Thermal & Statistical Physics
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PHYS 343
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LECTURE 9

Internal Energy

Energy Transfers

Conservation of Energy

Work and Heat

Thermodynamic Systems

Remember….

Thermodynamics: Fundamental laws that heat and work obey

System: Collection of objects on which the attention is being paid

Surrounding – Everything else around

System can be separated from surrounding by:

Diathermal Walls – Allows heat to flow through

Adiabatic Walls - Perfectly insulating walls that do not allow flow of heat

State of a system – the physical condition – can be defined using various parameters such as **volume, pressure, temperature etc**.

Before We Start

- Why is $T \propto K_{\text{trans}}$?
- Why is C larger when there are more modes?
- Why does energy partition between modes?

Thermodynamic Paths

energy transfers

§ 19.3–19.4

Energy Transfers

Between system and surroundings

- Work
- Heat

Work

From a volume change of the system

$$W = -\int_{V_1}^{V_2} p \, dV$$

Heat and Work

$dW = F.ds = (PA)\ ds$

$= p\ (Ads = p\ dV$

$W = \int dw = \int p\ dV$

Work done represented by the area under the curve on pV diagram.

Area depends upon the path taken from i to f state. Also PV= nRT

For b) from i to a process volume increase at constant pressure i.e

$T_a = T_i\ (V_a/V_i)$

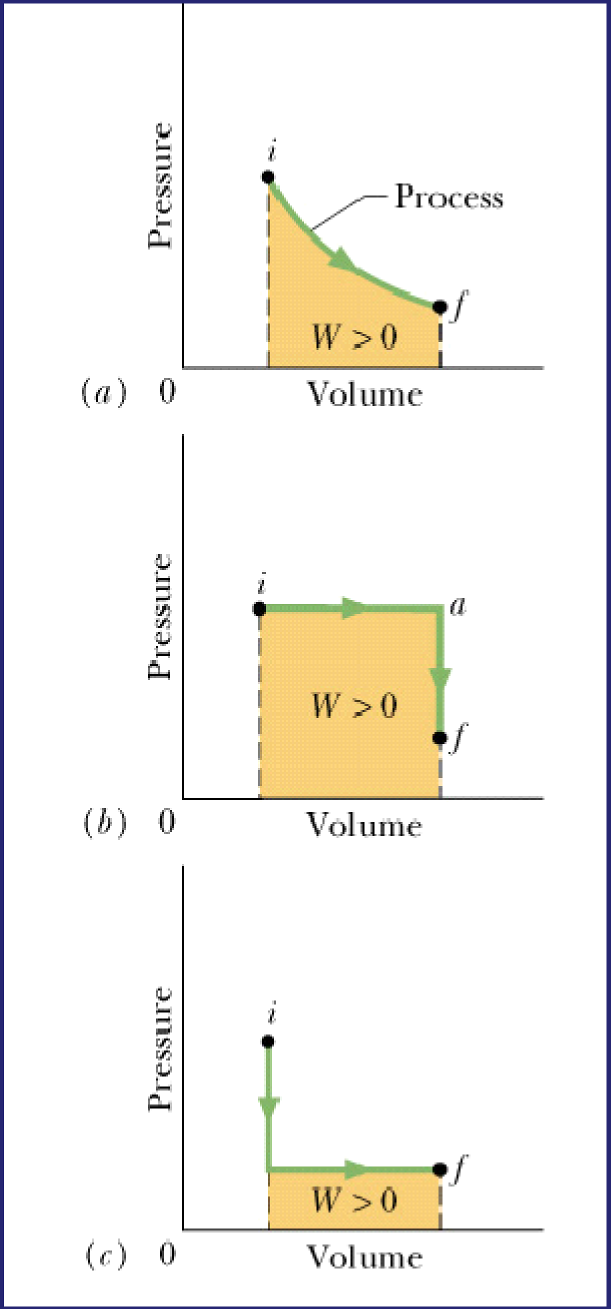
then $T_a > T_i$. Heat Q must be absorbed by the system and work W is done

