CHAPTER

1

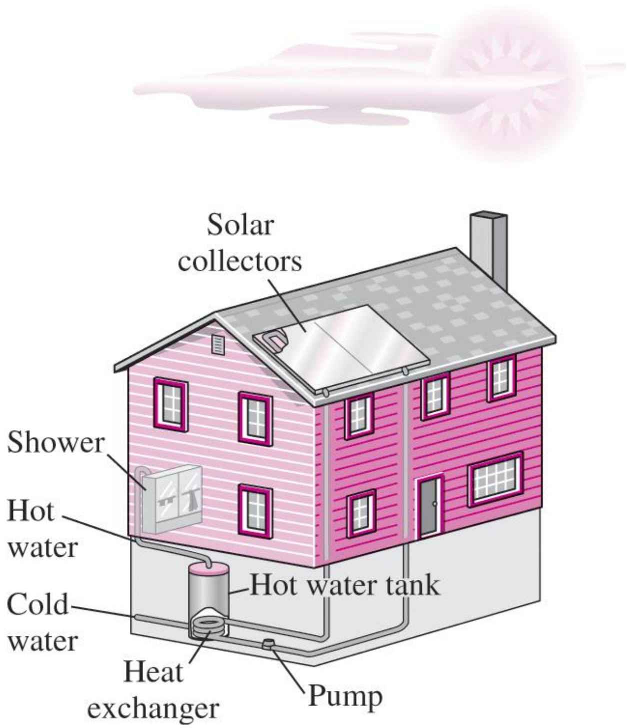
Thermodynamics

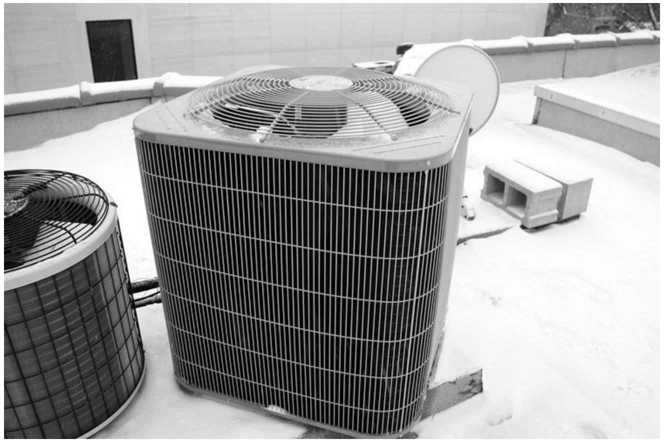
Fundamental Concepts

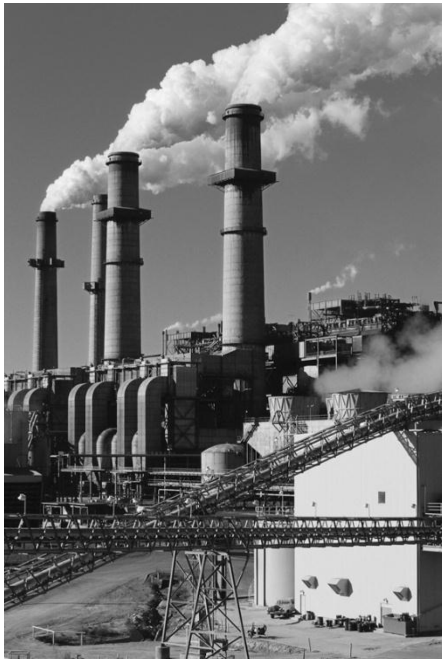
What is Thermodynamics?

- science which deals with the relations among heat, work and properties of system which are in equilibrium. It describes state and changes in state of physical systems.
- Energy transformations – mostly involve heat and work movements.
- The Fundamental law is the *conservation of energy* principle: energy cannot be created or destroyed, but can only be transformed from one form to another.
- Thermodynamics is the science of the regularities governing processes of energy conversion.
- Thermodynamics is the science that deals with the interaction between energy and material systems.

Application Areas of Thermodynamics







IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units**.
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while others such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or

TABLE 1–1

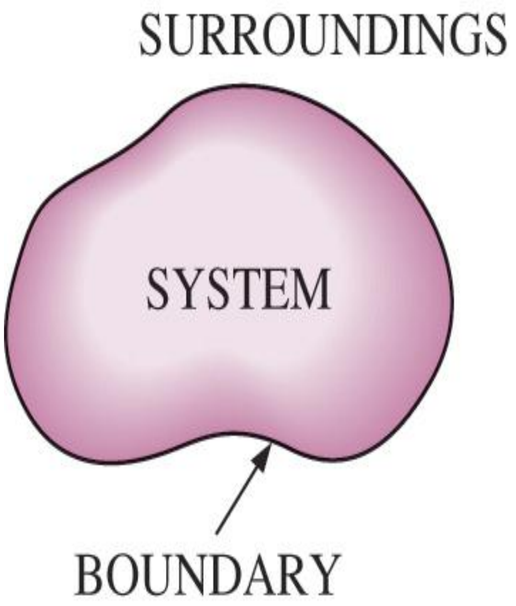
The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

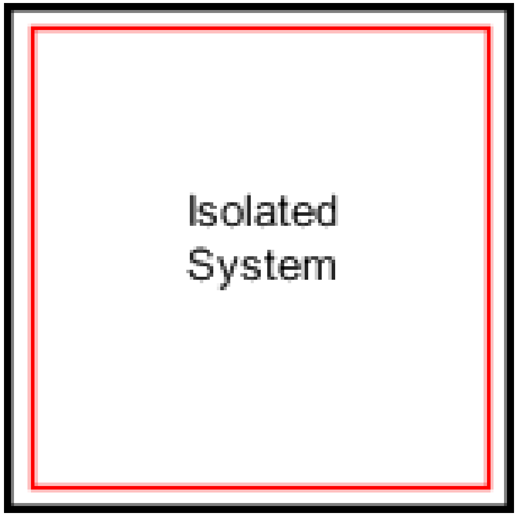
- **Metric SI system:** A simple and logical system based on a decimal relationship between the various units.
- **English system:** It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily

System, surroundings and boundary

- **System**: A quantity of matter or a region in space chosen for study.
- **Surroundings**: The mass or region outside the system
- **Boundary**: The real or imaginary surface that separates the system from its surroundings.



