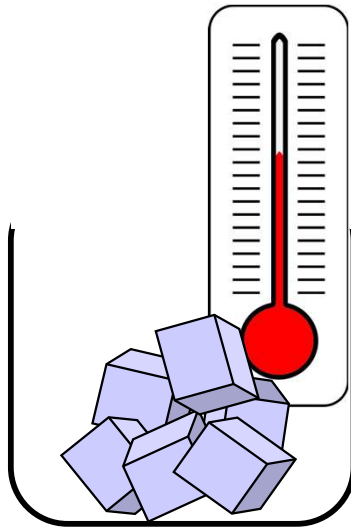
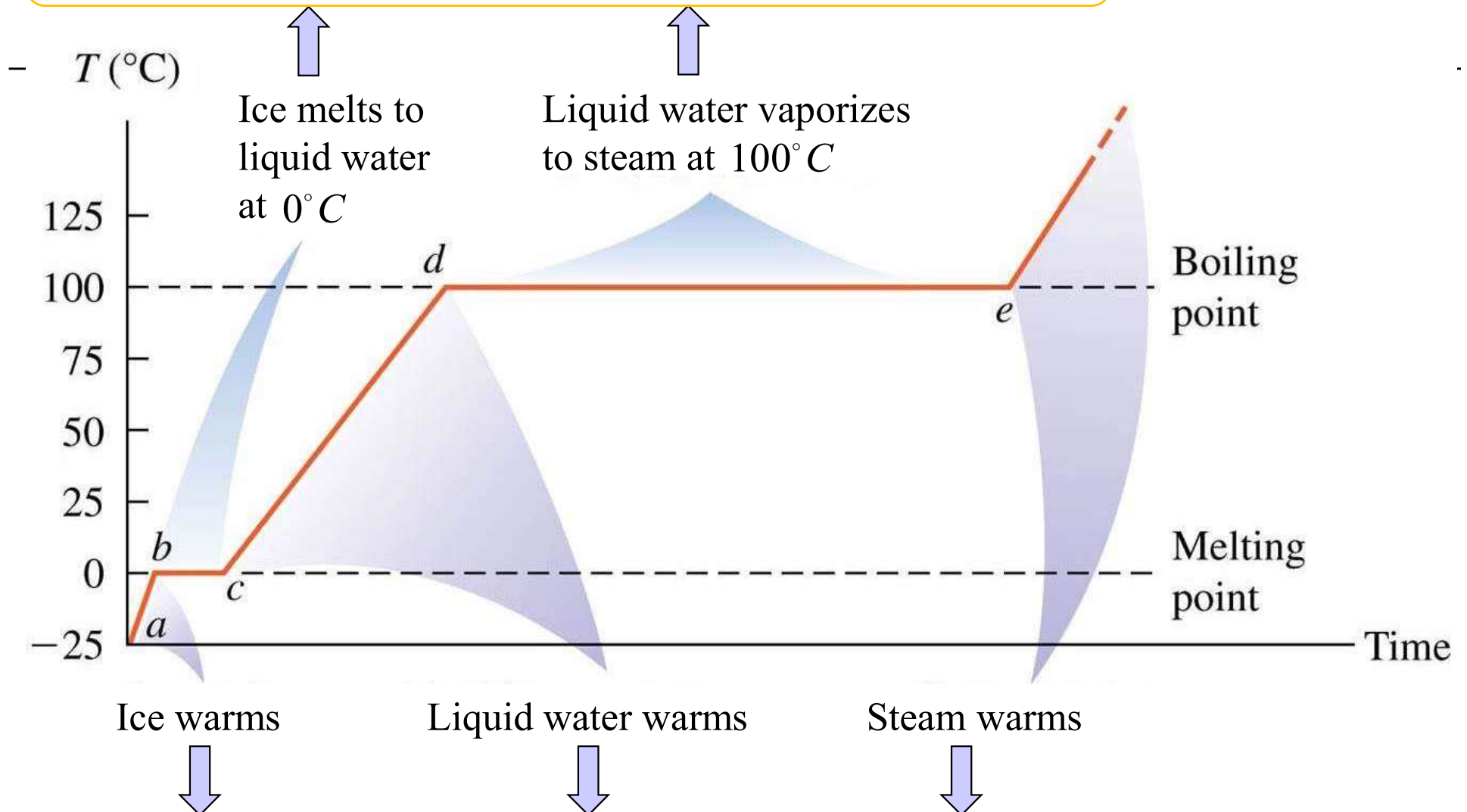


