Announcements

1. Physics colloquium on the physics of stars –

   Thursday 11/14 at 4 PM:

   http://www.wfu.edu/physics/seminars/iliadis.html

2. Vote on alternative final – Thurs. 12/12 at 9 AM

   (as well as scheduled time – Saturday 12/14 at 2 PM).

3. Presentations for extra exam credit:

   Thursday 11/14 at 6 PM

   Sunday 11/17 at 2 PM

4. Today's topic – Transfer of heat and the first law of thermodynamics

Review question

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

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

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

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

$$T_f = 50 - 333000/(2 \cdot 4186) = 10^{o}C$$

Thermodynamic statement of conservation of energy –

First Law of Thermodynamics

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

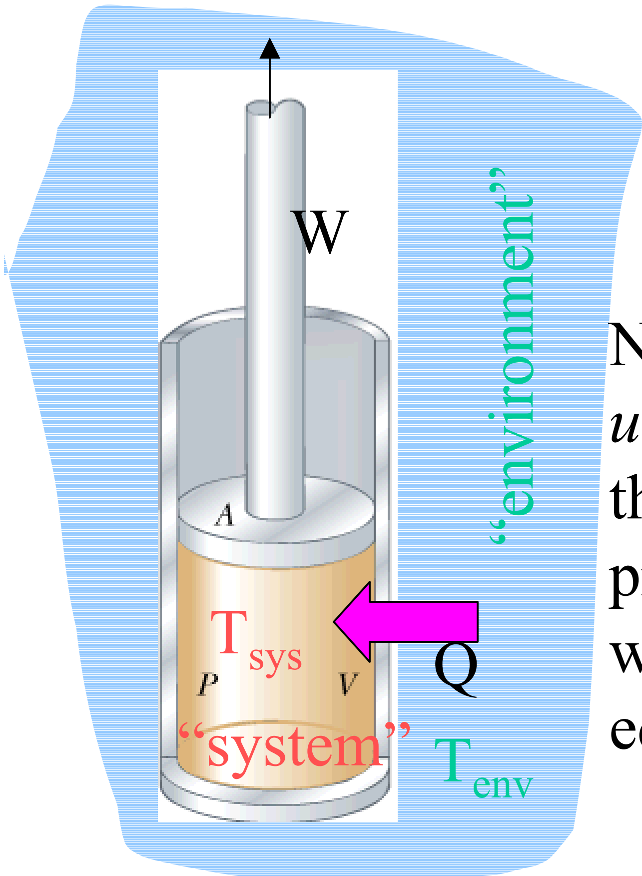
Work done by system

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.

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.

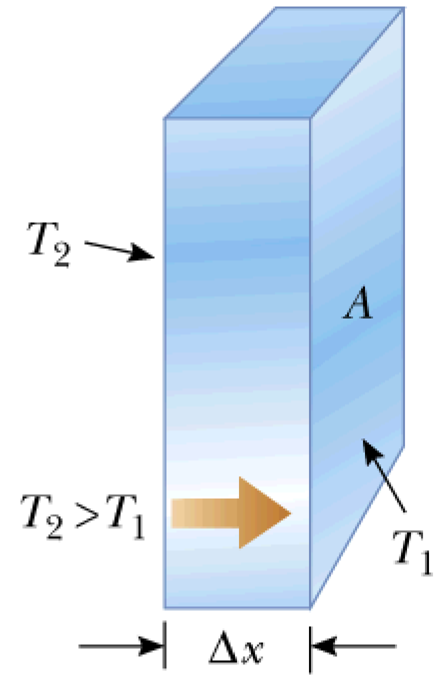
Quantitative statement of thermal conduction:

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

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

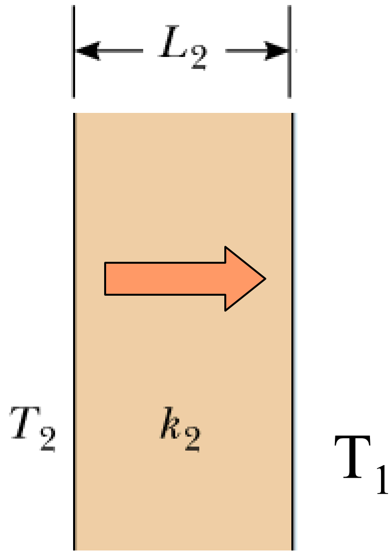
cross-sectional area

thermal conductivity coefficient

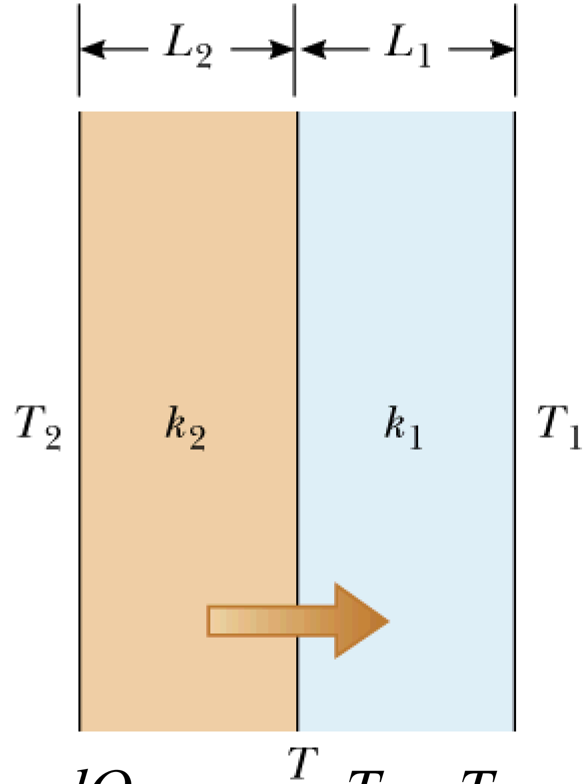


Material	k (W/(m·°C))
Copper	238
Glass	0.8
Water	0.6
Air	0.0234

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^{o}C, T2= 0^{o}C

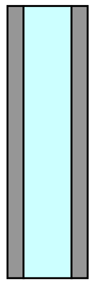
Single pane glass window: A=1m^2 , L_2 = 0.002m, k_2=0.8 W/m·^{o}C

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

Double pane glass window: L_1=0.01m, k_1=0.0234 W/m·^{o}C (air)

