Ch 19. The First Law of Thermodynamics

19-1. Thermodynamic Systems

Thermodynamic system:

A system that can interact (and exchange energy) with its surroundings

Thermodynamic process:

A process in which there are changes in the state of a thermodynamic system

Heat Q

added to the system *Q>0*

taken away from the system *Q<0*

(through conduction, convection, radiation)

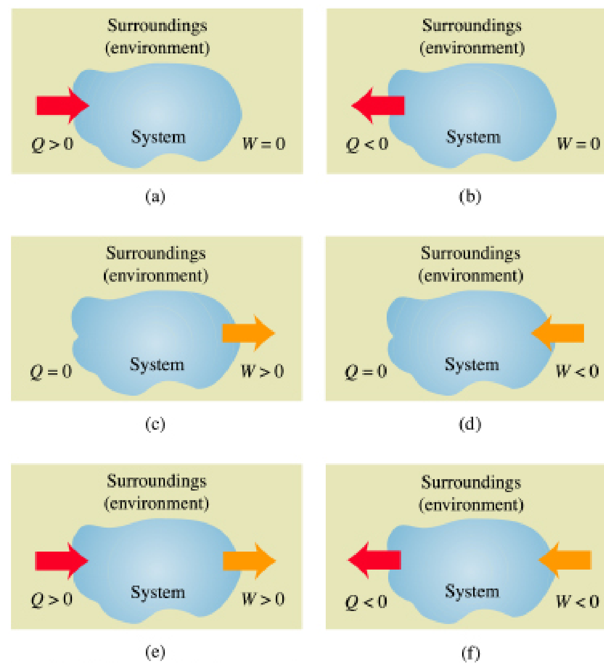
Work

done by the system onto its surroundings W>0

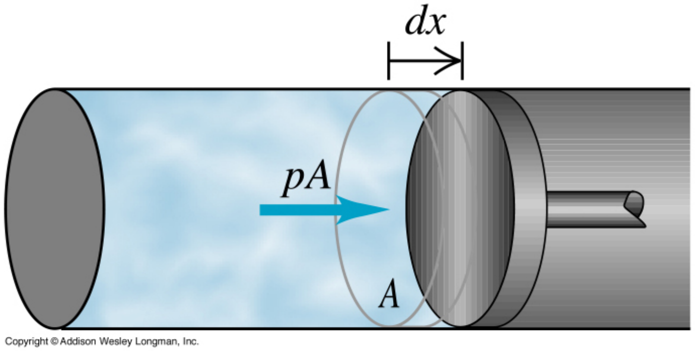
done by the surrounding onto the system W<0

