THERMODYNAMICS CONCEPTS

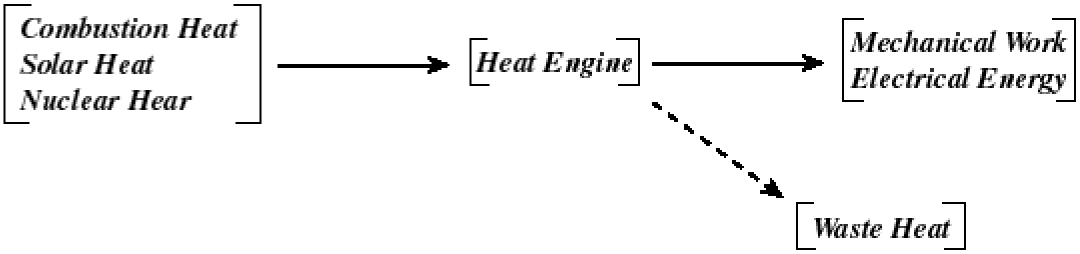
I. Thermodynamics (VW, S & B: Chapter 1)

A. **Describes processes that involve changes in temperature, transformation of energy, relationships between heat and work.**

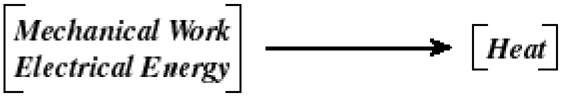
B. **It is a science, and more importantly an engineering tool, that is necessary for describing the performance of propulsion systems, power generation systems, refrigerators, fluid flow, combustion, ...**

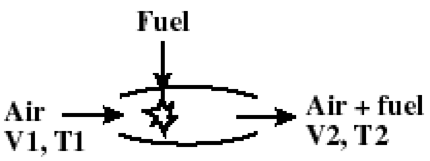
C. **Generalization of extensive empirical evidence (however most thermodynamic principles and can be derived from kinetic theory)**

D. **Examples of heat engines**

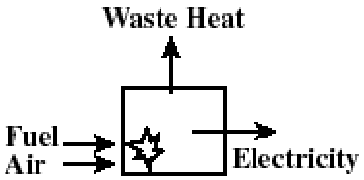


OR

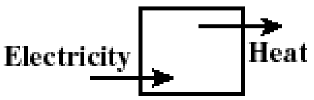




1. Propulsion system



2. Power generation



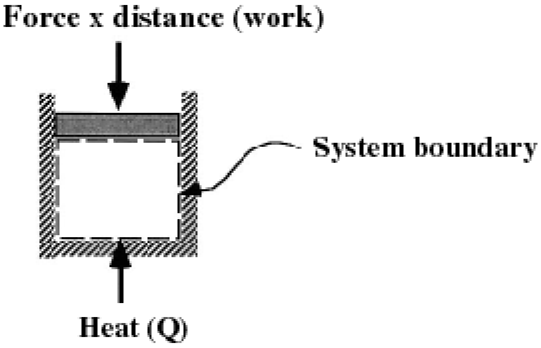
3. Refrigerator

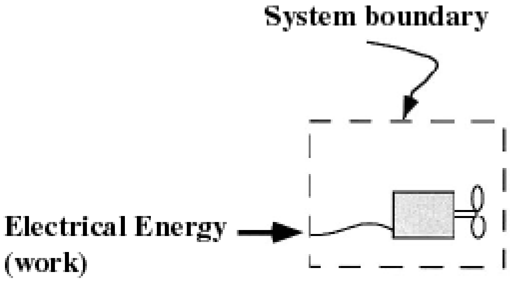
E. Questions:

1. Describe the energy exchange processes in ___________ (fill in the blank, e.g. a nuclear power plant, a refrigerator, a jet engine).
2. Describe the energy exchange processes necessary to use electricity from a nuclear power plant to remove heat from the food in a refrigerator.
3. Describe the energy exchange processes necessary for natural gas to be used to provide electricity for the lights in the room you are in.

