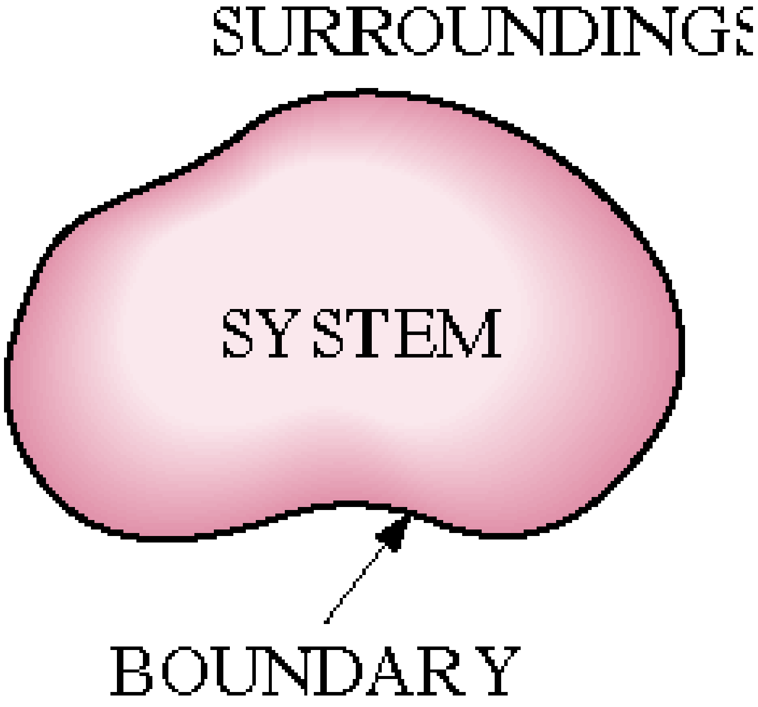
Chapter 2 : Topics

- System definition
- Properties
- Thermal Equilibrium
- State and Process
- Heat and Work modes

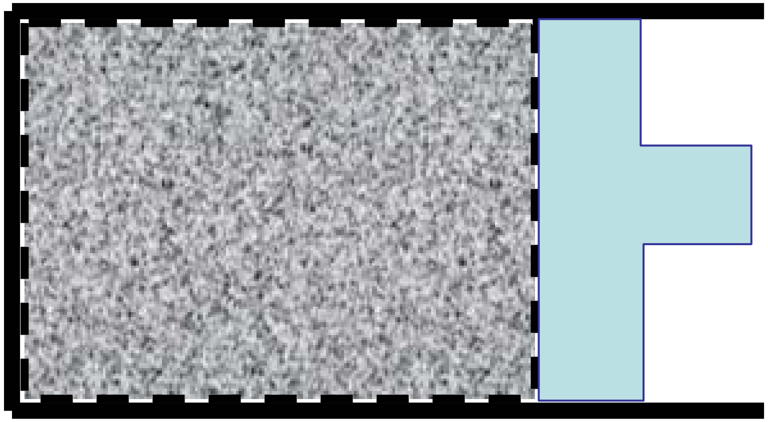
Thermodynamic System

- System is a region of space with a FIXED amount of MASS.
- The system's boundary separates the system from the surroundings.



- The boundary can be deformable or not, stationary or not;
- The boundary can exchange: work, heat, BUT NOT MASS

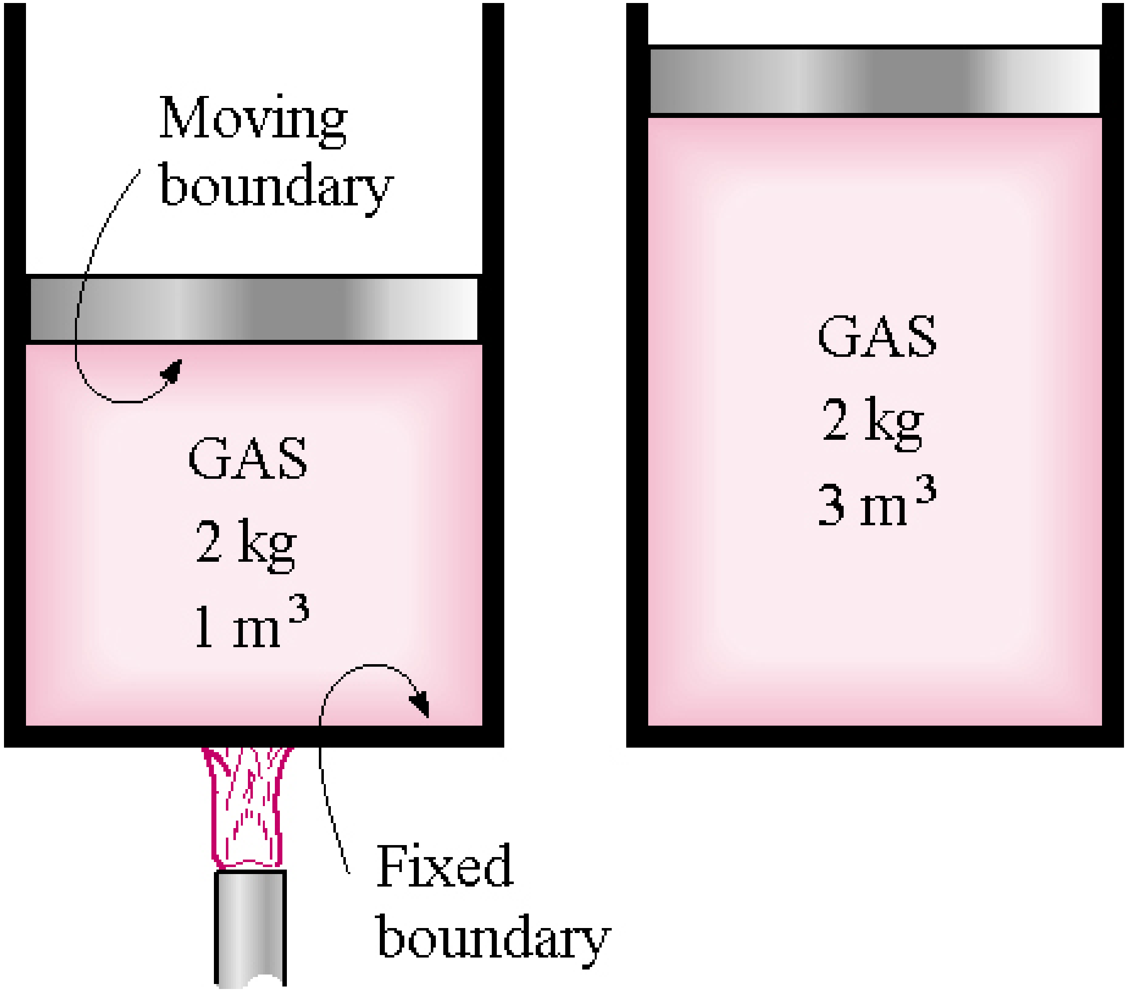
Example of a System



- Mass indicated by gray is system to study.
- Boundary can move (piston could go in and out)
- No mass crosses boundary (dashed line).

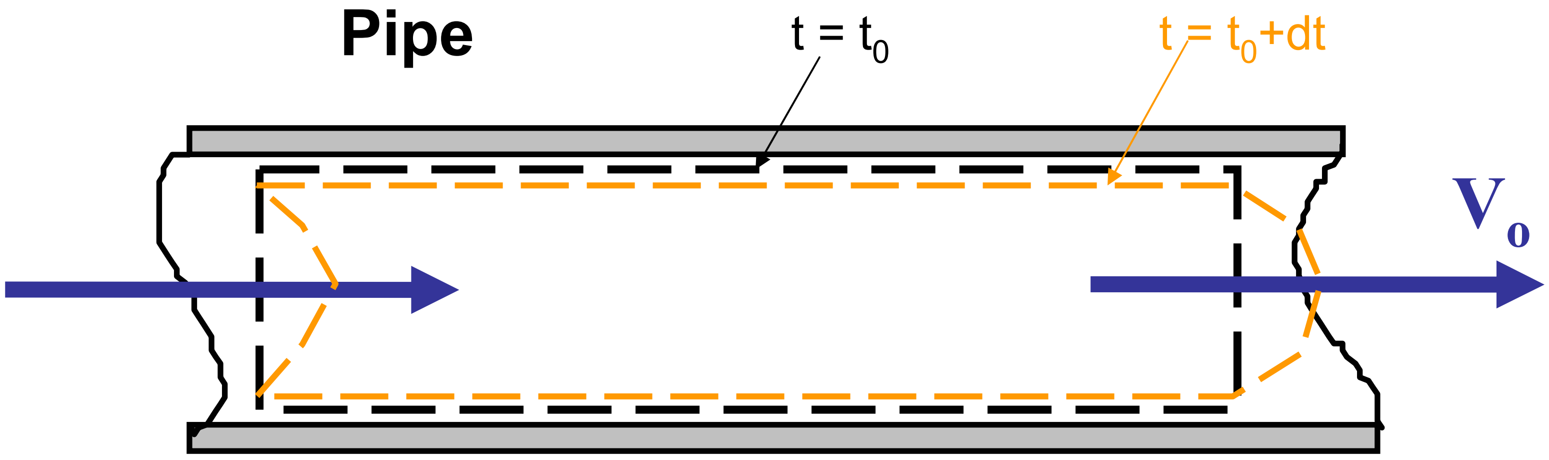
Example of a System

Energy (Heat or Work), not mass, crosses system boundaries



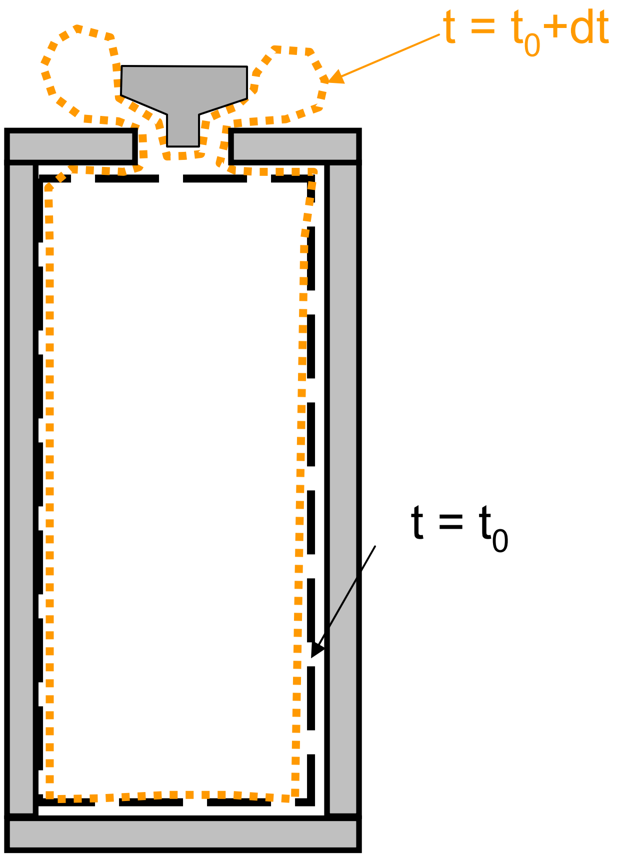
Fluid Flowing

- Very often there are applications where fluid is flowing in and out of a region (not a system).
- Tracking the system boundaries is not a easy task, since the fluid is a continuously deformable matter…