a to f process is at constant V ($P_f > P_a$) then

$T_f = T_a(p_f/p_a)$

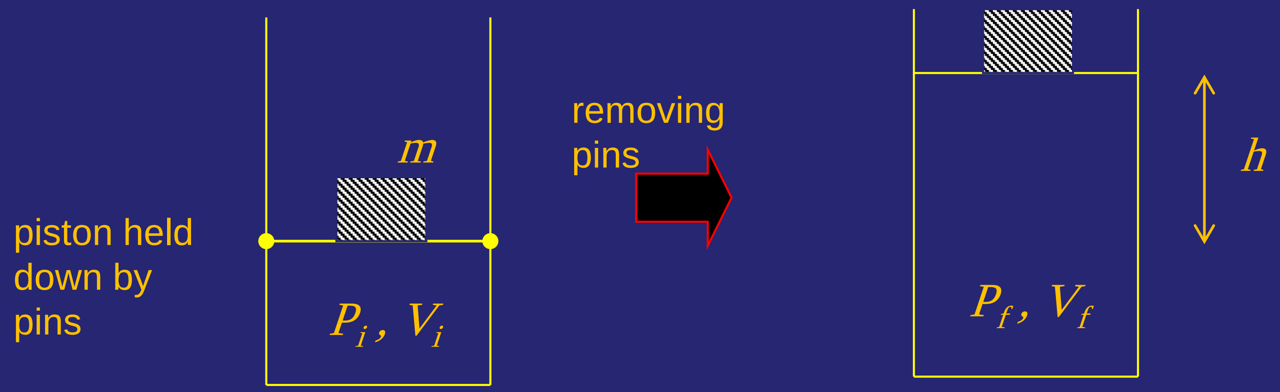
Since $T_f < T_a$, heat Q' must be lost by the system

For process iaf total work W is done and net heat absorbed is Q-Q'



Mechanical Work

Expansion of a gas



Work performed by the gas: $w = -P_{ext}\Delta V$

Infinitesimal volume change $\delta w = -P_{ext}\delta V$

Convention: work done on the system is taken as positive.

Mechanical work: $w = -\int_{V_i}^{V_f} P_{ext}(V)dV$

Reversible Processes

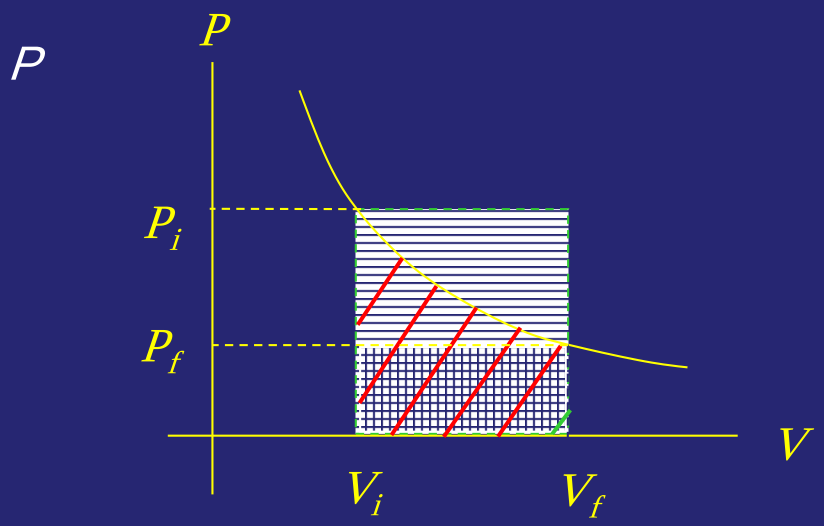
A process is called reversible if $P_{system} = P_{ext}$ at all times. The work expended to compress a gas along a reversible path can be completely recovered upon reversing the path.

When the process is reversible the path can be reversed, so expansion and compression correspond to the same amount of work.

$$w = -\int_{V_i}^{V_f} P(V)\,dV$$

- To be reversible, a process must be infinitely slow.