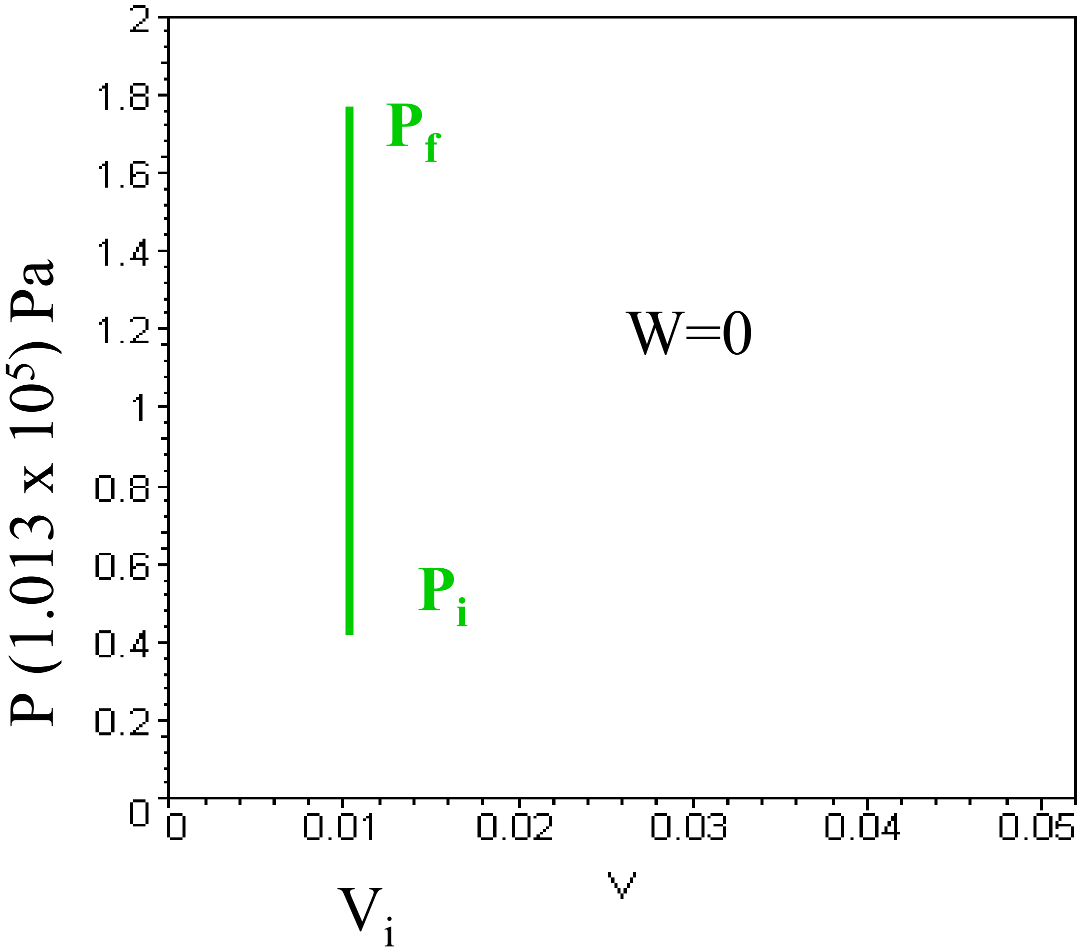
$$\frac{dQ}{dt} = k_{eff} A \frac{T_2 - T_1}{L_2 + L_1 + L_0}$$

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



Work done by ideal gas:

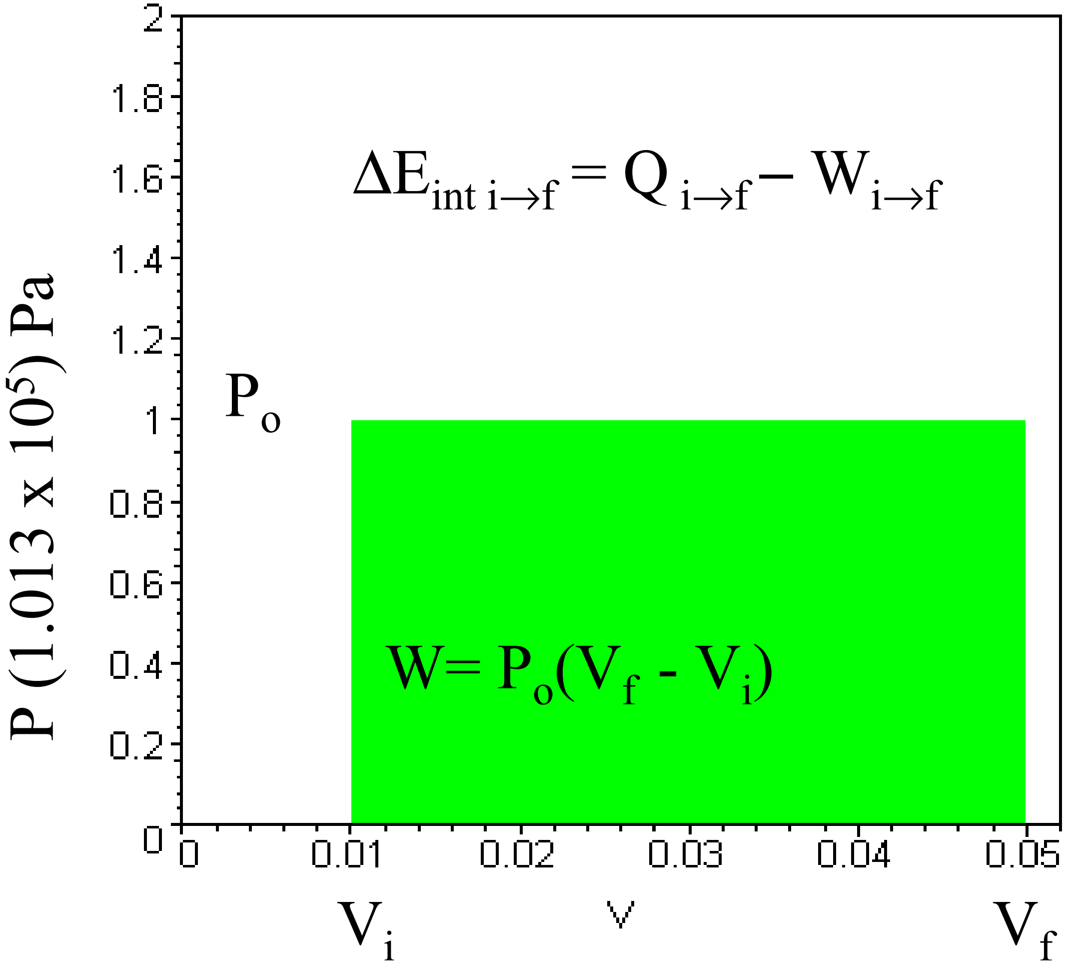
"Isovolumetric" (constant volume process)