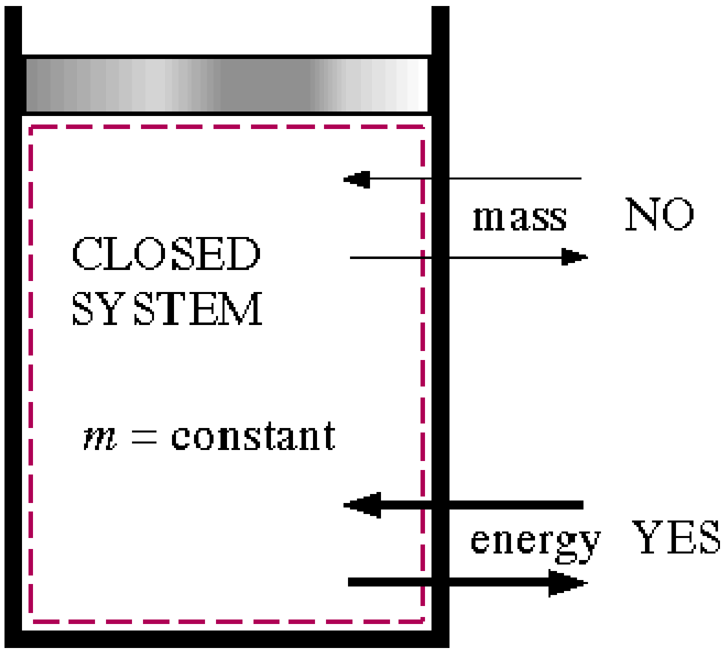
Type of system
(isolated system)



- Isolated system – No possibility of transfer either of energy or matter across the boundaries.

- Example (approximate): coffee in a closed, well-insulated thermos bottle

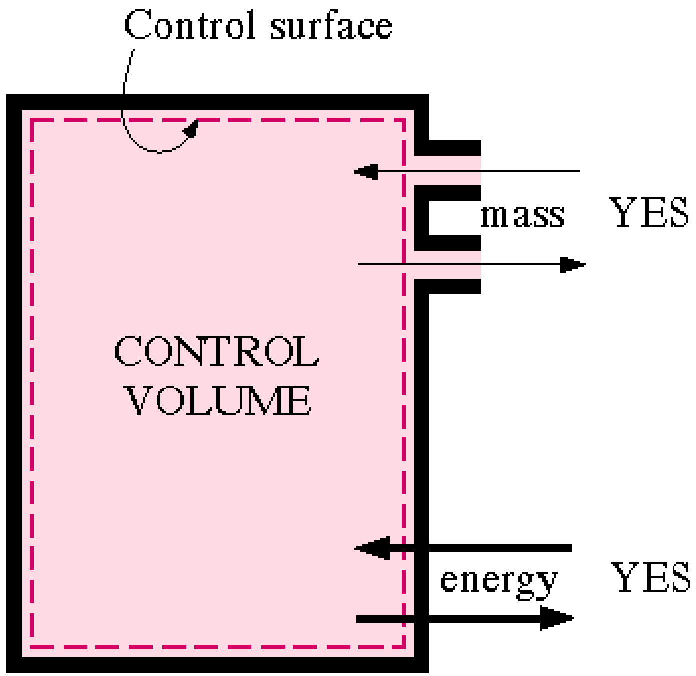
Type of system
(Closed system)



- Closed system – only energy can cross the selected boundary
- Examples: a tightly capped cup of coffee

Type of system

(Open system)



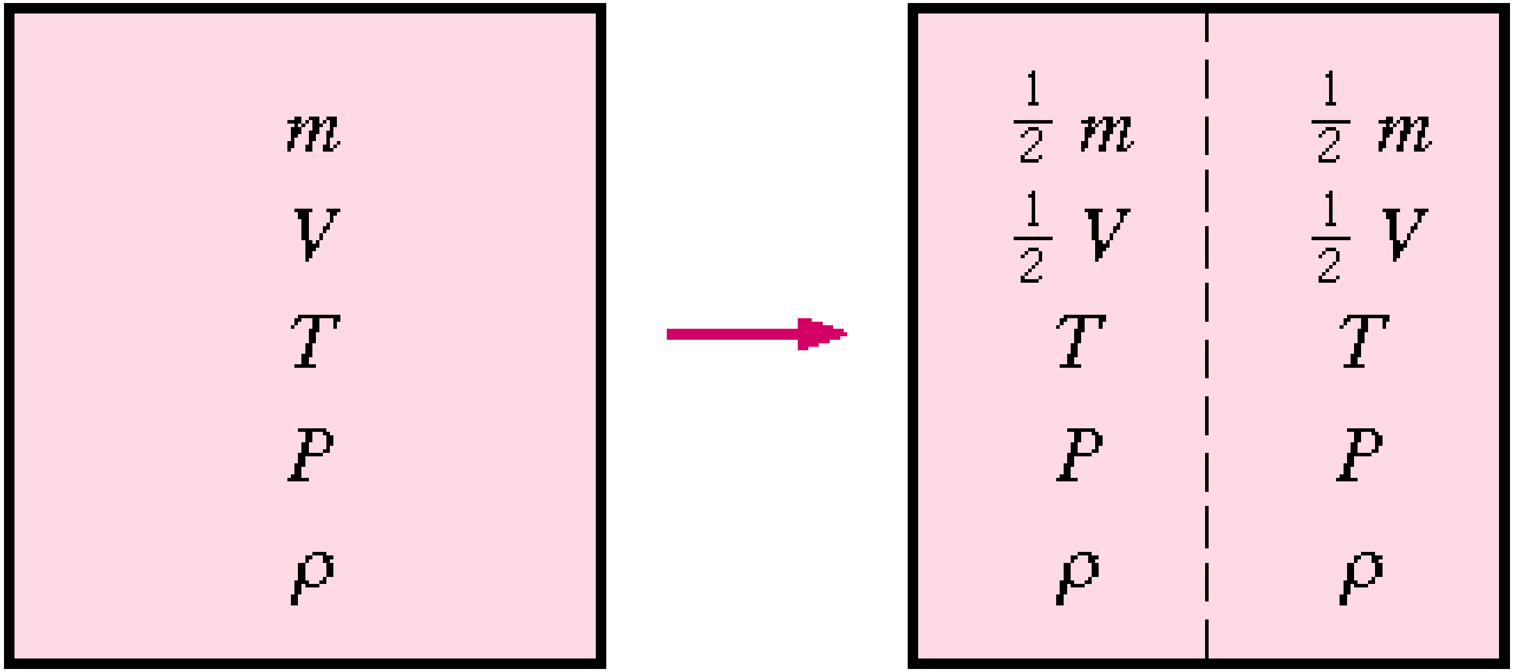
- Open system – both mass and energy can cross the selected boundary

- Example: an open cup of coffee

Properties of a system

Properties of a system is a measurable characteristic of a system that is in equilibrium.