Calorimetric Processes

Now we are ready to describe thermodynamic process such as the following:



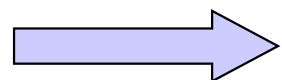
Phase of water changes: During these periods, temperature stays constant as heat is added: $Q = +mL$



Temperature of water changes: During these periods, temperature rises as heat is added: $Q = mc\Delta T$

Calorimetry: Problem Solving with Heat Exchanges (method 1)

- Main Concept: **Conservation of Energy**

 $\Sigma Q = 0$ (sum of all heat flows into and out of system =0)

- Sign Convention: heat enters a system is +
heat leaves a system is –
- $\Delta T = T_f - T_i$

Calorimetry: Problem Solving with Heat Exchanges (method 2)

- Main Concept: Conservation of Energy

$$\text{OR} \quad \sum |Q_{\text{gain}}| = \sum |Q_{\text{loss}}|$$

- Keep all heats as positive quantities

Calorimetry: Problem Solving with Heat Exchanges

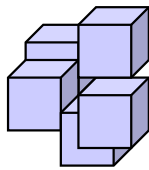
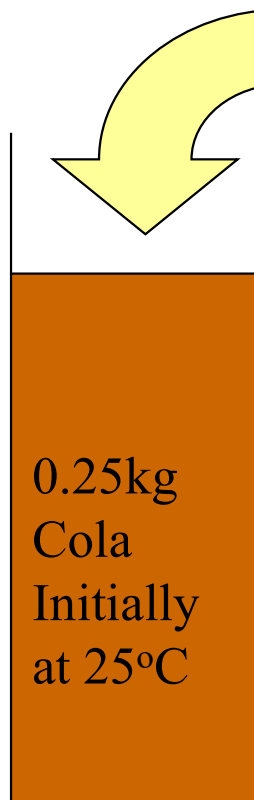
Steps:

1. **Identify all phase change pts**
2. Apply (either $Q=mc\Delta T$ or $Q=mL$) for each processes separately. (don't apply $Q=mc\Delta T$ across ph. changes!)
3. Use

$$\sum_{ALL} Q = 0 \quad \text{and follow sign convention}$$

or just do
$$\sum |Q_{gain}| = \sum |Q_{loss}|$$

Calorimetry (example 17.8)



Ice initially at -20°C

[note](#)

Question:

How much ice needed so that the final mixture is all liquid water with a temperature of 0°C?

Mechanisms of Heat Transfer

#1: Conduction

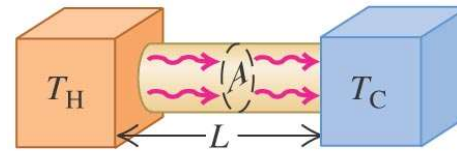
$$H = \frac{dQ}{dt} = kA \frac{T_H - T_C}{L} \quad (+H \text{ is in the dir. of decreasing } T)$$

$H \rightarrow$ **heat current** [J/s]
(heat flow rate)

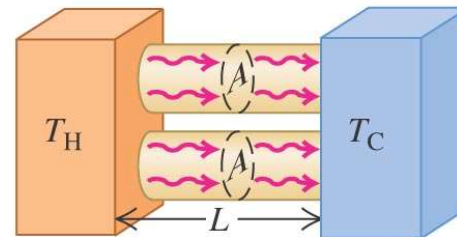
$k \rightarrow$ **thermal conductivity** [$W / m \cdot K$]
(characteristic of the material)

$R = L/k \rightarrow$ **thermal resistance**
(larger is better)

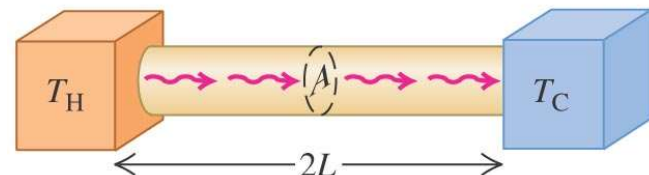
(a) Heat current H



(b) Doubling the cross-sectional area of the conductor doubles the heat current (H is proportional to A).



