a cold object.

It is important to understand that heat "flow" is not the movement of a material substance (like water flow, air flow, lava flow,...). Heat flow is a transfer of energy. ..... [snip] .....

7.3 The Ideal Gas Law

When the behavior of gas in a container is analyzed, it is found that gas pressure **P**, volume **V**, number of moles **n**, and temperature **T** are approximately described by

$$\mathbf{P\ V\ =\ n\ R\ T}$$

..... [snip] ..... Two common ways to use PV=nRT are **substitute-and-solve** and **ratio logic**.

Substitute and Solve

When you substitute into PV=nRT, use consistent units, either SI (listed above the equation) or non-SI (below the equation). .....

Ratio Logic

Let's look at how a change in n, T or V (with everything else remaining constant) affects gas pressure. If "n" doubles there are twice as many gas molecules; they hit the wall twice as often so P doubles. If "T" doubles the molecules will, as explained in Section 7.4, move faster by a factor of $\sqrt{2}$ = 1.414. They will hit the wall 1.414 times as often, and they hit it with 1.414 times as much "mv" momentum, so P is multiplied by a factor of 1.414 x 1.414 = 2. If "V" doubles, the same number of molecules hit the container-walls with the same mv, but 1) the walls are further apart so molecules hit the walls less often, and 2) these collisions are spread out over a larger surface area. As discussed in Problem 7-##, these factors combine to make P decrease by a factor of 1/2 when V is doubled.

A good student is equally comfortable using intuitive ratio logic (as described above) or the mathematical techniques discussed in Section 18.9, because math is a way to express physical concepts. For example, ...

Another useful math technique is *dividing equations.* If Situation #1 and Situation #2 are described by $P_1 V_1 = n_1 R T_1$ and $P_2 V_2 = n_2 R T_2$, we can divide the left & right sides of the second equation by $P_1 V_1$ & $n_1 R T_1$, respectively. { Do you see why this "does the same thing to both sides of the equation" and is thus a valid algebra operation? }

$$\frac{\mathbf{P_2\ V_2}}{\mathbf{P_1\ V_1}} = \frac{\mathbf{n_2\ R\ T_2}}{\mathbf{n_1\ R\ T_1}}$$

Most textbooks discuss PV=nRT ratio logic in a historical context, using the "laws" of Boyle, Charles, Gay-Lussac, Avagadro and Dalton. This is a good way to learn about scientific method and the development of ideas. But to use these laws for problem-solving, you must remember all of the different equations and the "If... , then..." requirements for using each one.

An alternative problem-solving strategy is based on the fact that these laws can be easily derived by using "dividing-equations ratio logic." Here are examples to show .....

7.5 Heat Capacity and Phase Changes

When heat is added to an object, several things can happen. Two of the most common are a *temperature increase* and a *phase change.*

Imagine a piece of ice at –15° C, surrounded by a "heat bath" whose temperature remains constant at +120° C. As described in Section 7.1, heat will flow from the hot bath to the cold ice until both objects are at 120° C. When the ice absorbs energy, five changes occur; these are shown by five arrows on the diagram below. .....

7.7 The First Law of Thermodynamics

Section 4.4 studies changes in potential energy & kinetic energy, and the reasons for *conservation of mechanical energy.* Section 4.8 describes an *inelastic collision* that conserves momentum but loses kinetic energy. Now we'll look at what happens to the kinetic energy that is "lost" during an inelastic collision. Is it really lost or is it just hiding?

When a ball of clay is thrown toward a wall, the clay has two kinds of kinetic energy. If the ball has mass M and moves forward with speed V, the entire ball has KE = $\frac{1}{2}$ mv^2; this is the KE we studied in Chapter 4. The atoms and molecules inside the ball are also in continuous motion. They vibrate rapidly back & forth, as shown by ↔'s below; these atomic/molecular motions make their own individual "$\frac{1}{2}$ mv^2" contributions to the total kinetic energy.

[a picture will be here]

If the ball hits the wall and sticks in a *totally inelastic* collision, the ball no longer has a forward-motion kinetic energy of $\frac{1}{2}$ MV^2. What happens to this kinetic energy? The temperature of clay & wall increase slightly and the KE-per-molecule increases. This increase in *molecular-motion kinetic energy* equals the loss of *forward-motion kinetic energy,* and energy is conserved. ..... [snip] .....

7.8 The Second Law of Thermodynamics

If you flip 100 coins, it wouldn't violate any "laws of physics" to get 100 heads, but you don't expect it to happen because it is extremely improbable. There are 10^{29} ways to get 50 heads & 50 tails, but only 1 way to get 100 heads: every coin must be heads. Therefore, a 100-heads result is $1/10^{29}$ as likely as a 50-heads result.

Scientists have defined a quantity called ***entropy*** as a quantitative measure of the probability of a result. .....