Properties may be intensive or extensive.



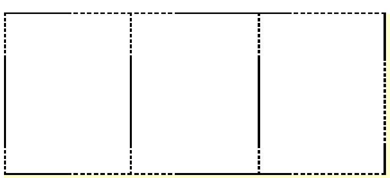
Properties of a system

Specific properties – The ratio of any extensive property of a system to that of the mass of the system is called an average specific value of that property (also known as intensives property)

Specific Volume	$V/m = v$	m^3/kg
Total Energy	$E/m = e$	J/kg
Internal Energy	$U/m = u$	J/kg

Classes of properties

Box with 3 sections after equilibrium

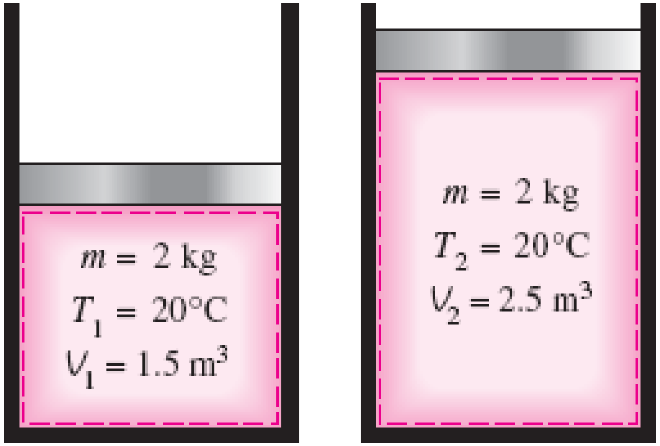


Extensive: Total :	Intensive: not size independent
$V = V_1 + V_2 + V_3$	$v = v_1 = v_2 = v_3 = V/m$
$E = E_1 + E_2 + E_3$	$e = e_1 = e_2 = e_3 = E/m$
$m = m_1 + m_2 + m_3$	T, P

State, Equilibrium and Process

- State – a set of properties that describes the conditions of a system. Eg. Mass m, Temperature T, volume V

- Thermodynamic equilibrium - system that maintains thermal, mechanical, phase and chemical equilibriums.



(a) State 1 (b) State 2

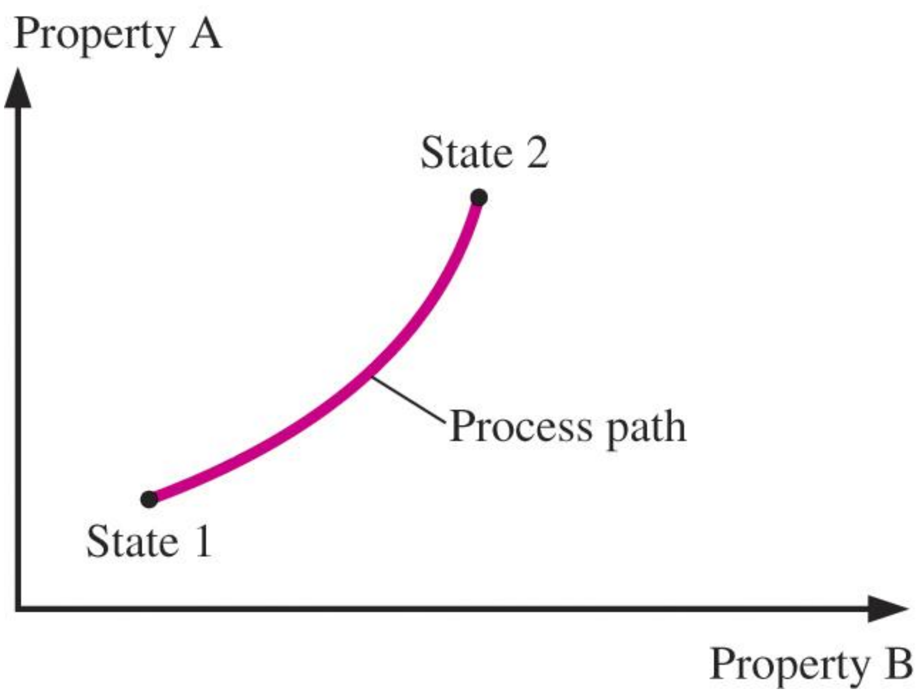
PROCESSES AND CYCLES

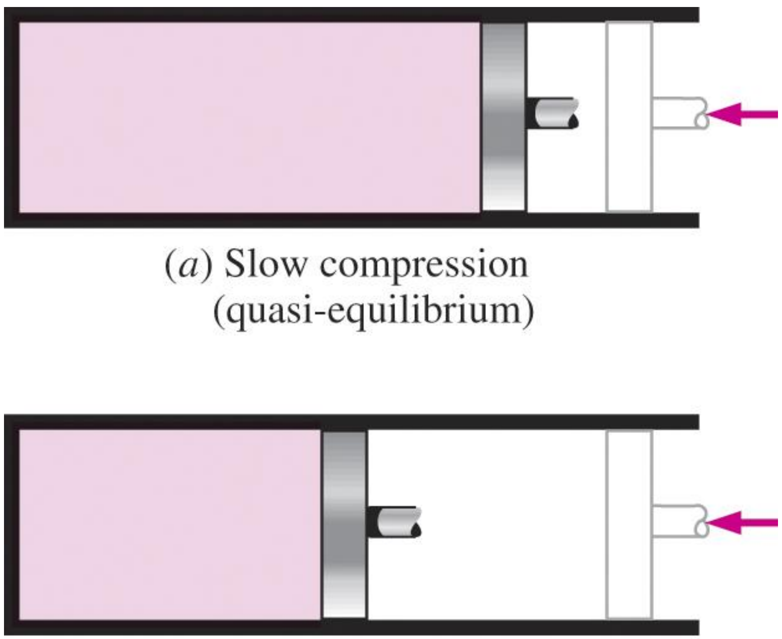
Process: Any change that a system undergoes from one equilibrium state to another.

