

AREN 2110

Chapter 2. Sections: State of Systems, Thermodynamic Processes, Properties and Measurements.

Learning objectives.

## CONCEPTS

1. Define and give examples of the state of a system
  - a. Be able to define the state of a system from its thermodynamic properties
    - i. State postulate
    - ii. Independent properties
    - iii. Measureable and derived properties and state
  - b. Be able to define **EQUILIBRIUM** with respect to the state of a system
2. Define thermodynamic processes and related concepts
  - a. Relation to state of a system
  - b. Path of a process
  - c. Quasi-static processes
3. Know the difference between path and state.
4. Be able to produce and interpret processes using graphical representation to link states, properties, and paths.
5. Measureable thermodynamic properties – pressure and temperature.

The state of a system is like its **CONDITION**, and is defined by a set of properties.

Why do we need to know the state of a system?

1. Primarily, calculating energy transfer requires knowledge of the change in the state of a system (i.e., beginning and ending states)

Any system has numerous properties. However only a small subset must be known to define (fix) its state, as described by the **STATE POSTULATE**:

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

“**Simple**” = no electrical, magnetic, kinetic, gravity, or surface tension effects. If any of these must be considered, then one additional property must be known for each added effect. Example: for motion (kinetic) effects, velocity must be known.

“**Compressible**” = volume not fixed.

“**Independent**” = one property of a pair can be changed without affecting the other. Example:

- a. temperature and specific volume ( $\text{density}^{-1}$ ) are always independent.
- b. Temperature and pressure are sometimes independent (in a single-phase system) but not in a system undergoing phase change. Temperature at which water boils varies with pressure (100 C at sea level, ~93 C in Boulder).

“**Intensive**” = the value of the property is not dependent on that amount of material in the system.

Special state: **EQUILIBRIUM**.

1. No unbalanced potentials which would cause state of system to change.  
Example: temperature difference, internal or with surroundings
2. System can be isolated from surroundings without changing its state

Types:

1. Thermal: no temperature differences
2. Mechanical (no pressure differentials, except for gravity pressure distribution balance by fluid weight since system is mechanically stable in this condition).
3. Phase: mass distribution in solid, liquid, vapor phases does not change
4. Chemical: constant molecular compositions

Three fundamental intensive properties.

1. **Pressure, P (kPa)**
2. **Temperature T, (K)**
3. **Specific volume= 1/density ,  $v = 1/\rho$  ( $m^3/kg$ )**

Importance.

**These properties are measurable directly, unlike properties like internal energy.**

**These properties are used in important STATE relations so you knowing two enables you to get the others for the systems in 2110:**

$$Pv = RT \text{ (ideal gas law)}$$

**These properties are related to energy quantities.**

### **PRESSURE and SPECIFIC VOLUME ARE RELATED TO WORK**

$$\text{Work, } w \text{ (specific)} = \int P dv \text{ (J/kg) note units: } \left( \frac{Pa \cdot m^3}{kg} = \frac{N}{m^2} * \frac{m^3}{kg} = \frac{N \cdot m}{kg} = \frac{J}{kg} \right)$$

$$\text{Or Work, } W \text{ (total)} = \int P dV \text{ (J)}$$

Examples of “Pv” work:

- Piston cylinder where expansion of a gas ( $\Delta V$ ) represents a special kind of work called **BOUNDARY WORK** in a closed system.
- Pump where increasing the pressure of an incompressible liquid (water) requires **WORK** in an open system, and  $w = v \cdot (P_2 - P_1)$  (J)

Specific enthalpy,  $h$ , (a form of energy) =  $u + Pv$  (J/kg) where  $u$  = internal energy and  $Pv$  represents **FLOW WORK** in an open system

### **TEMPERATURE IS RELATED TO INTERNAL ENERGY (AND ENTHALPY)**

Specific internal energy,  $u$ , of an ideal gas or liquid =  $f(T)$  ( $du = C_v dT$ ) where  $C_v$  is specific heat.

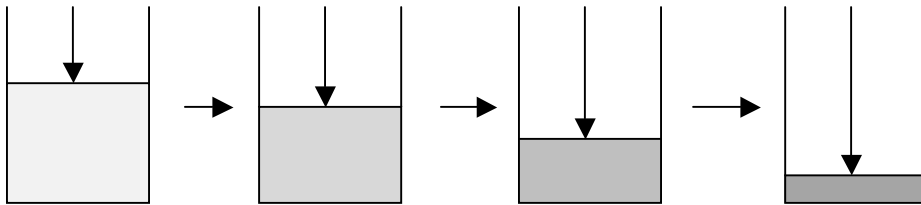
## PROCESSES AND CYCLES

### PROCESS

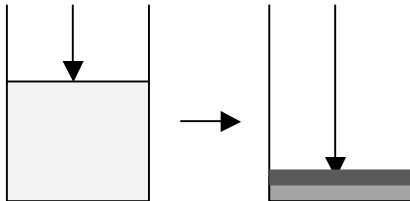
Is an event when a system undergoes a change from one state to another. Each state is associated with a different set of properties, generally considered from an initial equilibrium state to a new equilibrium state.

