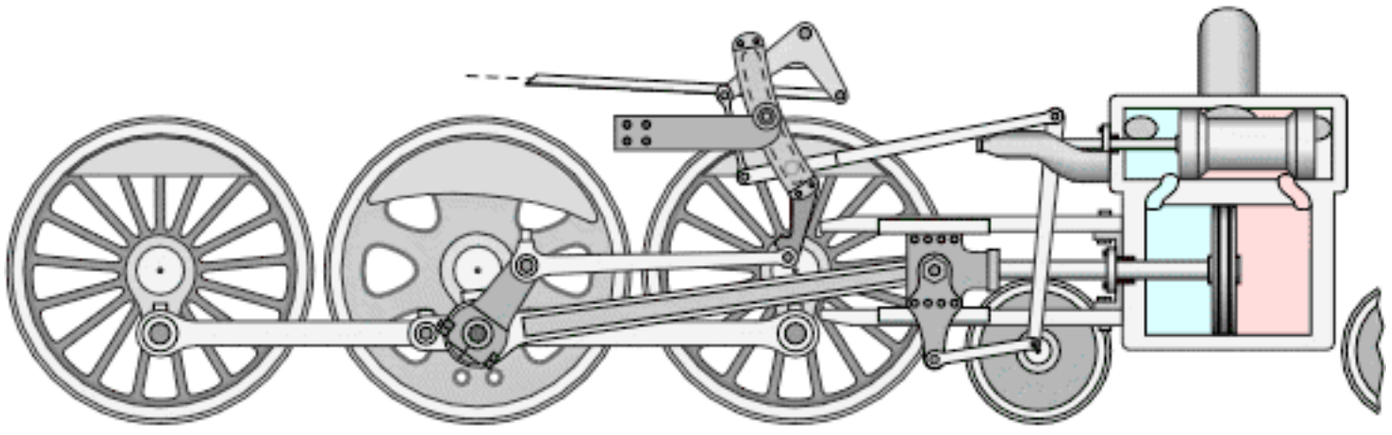
Thermodynamics

PHY 215
Thermodynamics and
Modern Physics

Fall 2025
MSU

Thermodynamics

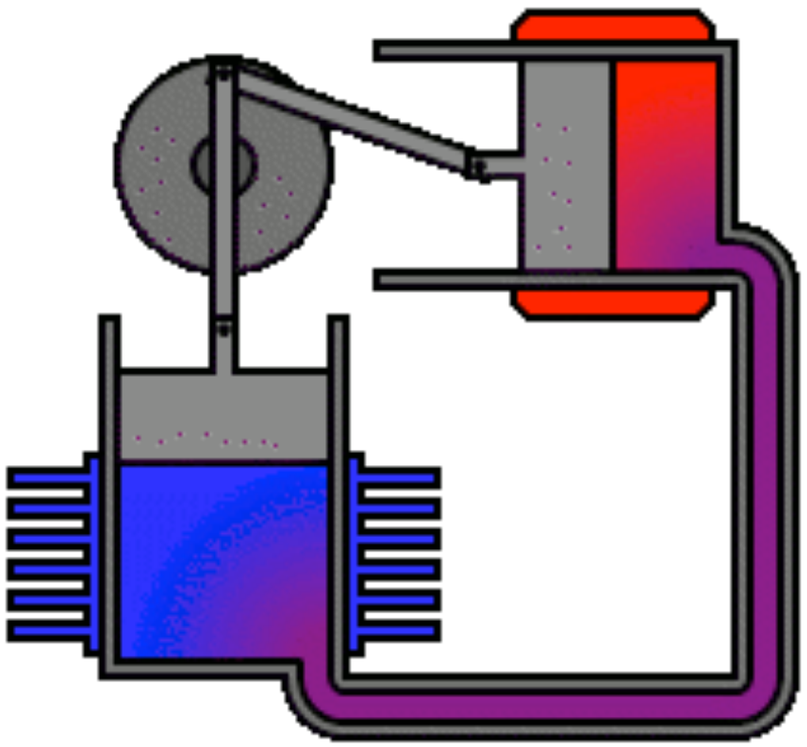


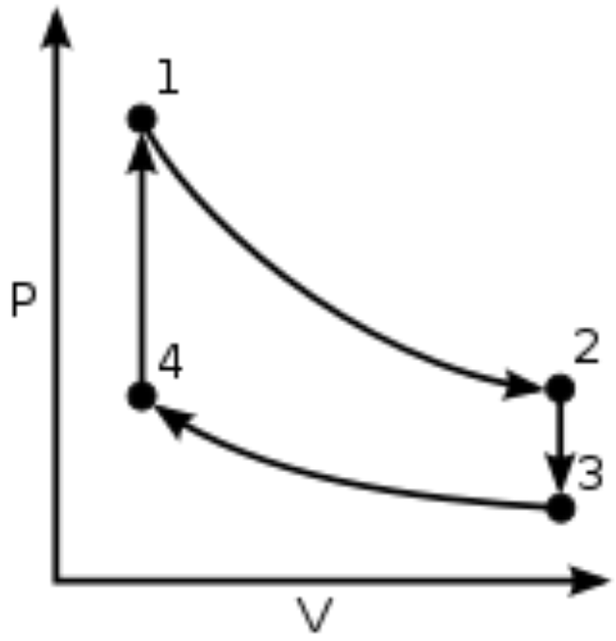
What is heat? What is Temperature?

