Announcements

1. Schedule –

   Chapter 19 – macroscopic view of heat (today)

   Chapter 20 – microscopic view of heat (Tuesday – 11/18)

   Review Chapters 15-20 – (Thursday – 11/20)

   Exam 3 – (Tuesday – 11/25)

2. **Physics colloquium today – Professor Gary Pielak from UNC will speak about "Protein Biophysics in Cells".**

3. **Today's lecture – Chapter 19**

   Temperature

   Heat

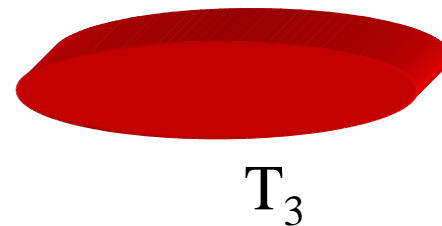   The first law of thermodynamics

Temperature, heat & thermodynamics

Dictionary definition: **temperature** – a measure of the the warmth or coldness of an object or substance with reference to some standard value. The temperature of two systems is the same when the systems are in thermal equilibrium.

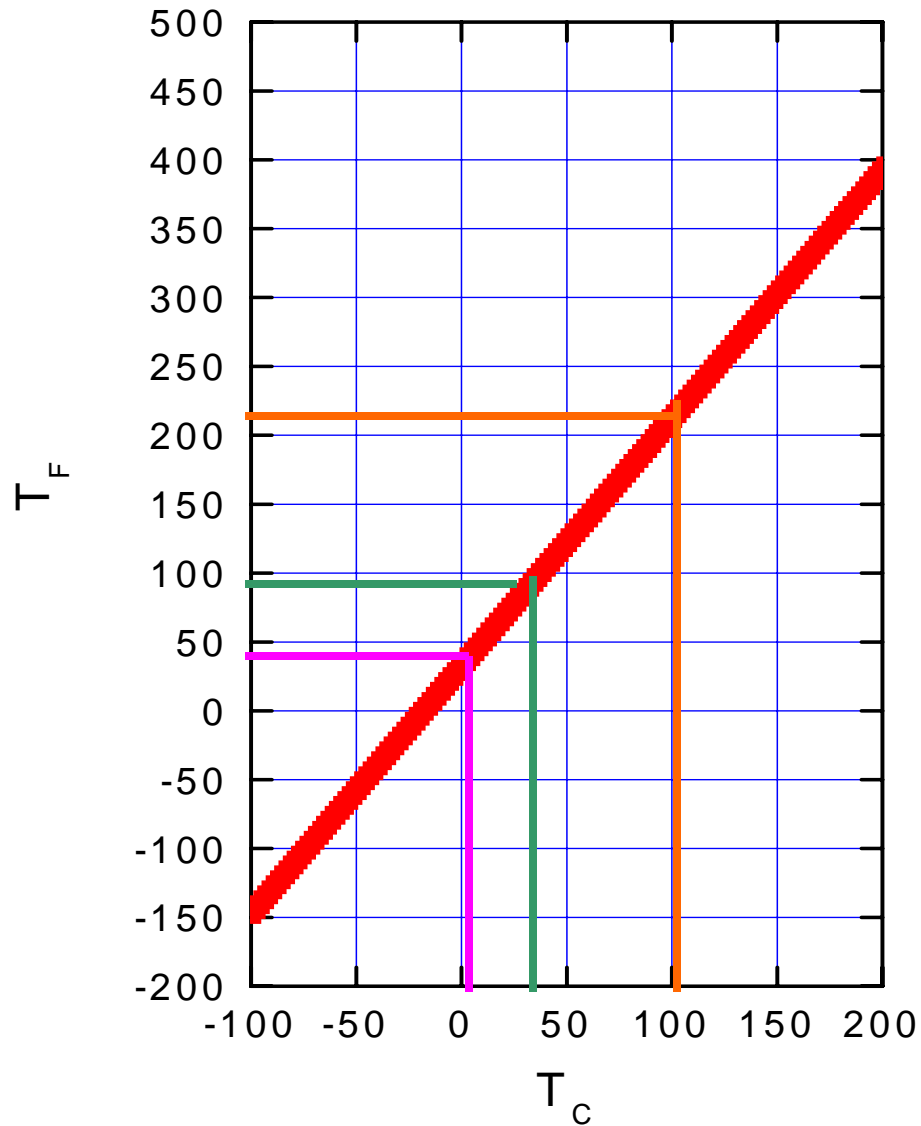Equilibrium:

Not equilibrium:

T_1 T_2

T_3
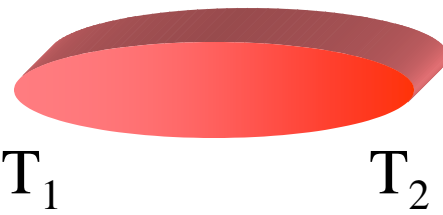
"Zeroth" law of thermodynamics:

If objects A and B are separately in thermal equilibrium with a third object C, then objects A and B are in thermal equilibrium with each other.

Temperature scales $\qquad$ $T_F = 9/5\ T_C + 32$

Kelvin scale:

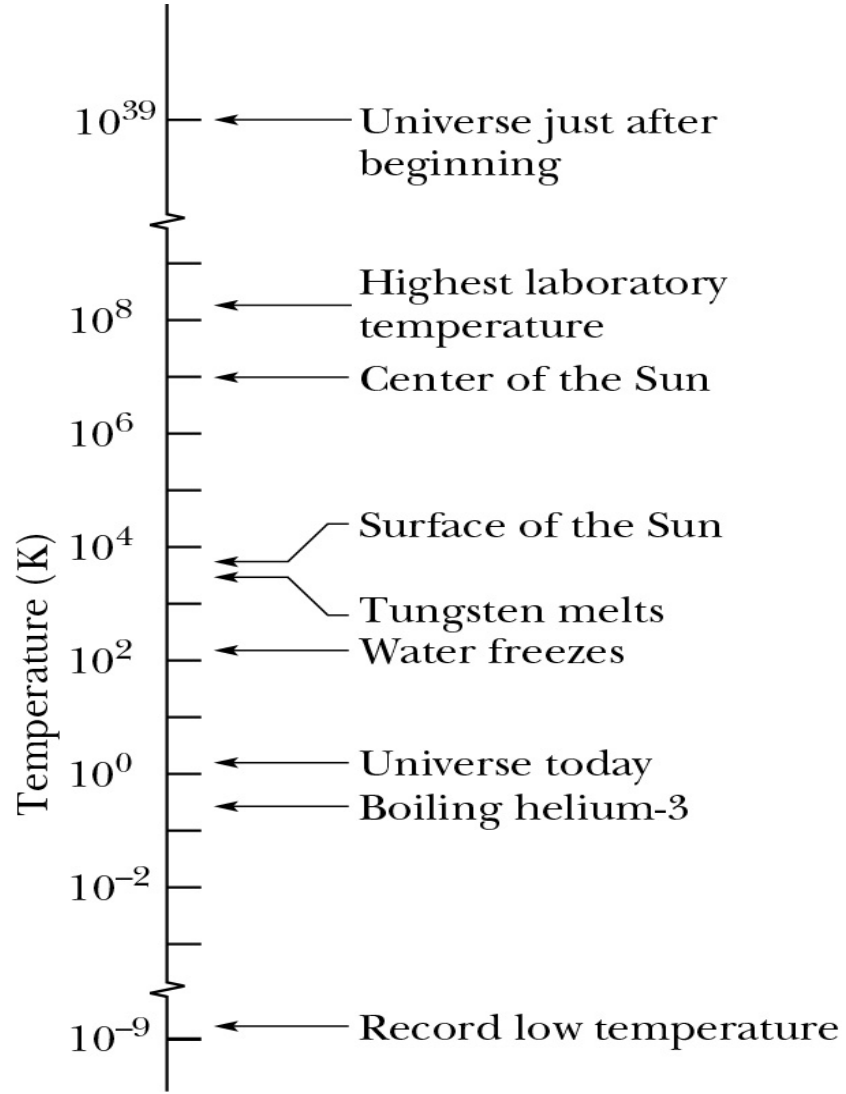$T = T_C + 273.15^o$

$T \geq 0$

There is a lowest temperature:

$T_0 = -273.15^o\ C = 0\ K$

Kelvin ("absolute temperature") scale

$T_C = -273.15 + T_K$

Example –

Room temperature $= 68^o\ F = 20^o\ C = 293.15\ K$

10^{39} — ← Universe just after beginning

10^{8} — ← Highest laboratory temperature

← Center of the Sun

10^{6} —

10^{4} — Surface of the Sun

Tungsten melts

10^{2} — ← Water freezes

10^{0} — ← Universe today

← Boiling helium-3

10^{-2} —

10^{-9} — ← Record low temperature

Temperature (K)

Effects of temperature on matter

Solids and liquids

Model of a solid composed of atoms and bonds

Thermal exansion:

$$\Delta L = \alpha \; L_i \; \Delta T$$

ΔL

L_i (equilibrium bond length at T_i)
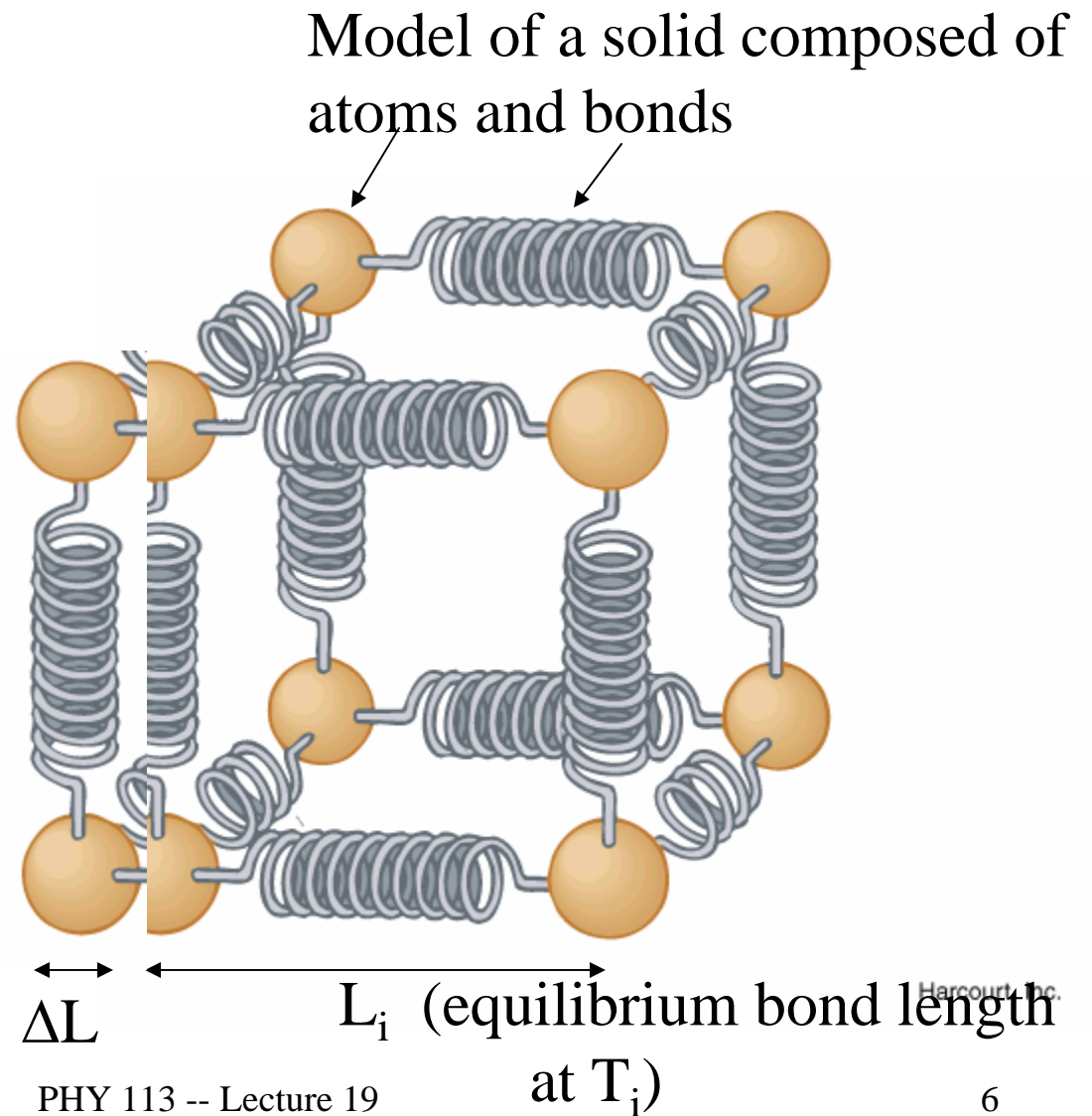
Typical expansion coefficients at $T_C = 20^o$ C:

Linear expansion: $\Delta L = \alpha \, L_i \, \Delta T$

Steel: $\alpha = 11 \times 10^{-6}/ \, ^oC$

Concrete: $\alpha = 12 \times 10^{-6}/ \, ^oC$

Volume expansion:
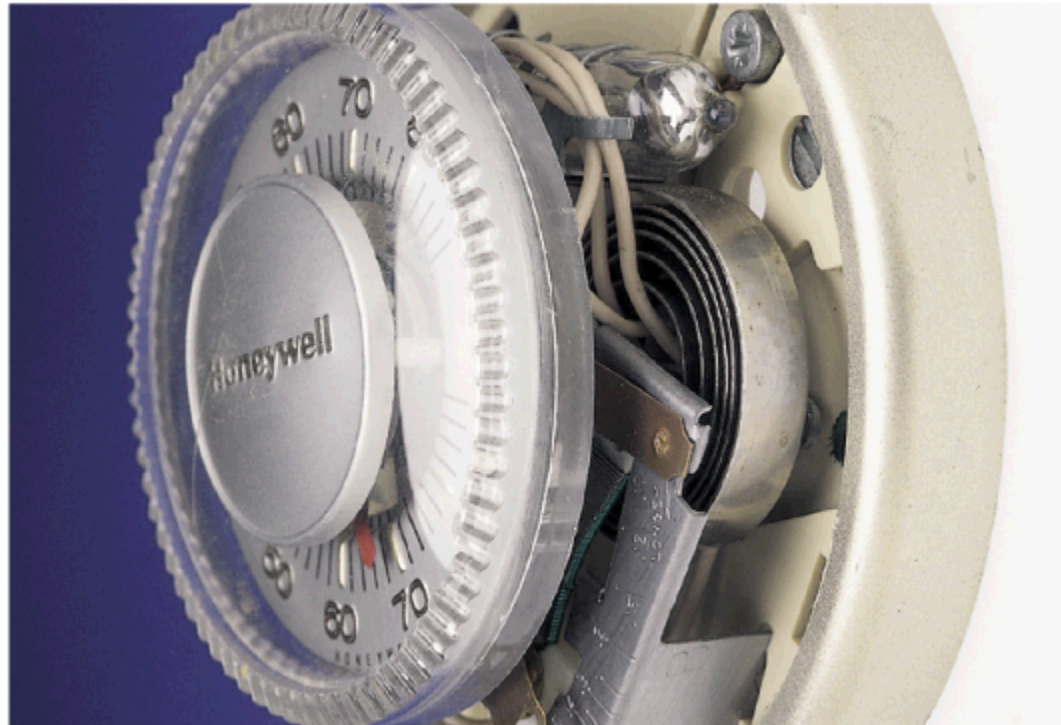
$V = L^3$ ➔ $\Delta V = 3\alpha \, V_i \, \Delta T = \beta \, V_i \, \Delta T$