Boundary of the system

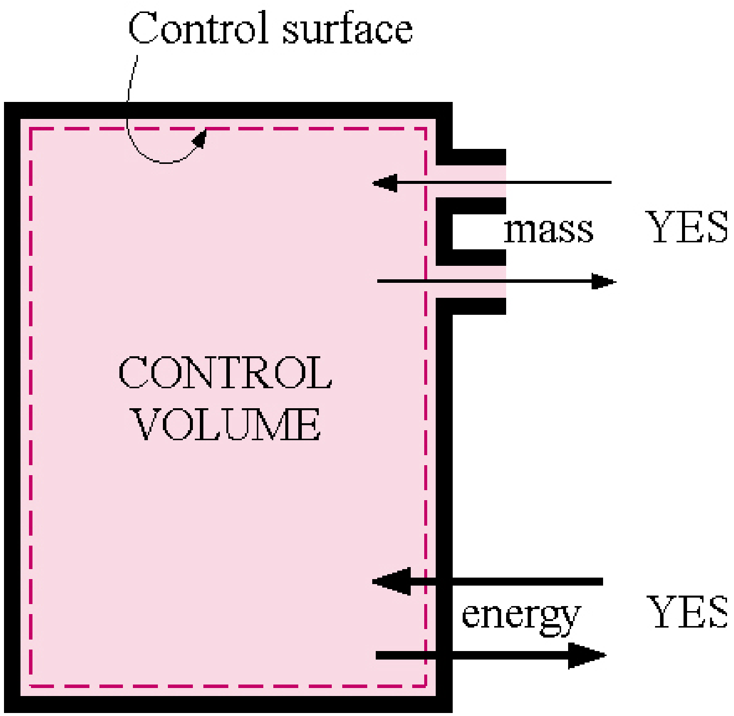
Fluid Flowing: Emptying a Tank



- Emptying/filling a tank is a classical example of a region of space loosing/gaining mass.
- How the system boundary behaves?

Control Volume: Chapter 5

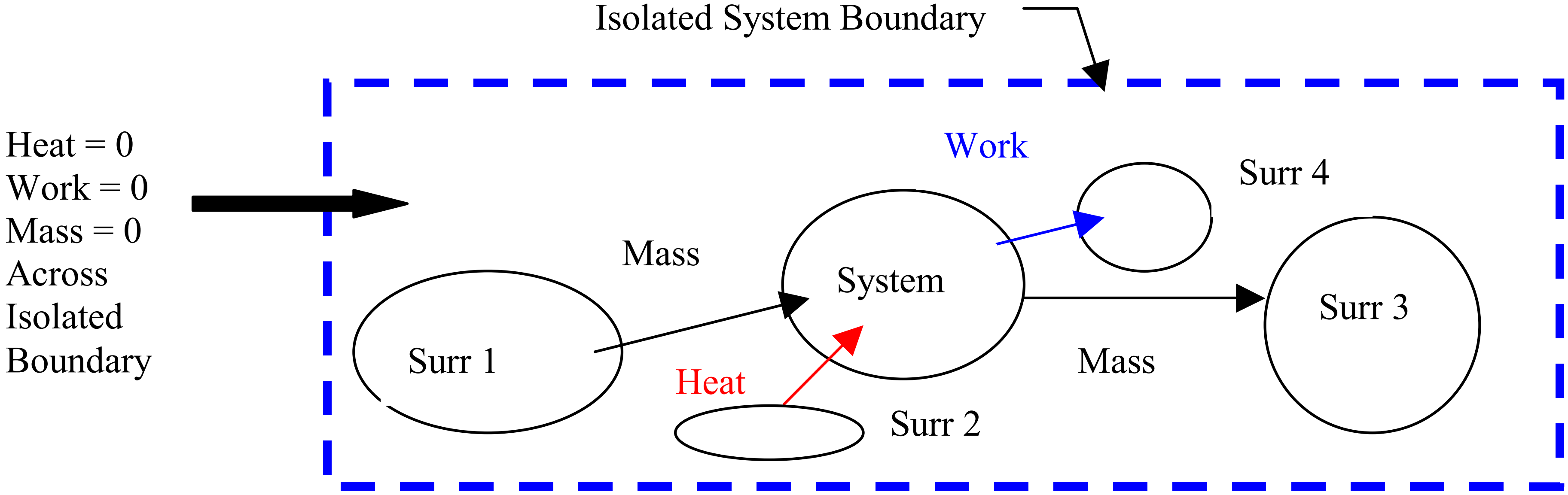
- Control Volume: Mass and energy can cross the boundary.
- System concept necessary to physical Laws. Control Volume concept necessary to experiments.



- Reynolds Transport Theorem relates the two concepts.
- Control surface can be stationary or not, deformable or not.
- We are just interested in the region bounded by the dashed lines.

Isolated System

A closed system is a system or a group of them where no heat or work may cross the boundaries.



TEAM PLAY

You take a bottle of Coke and put it in the refrigerator that is at 3°C. Should the bottle of Coke be treated as a system or a control volume?

Property

A property is a characteristic of a system to which numerical values can be assigned to describe the system.

- **Mass**
- **Temperature**
- **Pressure**
- **Density**

Extensive Property

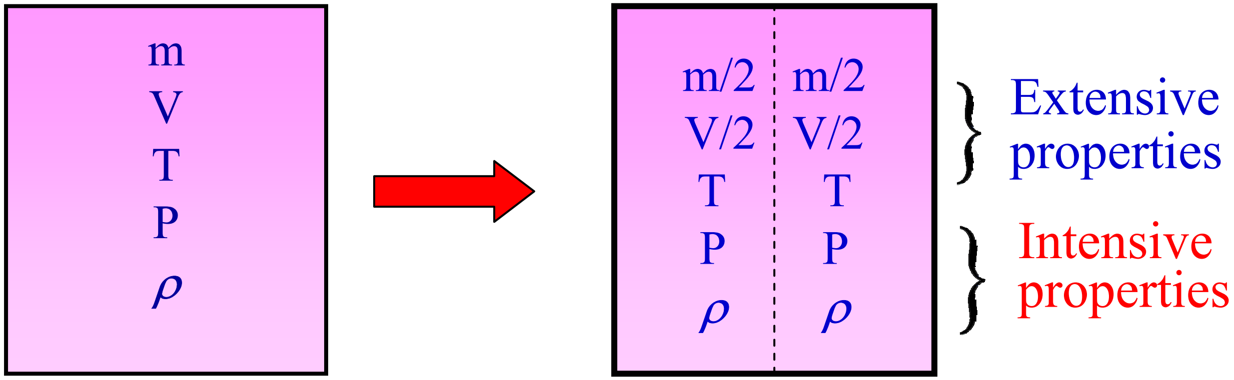
- **Extensive** properties are properties which can be counted and their value for the whole system is the sum of the value for subdivisions of the system.
- They depend on the extent of the system.

- Examples: Volume V, Mass M

Intensive Property

- **Intensive** properties are independent of the size (mass or volume) of the system.
- Examples: Density, Temperature, Pressure

Property



m
V
T
P
ρ

m/2 m/2
V/2 V/2
T T
P P
ρ ρ

Extensive properties

Intensive properties

Extensive properties per unit mass are intensive properties

Specific volume $$v = \frac{volume}{mass} = \frac{V}{m} \quad \left(\frac{m^3}{kg}\right)$$

density $$\rho = \frac{mass}{volume} = \frac{m}{V} \quad \left(\frac{kg}{m^3}\right)$$

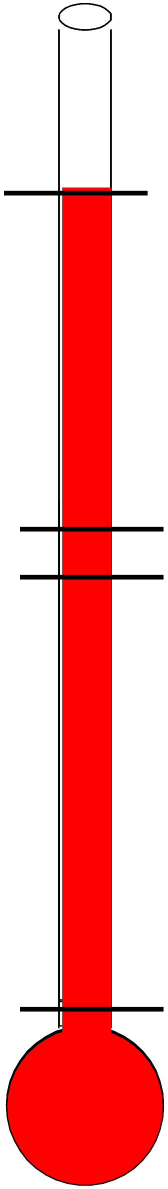
TEAM PLAY

- Decide if the following properties are extensive or intensive:
- Volume, mass, weight, temperature, density, specific volume, pressure, energy, momentum, color.

TEAM PLAY

- Decide if the following properties are extensive or intensive:
- Volume, mass, weight, temperature, density, specific volume, pressure, energy, momentum, color.