How much heat energy can be converted into mechanical energy?

Images from http://en.wikipedia.org/

Stirling Engine





External Combustion Engine

Images from http://en.wikipedia.org

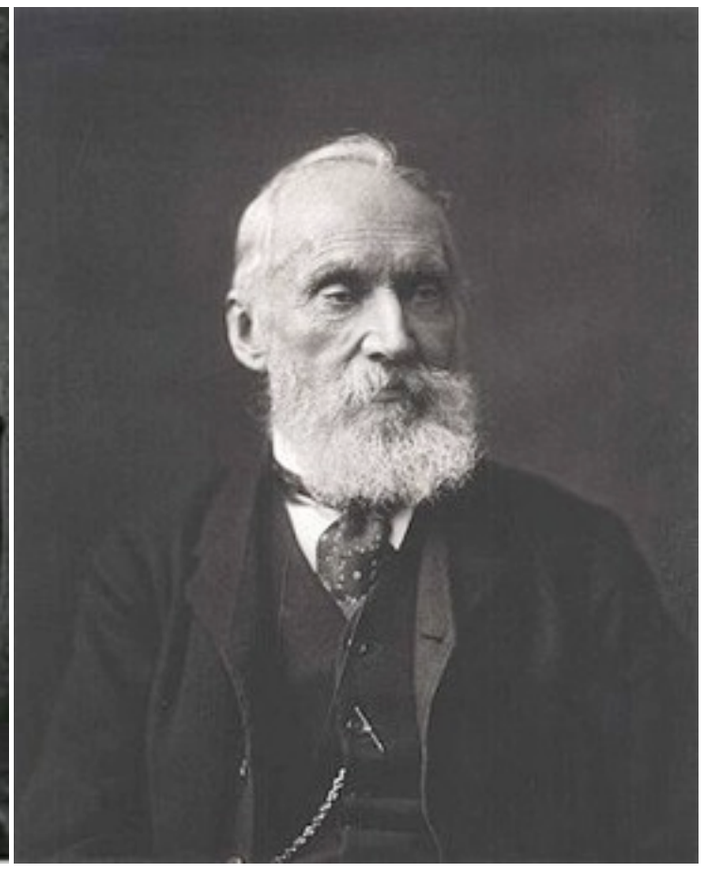
The Founders of Thermodynamics

Sadi Carnot

1796 –1832

James Joule

1818 - 1889



William Thomson, Lord Kelvin

1824 - 1907

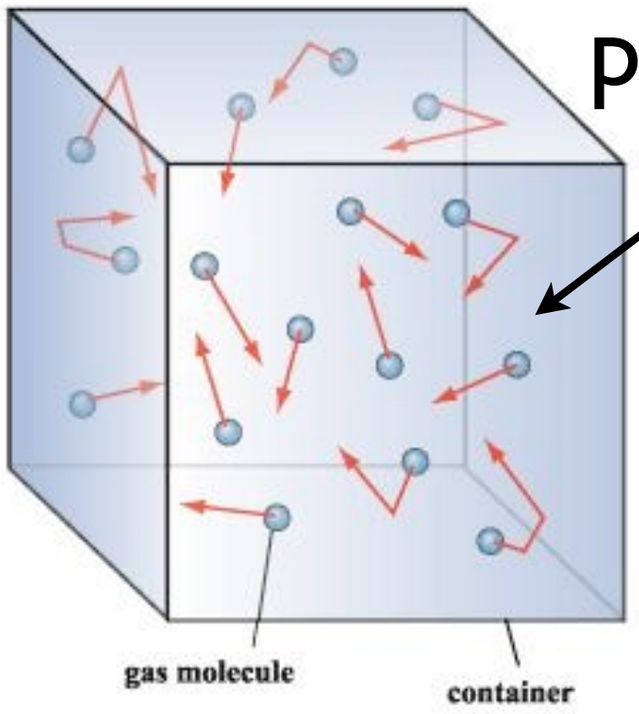
- Thermodynamics was developed before the atomic nature of matter was understood!

Images from http://en.wikipedia.org

The 3+1 Laws

- 0^{th}: Two systems in thermal equilibrium have the same temperature.
- 1^{st}: Heat is a form of energy in the work-energy theorem.
- 2^{nd}: You cannot extract all of the heat energy in a system and turn it into work.
- 3^{rd}: No reversible process can cool a system to absolute zero.