Alcohol: $\beta = 1.12 \times 10^{-4}/ \, ^oC$

Air: $\beta = 3.41 \times 10^{-3}/ \, ^oC$
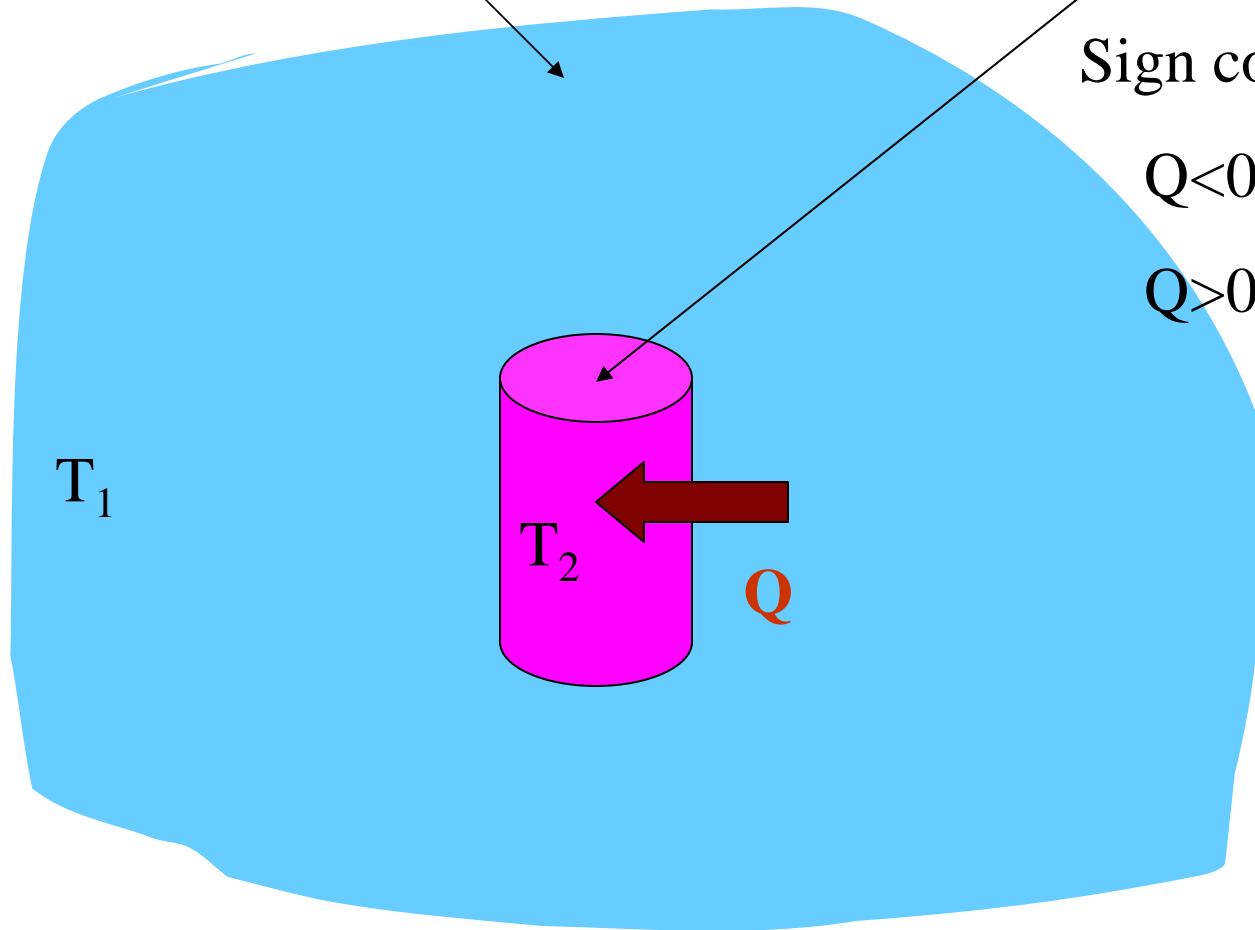
Brass →

Steel →

Serway, Physics for Scientists and Engineers, 5/e
Figure 19.9c
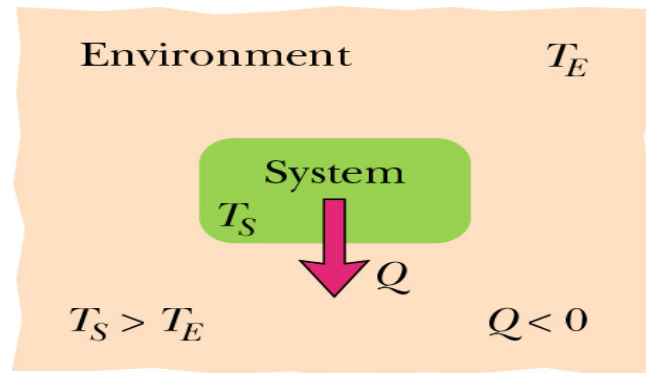

Honeywell

Harcourt, Inc.

Heat – Q -- the energy that is transferred between a "system" and its "environment" because of a temperature difference that exists between them.
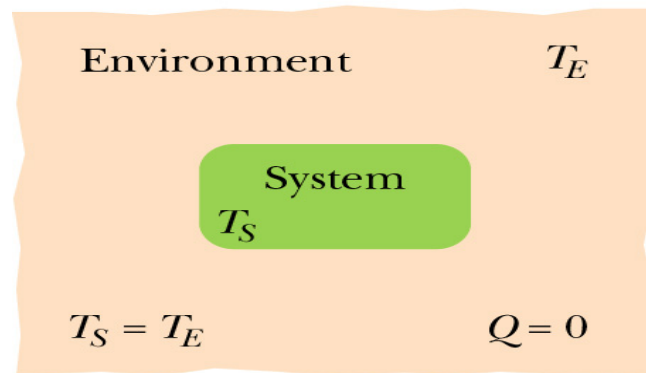
Sign convention:

$Q<0$ if $T_1 < T_2$

$Q>0$ if $T_1 > T_2$

T_1

T_2

Q
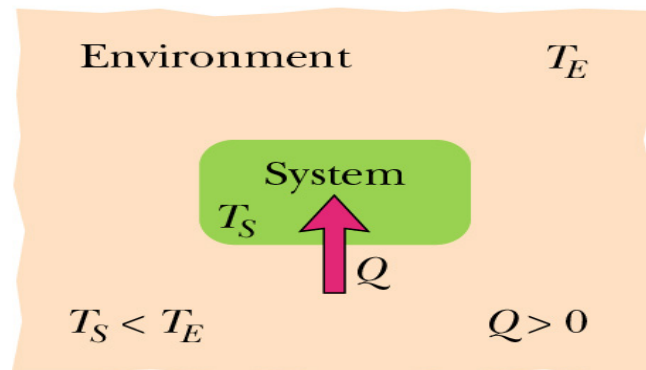
Heat **withdrawn** from system

Thermal equilibrium – no heat transfer

Heat **added** to system

Units of heat: Joule

Other units: calorie = 4.186 J

Kilocalorie = 4186 J = Calorie

Heat capacity: C = amount of heat which must be added
to the "system" to raise its
temperature by 1K (or 1° C).