$\Delta E_{int\ i\rightarrow f} = Q_{\ i\rightarrow f}$

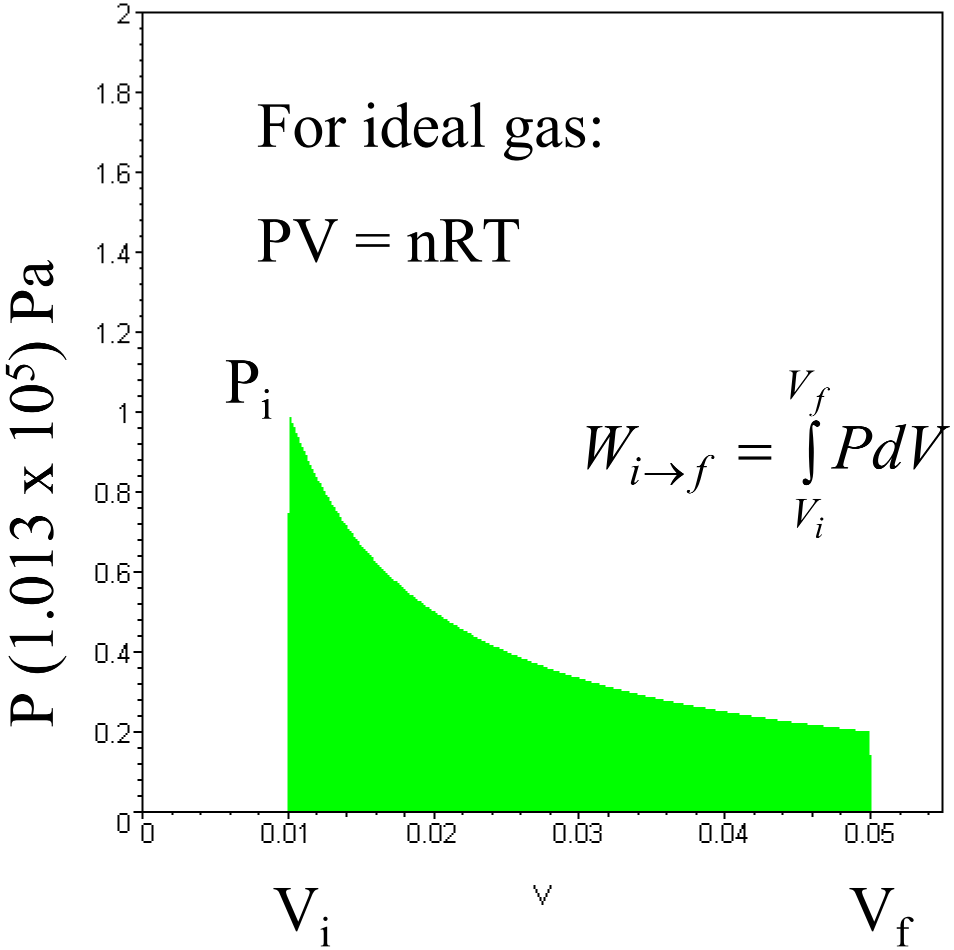
Work done by a gas:

"Isobaric" (constant pressure process)



Work done by a gas:

"Isothermal" (constant temperature process)



For ideal gas:

PV = nRT

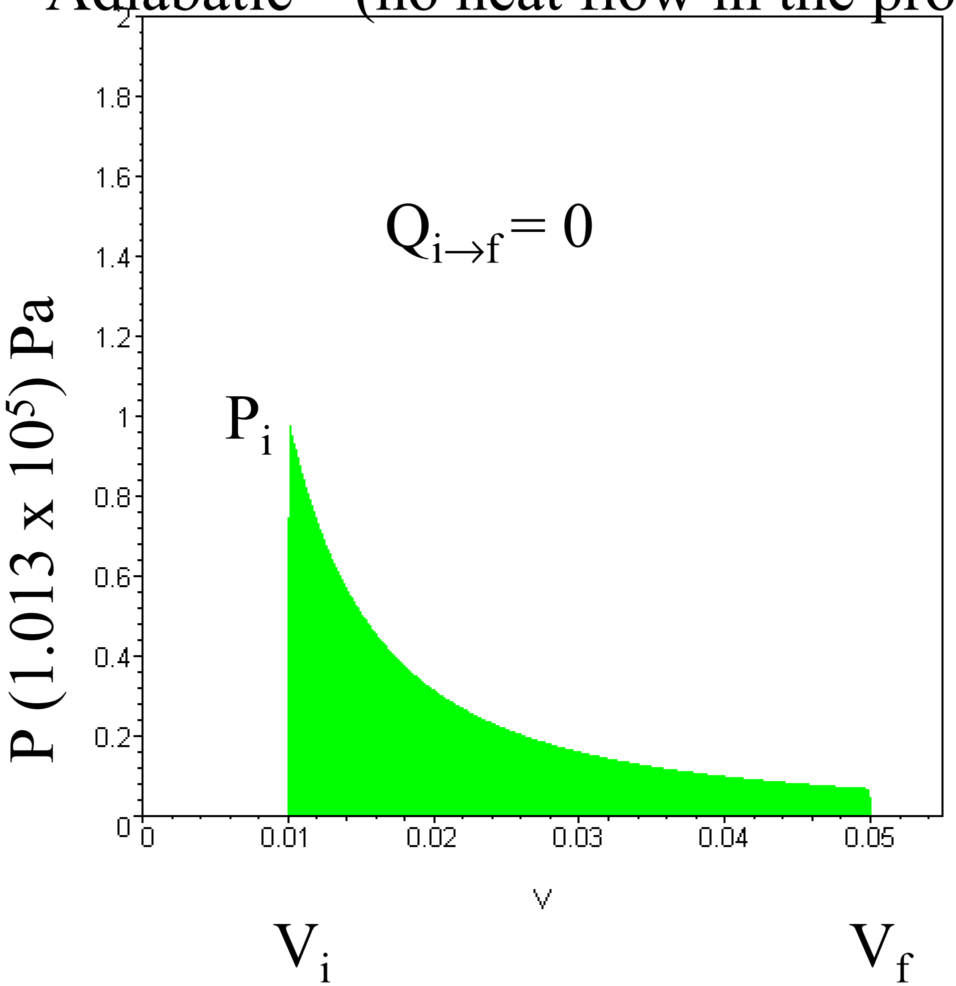
$$\Delta E_{int\ i \to f} = Q_{i \to f} - W_{i \to f}$$

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

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

Work done by a gas:

"Adiabatic" (no heat flow in the process process)



$$\Delta E_{int\ i\rightarrow f} = -W_{i\rightarrow f}$$

Peer instruction question

Which of the following are *not* true for an adiabatic expansion of a gas?

