

Thermodynamics

Planet Holloway Physics

Part I – Temperature

Temperature – The average kinetic energy of the molecules within a substance

Laws of Thermodynamics (memorize by number)

- **Zeroth Law of thermodynamics:** If A is in thermal equilibrium with B and B is in thermal equilibrium with C, then A and C are in thermal equilibrium with each other.
- **1st Law of thermodynamics:** the law of conservation of energy, an isolated system will maintain constant energy, but that energy may change forms
 - $\Delta U = Q + W_{on-sys}$
- **2nd Law of thermodynamics:** the entropy of an isolated system never decreases, but increases as the system moves toward thermal equilibrium.
- **3rd Law of thermodynamics:** The entropy of a system approaches a constant value as the temperature approaches zero. (we do not actually use this one)

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Thermal Equilibrium – when two objects have the same temperature

Know how to convert between Fahrenheit, Celsius and Kelvin.

$$T_F = \frac{9}{5}T_C + 32 \qquad T = T_C + 273.15$$

Note: Kelvin is not said with the word “degrees”, also T is always in Kelvin and ΔT can be either Celsius or Kelvin

Thermal Expansion

Almost all substances expand when heated. Note: water actually contracts when heated from 0 to 4°C (from ice to dense water) therefore, ice is less dense and floats.

$$\Delta L = \alpha L_0 \Delta T$$

$$\Delta A = \gamma A_0 \Delta T, \qquad \gamma = 2\alpha$$

$$\Delta V = \beta V_0 \Delta T, \qquad \beta = 3\alpha$$

When you heat a solid object with a hole, i.e. a ring, both the hole and the metal get larger.

Ideal Gas Law

$$PV = nRT$$

$$PV = Nk_B T$$

$$R = 8.31 \text{ J/(mol K)} = 0.0821 \text{ (L atm)/(mol K)}$$

n = number of moles, whereas N is the number of molecules

$$U = K_{total} = \frac{3}{2} nRT = \frac{3}{2} Nk_B T$$

remember that we are looking at average kinetic energy

$$v_{rms} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3RT}{M}}, \quad k_B = 1.38 \times 10^{-23} \text{ J/K} \quad (\text{from } K = \frac{1}{2}mv^2)$$

Part II - Thermal Processes

Heat is the transfer of energy between objects - Q (measured in Joules)

Three types of heat transfer

- **Conduction** - two substances are in direct contact
- **Convection** - a fluid (liquid or gas) carries energy between two substances
 - overturn in lakes, major wind patterns on Earth, rain shadow effect
- **Radiation** - energy transferred via electromagnetic waves (light, both visible and invisible).

1 cal = 4.185 J (on a side note, 1eV = 1.6×10^{-19} J, an electron volt is another unit for energy.)

$$H = \frac{kA\Delta T}{L}, \quad k = \text{J/(s m } ^\circ\text{C)} \quad \text{Used for conduction}$$

H is heat flow or Q/t, (J/s) which is equivalent to power. H is sometimes written with a script P (\mathcal{P})

Insulation reduces heat flow

R value is a rating system for insulation

$$Q = mC\Delta T$$

$$Q = \pm mL$$

During a phase change some energy must go into the rearrangement of the structure and does not change the temperature of the substance.

- Understand the temp vs. energy graph for water regarding latent heat and temp increase.

Part III - Work in thermal processes (Heat engines and pumps)

Understand PV graphs

- direction matters
- work is equal to the area under the curve
- total work is equal to the area inside the cycle
- must know processes by name and key characteristics

$$W_{sys} = -P\Delta V,$$

the old system used (not on the AP) $W_{enviro} = P\Delta V$

$$\Delta U = Q + W_{on-sys}$$

Know the following parts of a cycle and their key ideas:

- isovolumetric - (aka isochoric) means volume is constant therefore no Work
 - $\Delta U = Q$
- isobaric - means constant pressure
 - $W = -P\Delta V$
- isothermal - means constant temperature therefore
 - $\Delta U = 0, Q = -W$
- adiabatic - volume changes rapidly allowing no heat in or out therefore
 - $Q = 0, \Delta U = W$

Heat Pump – (aka refrigerator) push high temp gas away by using mechanical work (by a compressor)

Heat Engine – (i.e. a car engine) uses high temp to expand gas and do work

$$W_{engine} = |Q_h| - |Q_c|$$

Coefficient of performance (below)

$$COP_{engine} = \frac{|Q_h|}{W_{engine}}, COP_{pump} = \frac{|Q_c|}{W_{engine}}$$

Carnot Engine – theoretical best efficiency engine (not 100%)

$$e_c = 1 - \frac{T_c}{T_h} = \frac{W_{engine}}{|Q_h|} = \frac{|Q_h| - |Q_c|}{|Q_h|}$$

Entropy – the amount of disorder in a system when in a constant temp process (like phase change)

$$\Delta S = \frac{Q_R}{T}$$