**QUASI-STATIC (or QUASI-EQUILIBRIUM) PROCESS** is a special process which occurs slowly (with incremental changes in the state) so that the intermediate states approach equilibrium.

Example: compression of gas in piston cylinder



(above) Quasi-static: uniform distribution of molecules, minimizes resistance to compression force and minimizes work required for compression



(above) Rapid (non quasi-static) results in non-homogeneous distribution of molecules with higher density and greater resistance to compression at piston surface – increasing work required for same compression

## **PATH**

Is the series of states the system passes through to reach the new equilibrium state. During a process, in addition to the properties of the system (state) changing, work and/or heat can be exchanged with the surroundings.

**HEAT AND WORK EXCHANGED BETWEEN SYSTEM AND SURROUNDINGS ARE ASSOCIATED WITH THE PATH.**

**INITIAL AND FINAL STATES DO NOT DEPEND ON THE PATH. THAT IS, THERE CAN BE MANY COMBINATIONS OF HEAT AND WORK TRANSFERS BETWEEN THE SAME EQUILIBRIUM STATES.**

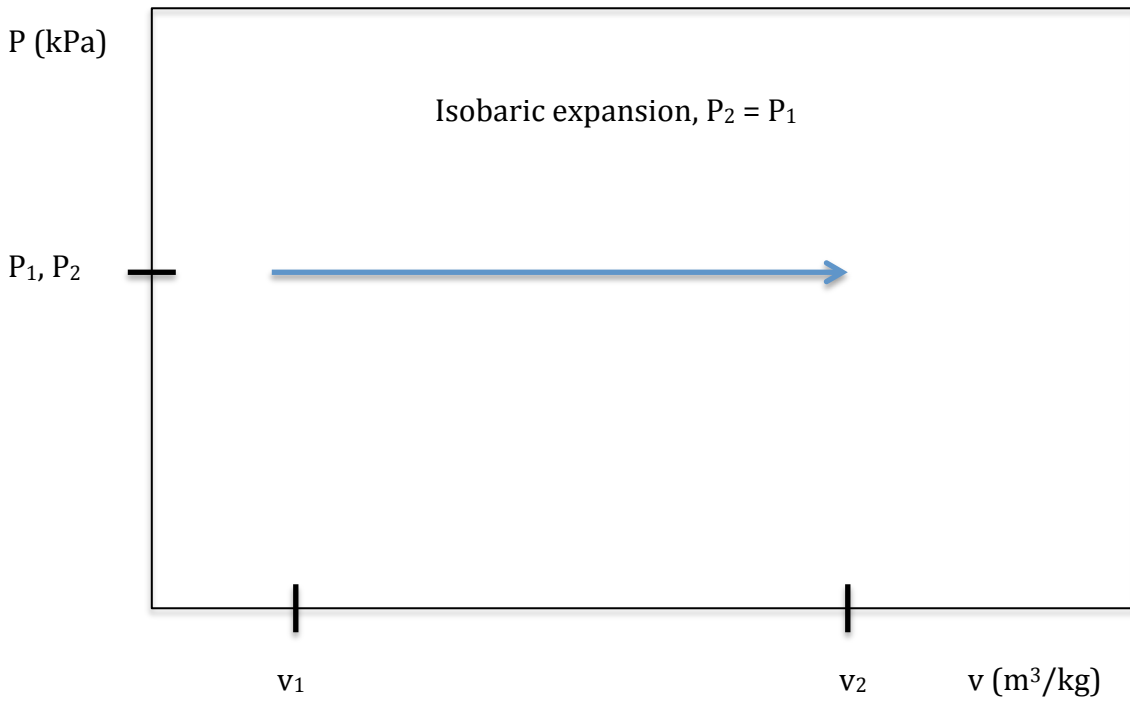
**COMBINE PROPERTY RELATIONS AND PATH IN PROCESS DIAGRAMS WHICH SHOW BOTH BEGINNING AND END STATES AND PATH.**

For properties,  $P$ ,  $v$  and  $T$ , will use  $P$ - $v$  and  $T$ - $v$  diagrams to show processes and paths.