We Need to Work With Temperatures



	ºC	ºF	K	R
Boiling point	100	212	373.15	671.67
Triple point @ 0.006 atm, T = 0.01 ºC				
Ice point	0.00	32.00	273.15	491.67
Absolute Zero	-273.15	-459.67	0	0

Temperature relationships

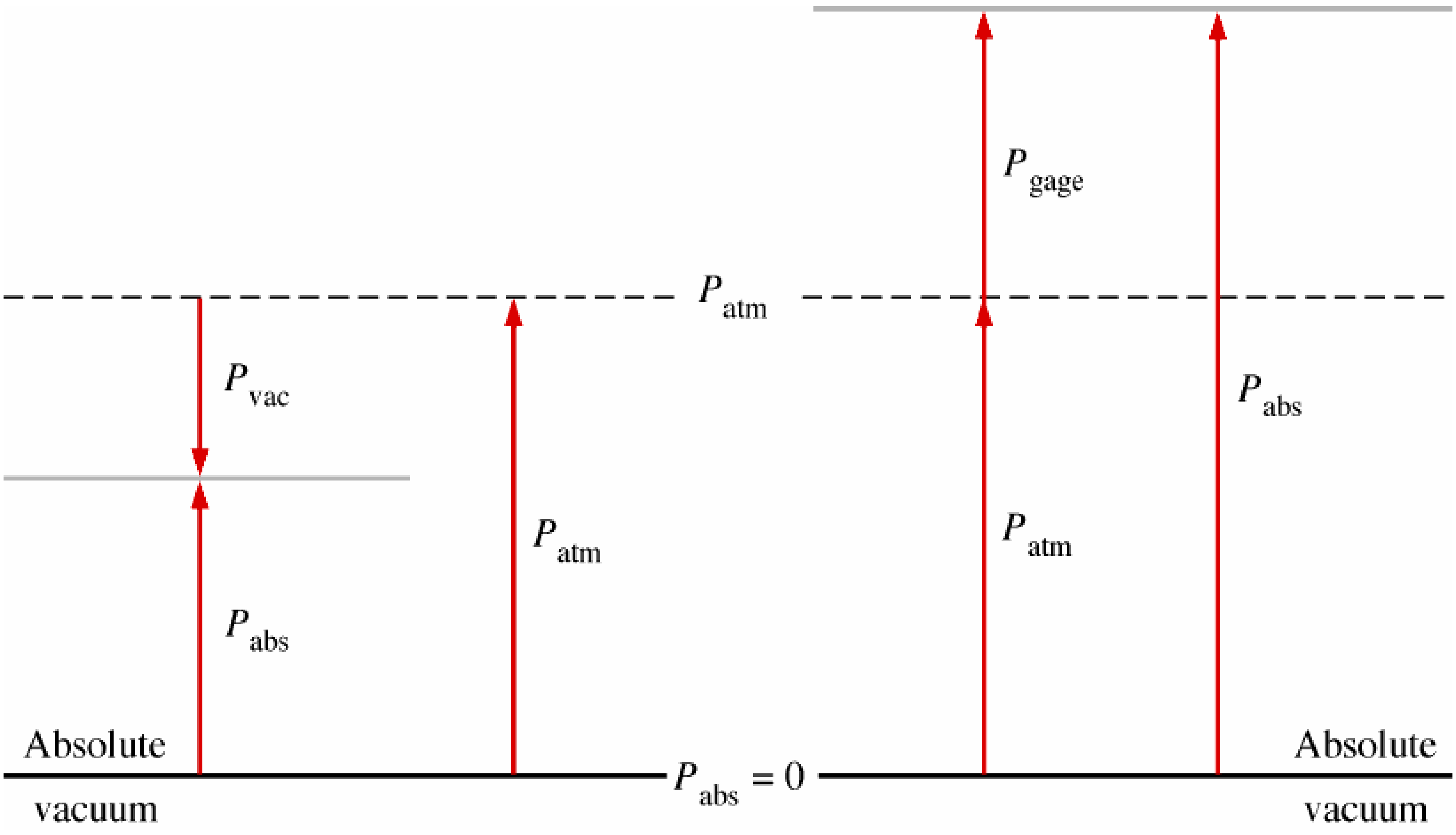
- T (R) = T (°F) + 459.67 [use 460]

- T (K) = T (°C) + 273.15 [use 273]

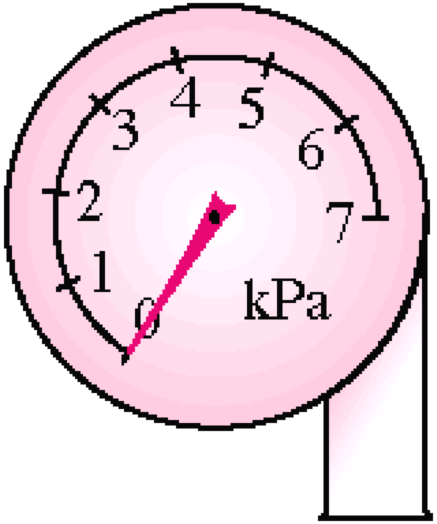
Pressure

- The normal force exerted on a (small) area.
- Continuum (macroscopic approach)

Atmospheric, Absolute, Gage, and Vacuum Pressures



Gage Pressure



$$P_{gage} = P_{abs} - P_{atm} \qquad (P > P_{atm})$$

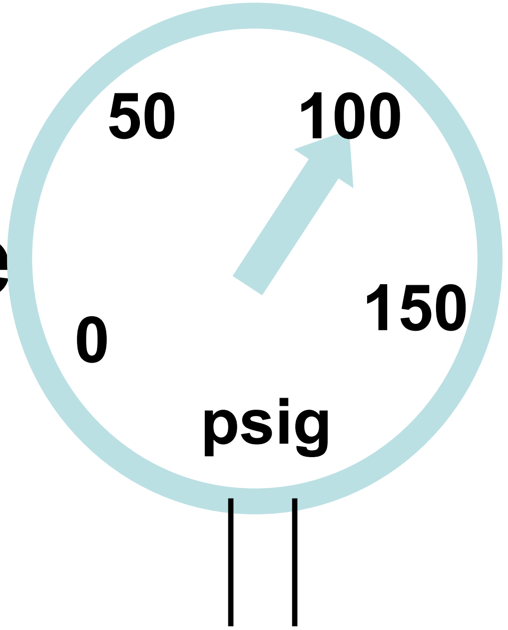
$$P_{vac} = P_{atm} - P_{abs} \qquad (P < P_{atm})$$

In the SI system we use

- SI Pressure unit is **Pascal**
- 1 Pa = 1 N/m^2
- 1 kPa = 1,000 N/m^2
- 1 bar = 100,000 N/m^2
- 1 MPa = 1,000,000 N/m^2

In the Bristh system

- lbf/in^2 or psi, usually with an “a” suffix or a “g” suffix, for absolute or gage.
- psia: Absolute pressure
- psig: gage pressure



Atmospheric pressure is

- 1 atm = 14.696 psia = 101,325 kPa
- = 1.01 bar = 760 mmHg

- 0 psig = 14.696 psia
- Absolute pressure (P_{abs}) =

gage pressure (psig) + atmospheric pressure (P_{atm})

Equilibrium

- A system is in equilibrium if its properties are not changing at any given location in the system.
- This is also known as “thermodynamic equilibrium” or “total equilibrium.”
- Equilibrium implies balance: no unbalanced potentials (driving forces) in the system.
- We will distinguish four different types of equilibrium

Types of thermodynamic equilibrium:

- Thermal equilibrium -- the temperature does not change with time
- Mechanical equilibrium -- Pressure does not change with time
- Chemical equilibrium -- molecular structure does not change with time
- Phase equilibrium – mass of each phase is unchanging with time (i.e., same liquid/gas or liquid/solid composition)

State

- The state of a system is defined by the values of its properties.

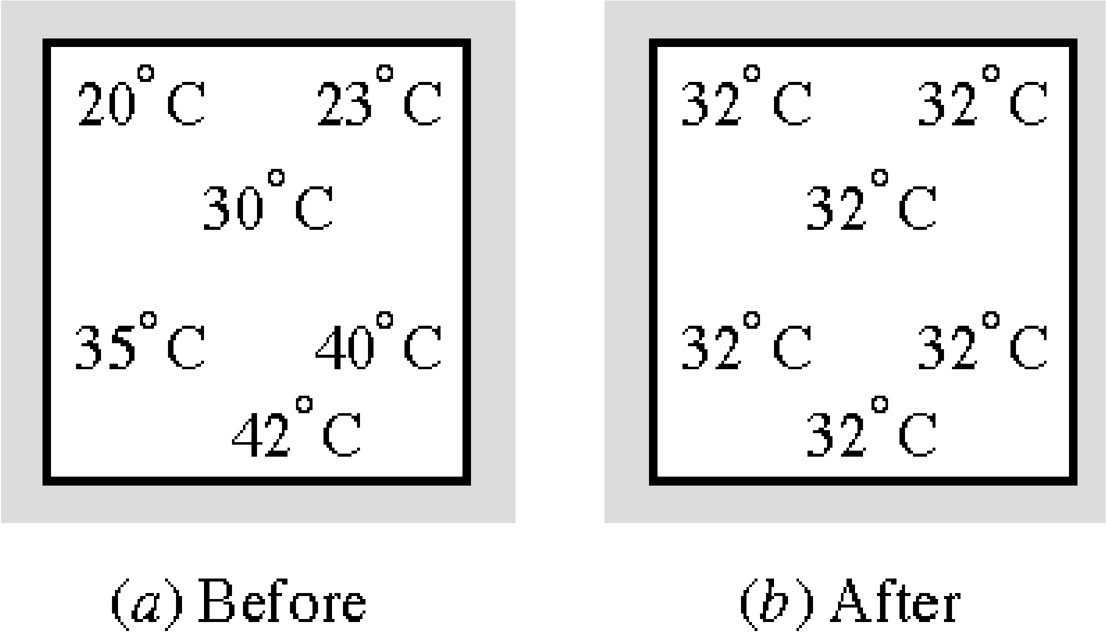
State and Equilibrium

•Thermodynamics deals with equilibrium states;

*** A system is in thermodynamic equilibrium if it maintains thermal, mechanical, phase, and chemical equilibrium**

Thermal Equilibrium

- Occurs when two bodies are at the same temperature T and no heat transfer can occur.