Energy change of the system is Q + (-W) or Q-W

Gaining energy: +; Losing energy: -



19-2. Work Done During Volume Changes



Area: A
Pressure: p

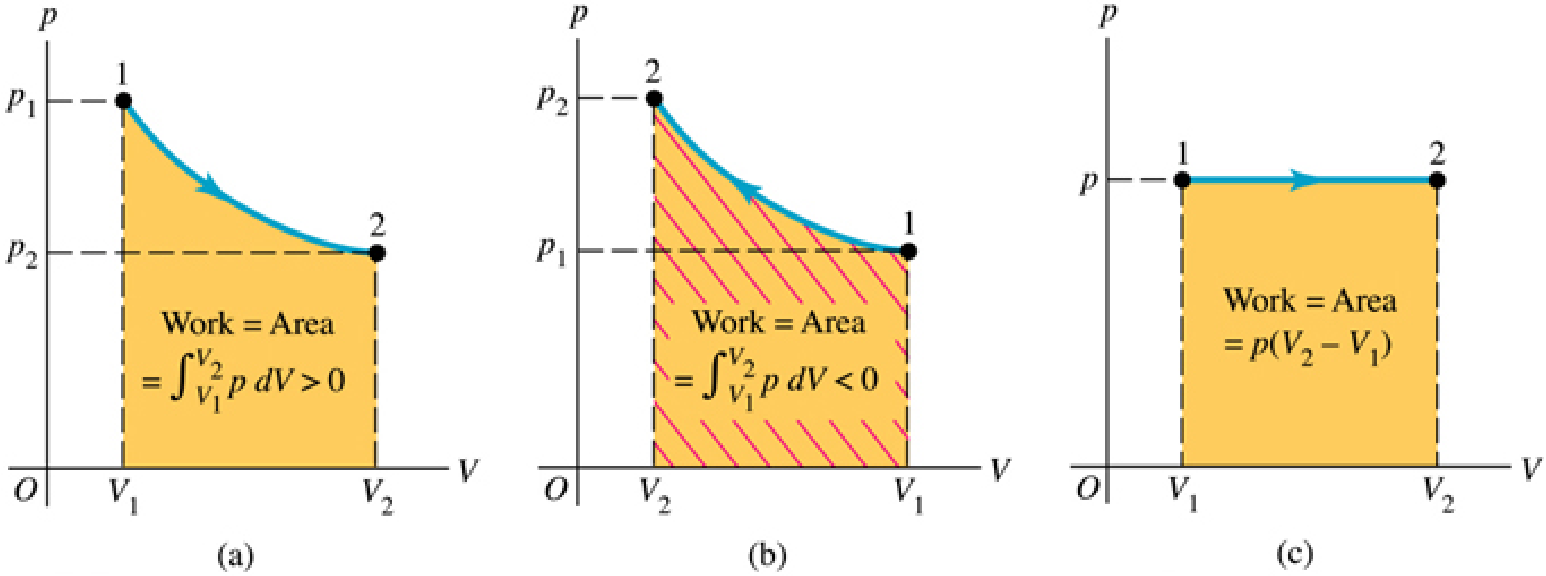
Force exerted on the piston: $F=pA$

Infinitesimal work done by system $dW=Fdx=pAdx=pdV$

Work done in a finite volume change

$$W = \int_{V_{initial}}^{V_{final}} p\,dV$$

Graphical View of Work



Gas expands
$dV>0$, $W>0$

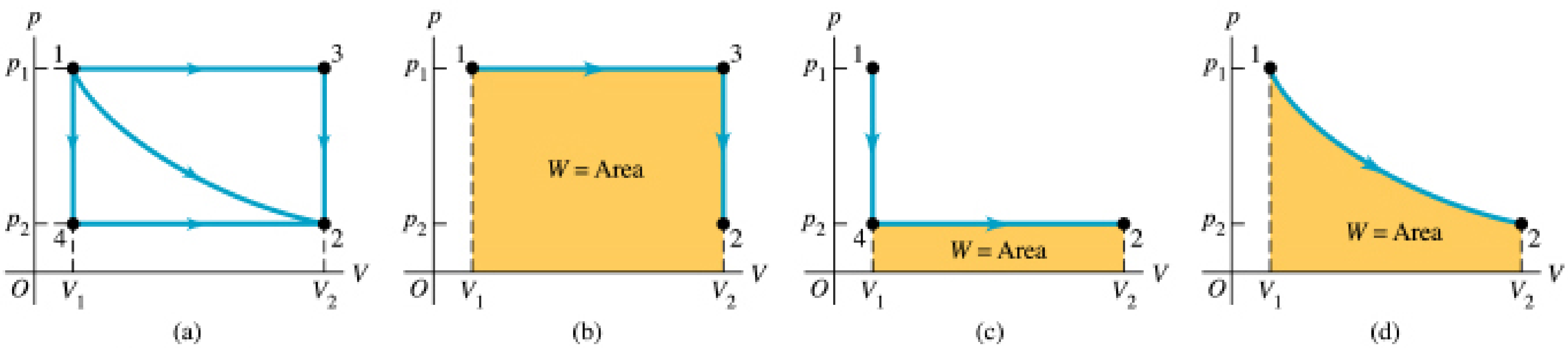
Gas compresses
$dV<0$, $W<0$

Constant p
$W=p(V_2-V_1)$

19-3. Paths Between Thermodynamic States

Path: a series of intermediate states between initial state (p_1, V_1) and a final state (p_2, V_2)