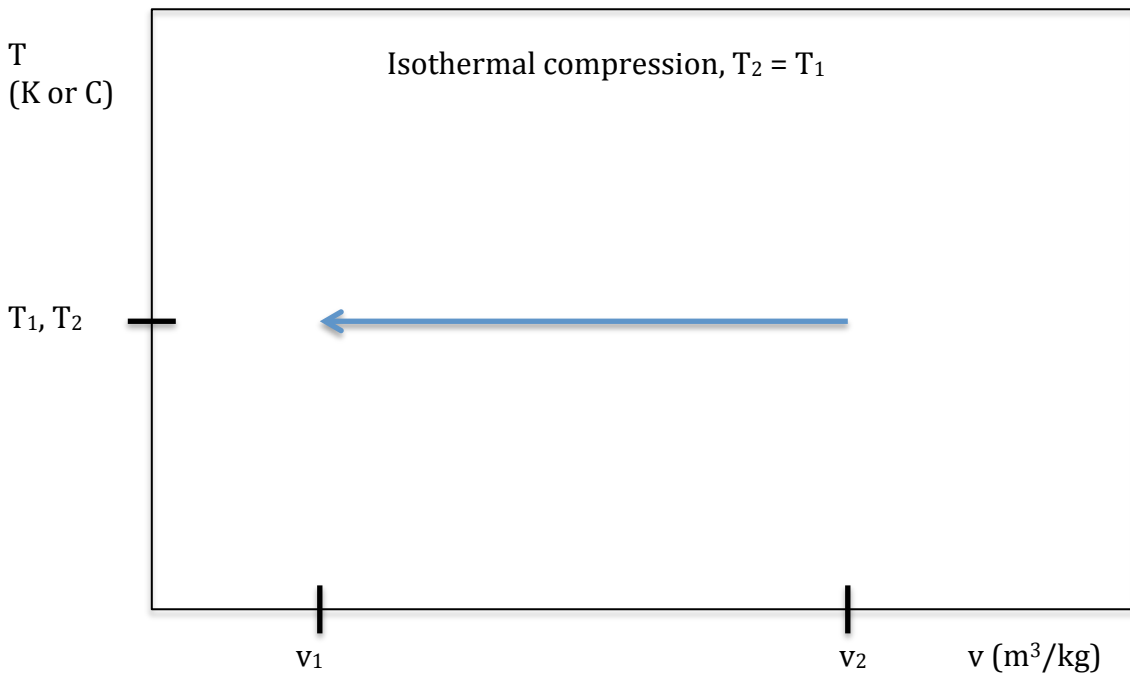
Examples on next page of simple processes and paths and a cycle. All paths for these examples are straight lines. That is not necessarily the case for many paths – that is, you can't connect two equilibrium states with a straight line, unless you know the PATH justifies that.