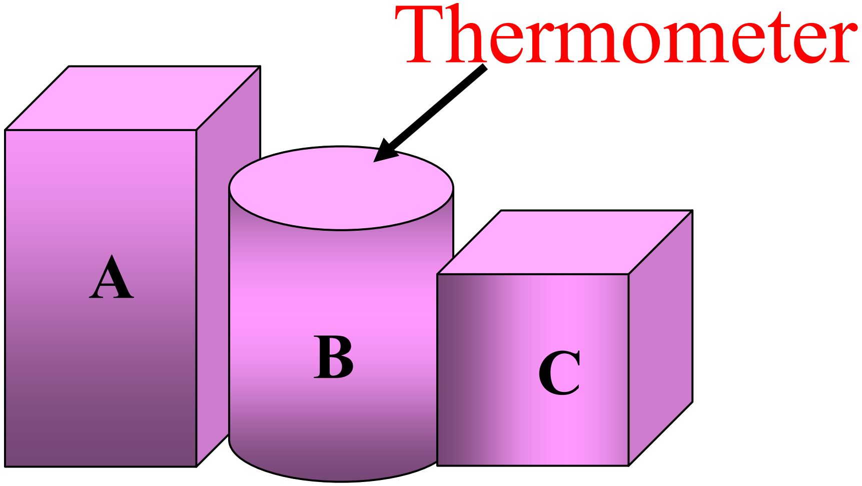


(a) Before

(b) After

Zeroth Law of Thermodynamics

- Two bodies are in *thermal equilibrium* if both have the *same temperature reading* even if they are not in contact.



State Principle or State Postulate

- Text says, “The state of a simple compressible system is completely given by two independent, intensive properties.”

- Properties are independent if one can be constant while the other varies.

- This only applies at equilibrium.

Simple system

- A simple system is defined as one for which only one quasiequilibrium work mode applies.

- **Simple compressible systems**
- **Simple elastic systems**
- **Simple magnetic systems**
- **Simple electrostatic systems, etc.**

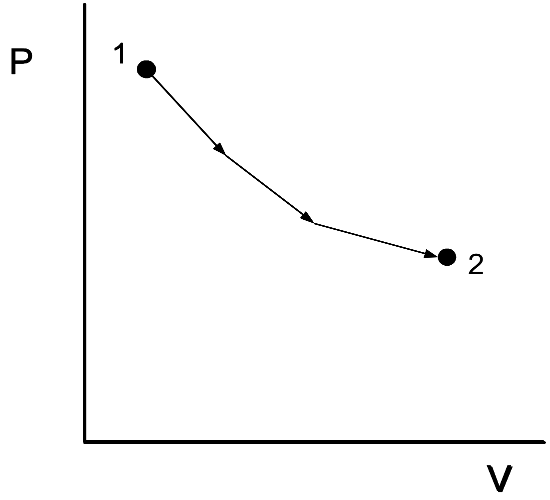
State Postulate

- The thermodynamic state of a simple compressible system is completely specified by two independent intensive properties.

$$\boxed{\begin{aligned} P &= P(\rho, T) \\ T &= T(P, v) \end{aligned}}$$

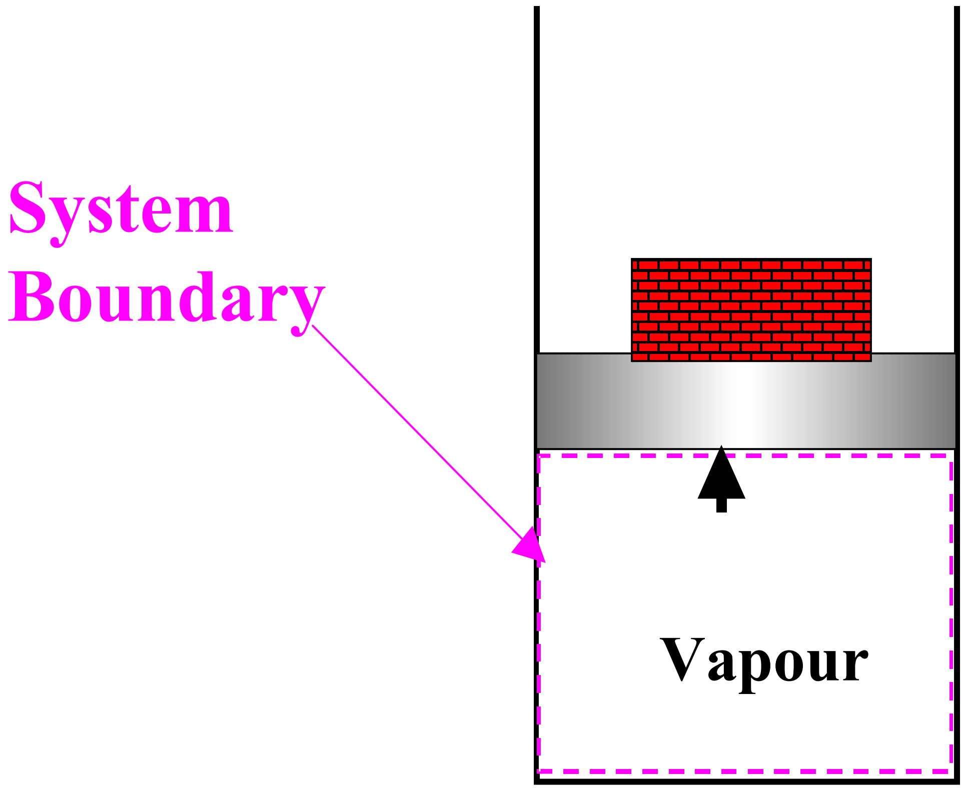
Process/Path

- Change in state of a system from one equilibrium state to another.
- Series of states through which a system passes.



Process	**Property held constant**
isobaric	pressure
isothermal	temperature
isochoric	volume
isentropic	entropy (see Chapter 6)

Example: Constant Pressure Process



Heat and Work

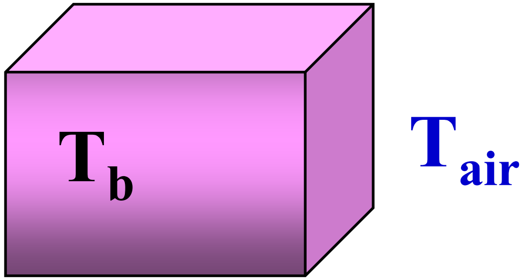
- If the ENERGY transfer across the boundaries of a system is due to a temperature difference, it is ***heat***; otherwise, it is ***work***.

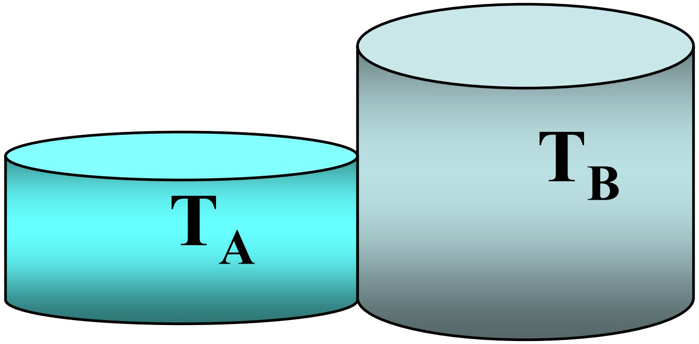
HEAT TRANSFER

Heat is a form of energy transfer that occurs solely as a result of a temperature difference

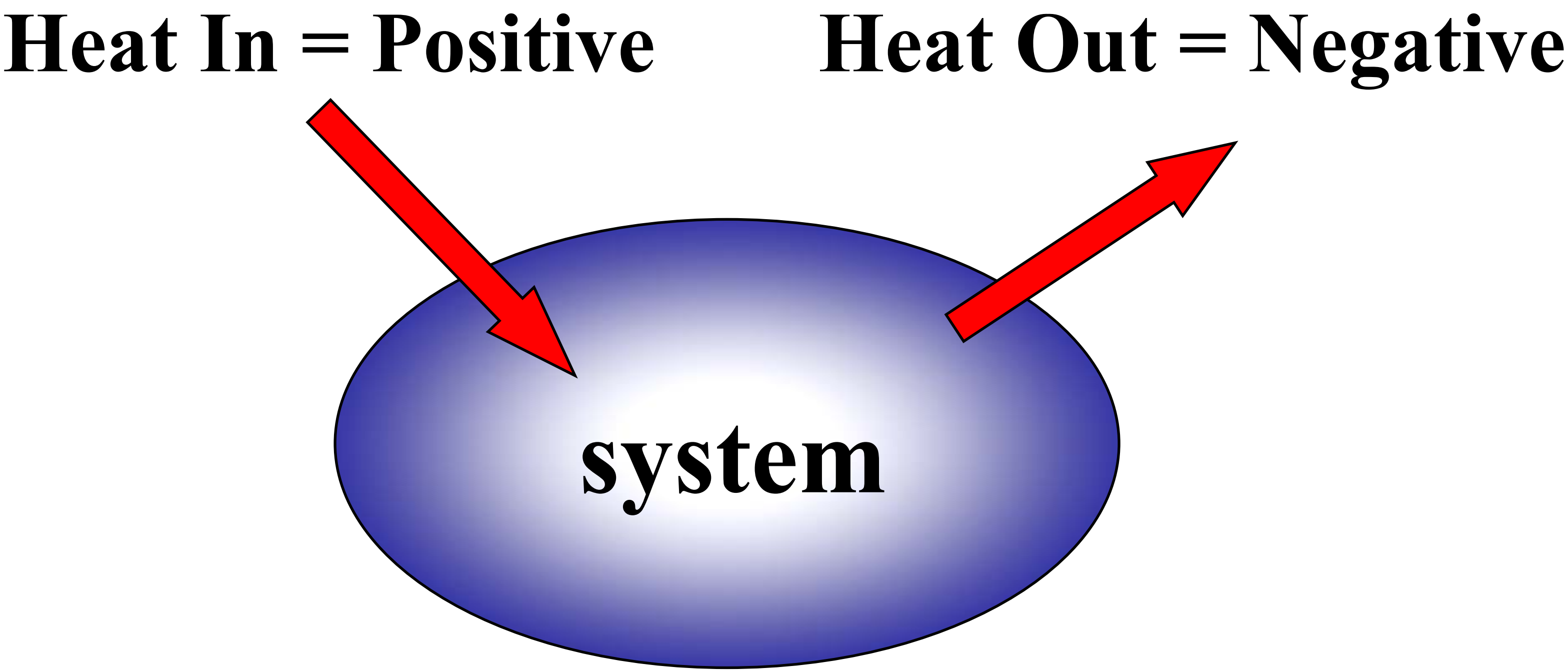
Heat can be transferred to and from the system or transformed into another form of energy.