Thermodynamic State



O(6x10^{23}) molecules, positions, momenta

Equilibrium State:
"State Variables"
time-independent

Focus on "averages"

- Volume
- Amount (moles, or #, gm)
- Pressure
- Temperature

System could be: gas, liquid, solid

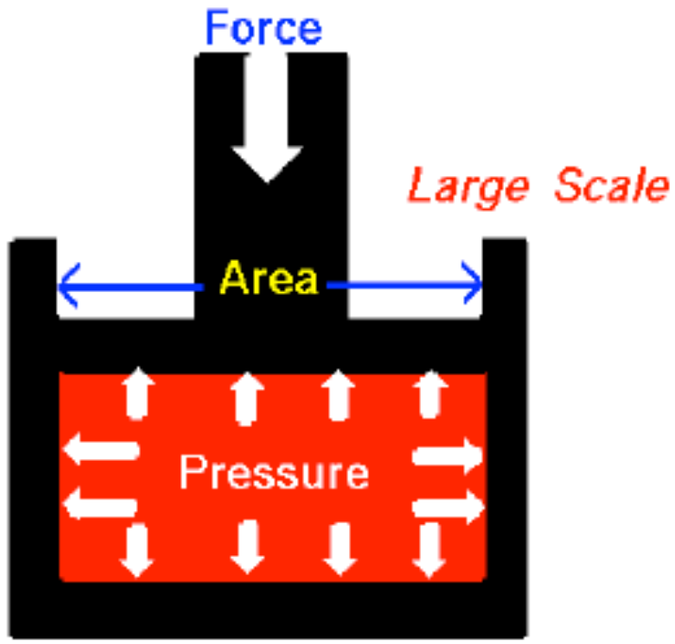
Will be made more precise... Kinetic Theory of Gases

Image: http://www.phy.cuhk.edu.hk

Pressure

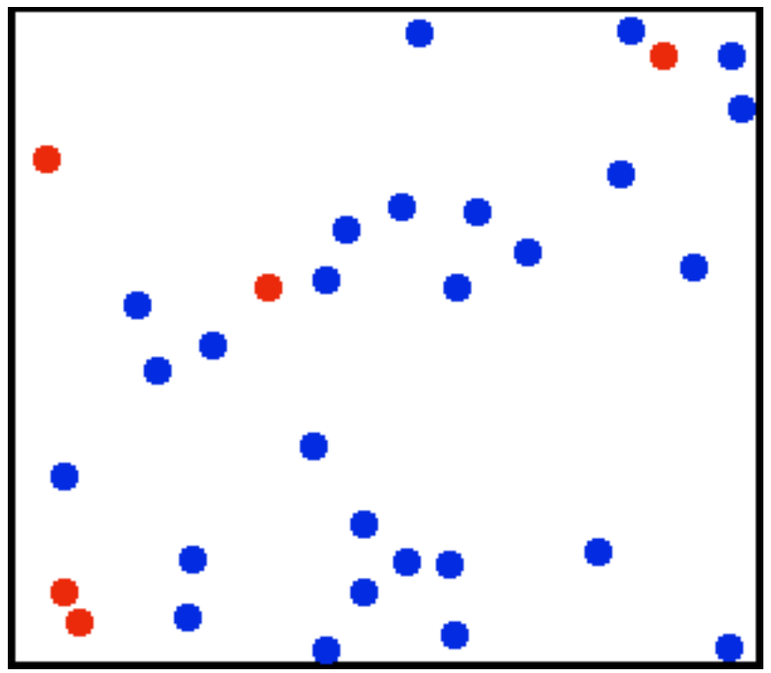
Pressure is $\frac{\text{Force}}{\text{Area}}$

Pressure is a scalar quantity.
(magnitude, no direction)



Pressure force acts perpendicular to enclosing surfaces.

Microscopic view:



Pressure: Molecules bounce off walls

Pressure Units

	pascal (Pa)	bar (bar)	technical atmosphere (at)	atmosphere (atm)	torr (Torr)	pound-force per square inch (psi)
1 Pa	= 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	100,000	= 10^6 dyn/cm^2	1.0197	0.98692	750.06	14.5037744
1 at	98,066.5	0.980665	= 1 kgf/cm^2	0.96784	735.56	14.223
1 atm	101,325	1.01325	1.0332	= 1 atm	760	14.696
1 torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	= 1 Torr; ≈ 1 mmHg	19.337×10^{-3}
1 psi	6.894×10^3	68.948×10^{-3}	70.307×10^{-3}	68.046×10^{-3}	51.715	= 1 lbf/in^2

Images: http://wright.nasa.gov, http://wikipedia.org

Temperature

Temperature Scales

- Daniel Fahrenheit (1686-1736)
  - 0°F = mixture of ice, water, salt
  - 100°F = Human body temp (~98.6°F)

- Anders Celsius (1701-1744)
  - 0°C = Freezing point of H_2O
  - 100°C = Boiling point of H_2O

- Lord Kelvin (1824-1907)