(c) Doubling the length of the conductor halves the heat current (H is inversely proportional to L).

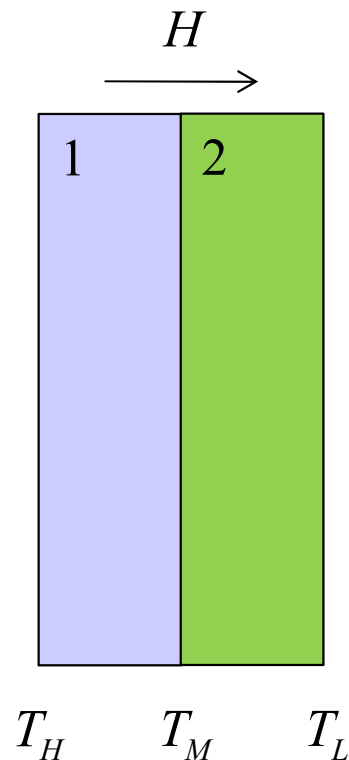


Thermal Resistivity (additive R values)

$$H(\text{heat current}) = kA(T_H - T_L) / L = A(T_H - T_L) / R$$

where $R = L / k$

For a composite system, we have the following:



$$H_1 = \frac{A(T_H - T_M)}{R_1} \quad \text{and} \quad H_2 = \frac{A(T_M - T_L)}{R_2}$$

Now, by conservation of energy, we need to have $H_1 = H_2 = H$

Re-arranging and adding the two equations gives:

$$T_H - T_M = \frac{HR_1}{A}$$

$$\oplus \Rightarrow T_H - T_L = \frac{H(R_1 + R_2)}{A} \Rightarrow H = \frac{A(T_H - T_L)}{R_1 + R_2}$$

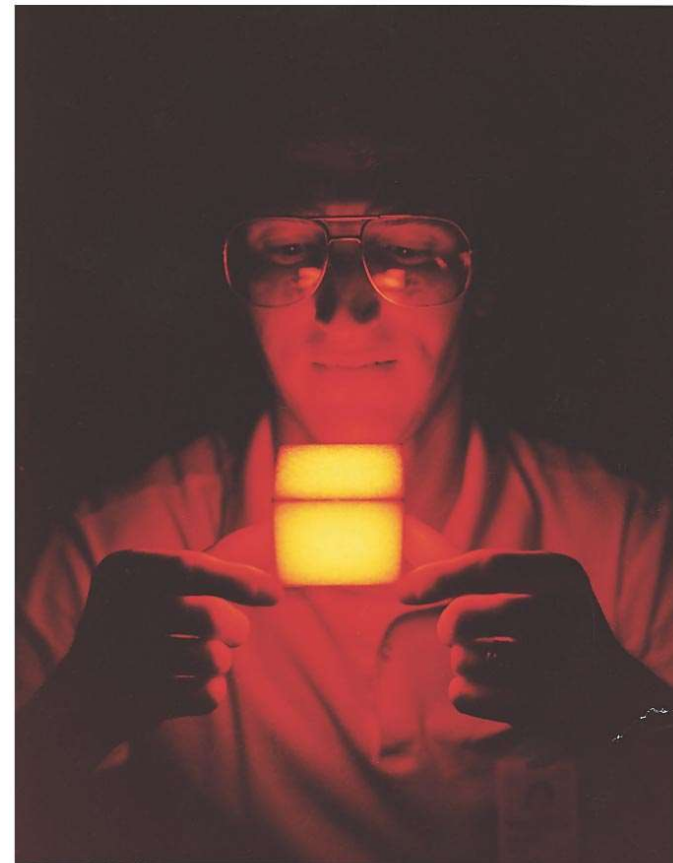
$$T_M - T_L = \frac{HR_2}{A}$$

So, for composite system, R is additive.