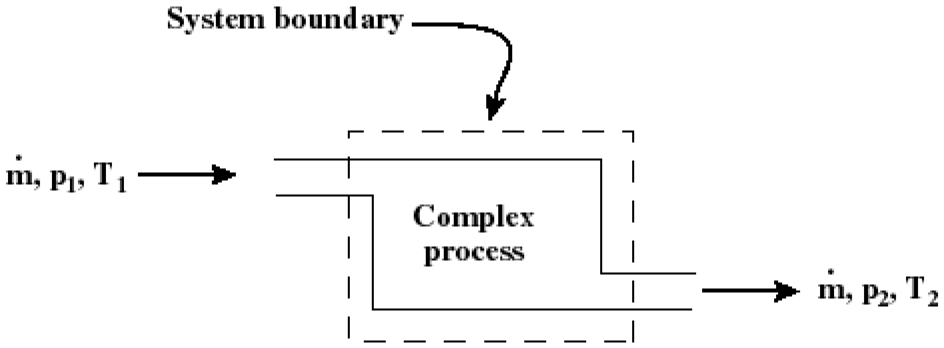
I. Concept of a thermodynamic system *(VW, S & B: 2.1)*

A. A quantity of matter of fixed identity, boundaries may be fixed or movable, can transfer heat and work across boundary but not mass





B. Identifiable volume with <u>steady flow</u> in and out, a control volume. Often more useful way to view devices such as engines



II. Thermodynamic state of a system

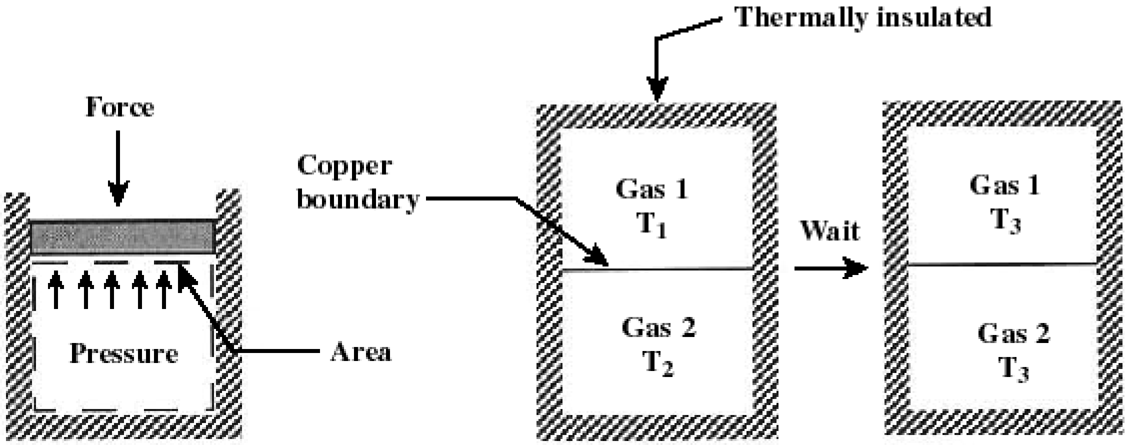
A. **The thermodynamic state of a system is defined by specifying a set of measurable properties sufficient so that all remaining properties are determined. Examples of properties: pressure, temperature, density, internal energy, enthalpy, and entropy.**

B. **For engineering purposes we usually want gross, average, macroscopic properties (not what is happening to individual molecules and atoms) thus we consider substances as continua -- the properties represent averages over small volumes. For example, there are 10^{16} molecules of air in 1 mm^3 at standard temperature and pressure.** ***(VW, S & B: 2.2)***

C. **Intensive properties do not depend on mass (*e.g.* p, T, ρ , $v=1/\rho$, u and h); extensive properties depend on the total mass of the system (*e.g.* V, M, U and H). Uppercase letters are usually used for extensive properties.** ***(VW, S & B: 2.3)***

D. **Equilibrium: States of a system are most conveniently described when the system is in equilibrium, *i. e.* it is in steady-state. Often we will consider processes that change "slowly" -- termed quasi-equilibrium or quasi-static processes. A process is quasi-equilibrium if the time rate of change of the process is slow relative to the time it takes for the system to reach thermodynamic equilibrium. It is necessary that a system be quasi-equilibrium before applying many of the thermodynamics relations to that system.**
If the system is not in equilibrium, then different parts of the system exist at different states at the same time and it is not possible to define one “state” of the system. Since many of the thermodynamic relations relate to the state of the system, it is

necessary that a state can be defined for the system before applying them. ***(VW, S & B: 2.3-2.4)***



1. Mechanical equilibrium (force balance pressure times area)

2. Thermal equilibrium (same temperature)

1. mechanical equilibrium

(force balances pressure times area)

2. thermal equilibrium

(same temperature)

E. Two properties are needed to define the state of any pure substance undergoing a steady or quasi-steady process. (This is an experimental fact!) *(VW, S & B: 3.1, 3.3)*

1. For example for a thermally perfect gas (this is a good engineering approximation for many situations, but not all (good for $p \ll p_{crit}$, and $T > 2T_{crit}$ up to about $4p_{crit}$). *(VW, S & B: 3.4)*:

$$p\bar{v} = RT$$

$\bar{v}$ is volume per mol of gas, R is the universal gas constant R = 8.31kJ/Kmol-K.