7.90 Memory-Improving Flash Cards

7.1	__ bond together to form __ .	atoms, molecules
7.1	A hot object has __ , __ and __ .	fast molecules, high KE, high T
7.1	Heat is __ , not a __ it is caused by __ , its direction is __ ,	a transfer of energy, material substance T difference, "flow" from high-T to low-T
7.1	$T_{freezing\ water}$ = __ , $T_{boiling\ water}$ = __ . T-scales can vary in __ and/or __ . 100° C is __ (__), 100 C° is __ (__).	32°F = 0°C = 273°K, 212°F = 100°C = 373°K size of degree-unit, "starting point" T, 100 degrees C, ΔT, 100 C-degrees
7.2	A mole is __ of __ .	a certain number (6.022 x 10^{23}), anything
7.2	Atomic mass (or molecular mass) is __ of __ .	the mass, 6 x 10^{23} atoms (or molecules)
7.2	"amount of something" can be described by __ . Some useful conversion factors are __ . Conversion-factor equations have __ , so __ .	number (things, moles), m (g), V (cm^3) N_A , atomic or molecular mass, density 3 factors, if you know 2 you can find other
7.3	Some common PV=nRT strategies are __ .	substitute-solve, divide-equations ratio logic
7.3	For s-and-s, you must use __ , either __ (__) or __ (__).	consistent units, SI (Pa,m^3,moles,8.314,K) lit-atm (atm,1,moles,.08207,K)
7.3	If gases A & B share the same container, __ , and __ because __ is independent of __ .	$V_A = V_B = V_{total}$ and $T_A = T_B = T_{total}$ P-ratio = n-ratio, P, molecular mass
7.3	If P decreases by 20%, then __ . If gas is in a rigid container, __ . If __ and __ , $n_2 = n_1$. (cut?) If no gas enters or escapes, __ unless __ . (yes?)	$P_2 = .80\ P_1$ $V_2 = V_1$ no gas enters or escapes, no reaction→Δn $n_2 = n_1$, a reaction causes Δn ==[choose]
7.4	Ideal gas assumptions: molecules __	have negligible V, exert no attractive forces
7.4	__ and __ are proportional.	T (in K°), rms molecular translational-KE
7.4	The Maxwell-Boltzmann __ show that __ .	equation & curve, molecular speeds vary
7.4	levels: The T-KE equation can have __ or __ .	k & m (per molecule), R & M (per mole)
7.4	Temperature doesn't depend on __ or __ . __ does depend on number, __ doesn't.	number of molecules, molecular mass total KE, KE-per-molecule
7.5	Specific heat is __ needed to __ of __ by __ .	energy, raise the T, 1 kg, 1 C° (or 1 K°)
7.5	Heat flows __ until their __ .	to cold-object from hot-object, T's are =
7.5	Equation-factors: T-Δ has __ , phase-Δ has __ . Be sure that __ to give __ . T-scales: for T use __ , for ΔT use __ . Overall Equations: basic idea is __ , ΔT = __ . and ± sign of $Q_{phase\text{-}\Delta}$ __ . (choose between these equations, depending on which one you use)	( ) ( ) ( ) , ( ) ( ) because no ΔT-term units cancel, consistent energy units only °K, either K° or C° $Q_{gain\ by\ cold} = Q_{loss\ by\ hot}$, $T_{high} - T_{low}$ is always + (all terms are always +) $Q_{gain\ by\ cold} + Q_{loss\ by\ hot} = 0$, $T_f - T_i$ must be decided (+ if absorb, – if release)

7.5	If end-point is __ , solve for __ . (2 answers)	___•__| phase-Δ amount , ___|• T_f
	If a T-guess is wrong, __ will be __ .	phase-Δ amount or T_f , impossible
7.5	If heater is used, __ = __ .	heat supplied = heat required for job
7.6	__ is heat-transfer caused by __ . __ is heat-transfer caused by __ . __ is heat-transfer caused by __ .	conduction, neighbor-neighbor interactions convection, whole-group fluid movement radiation, electromagnetic wave movement
7.6	Important difference: __ (in __) ≠ __ (in __).	Q (heat amount), J ; Q/t (heat rate), J/s
7.6	Net $Q_{radiation}$ = __ = e ρ A __ .	$Q_{absorbed} - Q_{emitted}$, $(T_{surr}^4 - T_{object}^4)$
7.6	e varies from __ (for __) to __ (for __). and is __ .	0, shiny reflector, 1, black absorber the same for absorption & emission
7.7	Work (or __) ⇒ __ + __ . The usual name for molecular-motion KE is __ .	$-\Delta PE$, $\Delta KE_{forward\text{-}motion} + \Delta KE_{mol\text{-}motion}$ thermal energy
7.7	The First Law is energy __ for __ . (2)	accountability, system; conservation, univ.
	For either situation, you must include __ .	forward-motion KE, molecular-motion KE, electromagnetic radiation (light), mass PE (grav, elec, chem, spr, magn, nucl,...)
7.7	{Answer this for the equation you use.} For $\Delta U = Q - W$, Q & W are + if __ . For $\Delta U = Q + W$, Q & W are + if __ .	 heat absorbed, work done by system (loss) heat absorbed, work done on system (gain)
7.8	__ is related (mathematically) to __ , and (subjectively) to __ .	entropy, probability "disorder"
7.8	Entropy increases if __ . (5)	V ↑, l → g, mixing, molecules split, T ↑
7.8	The Second Law of Thermo is based on __ .	probability (with large molecule-numbers)
7.8	4 (of many) Second Law forms deal with __ .	heat, $entropy_{universe}$, ΔG_{system}, engines
	The Second Law is __ . (4 equivalent forms)	no spontaneous cold-to-hot heat transfer during change, universe-entropy increases, $\Delta S_{system} + \Delta S_{surroundings}$ is + ΔG_{system} (≡ $\Delta H_{system} - T\,\Delta S_{system}$) is –, reaction motivation: strong bonds, entropy ↑ engine cannot convert heat→work 100%
7.8	When defining __ it is important to __ .	disorder-and-entropy, consider all factors
	$\Delta S_{system} = \Delta S_{universe}$ if __ .	closed system (no mass- or energy-transfer)
	Problem 7-E: In Step 1, S_{univ} ↑ because __ . In Step 2, S_{univ} ↑ because __ .	S ↑ due to T ↑ > S ↓ due to $2H \rightarrow H_2$ S_{surr} ↑ due to T ↑ > S_{sys} ↓ due to $2H \rightarrow H_2$
7.8	An __ system-Δ (and __) can be caused by __ .	"un-natural", S ↓ , work done by surr
7.8	Engine efficiency is determined by __ .	Second Law limitations, design-and-friction