Path: The series of states through which a system passes during a process.

To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

Quasistatic or quasi-equilibrium process: When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.

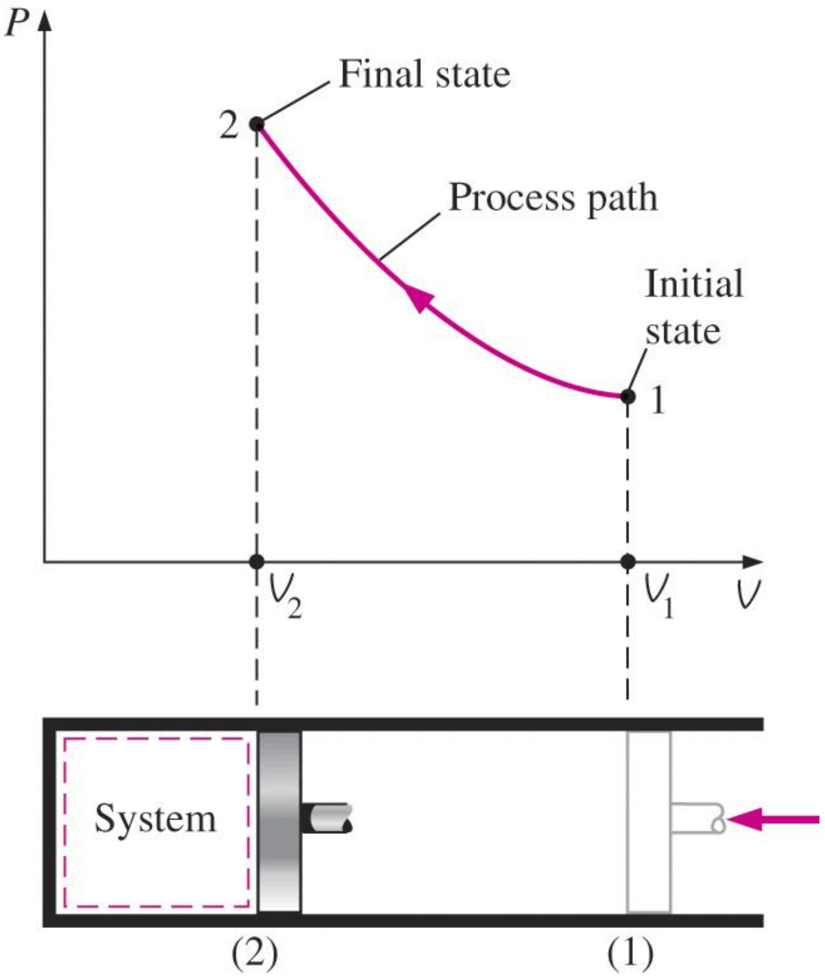




(*a*) Slow compression (quasi-equilibrium)

(*b*) Very fast compression (nonquasi-equilibrium)

- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature *T*, pressure *P*, and volume *V* (or specific volume *v*).
- The prefix *iso-* is often used to designate a process for which a particularproperty remains constant.
- **Isothermal process**: A process during which the temperature *T* remains constant.
- **Isobaric process**: A process during which the pressure *P* remains constant.
- **Isochoric (or isometric) process**: A process during which the specific volume *v* remains constant.
- **Cycle**: A process during which the initial and final states are identical.

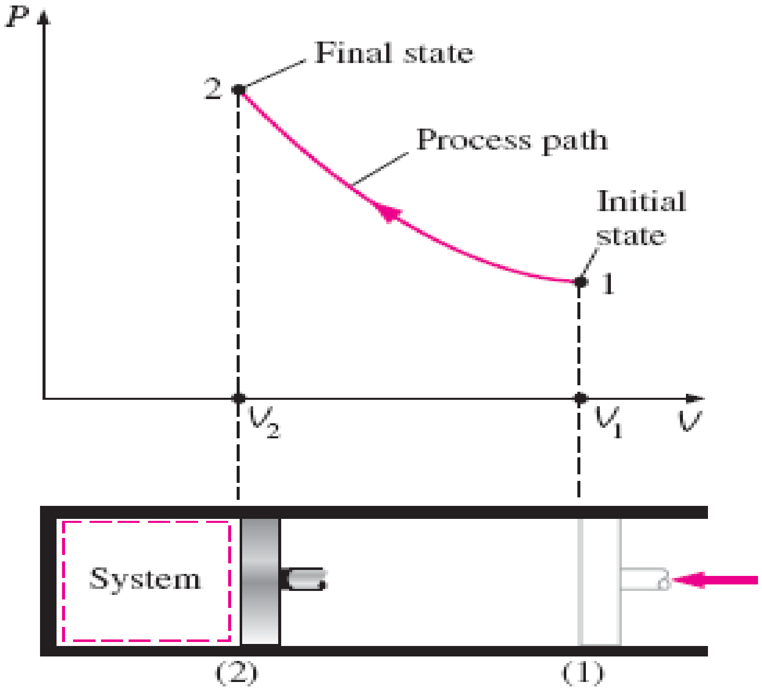


The *P*-*V* diagram of a compression process.

State, Equilibrium and Process

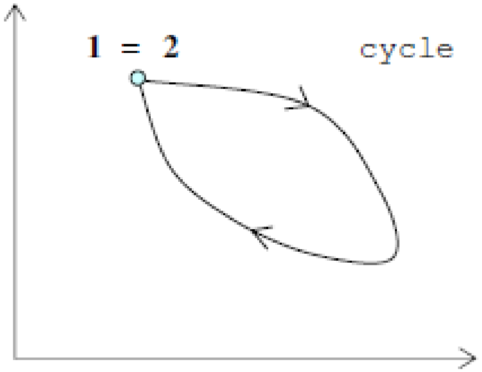
- Process – change from one equilibrium state to another.

Process	Property held constant
isobaric	pressure
isothermal	temperature
isochoric	volume
isentropic	entropy



Types of Thermodynamics Processes

- **Cyclic process** - when a system in a given initial state goes through various processes and finally return to its initial state, the system has undergone a cyclic process or cycle.