H_2O boil : 100°C = 212°F = 373 K

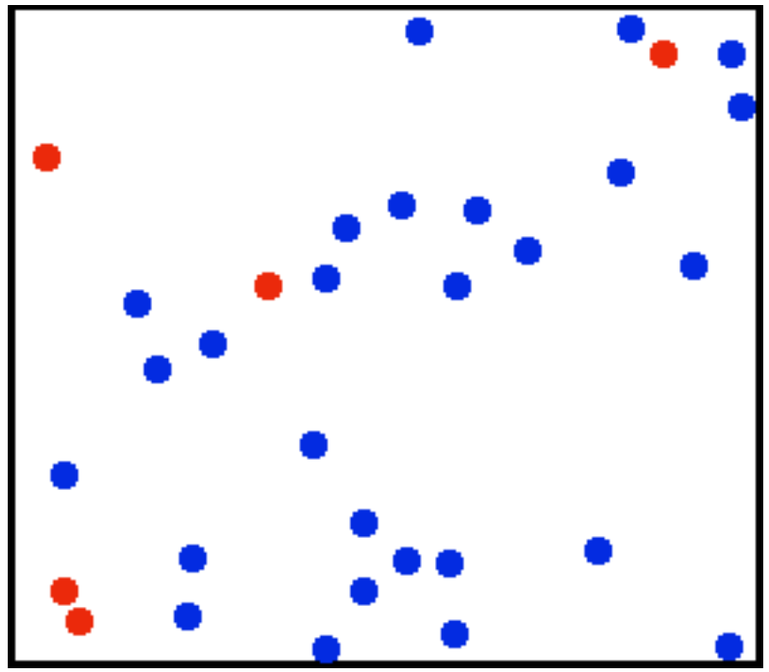
H_2O freeze : 0°C = 32°F = 273 K

Absolute zero : -273°C = -460°F = 0 K

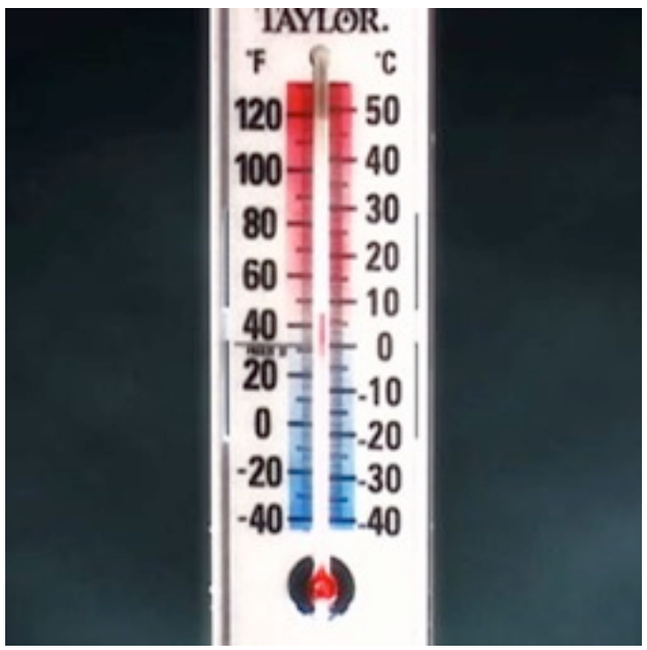
$T_C = T_K - 273.15$

$T_F = (9/5)T_C + 32$

Microscopic view:



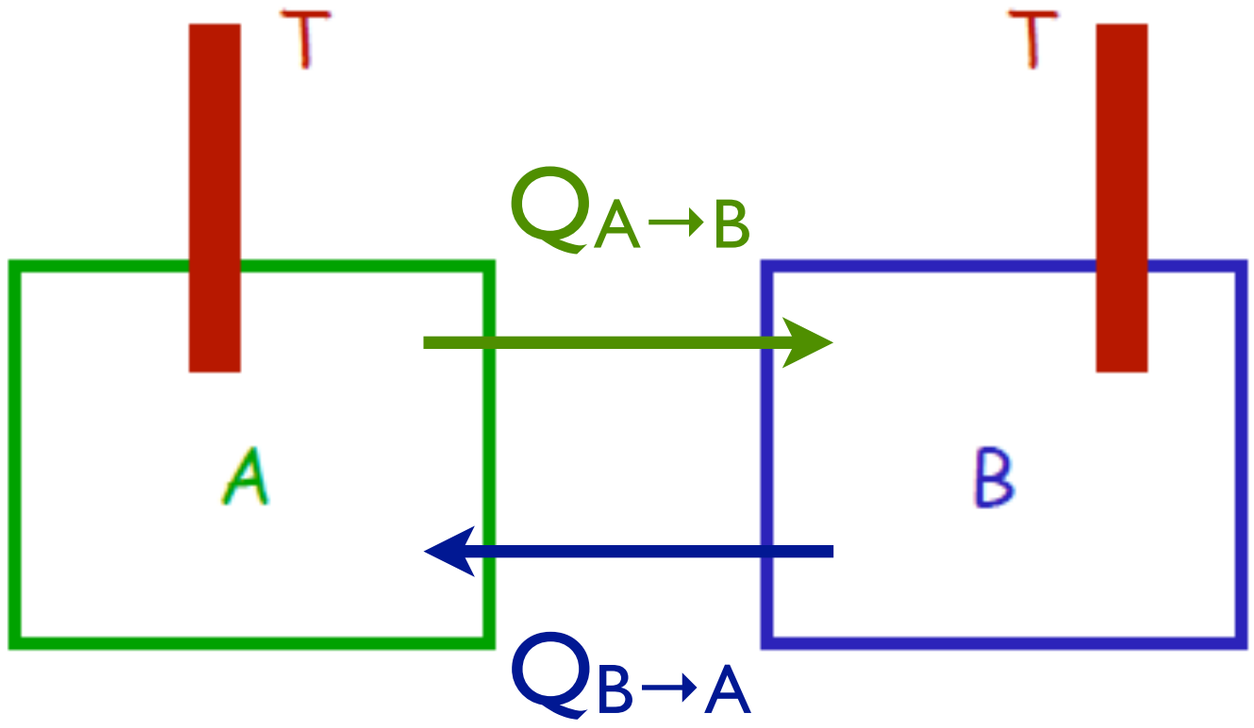
Temperature: molecular velocity, rotation, vibration