Mechanisms of Heat Transfer

Table 17.5 Thermal Conductivities

Substance	k (W/m · K)
<i>Metals</i>	
Aluminum	205.0
Brass	109.0
Copper	385.0
Lead	34.7
Mercury	8.3
Silver	406.0
Steel	50.2
<i>Solids (representative values)</i>	
Brick, insulating	0.15
Brick, red	0.6
Concret	0.8
Cork	0.04
Felt	0.04
Fiberglass	0.04
Glass	0.8
Ice	1.6
Rock wool	0.04
Styrofoam	0.01
Wood	0.12–0.04
<i>Gases</i>	
Air	0.024
Argon	0.016
Helium	0.14
Hydrogen	0.14
Oxygen	0.023



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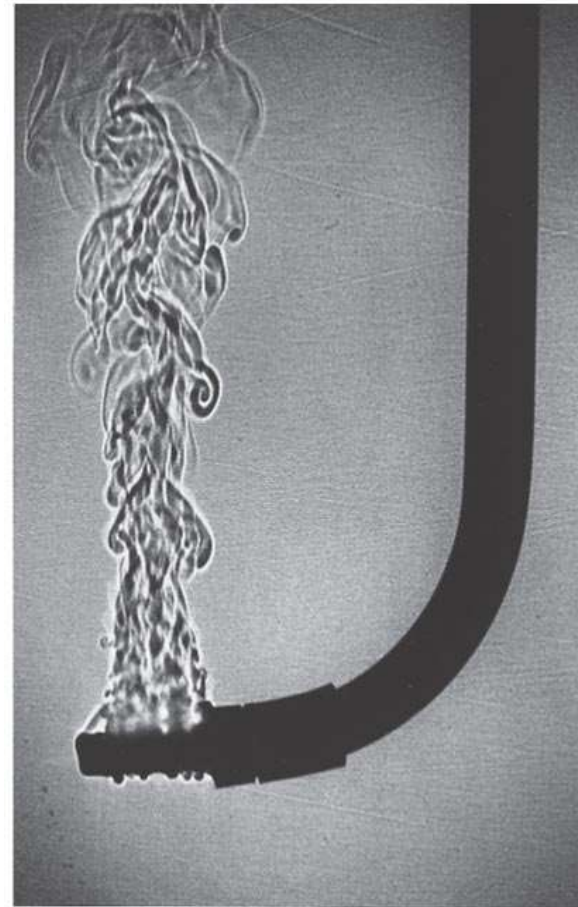
Protective tile for the space shuttle has both low values of k and c !

Mechanisms of Heat Transfer

#2: Convection

- Heating by moving large amounts of hot fluid, usually water or air.

- Heating element in the tip warms surrounding water. Heat is transferred by convection of the warm water movement.



Mechanisms of Heat Transfer

#3: Radiation

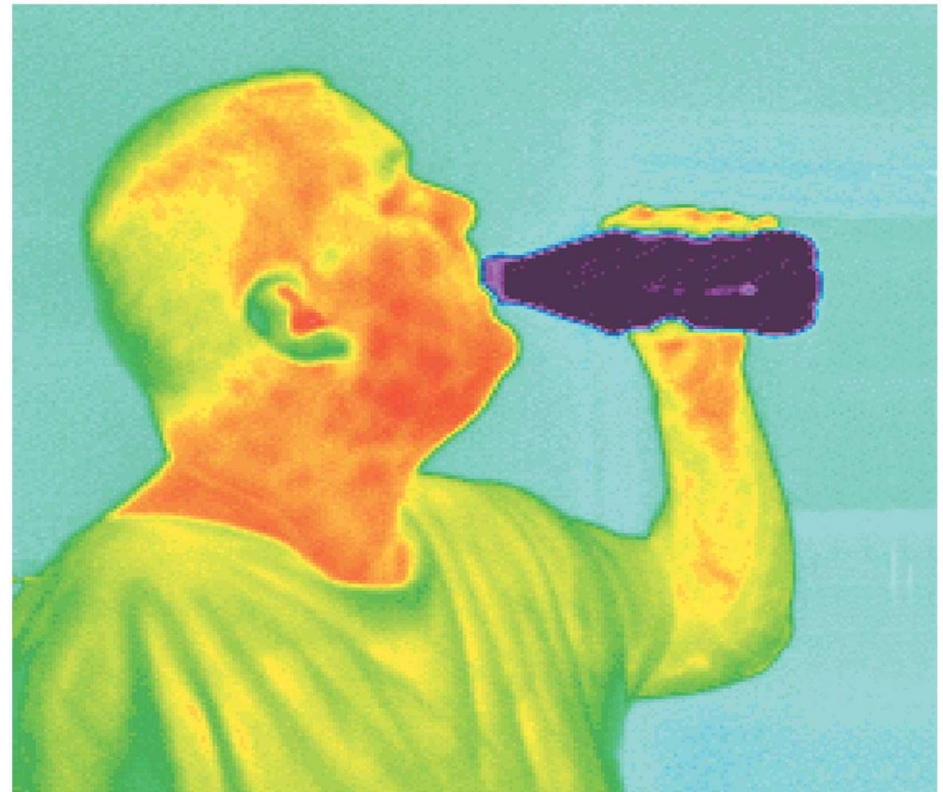
- Infrared lamps, hot objects, a fireplace, standing near a running furnace ... these are all objects heating others by “broadcasting” EM radiation.