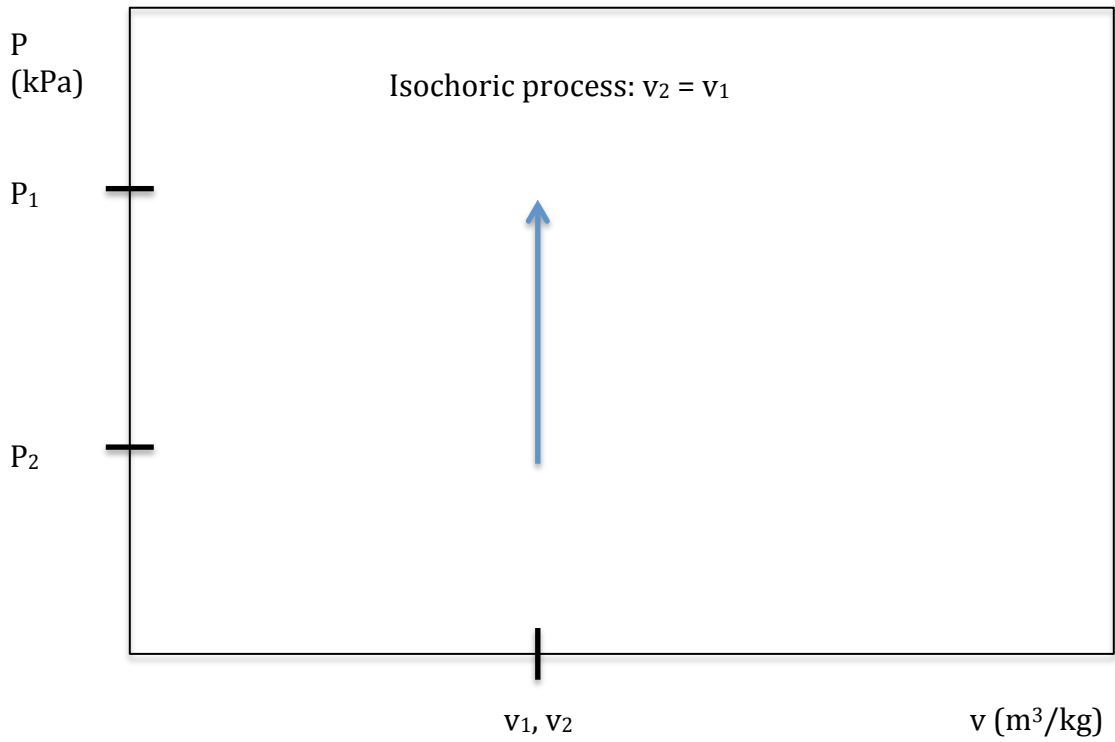
EXAMPLES OF **PROPERTY DIAGRAMS SHOWING PROCESS AND PATH**



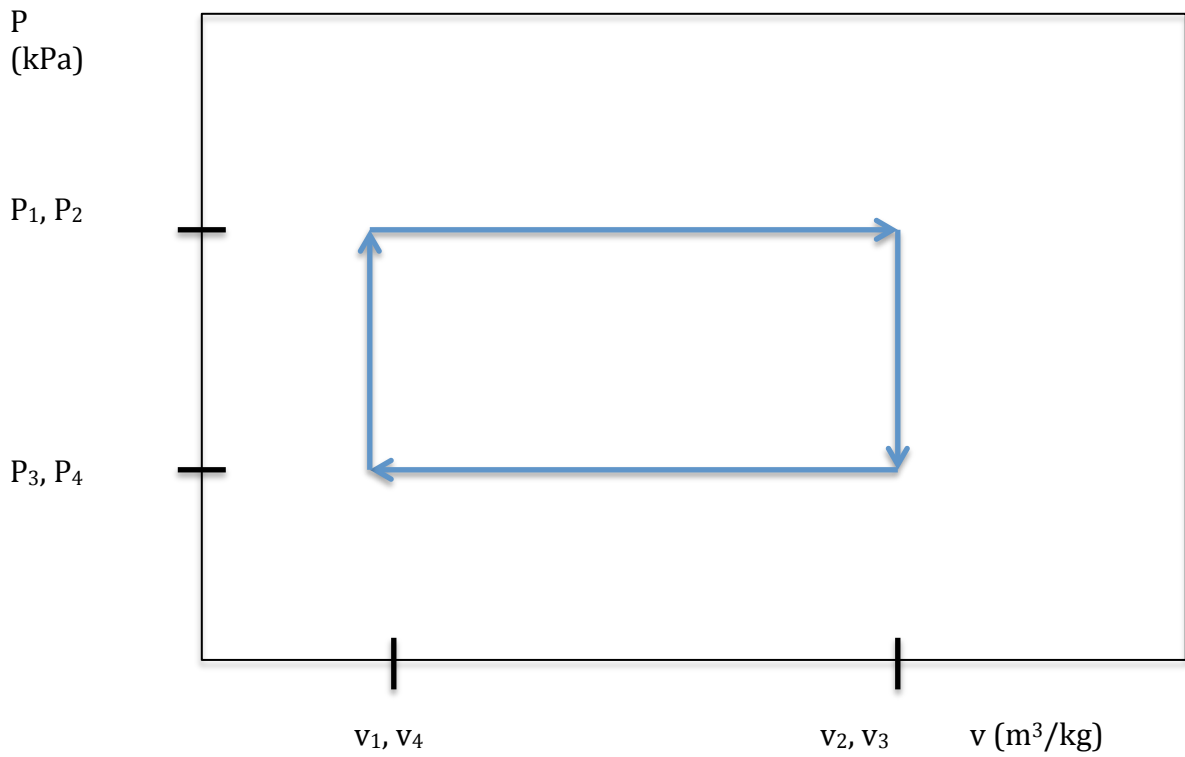
**PROCESS** from state 1 to state 2 is an expansion. **PATH** is isobaric



**PROCESS** from state 1 to state 2 is a compression. **PATH** is isothermal.



**PROCESS is pressure increase. PATH is ISOCHORIC**



**CYCLE producing net work (+). PATHS are 2 ISOBARIC and 2 ISOCHORIC**