Images: http://wikipedia.org, http://www.learner.org

0^{th} Law of Thermodynamics

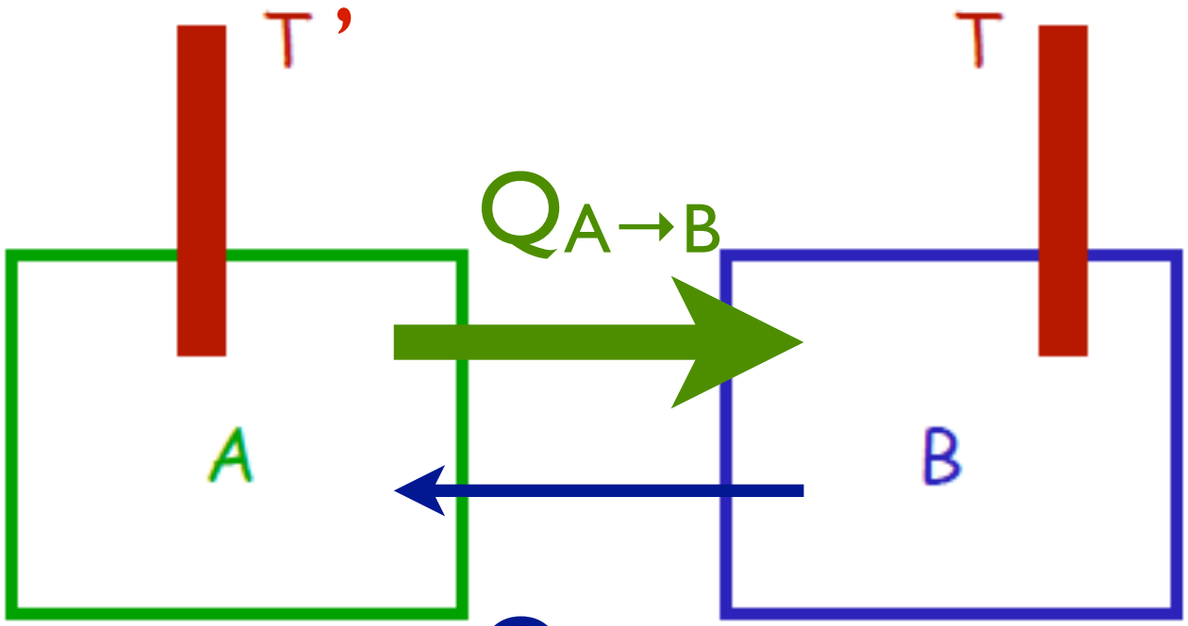
If bodies A and B are each in thermal equilibrium with a third body T, then they are in thermal equilibrium with each other.



Objects in thermal equilibrium are at the same temperature.