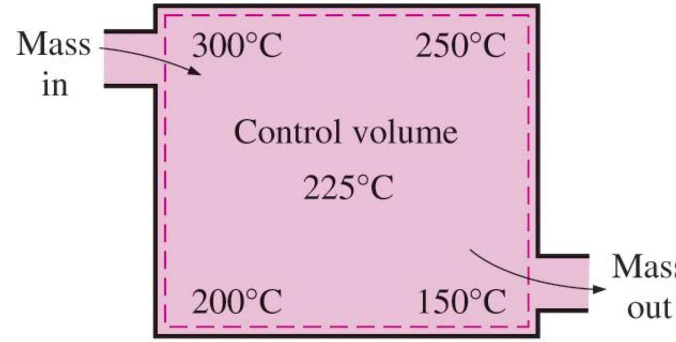


- **Reversible process** - it is defined as a process that, once having take place it can be reversed. In doing so, it leaves no change in the system or boundary.

- **Irreversible process** - a process that cannot return both the system and surrounding to their original conditions

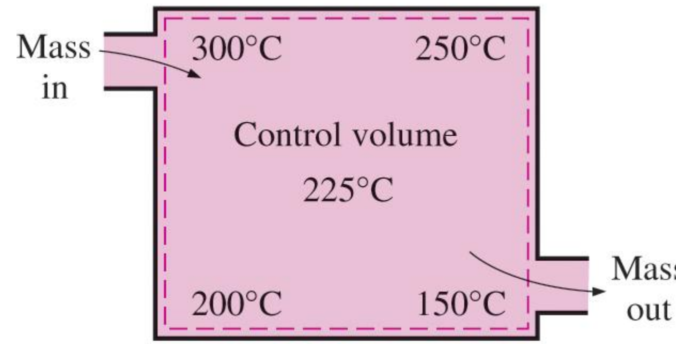
The Steady-Flow Process

- The term *steady* implies *no change with time*. The opposite of steady is *unsteady*, or *transient*.
- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily.
- Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.

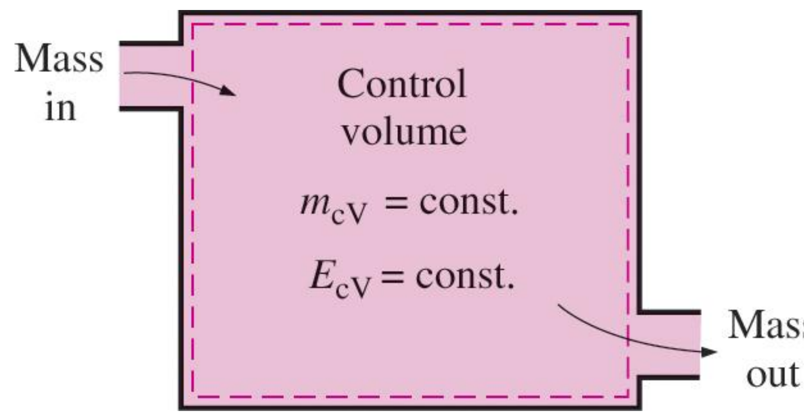


Time: 1 PM

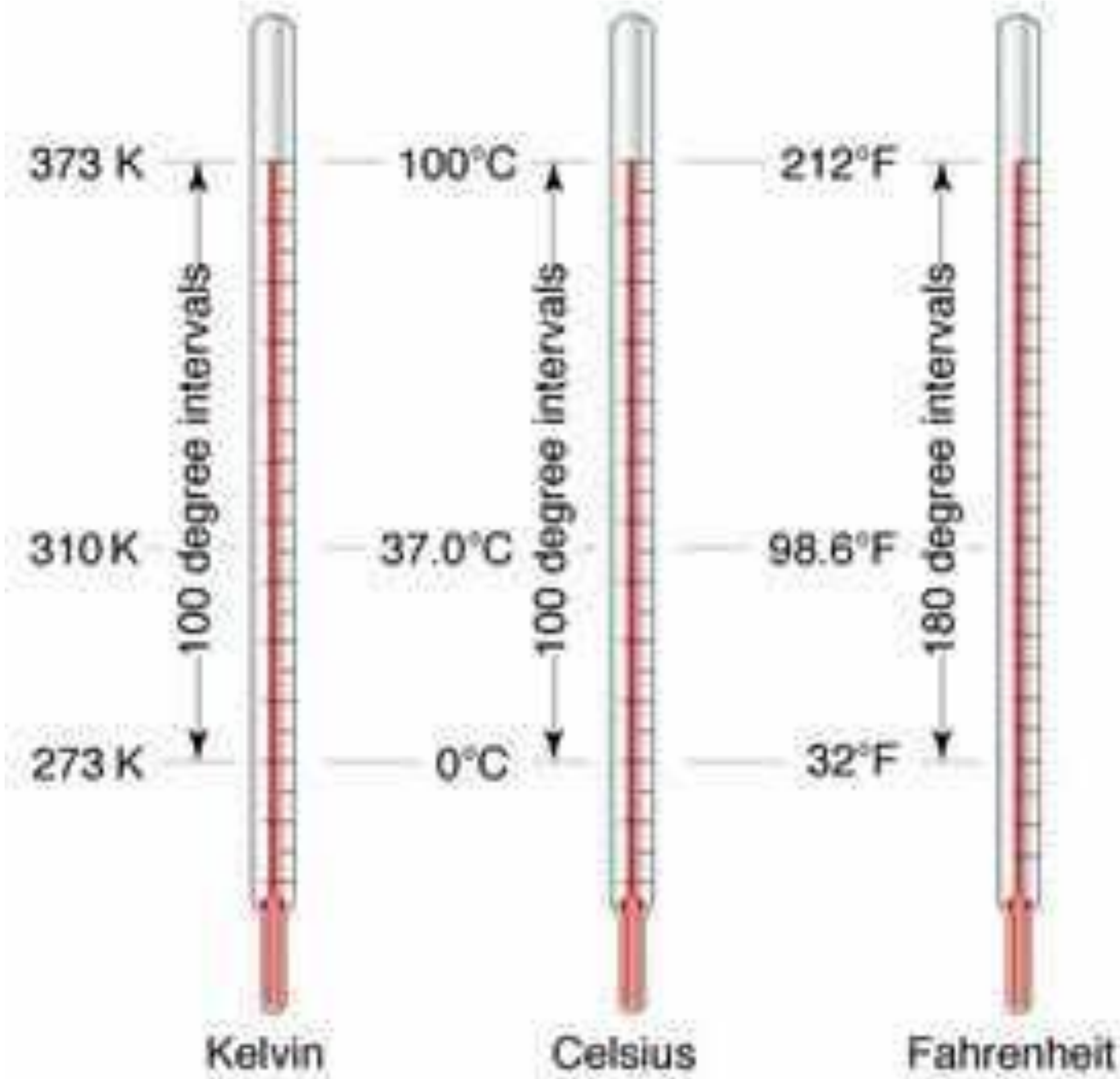
During a steady-flow process, fluid properties within the control volume may change with position but not with time.