Reversible Isothermal Expansion/Compression of Ideal Gas



$$w = -nRT \ln \frac{V_f}{V_i}$$

Reversible isothermal compression: minimum possible work

Reversible isothermal expansion: maximum possible work

Heat

From a temperature difference

$$dQ/dT \propto T_{\mathrm{surr}} - T_{\mathrm{sys}}$$

Work and Heat

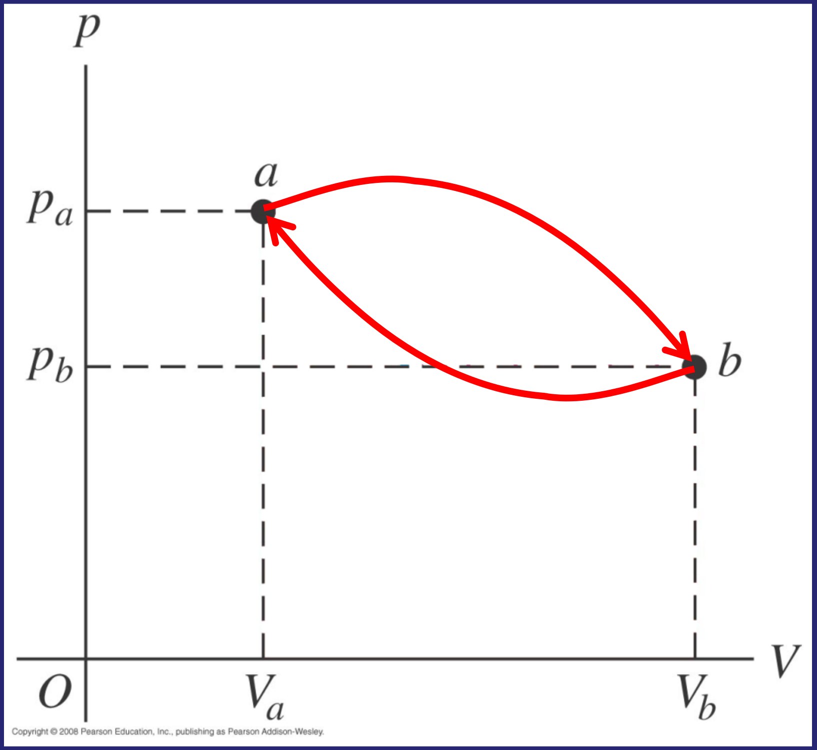
Depend on the path taken between initial and final states.

Question

Is the work done by a thermodynamic system in a cyclic process (final state is also the initial state) zero.

A. True.

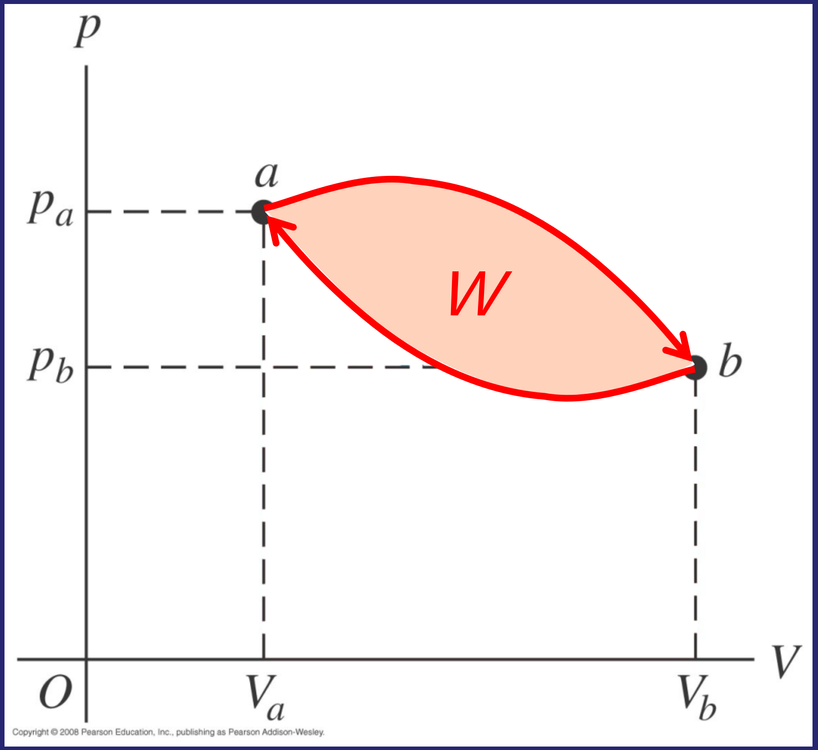
B. False.