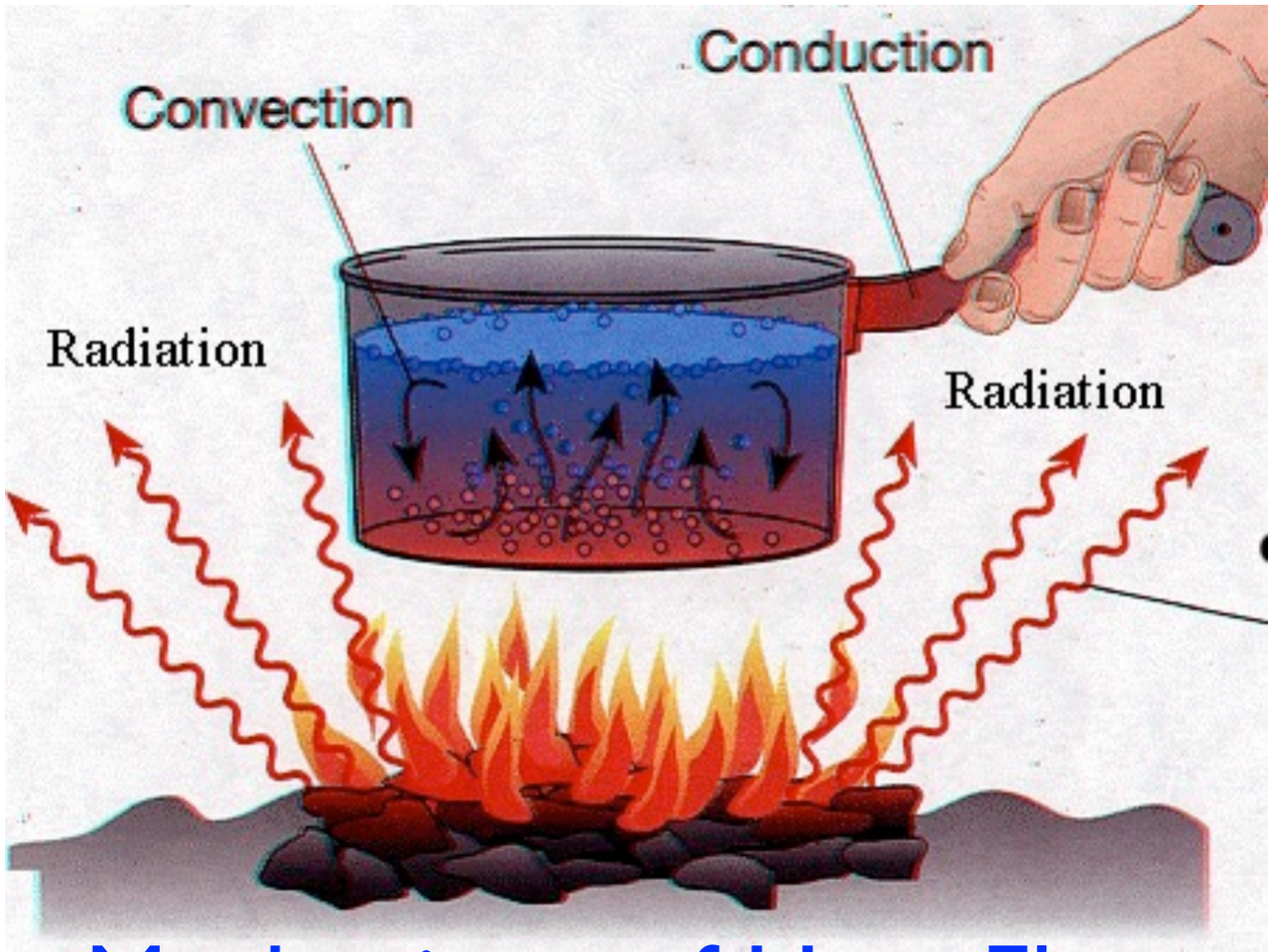
$$Q_{B\to A}=Q_{A\to B}$$

Heat Flow: Hot → Cold



T'>T

$Q_{A\to B} > Q_{B\to A}$



Mechanisms of Heat Flow

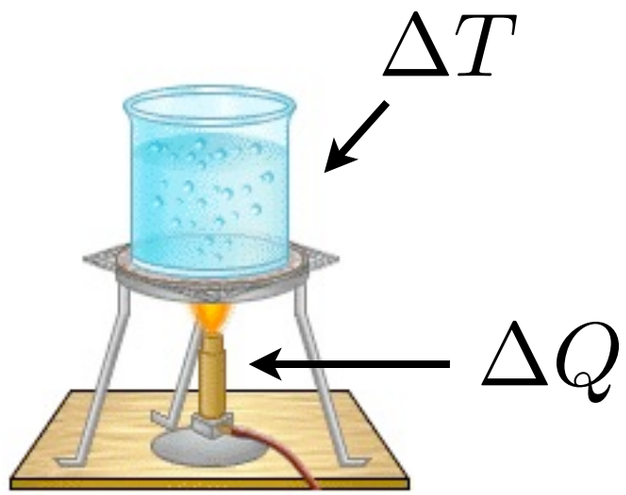
Flow: In the "caloric" theory heat was thought to be a "fluid"

Image: http://www.aos.wisc.edu/~aalopez/

Heat vs. Temperature

- Specific heat capacity

$$\Delta Q = c m \, \Delta T$$



- 1 calorie = heat energy needed to raise 1 gm of water 1 degree K.

$$c_{H_2O} = 1 \ \frac{cal}{gm \circ K}$$

1 Cal = 1 kcal

- Unit of heat: cal

$$[Q] = \text{cal}$$

Thermal Energy

Heat ≠ Temperature!