$$H = Ae\sigma T^4 \quad (\text{Stefan-Boltzmann Law})$$

$A \rightarrow$ surface area of object at T

$e \rightarrow$ emissivity [0,1]
(effectiveness of surface in emitting EM radiation)

$\sigma \rightarrow$ Stefan-Boltzmann constant
(a fundamental physical constant)



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Camera sensitive to these radiation can be used to take this picture.

Mechanisms of Heat Transfer

□ Radiation and Absorption

The *environment* around an object at a given T also radiates electromagnetic energy and the radiating object will *absorb* some of this energy.

In general, the absorption will again depends on the surface properties of the object, i.e., the same A , e , and σ . Now, if the surrounding environment is at T_s , the *net* heat current radiated by the object will be,

$$H_{net} = \underbrace{Ae\sigma T^4}_{\text{(radiate)}} - \underbrace{Ae\sigma T_s^4}_{\text{(absorb)}} = Ae\sigma(T^4 - T_s^4)$$

PHYS 262/266

George Mason University

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Chapter 18: Thermal Properties of Matter

Topics for Discussion

- Equations of State
- Ideal Gas Equation
- PV Diagrams
- Kinetic-Molecular Model of an Ideal Gas
- Heat Capacities
- Distribution of Molecular Speeds



Equations of State

□ State Variables

→ physical variables describing the macroscopic state of the system:

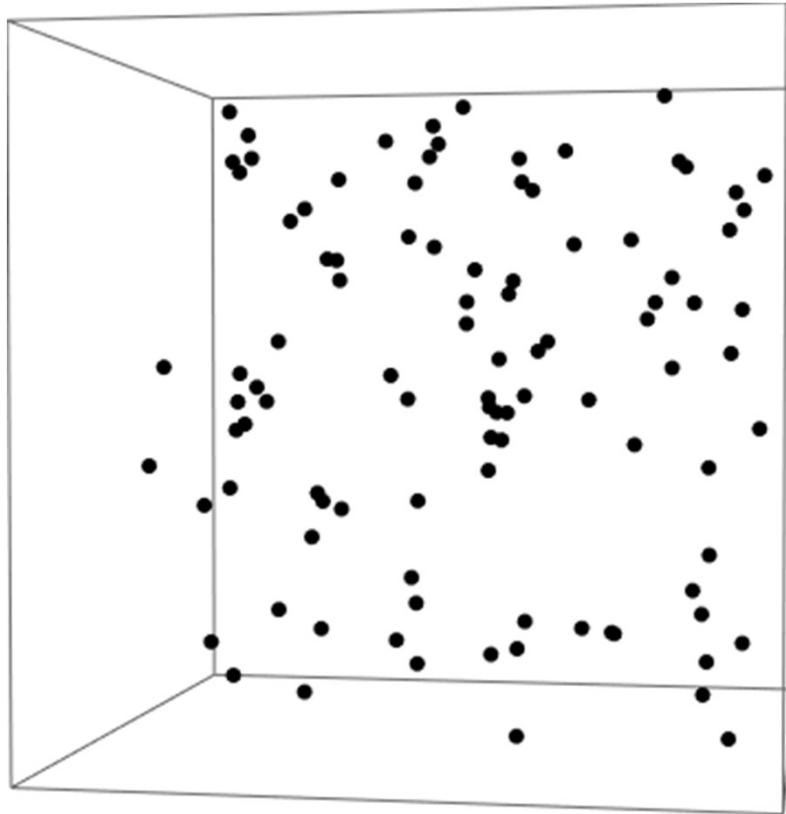
$$P, V, T, n \text{ (or } m)$$

□ Equation of State

→ a mathematical relationship linking these variables

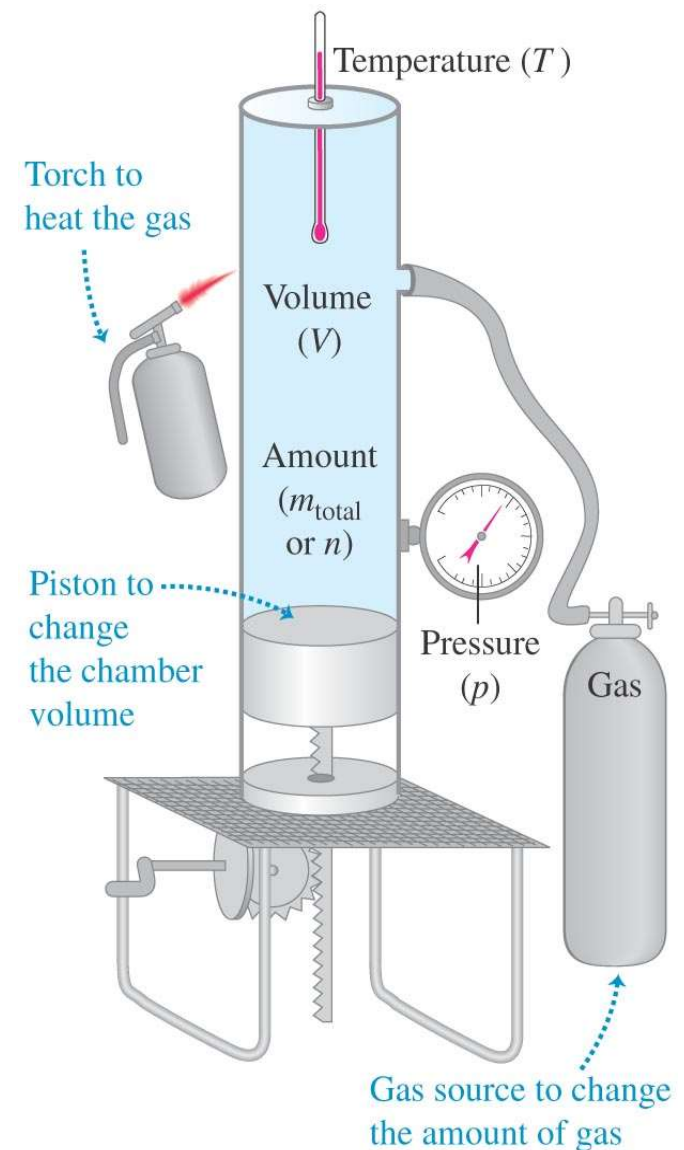
Ideal Gas – a Box of Dilute Gas

This discussion applies in general to all physical systems ... now we focus on a system of dilute gas



The Ideal Gas Equation

- Properties of a gas is studied by varying the macroscopic variables: P , V , T , n and observing the result.
- Observations:
 1. $P \propto 1/V$ e.g. air pump
 2. $V \propto T$ e.g. hot air balloon
 3. $P \propto T$ e.g. hot closed spray can
 4. $V \propto n$ e.g. birthday balloon



Ideal Gas Law (summary)

- By putting all these observations together, we have

$$PV = nRT$$

$R \rightarrow$ Universal Gas Constant ($R = 8.314 \text{ J/mol K}$)

(This is an important example of an **Equation of State** for a gas at *thermal equilibrium*.)

