Chapter 04: Heat and Temperature

Section 4.1: The Kinetic Molecular Theory

Aristotle: Wrong Again!
- So, this guy called Democritus suggests that matter is made of tiny, tiny indivisible particles. He called them atoms.
- Aristotle says no: Earth, air, fire, water, duh!
- Newton was thinking about this, but couldn't formalize
- As chemistry develops, strong indirect evidence of atoms/molecules

Molecules
- An atom is a single unit of an element: sodium (Na), maybe chlorine (Cl)
- All atoms of a specific element are the same as each other, but the atoms of another element are different
- A molecule sticks several atoms together: NaCl = one sodium stuck to one chlorine = table salt
- For purposes of kinetic theory, molecule = smallest unit, either molecule or elemental atom

Molecules Interact
- Cohesion: Stuff sticks to itself!
- Adhesion: Stuff sticks to other stuff!

Phases of Matter

Solids
- Strong cohesive forces
- Fixed volume, fixed shape

Liquids
- Less cohesion (but definitely not zero)
- Fixed volume, variable shape
- Liquids take the shape of their container; not compressible

Gases
- Extremely weak cohesion (practically zero, sometimes literally zero)
- Variable volume, variable shape
- Gases expand to fill closed container; highly compressible

Plasmas
- Gas made of ionized particles
- Ionized means electrically charged

Molecules Move
- Diffusion: You don't have to be in the oven to smell the cookies baking!
- That smell means molecules moved through the air and got sucked in to your nose
- Molecules are always moving, even in liquids and solids

Kinetic Theory
- Solid, liquid, gas, plasma: All molecules are moving—all the time
- Each and every molecule has kinetic energy (because it’s moving!)
- Solids: Slowest motion, least KE (gases/plasma have highest energy)

Section 4.2: Temperature

Define Temperature
- Average kinetic energy per molecule
- Has to be an average: Not every molecule is doing exactly the same thing at exactly the same time!
- Increase temperature: Increase speed of molecular motion (the molecules don't get more massive!)
- Decrease temperature: Decrease speed (the molecules don't get less massive, either!)
Thermal Expansion
- Matter expands when you increase its temperature (contracts when temperature decreases)
- Faster-moving molecules need more room: Space between adjacent molecules increases
- Decrease temperature: Slower molecules can get closer together (thus occupying less volume)

Thermometers
- Thermal expansion is the basis: Fill a tube with colored liquid, it will expand when heated
- Or, bond different materials together: They expand at different rates
- Or, measure the infrared coming out of your eardrum! (It would help if we knew what infrared meant)

Temperature Scales
- Relative: Scale is based on something arbitrary (like freezing/boiling of water, or human body temperature)
- Absolute: Scale references the idea of kinetic energy (lowest possible temperature occurs when all molecular motion stops)
- Fahrenheit, Celsius are relative (Rankine, Kelvin are absolute)

Section 4.3: Heat

Internal vs External Energy
- External: The overall KE and PE of an object (in bulk)
- As our ball drops from the top of the Tower of Pisa, all of its molecules are falling; the whole ball loses PE as it gains KE
- Internal: The total KE and PE of the molecules comprising the object
- As our ball drops, friction with the air causes some of its molecules to move faster, slightly increasing the temperature

Heat As Energy Transfer
- Temperature is not the same thing as heat!
- Historically, heat was thought to be a “caloric fluid”
- Benjamin Thomson (in between inventing thermal underwear and the coffee percolator) determined that heat could not be a fluid
- Cannon boring: Why do your drill bits get so hot???

Heat Defined
- Definition: Total internal energy absorbed or transferred from one object to another
- Energy transfer only happens in one direction: high to low (never the other direction!)
- An object with greater temperature can give energy to an object with lower temperature

Two Heating Methods
- Temperature Difference: Higher energy molecule can give energy to a lower energy molecule
- Form Conversion: Converting energy from one form to another always creates waste heat

Measures of Heat
- Imperial: BTU = British Thermal Unit = energy required to raise 1lb of water by 1°F
- Metric: Calorie = energy required to raise 1 g of water by 1°C
- Heat is, of course, still energy, and can be measured in Joules as well: 1 cal = 4.184 J

Specific Heat
- Not everything "heats up" the same way: Material makes a difference
- Low c: iron \( c_p = 0.11 \text{ cal/g °C} \)
- High c: water \( c_{water} = 1 \text{ cal/g °C} \)
- So, one calorie of energy raises 1g of water by 1°C, but it raises that 1g of iron by almost 10°C!
Heat Flow

- Energy in the form of heat: \( Q = mc\Delta T \)
- \( m \): The more mass you have, the more energy required to raise its temperature
- \( c \): The higher the specific heat, the more energy you need to raise the temperature
- \( \Delta T \): The more you want to raise the temperature, more energy you need

Conduction

- Heat transfer via molecular interaction: Higher energy molecule gives energy to a lower energy molecule
- Requires contact
- Metallic materials are good conductors: Molecules are close together, crystal structure, elasticity

Convection

- Energy transfer via bulk motion of the medium: Move the energy by moving the whole molecule
- Only works with fluids: Solids cannot do this
- Boiling water, Earth's atmosphere, surface of the sun

Radiation

- Energy transfer requires no material medium! Radiant energy can travel through vacuum
- Anything that is a thing has \( T > 0K \), and thus radiates
- You: \( T \approx 300K \), radiation = infrared
- Sun: \( T \approx 6000K \), radiation = visible light

Section 4.4: Energy, Heat, and Molecular Theory

Phase Change

- Add or subtract energy, but don't change the temperature
- Use the energy to make or break intermolecular bonds
- Absorb energy: Break bonds (solid to liquid or liquid to gas)
- Release energy: Form bonds (gas to liquid or liquid to solid)

Latent Heat of Fusion

- Latent heat of fusion \( L_f \) (either direction: solid-liquid or liquid-solid)
- Energy required to freeze/melt 1g of a substance at whatever its freezing point temperature is
- Water: \( L_f = 80\text{cal}/\text{g} \) means adding 80 calories changes 1 gram of ice into liquid water

Latent Heat of Vaporization

- Latent heat of vaporization \( L_v \) (either direction: liquid-gas or gas-liquid)
- Energy required to boil/condense 1g of a substance at whatever its boiling point temperature is
- Water: \( L_v = 540\text{cal}/\text{g} \) means adding 540 calories changes 1g water into steam

Evaporation

- Not quite the same as boiling!
- Average energy means some molecules have more energy than others—possibly much more
- Highest energy molecules can escape, leaving lower energy molecules behind
- Overall average can be significantly less than the boiling point of the liquid

Condensation

- Not quite the same thing as melting!
- Bathroom mirror is cooler than the steam from the shower
- Higher energy water molecules give energy to the lower energy molecules of the mirror
- The water molecules (now stuck to the mirror) have lower energy, and return to the liquid phase
Evaporation Rate

- Increase the overall temperature, increase the rate of evaporation
- More surface area exposed, greater rate of evaporation
- Lower humidity (or a breeze!), faster evaporation
- Reduce air pressure for quicker evaporation