"Hotness": ability to give or absorb heat

Image: http://educationalelectronicsusa.com

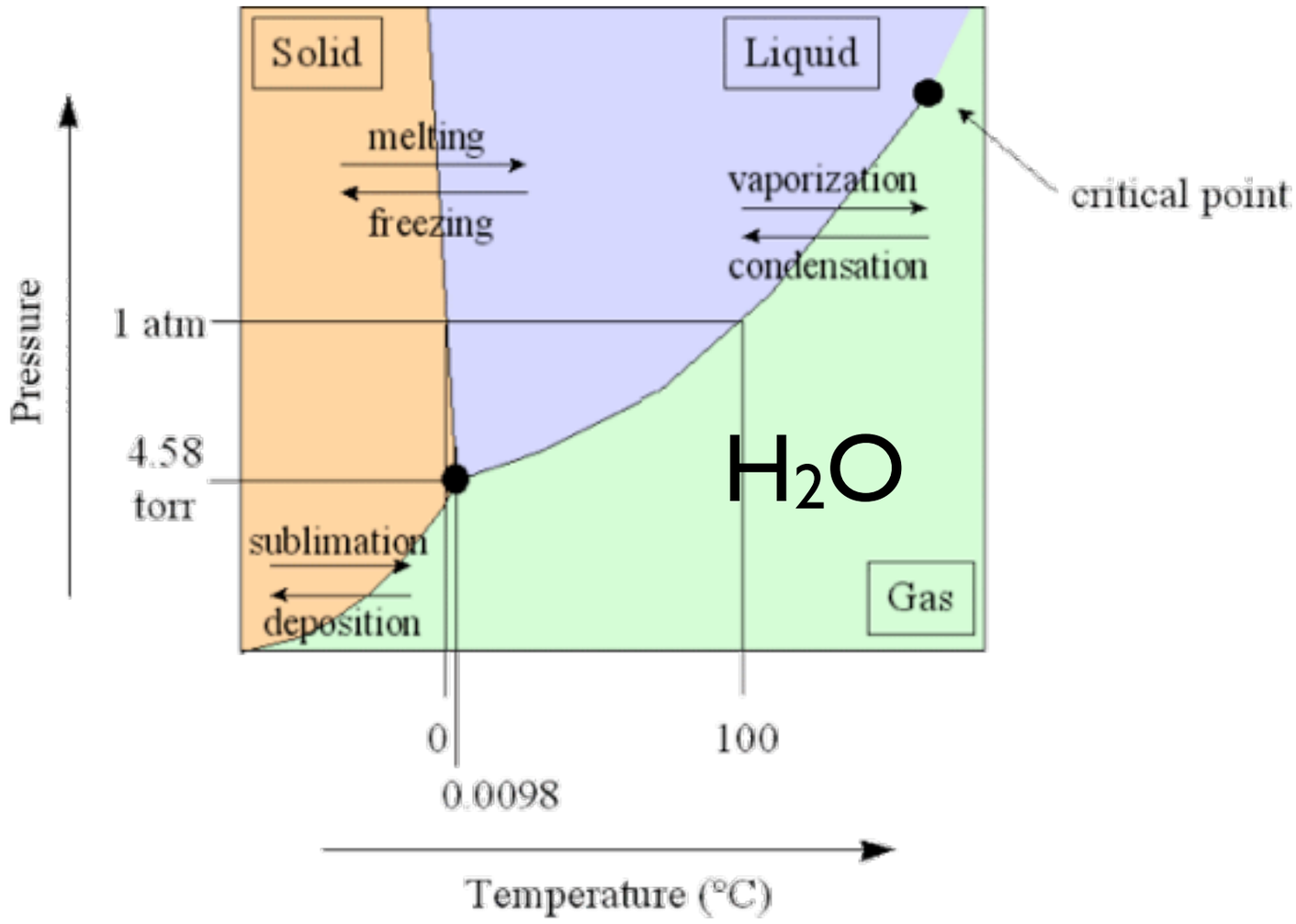
Concept Test

- The heat capacity of the cooling fluid for an engine should be

A. Large

B. Small

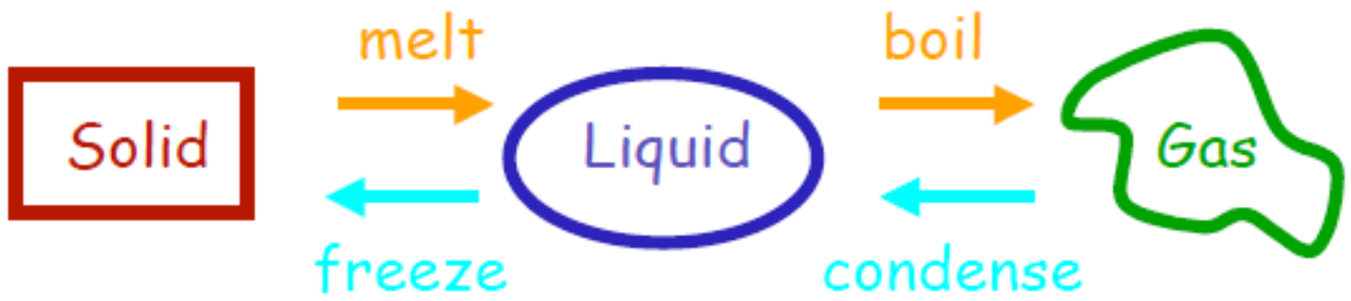
Phase Changes



- Heat can be absorbed or emitted when the phase of a substance is changed
  - Density can change during a phase transition