Time: 3 PM



Under steady-flow conditions, the mass and energy contents of a control volume remain constant.



$$\frac{F - 32}{212 - 32} = \frac{C - 0}{100 - 0} = \frac{R - 0}{80 - 0} = \frac{K - 273}{373 - 273}$$

From	To Fahrenheit	To Celsius	To Kelvin
Fahrenheit (F)	F	(F - 32) * 5/9	(F - 32) * 5/9 + 273.15
Celsius (C or °)	(C * 9/5) + 32	C	C + 273.15
Kelvin (K)	(K - 273.15) * 9/5 + 32	K - 273.15	K

$$\frac{F - 32}{212 - 32} = \frac{C - 0}{100 - 0} = \frac{R - 0}{80 - 0} = \frac{K - 273}{373 - 273}$$

Pressure

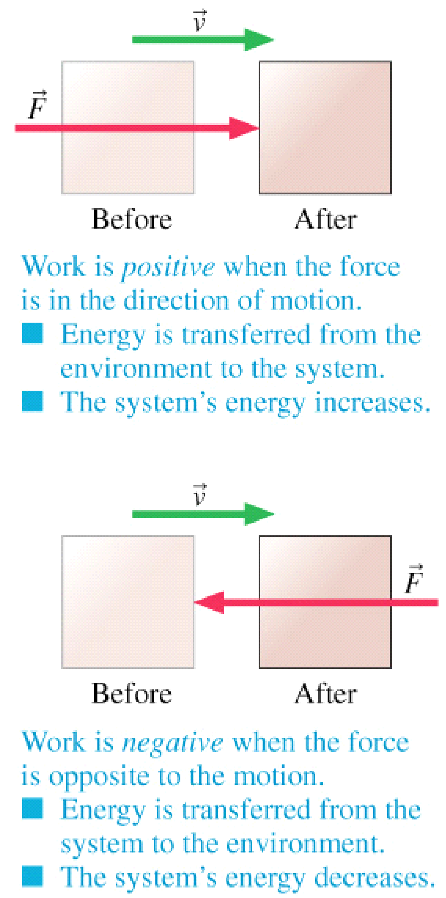
- **Pressure** is defined as a *normal force exerted by a fluid per unit area*.
- Units of pressure are N/m^2, which is called a **pascal** (Pa).
- Since the unit Pa is too small for pressures encountered in practice, *kilopascal* (1 kPa = 10^3 Pa) and *megapascal* (1 MPa = 10^6 Pa) are commonly used.
- Other units include *bar*, *atm, kgf/cm*^{2}*, lbf/in*^{2}*=psi*.

Absolute, gage, and vacuum pressures

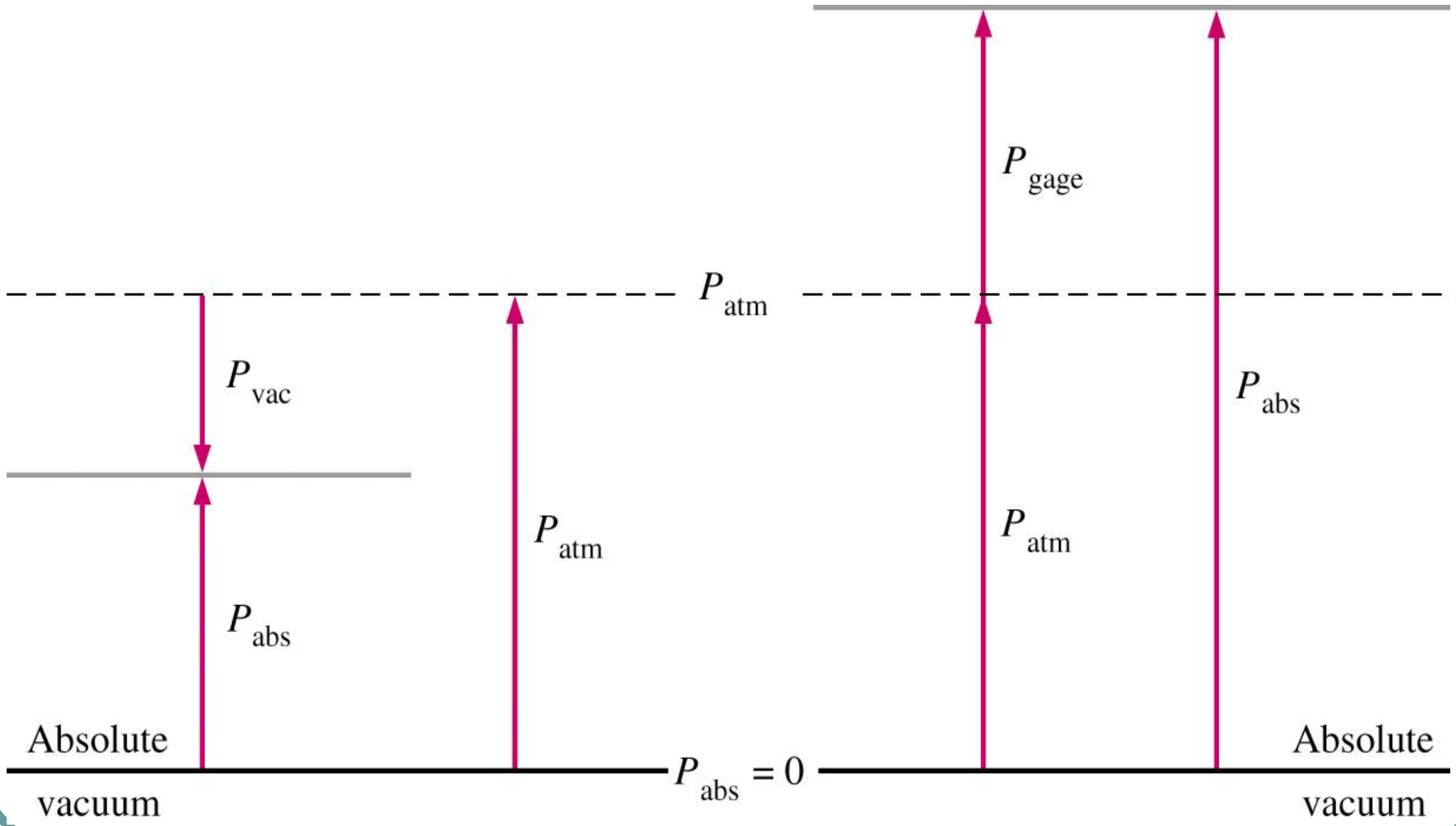
- Actual pressure at a give point is called the **absolute pressure**.
- Most pressure-measuring devices are calibrated to read zero in the atmosphere, and therefore indicate **gage pressure**, $P_{gage}=P_{abs} - P_{atm}$.
- Pressure below atmospheric pressure are called **vacuum pressure**, $P_{vac}=P_{atm} - P_{abs}$.