More generally:

$Q = C \, \Delta T$

$$Q_{i \to f} = \int_{T_i}^{T_f} C(T) dT$$

Heat capacity per mass: C=mc

Heat capacity per mole (for ideal gas): C=nC$_v$
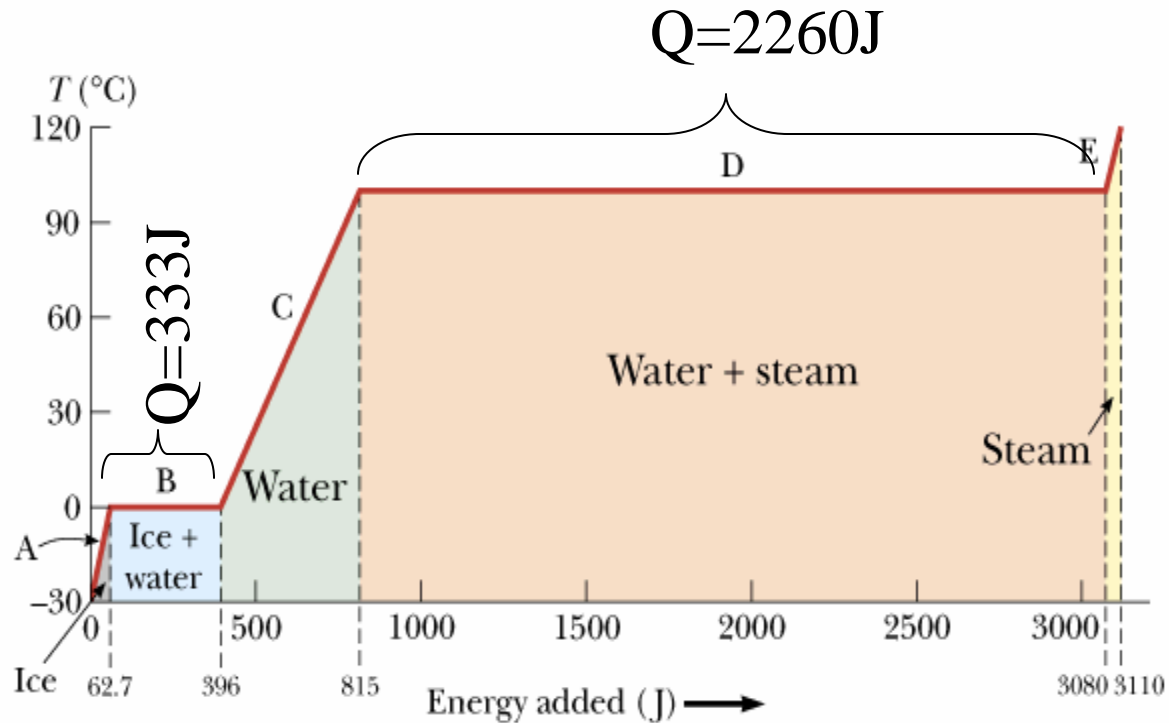
C=nC$_p$

Some typical specific heats

Material	J/(kg·oC)	cal/(g·oC)
Water (15oC)	4186	1.00
Ice (-10oC)	2220	0.53
Steam (100oC)	2010	0.48
Wood	1700	0.41
Aluminum	900	0.22
Iron	448	0.11
Gold	129	0.03

Heat and changes in phase of materials

Example: A plot of temperature versus Q added to

$1g = 0.001$ kg of ice (initially at T=-30°C)

Serway, Physics for Scientists and Engineers, 5/e
Figure 20.2

Some typical latent heats

Material	J/kg
Ice $\Rightarrow$ Water (0^oC)	333000
Water $\Rightarrow$ Steam (100^oC)	2260000
Solid N $\Rightarrow$ Liquid N (63 K)	25500
Liquid N $\Rightarrow$ Gaseous N_2 (77 K)	201000
Solid Al $\Rightarrow$ Liquid Al (660^oC)	397000
Liquid Al $\Rightarrow$ Gaseous Al (2450^oC)	11400000

Peer instruction question

Suppose you have a well-insulated cup of hot coffee (m=0.25kg, T=100°C). In order to get to class on time you add 0.25 kg of ice (at 0°C). When your cup comes to equilibrium, what will be the temperature of the coffee.

(A) 0°C   (B) 10°C   (C) 50°C   (D) 100°C

Review question

Suppose you have a well-insulated cup of hot coffee (m=0.25kg, T=100°C). In order to get to class on time you add 0.25 kg of ice (at 0°C). When your cup comes to equilibrium, what will be the temperature of the coffee.

$$Q = m\, c_w\, (T_f - 100°C) + m\, L_{ice} + m\, c_w\, (T_f - 0°C) = 0$$

$$2\, c_w\, T_f = c_w \cdot 100 - L_{ice}$$
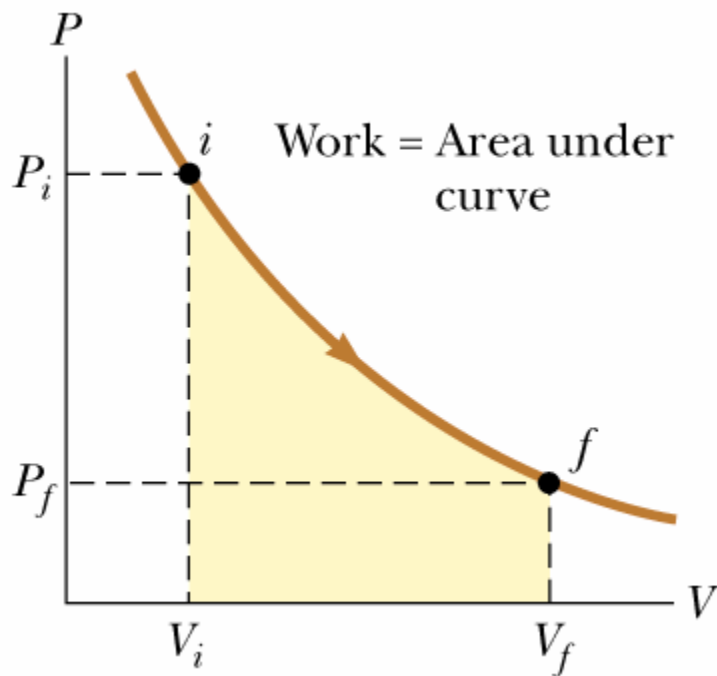
$$T_f = c_w \cdot 100/(2\, c_w) - L_{ice}/(2\, c_w)$$

$$T_f = 50 - 333000/(2 \cdot 4186) = 10°C$$

Energy in the form of work:

Work done *by the "system"* due to volume change

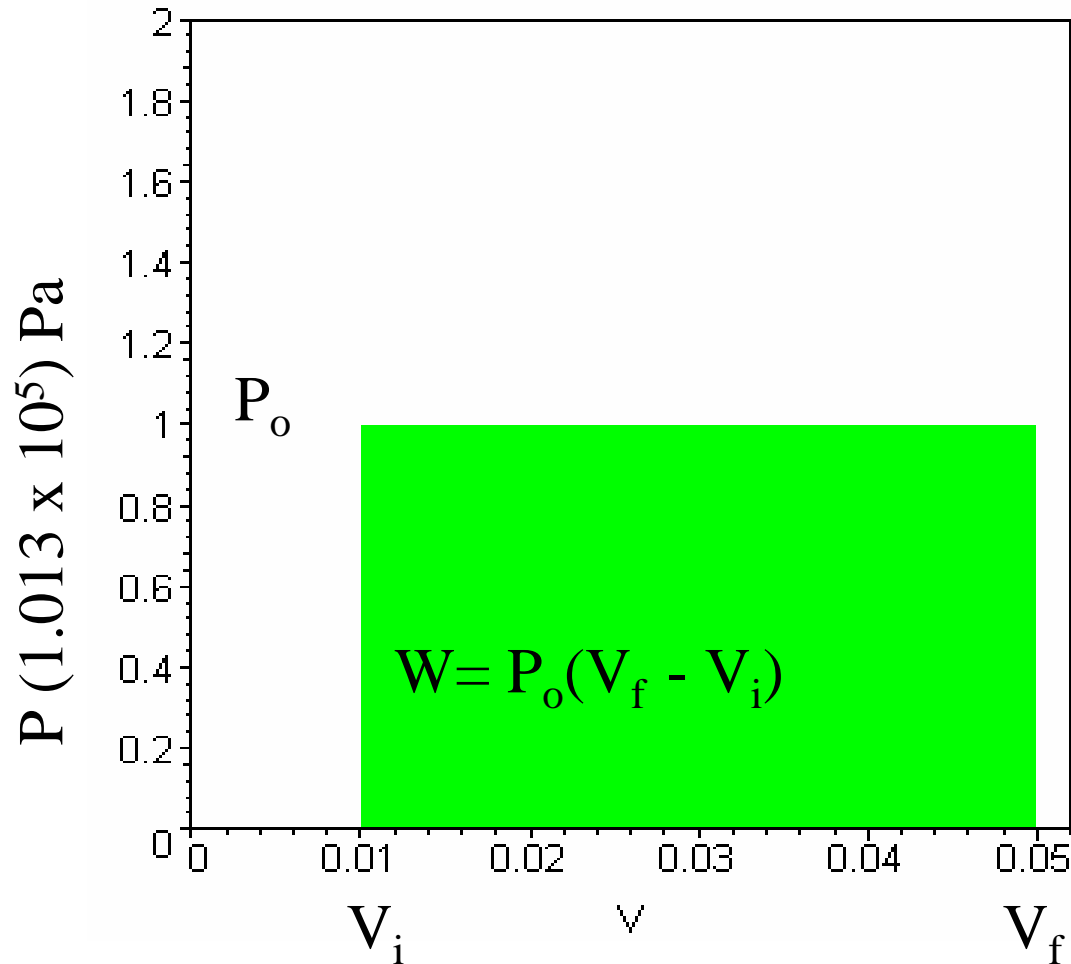$$W = \int_{x_i}^{x_f} F\,dx = \int_{x_i}^{x_f} \frac{F}{A} A\,dx = \int_{V_i}^{V_f} P\,dV$$

Work = Area under curve

Sign convention:

W>0 if $V_f > V_i$ (expansion)

W<0 if $V_f < V_i$ (contraction)

Work done by a gas:
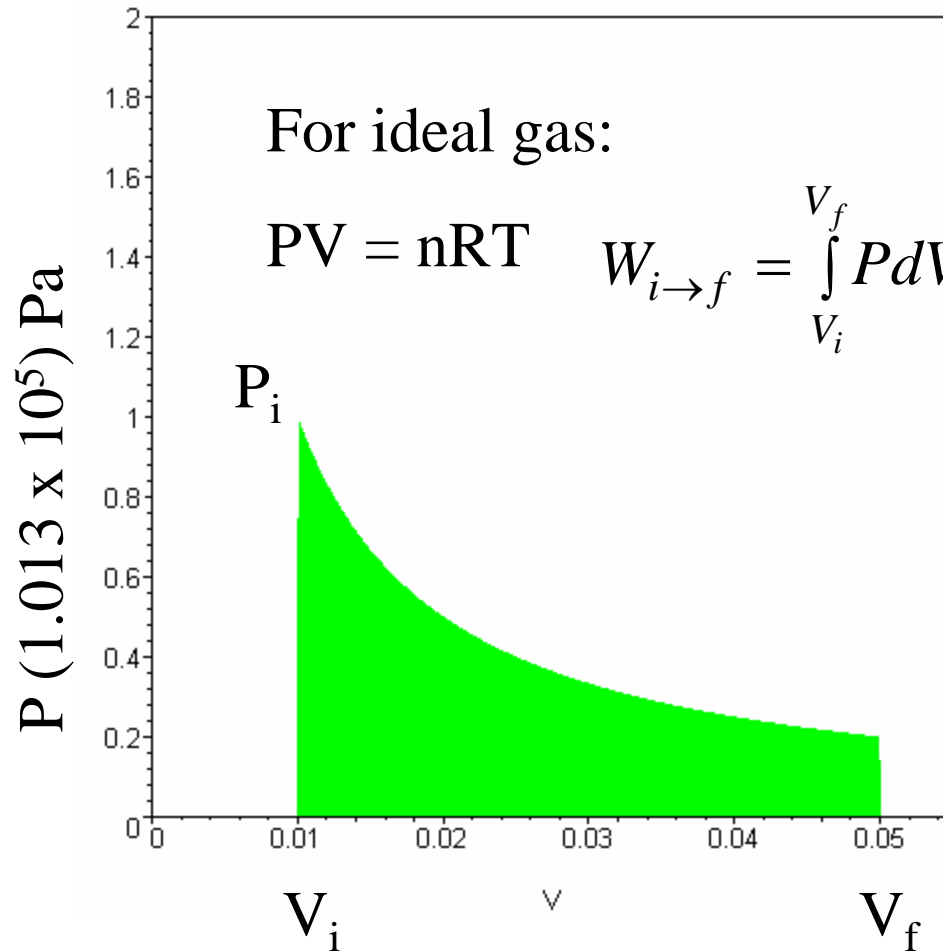
"Isobaric" (constant pressure process)

$$W = P_o(V_f - V_i)$$

Work done by ideal gas:

"Isovolumetric" (constant volume process)
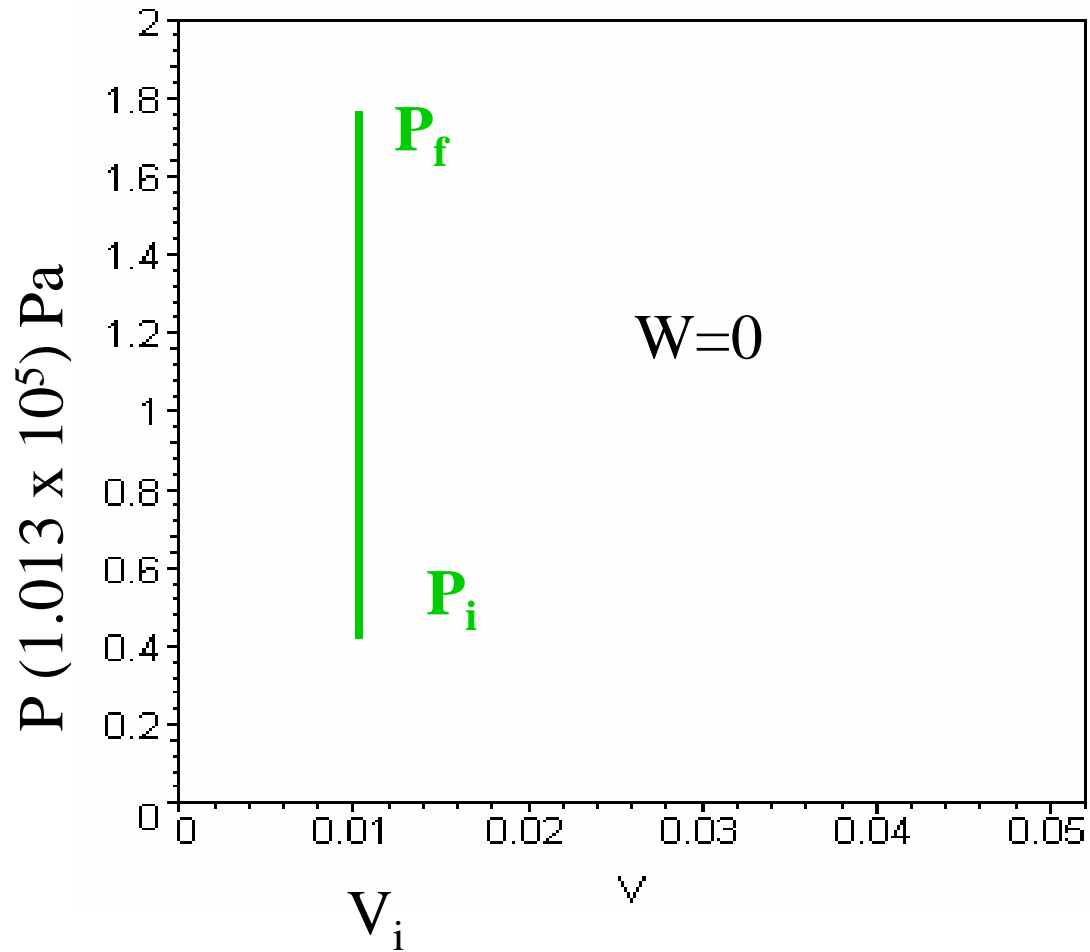
Work done by a gas:

"Isothermal" (constant temperature process)
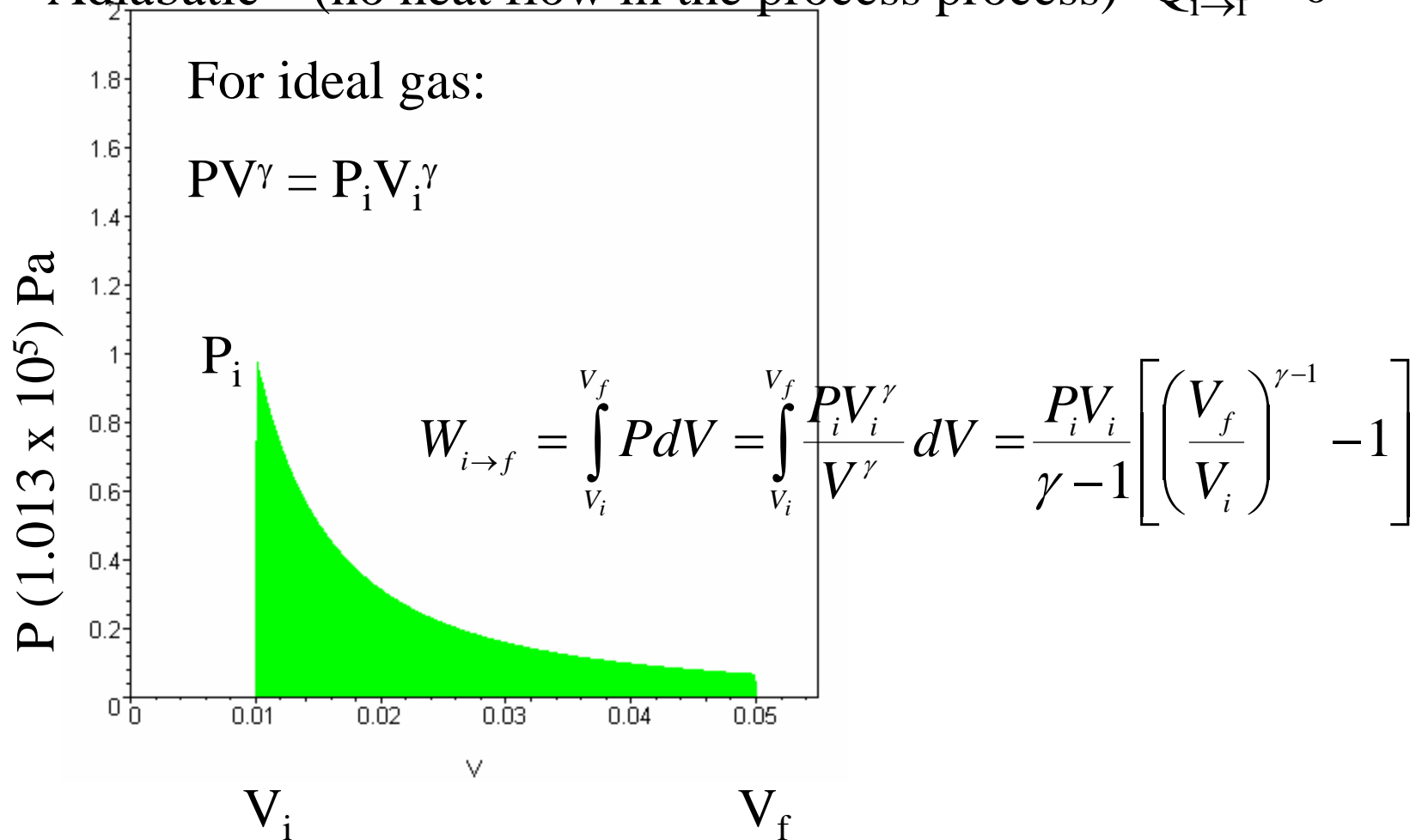
For ideal gas:

$$PV = nRT \qquad W_{i \to f} = \int\limits_{V_i}^{V_f} P dV = \int\limits_{V_i}^{V_f} \frac{nRT}{V} dV = nRT \ln\left(\frac{V_f}{V_i}\right)$$

$$= P_i V_i \ln\left(\frac{V_f}{V_i}\right)$$

P (1.013 x 10⁵) Pa

P_i

V_i V V_f

Work done by a gas:

"Adiabatic" (no heat flow in the process process) $Q_{i \to f} = 0$

For ideal gas:

$$PV^{\gamma} = P_i V_i^{\gamma}$$

$$W_{i \to f} = \int_{V_i}^{V_f} P \, dV = \int_{V_i}^{V_f} \frac{P_i V_i^{\gamma}}{V^{\gamma}} \, dV = \frac{P_i V_i}{\gamma - 1} \left[\left(\frac{V_f}{V_i} \right)^{\gamma - 1} - 1 \right]$$

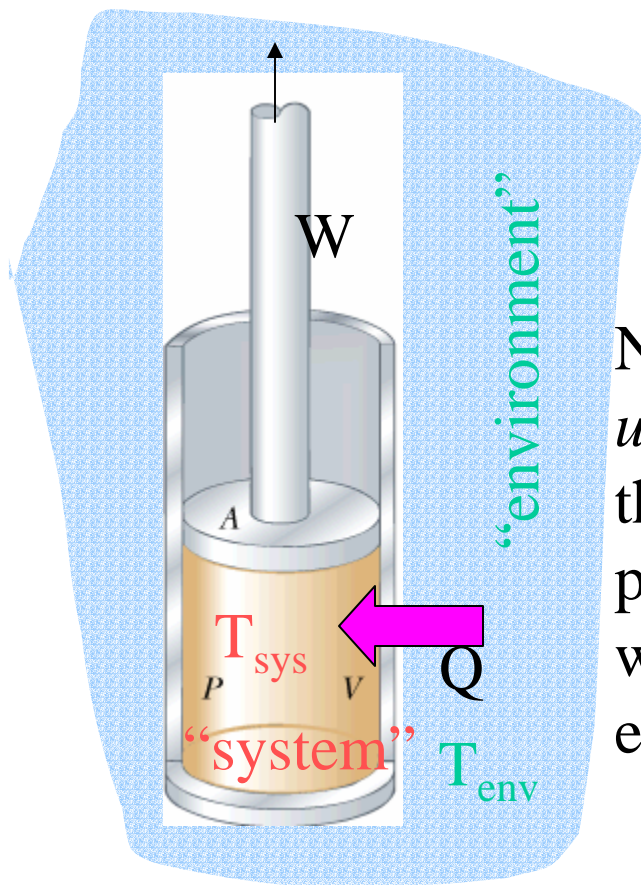Thermodynamic statement of conservation of energy –

First Law of Thermodynamics

$$\Delta E_{int} = Q - W$$

Work done by system

Heat added to system

"Internal" energy of system

"Internal energy" $E_{int}=E_{int}(T,V,P)$ (for an ideal gas, $E_{int}=E_{int}(T)$

can be changed by interaction with the system

$$\Delta E_{int} = Q - W$$

Note: Thermal equilibrium implies a *uniform* temperature. In this example, the system and the environment are presumed to be in thermal equilibrium within themselves but *not* in thermal equilibrium with eachother.

Examples process:
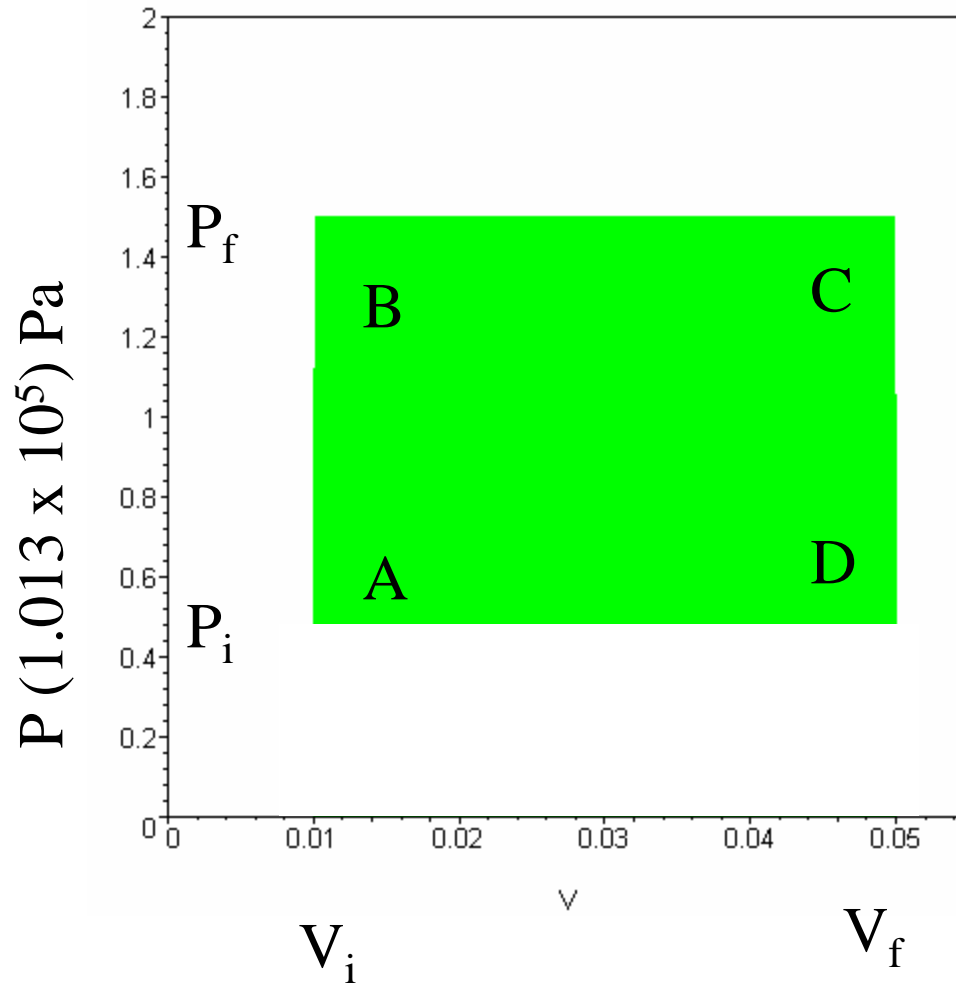
$$W_{net}=W_{(ABCDA)}=W_{BC}+W_{DA}$$

$$=(P_f-P_i)\,(V_f-V_i)$$

$$\Delta E_{int(ABCDA)}=\Delta E_{int(AB)}$$
$$+\Delta E_{int(BC)}+\Delta E_{int(CD)}$$
$$+\Delta E_{int(DA)}=0$$

$$\rightarrow Q_{net}=Q_{(ABCDA)}=W_{net}$$

3. HRW6 19.P.049. [52190] A sample of gas expands from 1.0 m^3 to 6.0 m^3 while its pressure decreases from 30 Pa to 10 Pa. How much work is done by the gas if its pressure changes with volume via each of the three paths shown in the *p-V* diagram in Fig. 19-34?