Image: http://www.its.caltech.edu/

Latent Heat



Requires energy →

← Releases energy

Amount of energy/unit mass is

Heat of transformation, L.

e.g. for water:

Heat of fusion

L_F = 79.5 cal/g = 333 kJ/kg = 6.01 kJ/mole

Heat of vaporization

L_V = 539 cal/g = 2256 kJ/kg = 40.7 kJ/mole

Heating Curve

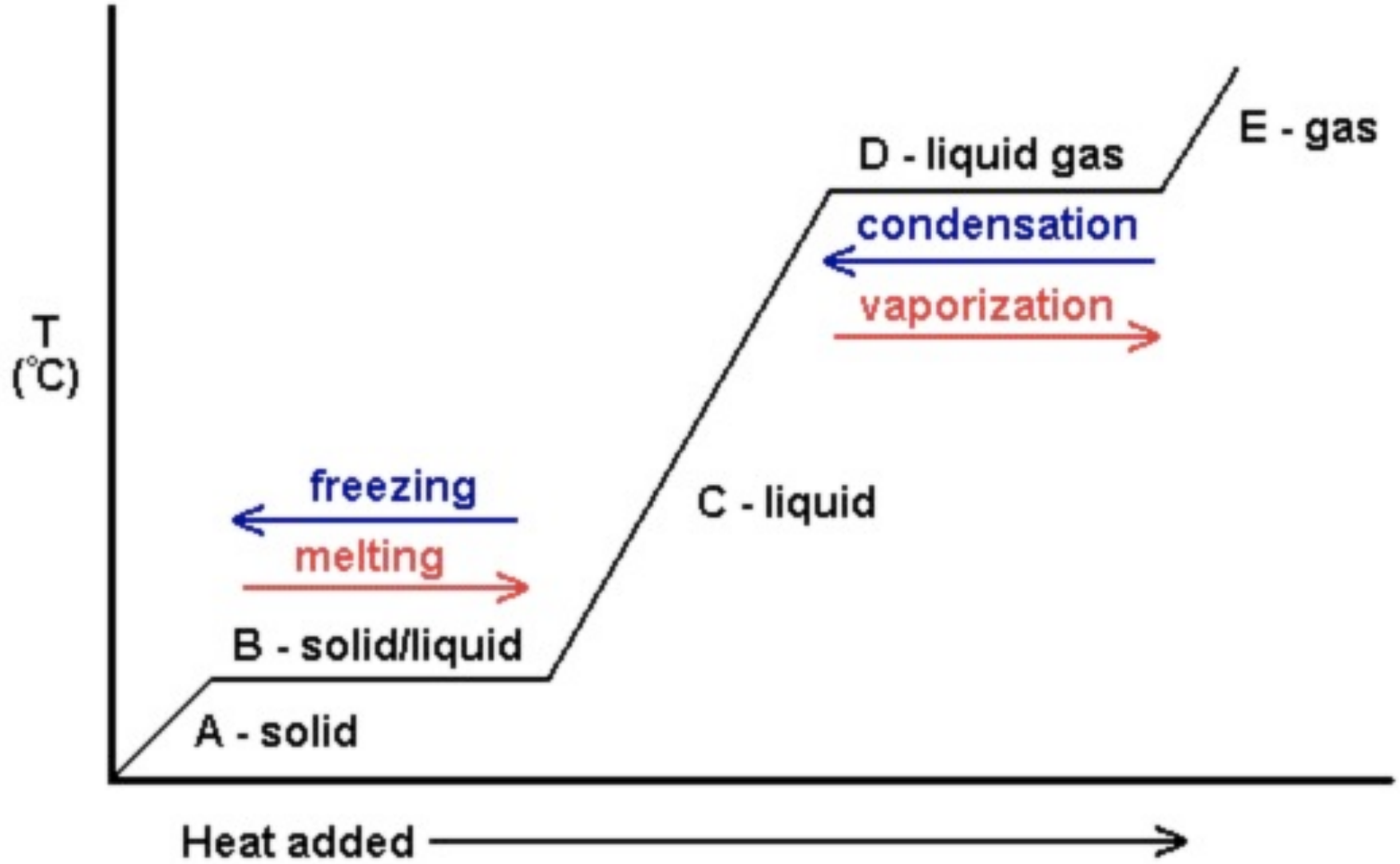


Image: http://library.thinkquest.org

Summary

- Thermodynamics is the study of heat, and its transformation to and from work.
- In "equilibrium", the state of the system is defined by a few variables: pressure, volume, temperature, amount.
- 0^{th} Law: Temperature makes sense!
- Heat is a form of energy; temperature a measure of the tendency to absorb or give off heat.
- (Latent) Heat absorbed/given off during phase change.