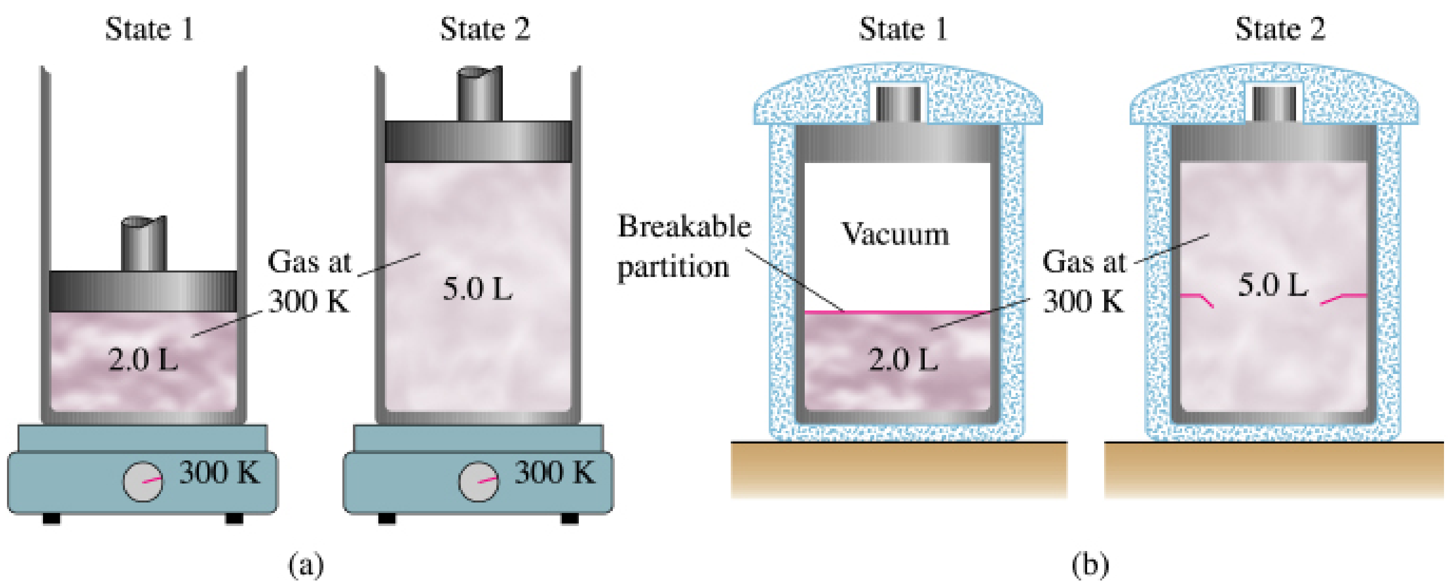
The path between two states is NOT unique.



W= $p_1(V_2-V_1) + 0$ W=0+ $p_2(V_2-V_1)$ $W = \int_{V_1}^{V_2} p dV$

Work done by the system is path-dependent.

Path Dependence of Heat Transfer



Isotherml: Keep temperature const.

Insulation +
Free expansion (uncontrolled expansion of a gas into vacuum)

Heat transfer depends on the initial & final states, also on the path.

19-4. Internal Energy & the First Law of Thermodynamics

Internal energy *U*: kinetic energies of all constituent particles + potential energies of particle-particle interactions

Recall energy change is Q-W

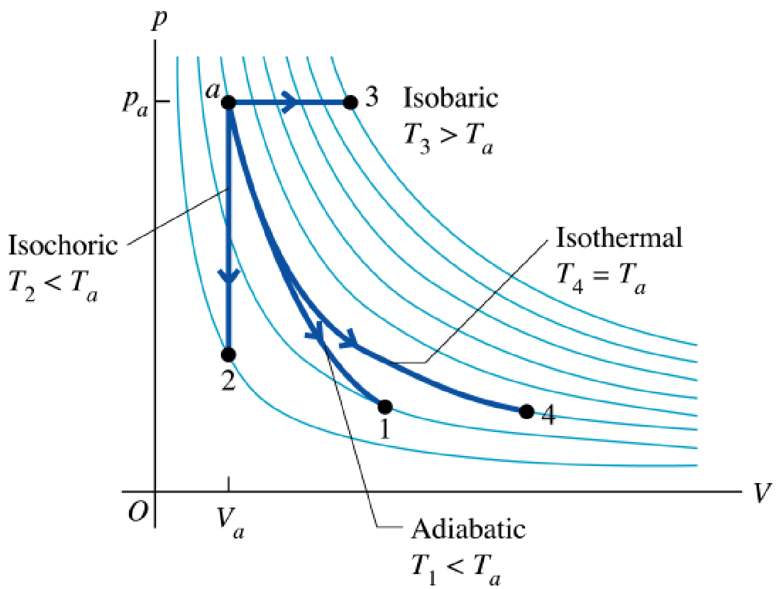
Thus $\Delta U = Q - W$ *First law of thermodynamics*