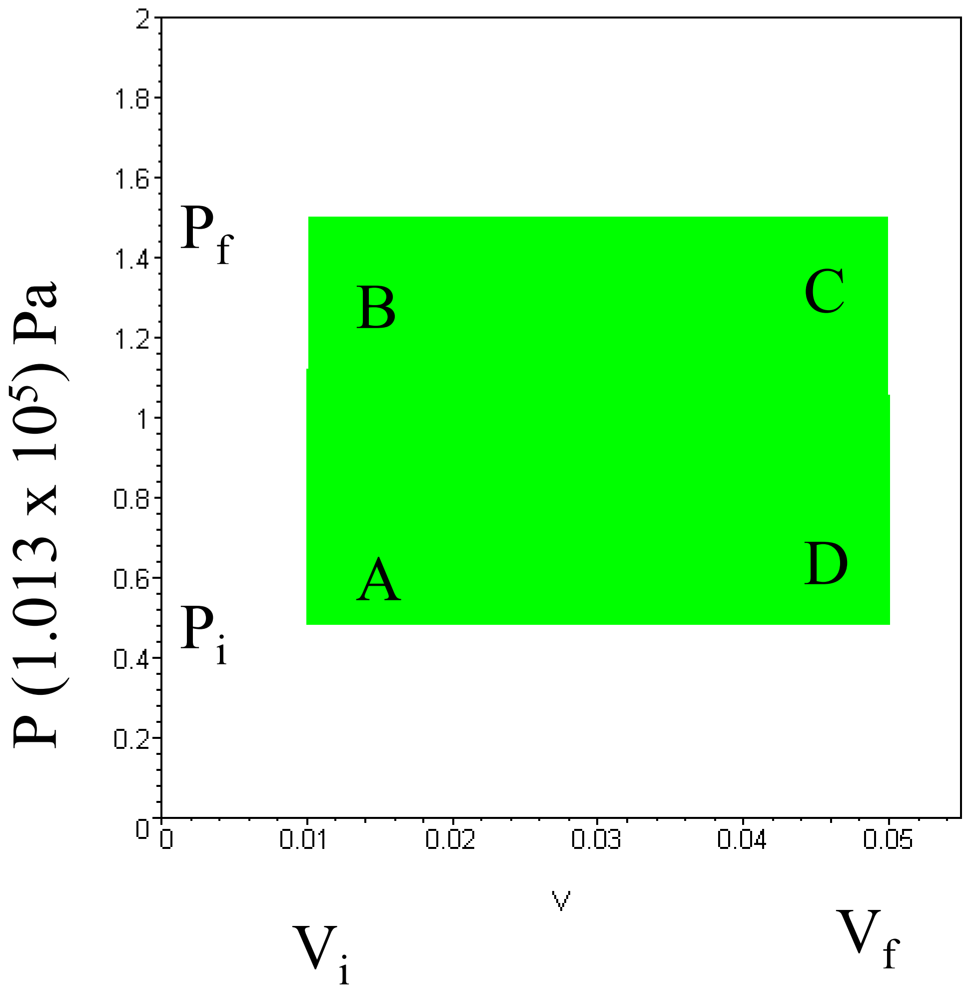
(A) There is no heat transfer.

(B) The temperature is constant.

(C) There is positive work done by the system.

(D) The internal energy of the system decreases.

Examples process by an ideal gas:



$$W_{net}=W_{BC}+W_{DA}$$

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

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