$$Q = f(\Delta T)$$





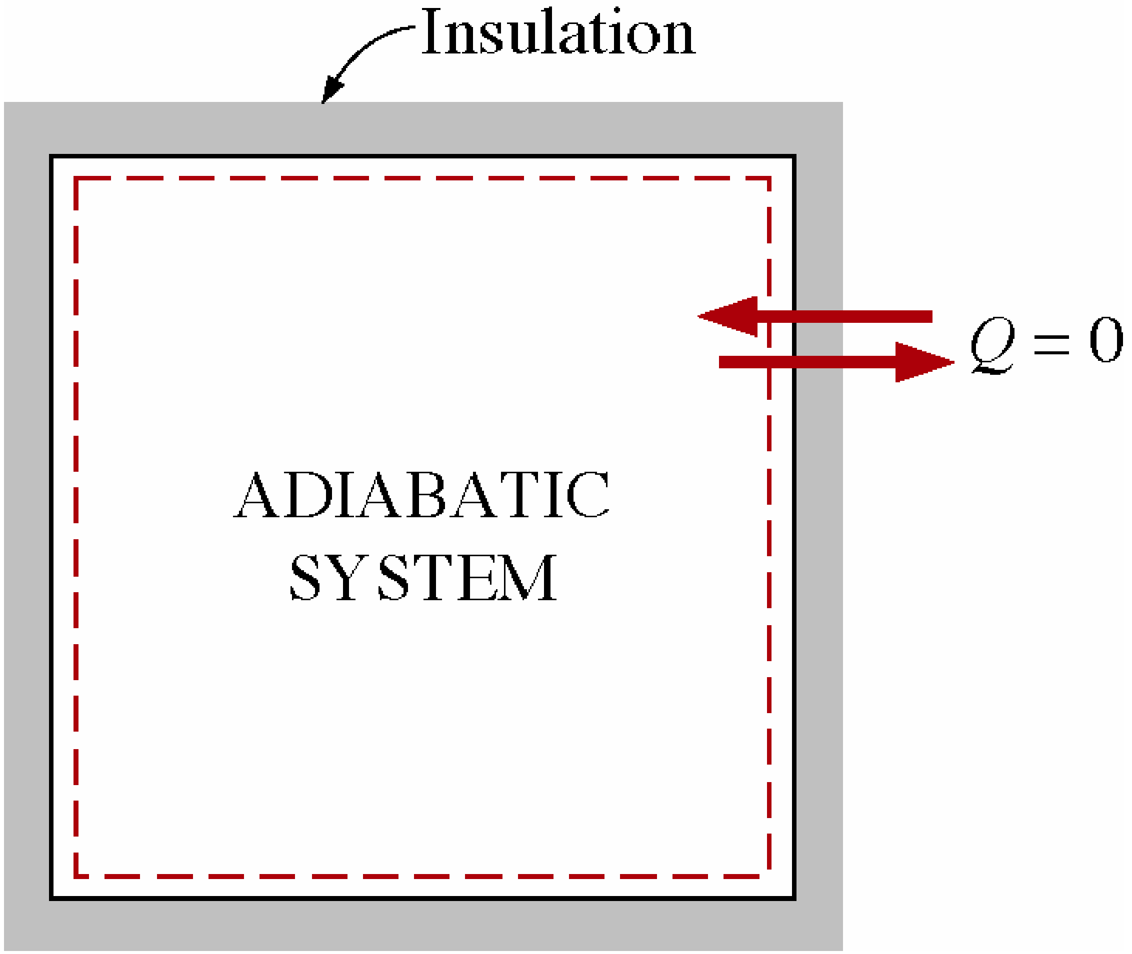
Remember
SIGN CONVENTION



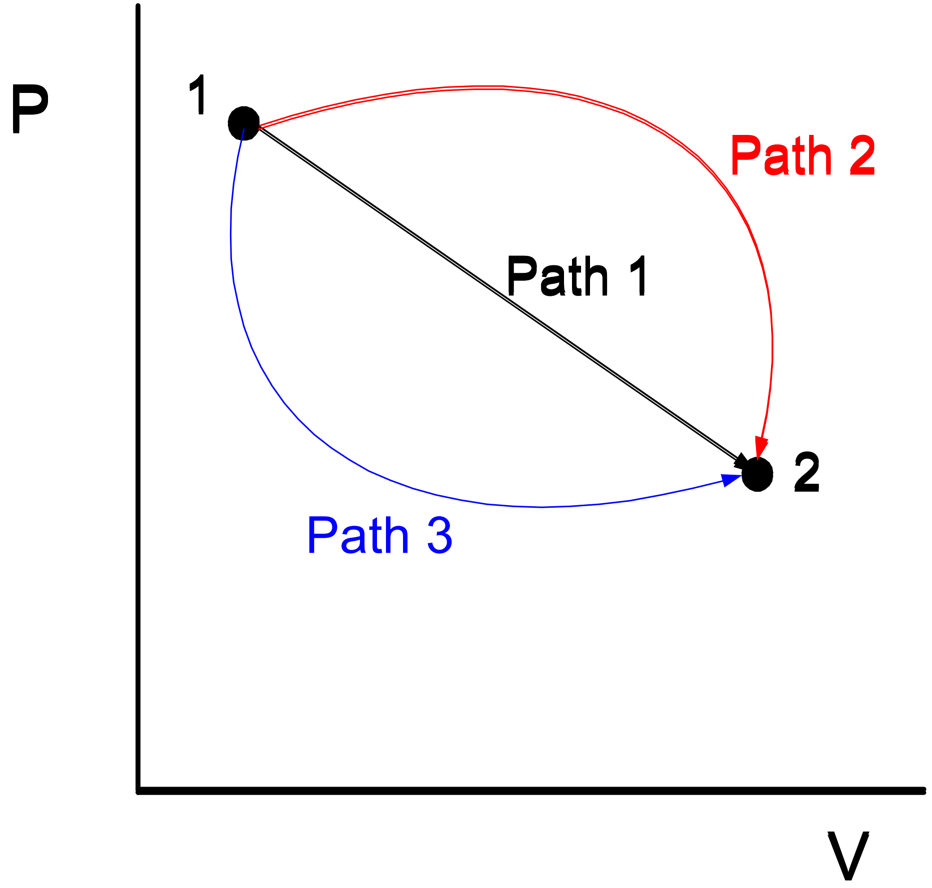
- **Q > 0: heat transfer <u>to</u> the system**
- **Q < 0: heat transfer <u>from</u> the system**
- **Q = 0: adiabatic**

Adiabatic Process

- No net heat transfer



Properties at end points are independent of the process



Exact Differential are path independent!

$$\int_{P_1}^{P_2} dP = P_2 - P_1$$

***P* is a “point function”**

Heat transfer is not a property of a system, just as work is not a property.

$$\boxed{Q = \int_1^2 \delta Q \neq Q_2 - Q_1}$$

We **can not** identify Q_2 (Q at state 2) or Q_1.

Q and W are path functions, not "point functions."

Units of HEAT

- Btu or kJ (1 Btu = 1.055056 kJ)
- Rate of heat transfer, $\delta Q/dt$, has units of Btu/h, ft-lbf/h, J/s or Watts
- 1 kJ = 1 kN•m = 1 kPa•m^3

WORK

- **Energy can cross the boundary of a closed system in the form of heat or work.**

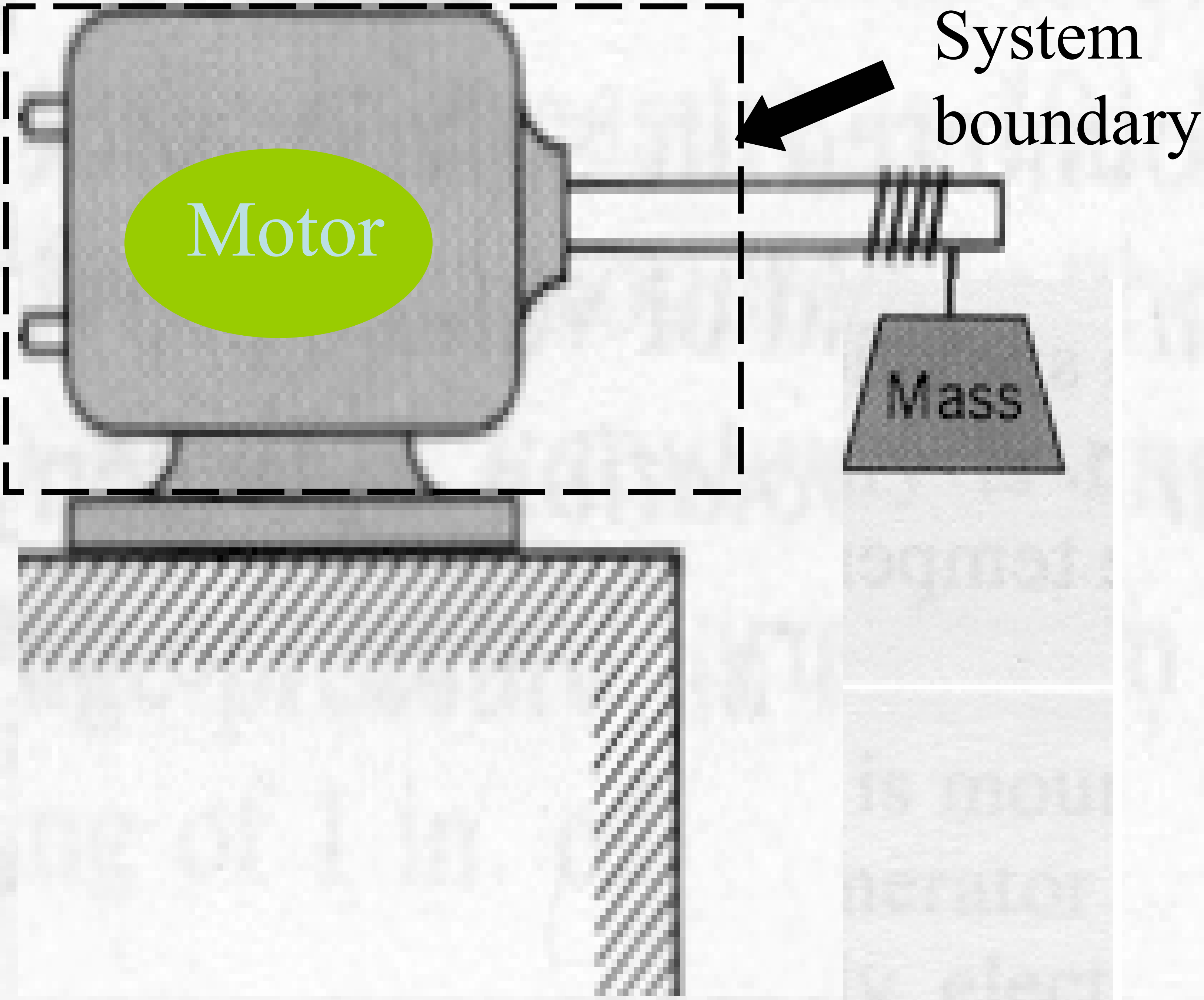
- **If the energy crossing the boundary is not heat, it must be work.**