Although Q & W are path-dependent, experiments found that

ΔU is path-independent

For an isolated system, $W=Q=0$, $\Delta U=0$

19-5. Kinds of Thermodynamic Processes



Adiabatic: No heat transfer in or out, $Q=0$

$\Delta U = -W$

Expansion, $W>0$, $\Delta U<0$

Compression, $W<0$, $\Delta U>0$

Isochoric: constant volume, $W=0$

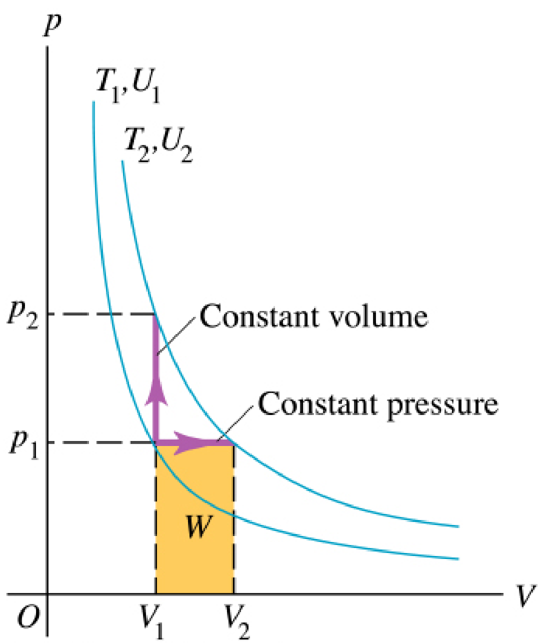
$\Delta U = Q$

Isobaric: constant pressure, $W=p(V_2-V_1)$

Isothermal: constant temperature

19-6 &7. Internal Energy & Heat Capacities of an Ideal Gas

Ideal gas: *U* only depends on T



$Q = nC\Delta T$

C_V: molar heat capacity at constant volume

C_p: molar heat capacity at constant pressure

Isochoric: $W=0,\ Q=\Delta U=nC_V\Delta T$

Isobaric: $Q=\Delta U+W$

$nC_p\Delta T= nC_V\Delta T+W$

Thus $C_p > C_V$ *(opposite if volume reduces during heating)*

$\mathbf{C_p = C_V+R}$ $\qquad \boldsymbol{\gamma= C_p/ C_V >1}$

Monatomic gas: $C_V=3R/2,\ \gamma= 5/3$

Diatomic molecules near RT: $C_V=5R/2,\ \gamma= 7/5$

19-8. Adiabatic Processes for an Ideal Gas

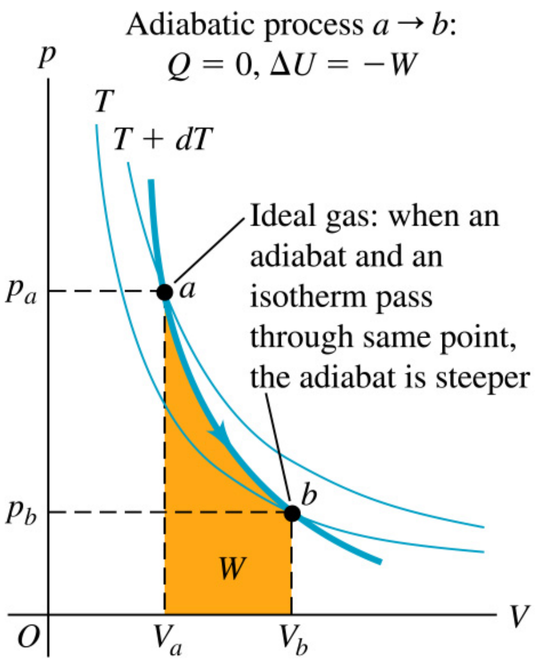
$$\Delta U = -W$$

State equations

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

or:

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma}$$



Since γ-1>0,
Adiabatic expansion dV>0, dT<0, temperature drops
Adiabatic compression, dV<0, dT>0, temperature rises

Work $W = nC_V(T_1 - T_2)$

$$= C_V(p_1V_1 - p_2V_2)/R$$

$$= (p_1V_1 - p_2V_2)/(\gamma - 1)$$

Summary for Ideal Gas

		W	Q	ΔU
		work done by system	*heat into system*	
Isochoric:	$\Delta V=0$	0	$nC_V\Delta T$	$nC_V\Delta T$
Isobaric:	$\Delta p=0$	$p(V_2-V_1)$	$nC_p\Delta T$	$nC_V\Delta T$
Isothermal:	$\Delta T=0$	$\int_{V_1}^{V_2} pdV$	$\int_{V_1}^{V_2} pdV$	0
Adiabatic:	$Q=0$	$-nC_V\Delta T$	0	$nC_V\Delta T$

Example

A cylinder with a piston contains 0.25 mol of O_2 (treat as ideal gas) at 2.40 x 10^5 Pa and 355K. The gas first expands isobarically to twice its original volume. It is then compressed isothermally back to its original volume, and finally cooled isochorically to its original pressure.

A) show the processes in a p-V diagram

B) T during isothermal process?

C) maximum pressure?

D) total ΔU during the cycle?

E) total work done by the piston on the gas during the processes?

Example

A monatomic ideal gas initially at $p=1.50\ x10^5$ Pa and $V=0.0800\ m^3$ is compressed adiabatically to a volume of $0.0400\ m^3$.

A) final pressure?

B) Work done by the gas?

C) $T_{final}/T_{initial}$?