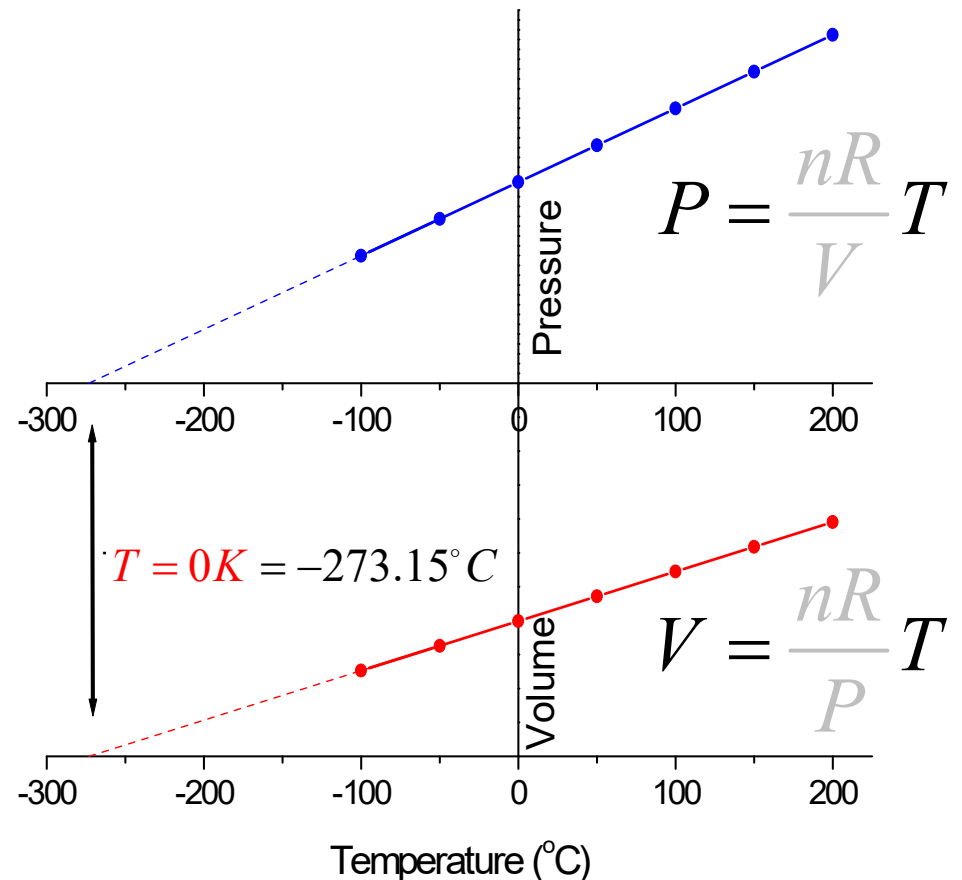
- An Ideal Gas (dilute):
 - No molecular interactions besides elastic collisions
 - Molecular volume \lll volume of container

Most everyday gases ~ Ideal!

The Ideal Gas Law

Important Notes:

- The relationship P vs. T (at cont V) & V vs. T (at cont P) are *linear* for all *diluted* gases.
 - diluted gas ~ Ideal
- They both extrapolate to a single *zero* point (absolute zero).
 - T has to be in K!



The Ideal Gas Law (alternative form)

Instead of the *number of moles* (n), one can specify the amount of gas by the actual *number of molecules* (N).

$$N = n N_A \quad (N_A = 6.02214 \times 10^{23} \text{ molecules/mole})$$

where N_A is the # of molecules in a *mole* of materials (**Avogadro's number**).

$$PV = nRT \quad \rightarrow \quad \boxed{PV} = \frac{N}{N_A} RT = \boxed{NkT}$$

where k is the Boltzmann constant,

$$k = \frac{R}{N_A} = 1.381 \times 10^{-23} \text{ J / molecule} \cdot \text{K}$$

Example 18.1 (V at STP)

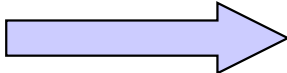
What is the volume of a gas (one mole) at *Standard Temperature and Pressure* (STP)?

→ STP: $T = 0^{\circ}\text{C} = 273.15\text{K}$
 $P = 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$

$$PV = nRT \quad \rightarrow \quad V = \frac{nRT}{P}$$
$$= \frac{(1 \text{ mole})(8.314 \text{ J/mol}\cdot\text{K})(273.15 \text{ K})}{1.013 \times 10^5 \text{ Pa}} = 0.0224 \text{ m}^3 = 22.4 \text{ L}$$

Typical Usage for the Ideal Gas Law

- For a fixed amount of gas ($nR=\text{const}$)

 $\frac{PV}{T} = nR = \text{const}$

- So, if we have a gas at two different states 1 (before) and 2 (after), their state variables are related simply by:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

We can use this relation to solve for any unknown variables with the others being given.