- **Energy interaction that is not caused by a temperature difference.**

- **Rising piston, rotating shaft, electric wire, gravity, acceleration, spring force, …….**

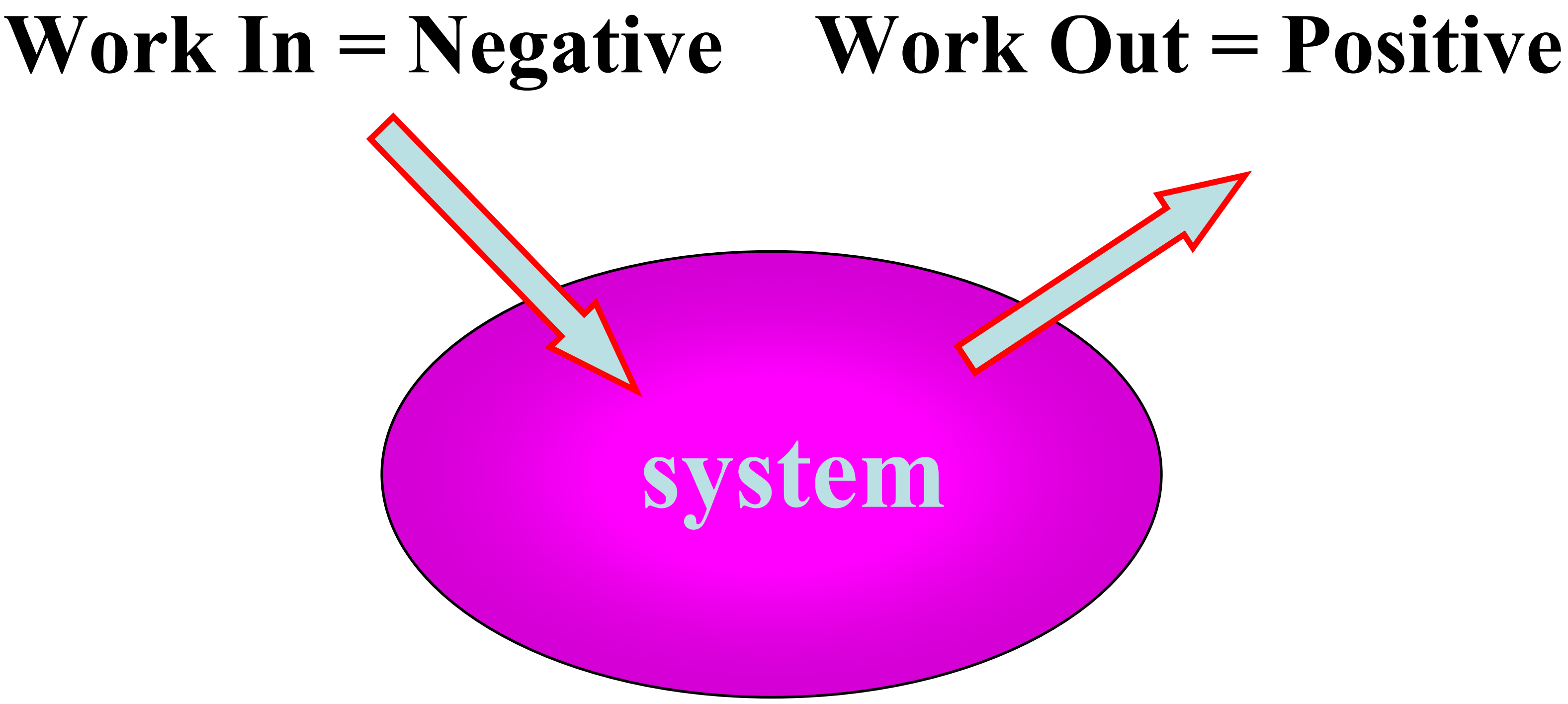
WORK

Work -- is done by a system (on its surroundings) if the sole effect on everything external to the system could have been the raising of a weight.



System boundary

Sign Convention



- W < 0 is work done on the system
- W > 0 is work done by the system

You've Seen Work Before in Mechanics

It's defined in terms of
<u>force</u> and <u>displacement</u>

$$W = \int \vec{F} \cdot d\vec{s}$$

Note that F and ds are vectors….

What is work again?

Work -- an interaction between a system and its surroundings whose equivalent action can be the raising of a weight.

Work is not a property of a system, just as heat is not a property

We also use an *inexact differential*, δ, with work.

$$W = \int_{1}^{2} \delta W$$

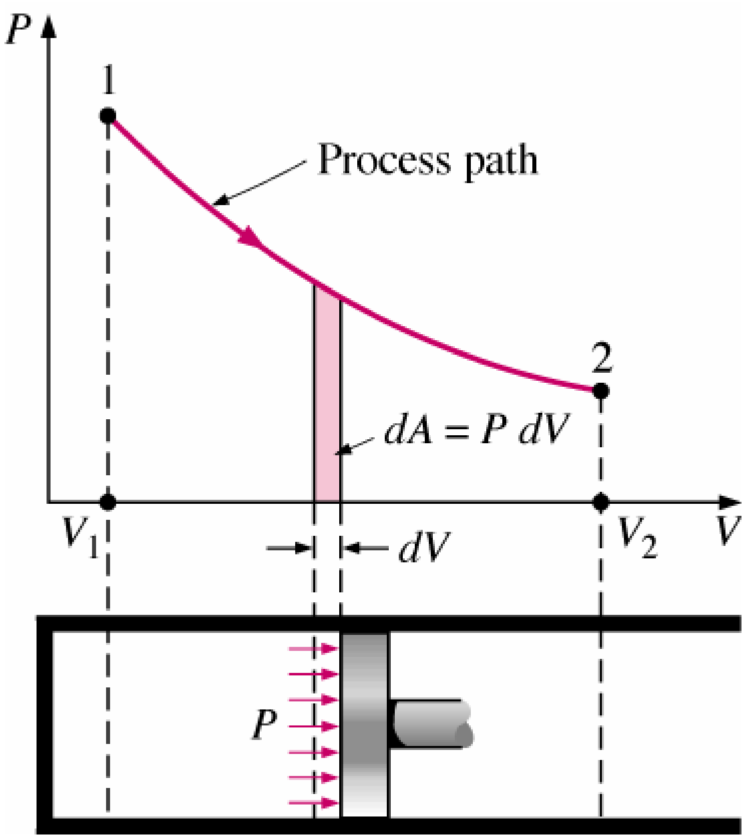
Heat and Work

- Both heat and work are boundary phenomena - recognized at the boundaries of a system as they cross them.
- System possess energy, but not heat or work.
- Both heat and work are path functions. Their magnitude depend on the path followed during the process as well as the end states.

Units of WORK

- Btu or kJ, the same as Heat
- Rate of doing work, $\delta W/dt$, has units of Btu/h, ft-lbf/h, J/s or Watts
- Rate of doing work is called POWER

Compressible Work Mode: The Moving Boundary Work



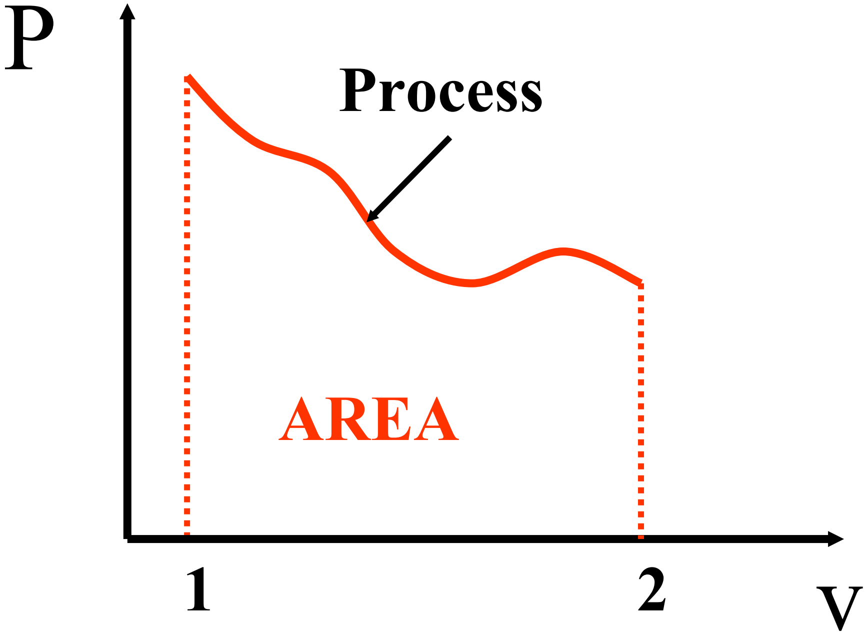
- The force on the piston is

$$F = P \times A_{piston}$$

$$W = \int F ds = \int P \times A_{piston} ds$$

$$W = \int_1^2 P dV$$

What did an Integral represent in Calculus?