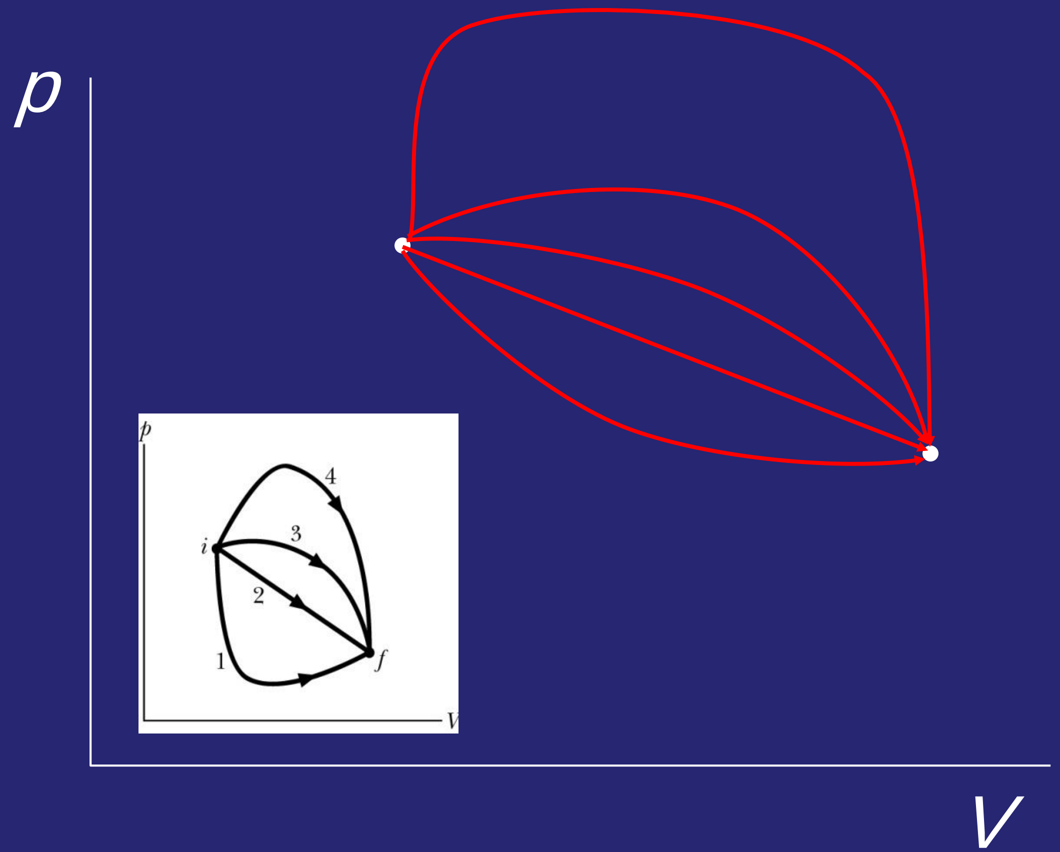
Source: Y&F, Figure 19.12

Cyclic Process

$W \neq 0$

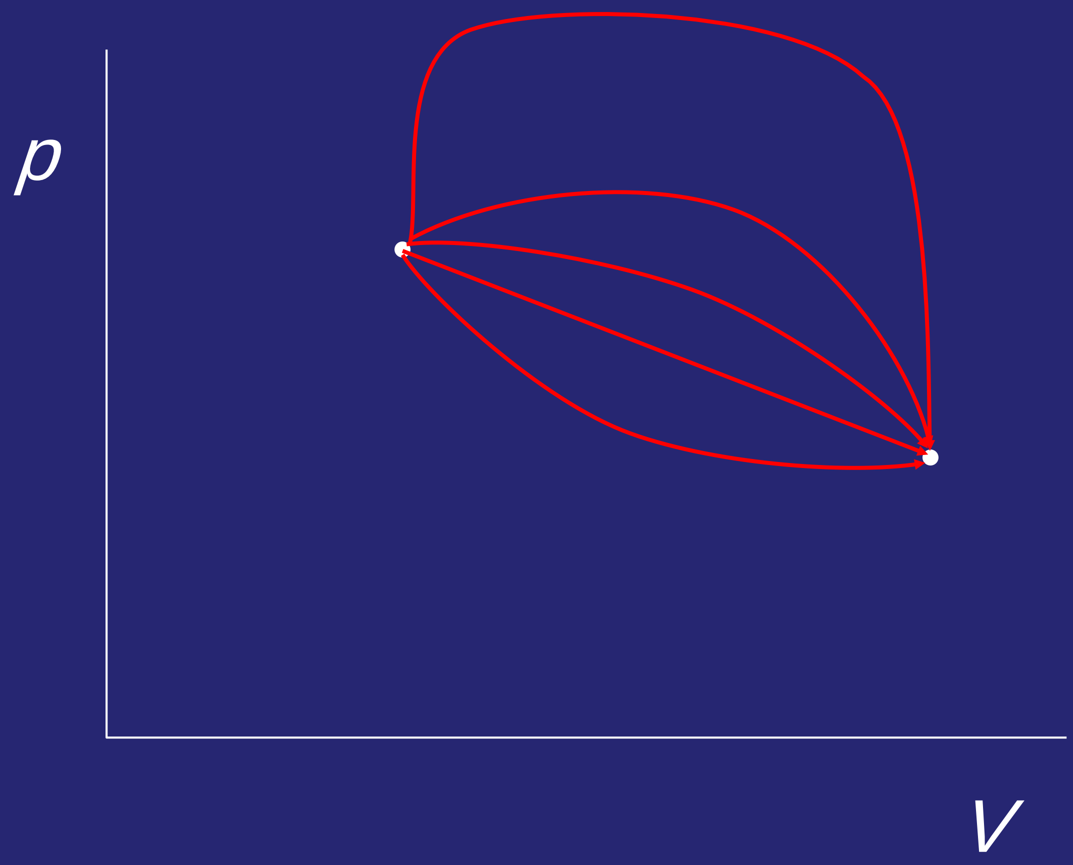


Work between States



W is not uniquely determined by initial and final states

What Are the Processes?



Group Work

Qualitatively sketch a pV plot for each described process A$\rightarrow$B.

a) Volume is gradually doubled with no heat input, then heated at constant volume to the initial temperature.

b) System is heated at constant pressure until volume doubles, then cooled at constant volume to the initial temperature.

c) System is allowed to expand into a vacuum (free expansion) to twice its volume.

d) Volume is gradually doubled while maintaining a constant temperature.

Group Work

Conservation of Energy

ΔE of a system =

work done on the system

+

heat added to the system

Internal Energy

Question

All other things being equal, adding heat to a system increases its internal energy E.

A. *True.*
B. *False.*

Question

All other things being equal, lifting a system to a greater height increases its internal energy U.

A. *True.*
B. *False.*

Question

All other things being equal, accelerating a system to a greater speed increases its internal energy E.

A. True.

B. False.

Question

All other things being equal, doing work to compress a system increases its internal energy E.

A. *True.*
B. *False.*

Cyclic Processes

$$\Delta E = E_1 - E_1 = 0$$

so

$$Q - W = 0$$

so

$$Q = W$$

- Work output = heat input

Work out = Heat in

Does this mean cyclic processes convert heat to work with 100% efficiency?

(Of course not.)

Waste heat is not recovered.

Example Problem

A thermodynamic cycle consists of two closed loops, I and II.

d) In each of the loops, I and II, does heat flow into or out of the system?

c) Over one complete cycle, does heat flow into or out of the system?