Work

- Work is the energy transferred between a system and environment when a net force acts on the system over a distance.
- The sign of the work
- Work is positive when the force is in the direction of motion
- Work is negative when the force is opposite to the motion



Absolute, gage, and vacuum pressures



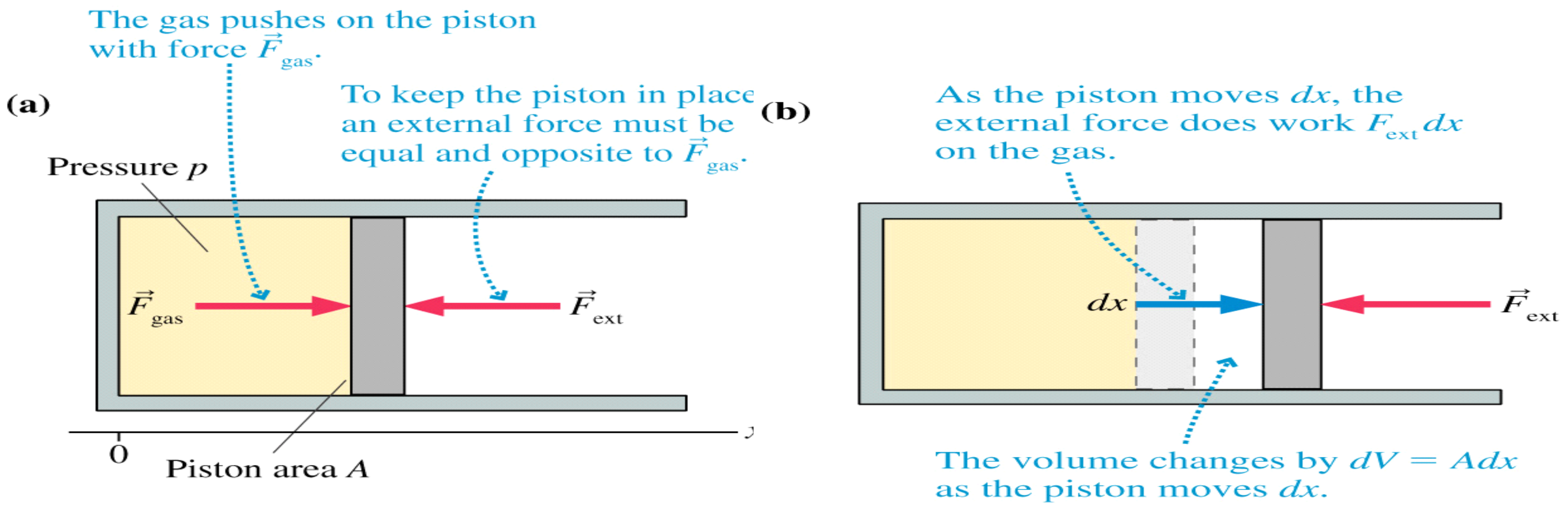
Pressure at a Point

- Pressure at any point in a fluid is the same in all directions.
- Pressure has a magnitude, but not a specific direction, and thus it is a scalar quantity.

Work in Ideal-Gas Processes

- The work done on the system $W = \int_{si}^{sf} F_s ds$
- When we press the gas, the gas volume becomes smaller, so the total work done by the environment on the gas