[0.133333] ⬚ J path A

[0.133333] ⬚ J path B

[0.133333] ⬚ J path C
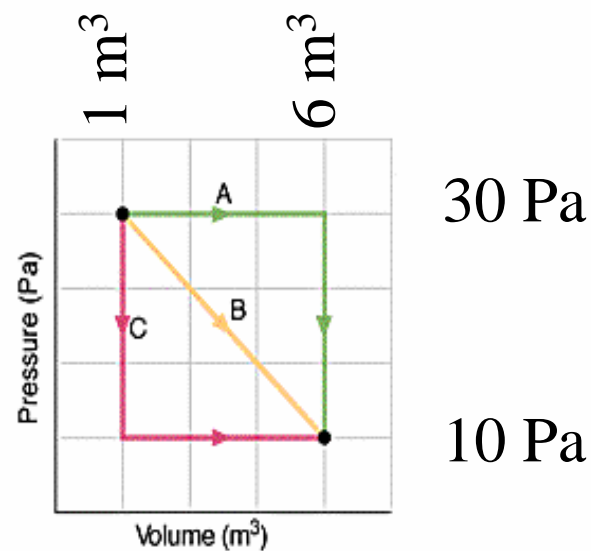
4. HRW6 19.P.052. [52191] Gas within a chamber passes through the cycle shown in Fig. 19-37. Determine the net heat added to the system during process CA if the heat Q_{AB} added during process AB is 25.0 J, no heat is transferred during process BC, and the net work done during the cycle is 12.0 J.
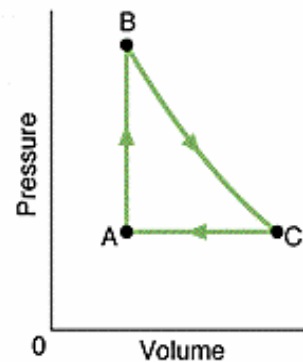
[0.133333] ⬚ J

Figure 19-37.

5. HRW6 19.P.053. [52192] When a system is taken from state i to state f along path iaf in Fig. 19-40, $Q = 65$ cal and $W = 10$ cal. Along path ibf, $Q = 65$ cal.
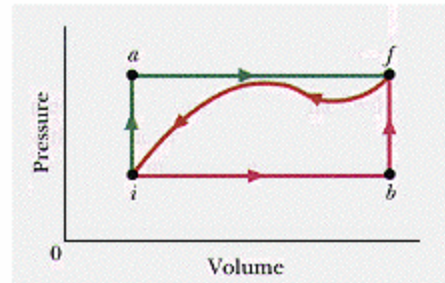

Figure 19-40.

(a) What is W along path ibf?

[0.133333] _____ cal

(b) If $W = -18$ cal for the curved return path fi, what is Q for this path?

[0.133333] _____ cal

(c) Take $E_{int,i} = 15$ cal. What is $E_{int,f}$?

[0.133333] _____ cal

Assume $E_{int,b} = 11$ cal.

(d) What is the value of Q for path ib?

[0.133333] _____ cal

(e) What is the value of Q for path bf?

[0.133333] _____ cal

Mechanisms of heat transfer:

1. Thermal convection

    Heat transmitted by heated fluid flow. (Ex. -- home heating units, stove top cooking)

2. Radiation

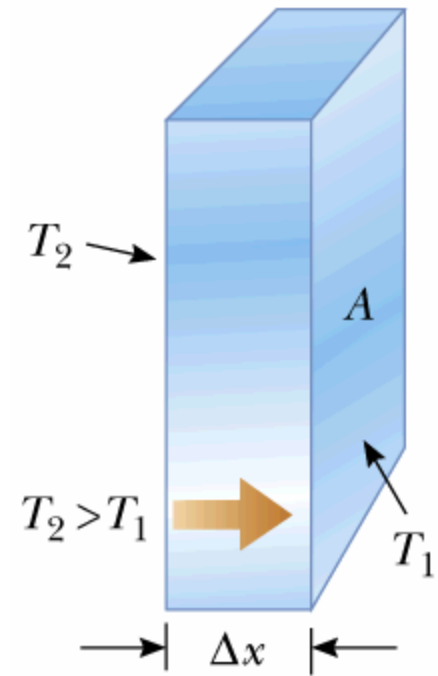   Heat transmitted by electromagnetic radiation. (Ex. – sun, microwave cooking)

3. Thermal conduction

    Heat transfer from one side of a material to another due to a temperature gradient.
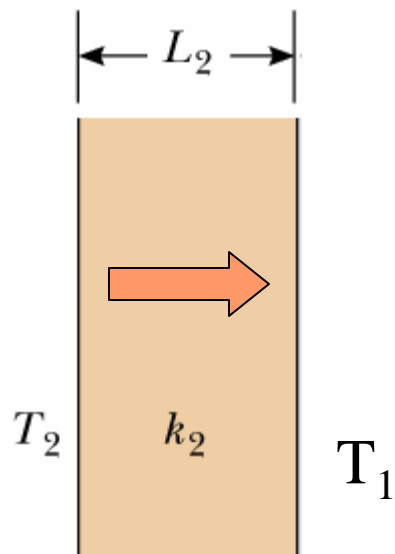
Quantitative statement of thermal conduction:

$$\frac{\Delta Q}{\Delta t} = kA \frac{\Delta T}{\Delta x}$$

Units: 1 J/s = 1 Watt (W)

cross-sectional area

thermal conductivity coefficient

Material	k (W/(m·ºC))
Copper	238
Glass	0.8
Water	0.6
Air	0.0234

Examples of thermal conduction

$$\frac{dQ}{dt} = k_2 A \frac{T_2 - T_1}{L_2}$$
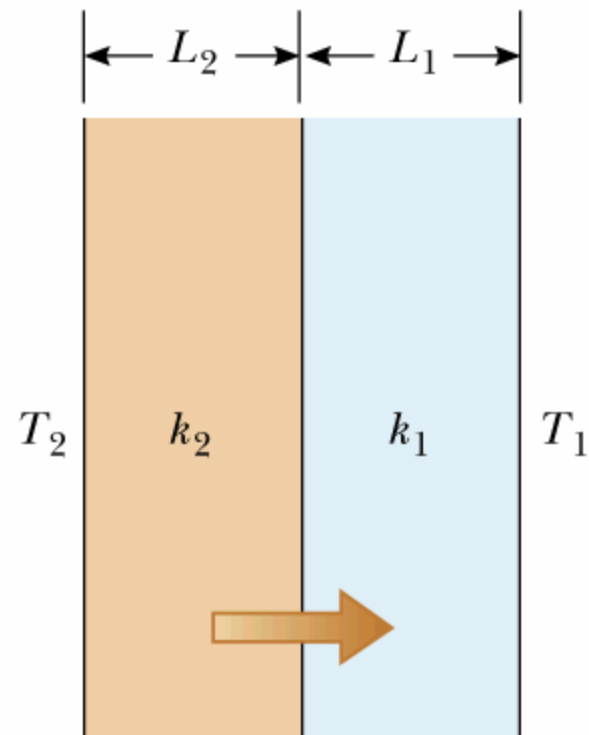
$$\frac{dQ}{dt} = k_{eff} A \frac{T_2 - T_1}{L_2 + L_1}$$

$$k_{eff} = \frac{L_2 + L_1}{L_2 / k_2 + L_1 / k_1}$$

Example: T_1=20°C,   T2= 0°C

Single pane glass window: A=1m^2 , L_2 = 0.002m, k_2=0.8 W/m·°C

$$\frac{dQ}{dt} = k_2 A \frac{T_2 - T_1}{L_2} = 8000\,W$$

Double pane glass window: L_1=0.01m, k_1=0.0234 W/m·°C (air)

$$\frac{dQ}{dt} = k_{eff} A \frac{T_2 - T_1}{L_2 + L_1 + L_0}$$

$$k_{eff} = \frac{L_2 + L_1 + L_0}{L_2 / k_2 + L_1 / k_1 + L_0 / k_0} = 46\,W$$