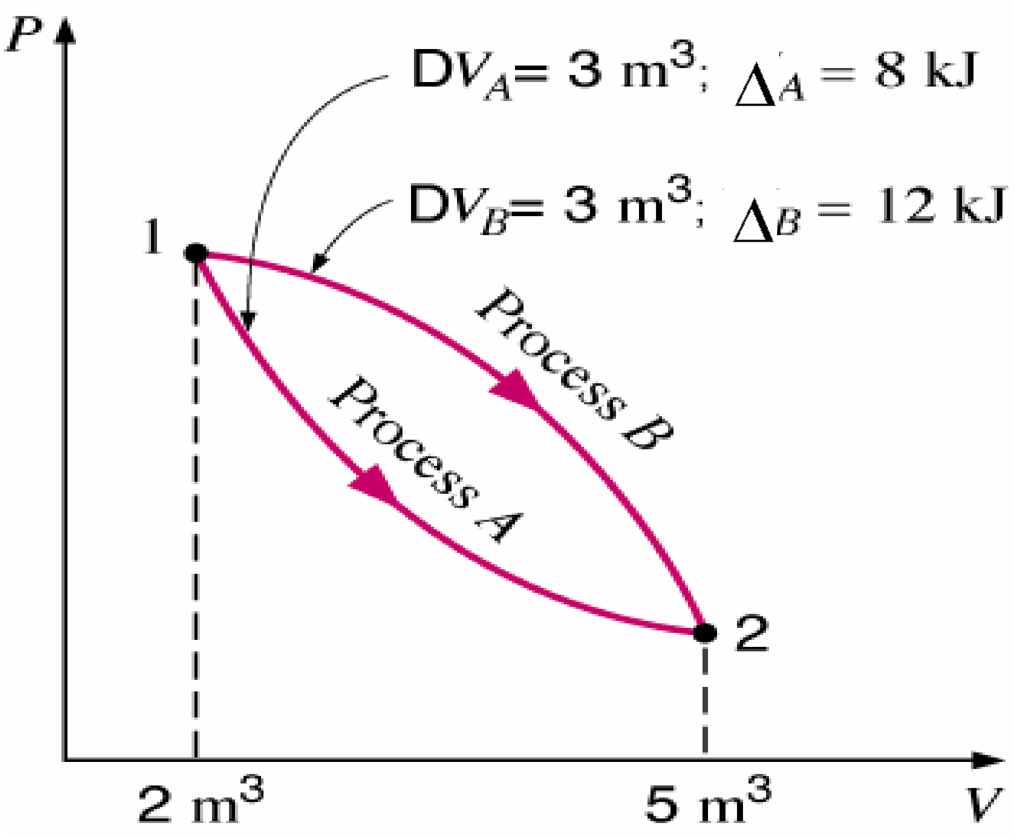


$$W_b = \int_1^2 P\, dV$$

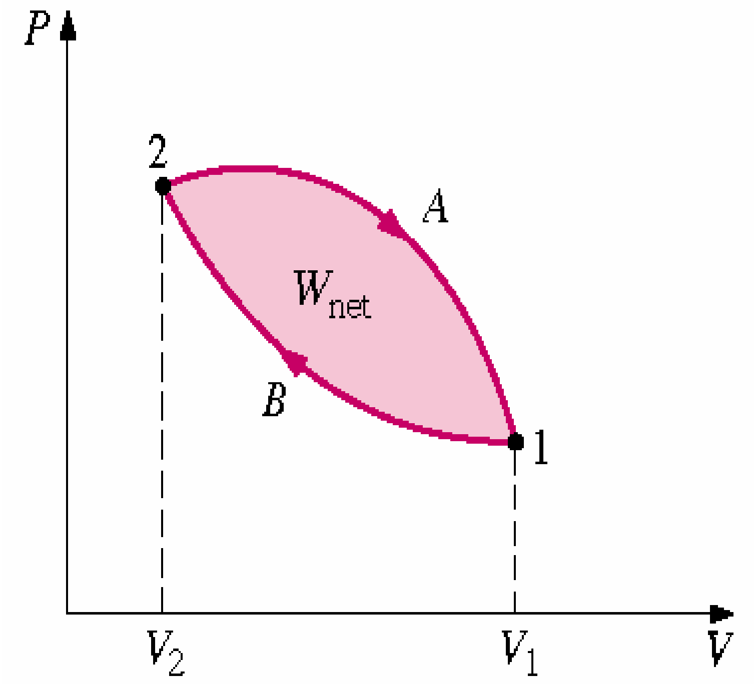
So, if we know P = P(V), then work due to compression can be interpreted as the area under a curve in pressure-volume coordinates.

Q & W: Path Functions

- **Both the heat and work are associated with a <u>process</u>, not a state!**



Net Work per Cycle



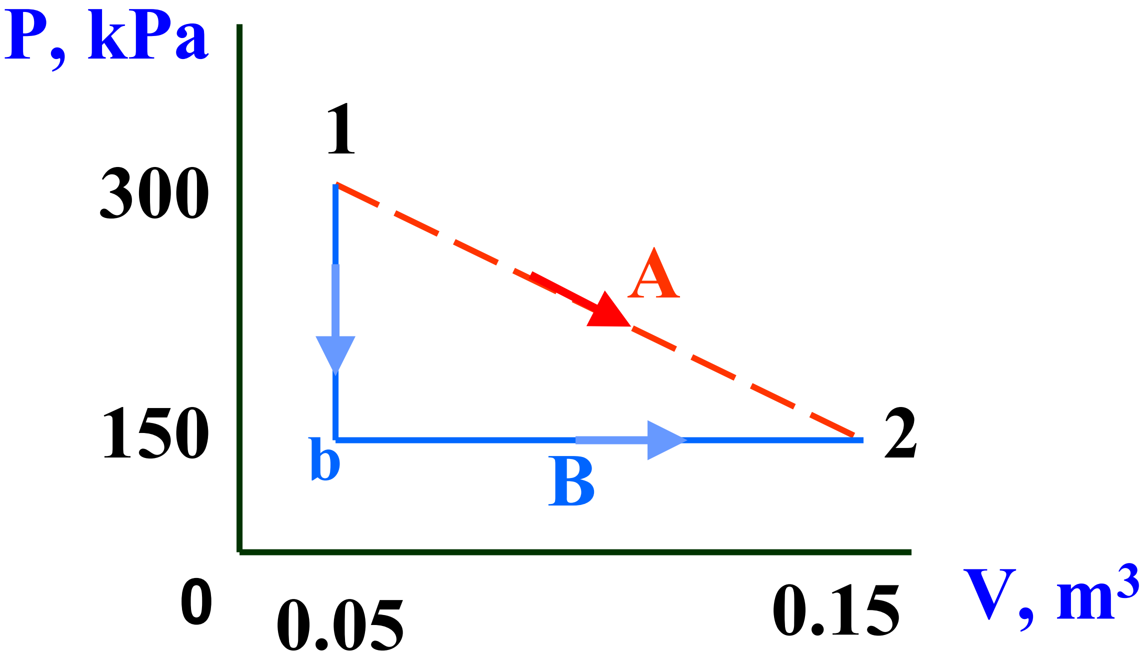
$$W_b = \int_1^2 P\,dV$$

- **For path functions** $\oint \delta W = \oint P dV \neq 0$

- This enables cyclic devices (car engines, power plants,……) to produce net work.

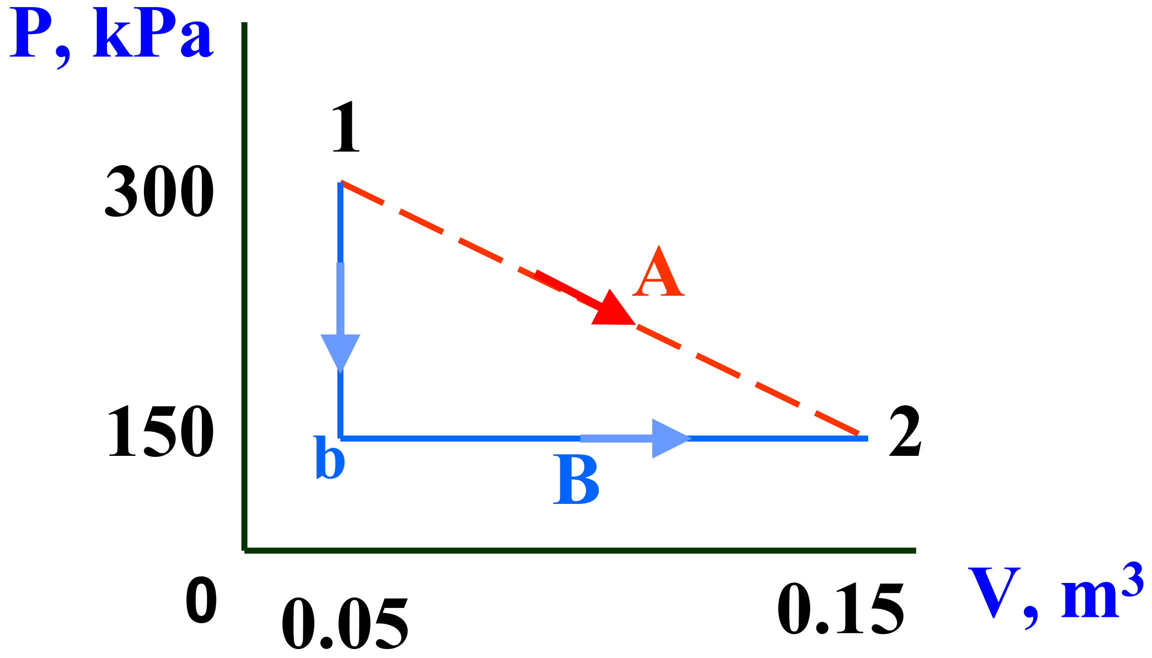
TEAMPLAY

For a piston-cylinder system, two paths are shown from point 1 to 2. Compute the work in kJ done in going by path A (W_A) and by path B (W_B).



QUESTION …..

Consider the piston-cylinder problem you just did. How could you accomplish this process by heating and cooling the system at process B?