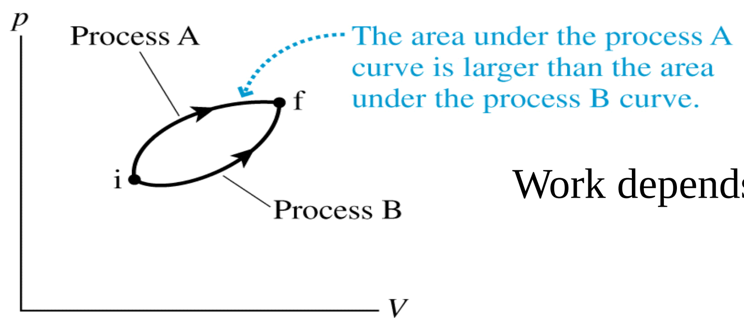
$$W = -\int_{vi}^{vf} PdV$$



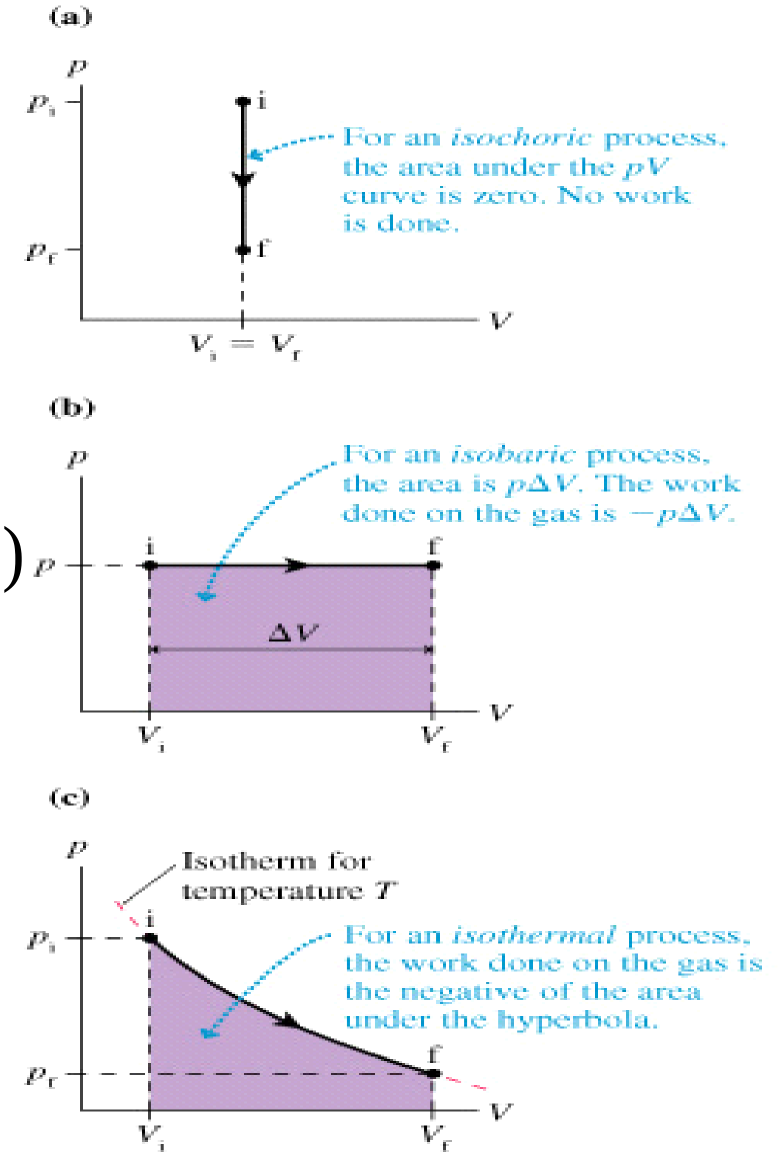
Work in some special processes

- Isochoric Process W = 0
- Isobaric Process W = -PΔV
- Isothermal Process

$$w = -\int_{vi}^{vf} pdV = -\int_{vi}^{vf} \frac{nRT}{V} dV = nRT \ln\left(\frac{V_i}{V_f}\right)$$

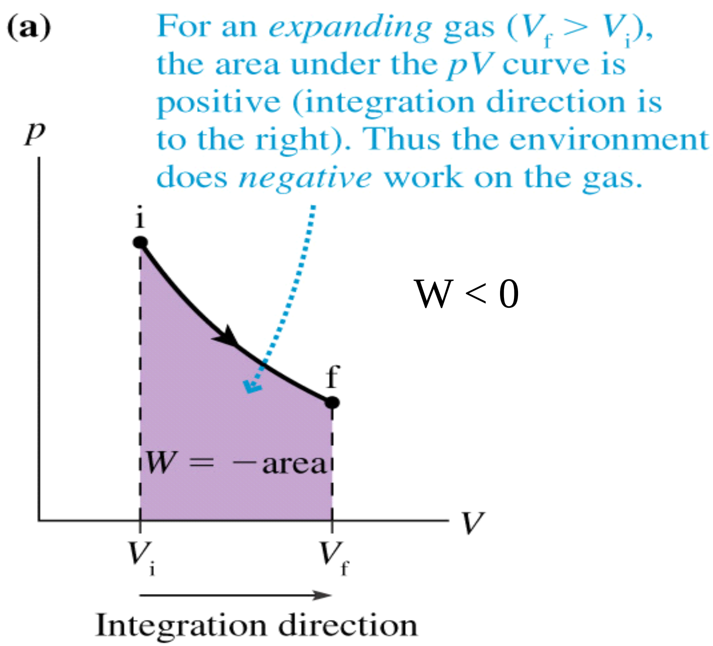


Work depends on path

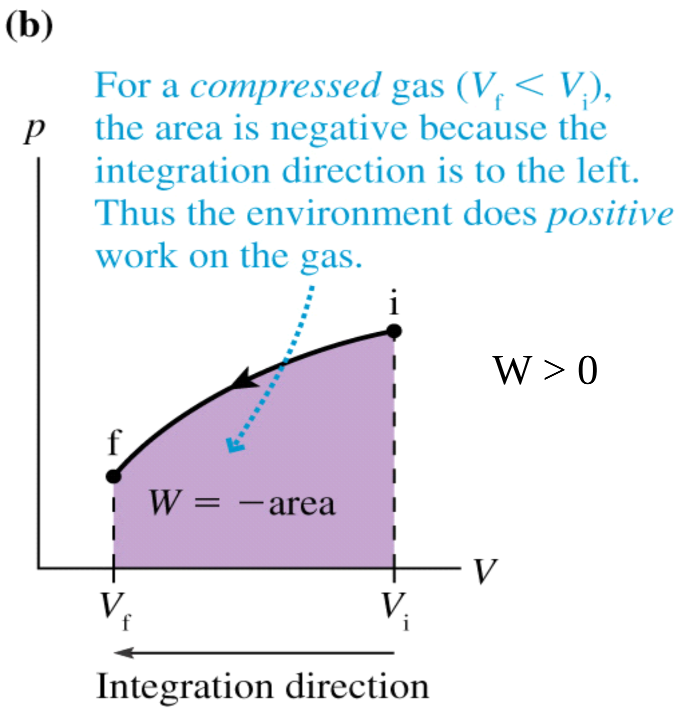


Finding work from the P-V diagram

- W = the negative of the area under the PV curve between Vi and Vf



W < 0



W > 0

Heat and Thermal interactions

- Heat is the energy transferred during a thermal interaction
- Units of heat
- The SI unit of heat is joule.
- Historically, unit for measuring heat, is calorie
- A cal = the quantity of heat needed to change the temperature of 1 g of water by 1 ^{o}C.
- 1cal = 4.186 J

1 food calorie = 1 Cal = 1000 cal =1 kcal