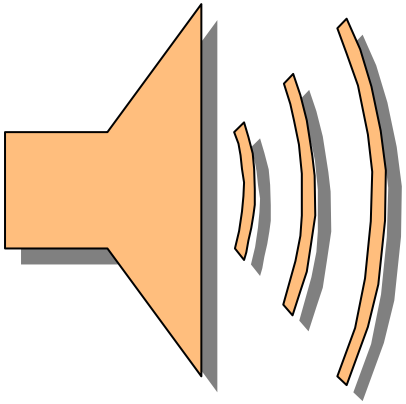


Isometric Process

- Isometric process -- dV = 0
- Heating or cooling at constant volume.

$$\boxed{W_b = \int_1^2 PdV = 0}$$

- The pressure change (increase or reduction) is achieved by heat transfer.



Types of Work Other Than Compression/Expantion

Shaft Work

$$W_{sh} = Fs = \left(\frac{T}{r}\right)(2\pi r)n = 2\pi nT$$

$$\dot{W}_{sh} = \frac{\delta W_{sh}}{dt} = (2\pi\dot{n})T = T\omega$$

- *T* : torque
- *n* : number of revolutions
- *ω* : angular velocity

Gravitational and Kinetic work

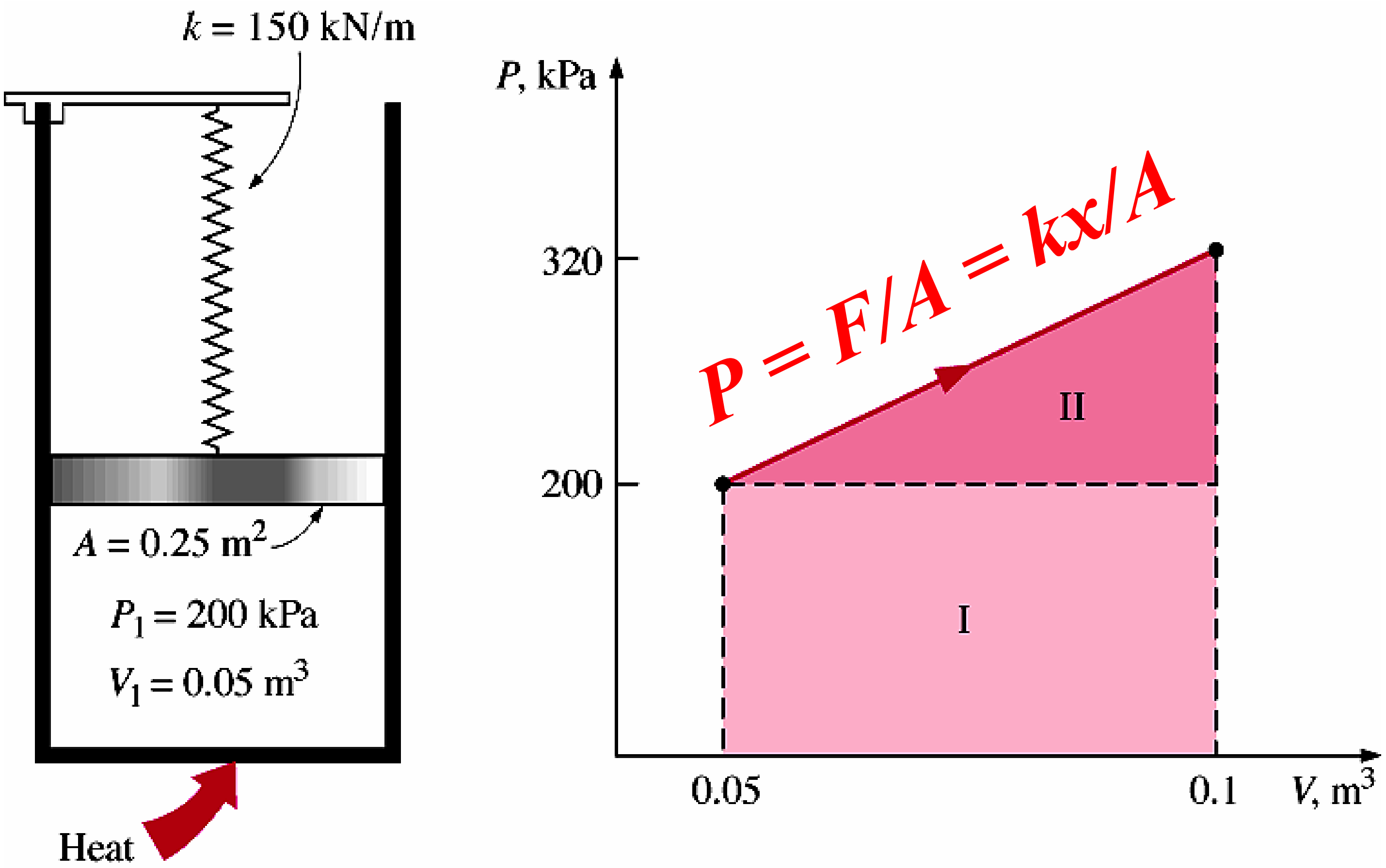
- **Gravitational work (=ΔPE):**
- $$W_g = mg(z_2 - z_1)$$ **(kJ)**
- **Kinetic work (=ΔKE):**
- $$W_a = \frac{1}{2}m\left(V_2^2 - V_1^2\right)$$ **(kJ)**

Spring Work

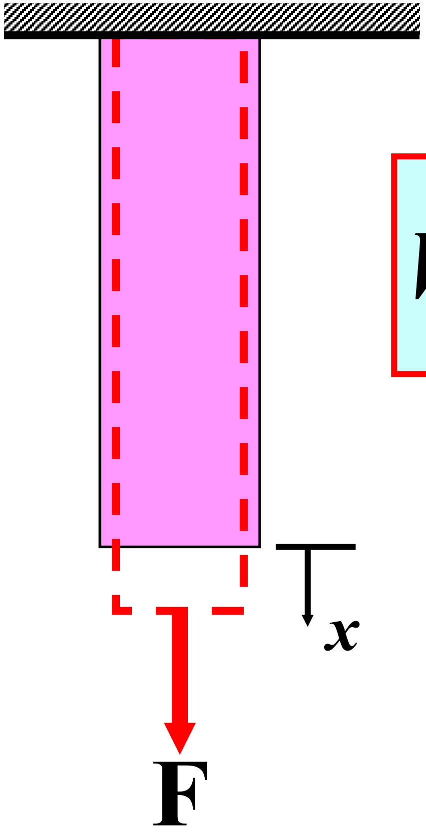
- Spring force : $F = k\,x$
- Spring work : $\delta W_{spring} = F\,dx$

$$\boxed{W_{spring} = \tfrac{1}{2}k(x_2^2 - x_1^2)}$$

Expansion of a Gas Against a Spring



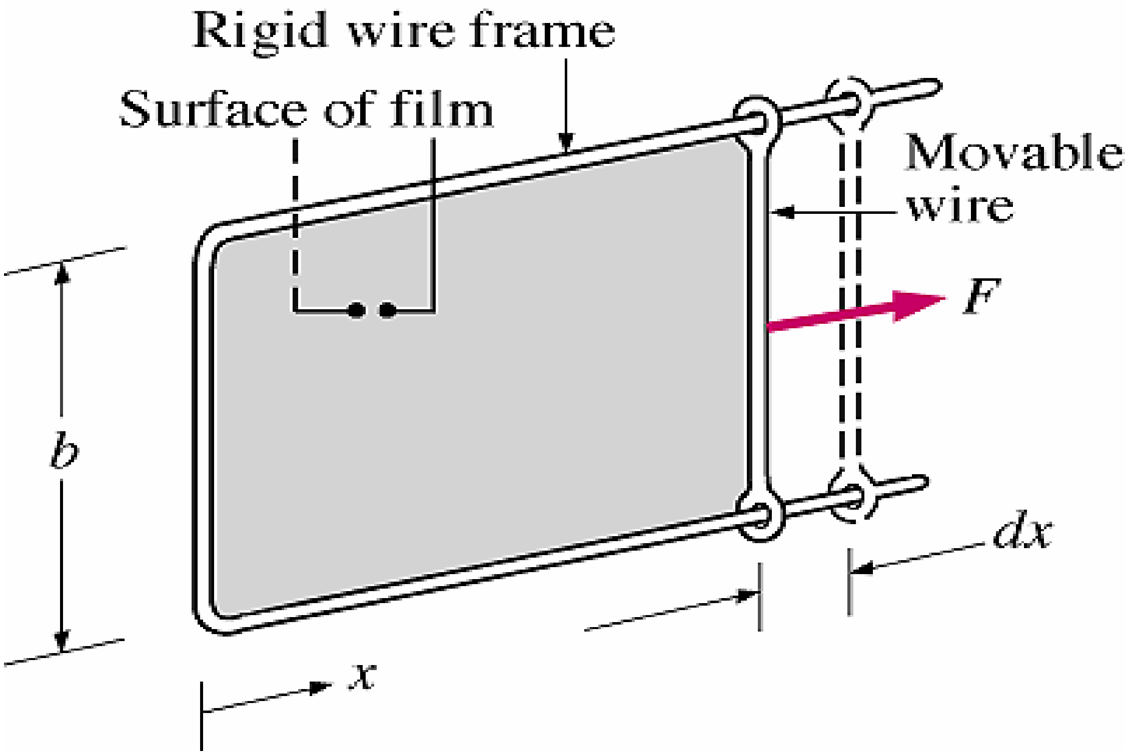
Expansion/Contraction Work of an Elastic Solid Bar



$$W_{elastic} = \int_1^2 \sigma_n dV = \int_1^2 \sigma_n A dx$$

normal stress $\sigma_n = F/A$

Stretching a Liquid Film



$$\boxed{W_{surface} = \int_1^2 \sigma_s dA}$$

Non-mechanical Forms of Work

- Electrical Work

$$\boxed{\frac{\delta W}{dt} = -VI}$$

- Magnetic Work
- Electrical Polarization work

Summary:
Heat and Work

- They are only recognized at the boundary of a system, as they cross the boundary.
- They are associated with a process, not a state. Unlike P and T which have definite values at any state, q and w do not.
- They are both path-dependent functions.
- A system in does not possess heat or work.