Dividing by molecular weight,

$$p\bar{v}/M = (R / M)\ T$$

where M is the molecular weight of the gas.

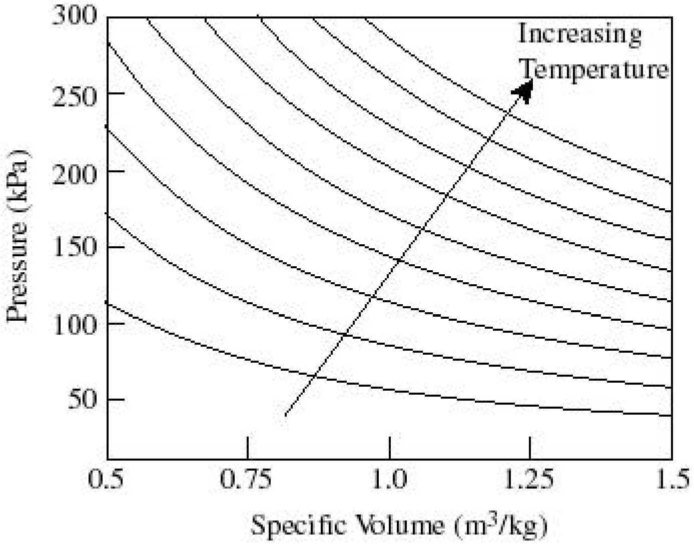
Most often written as

$$pv = RT \text{ or } p = \rho RT$$

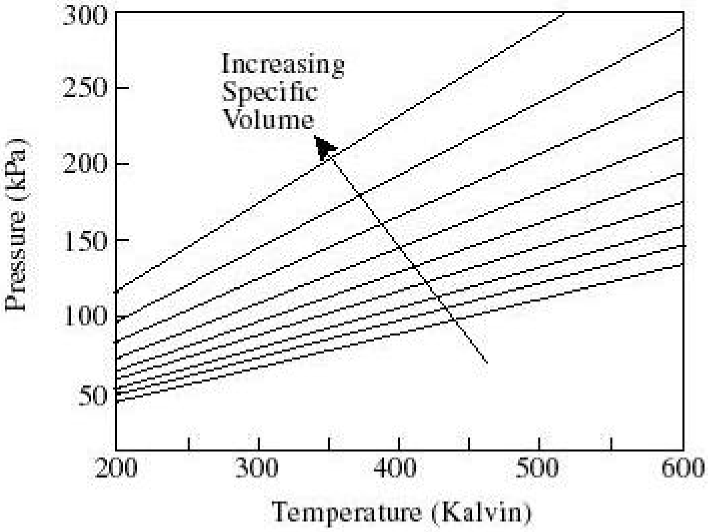
where v is the specific volume and R is the gas constant (which varies depending on the gas. R = 287J/kg - K for air).

Thus, if we know p and T we know ρ, if we know T and ρ, we know p, *etc.*

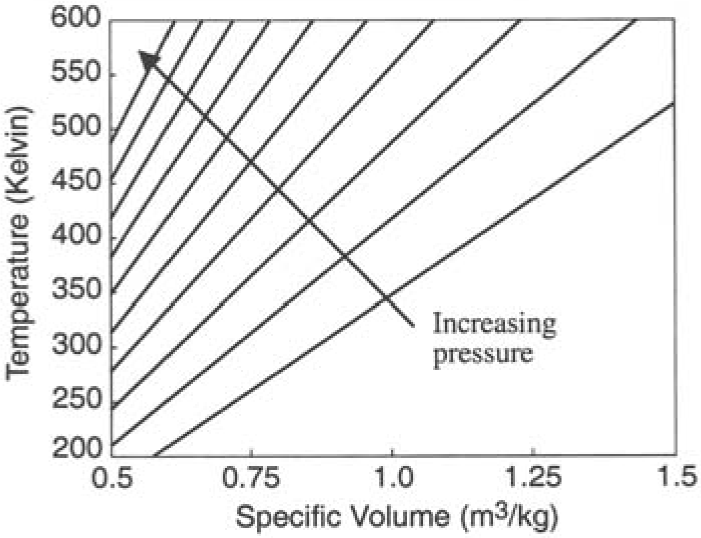
F. For thermodynamic processes we are interested in how the state of a system changes. So typically we plot the behavior as shown below. It is useful to know what a constant temperature line (isotherm) looks like on a p-v diagram, what a constant volume line (isochor) looks like on a T-p diagram, *etc.*



1.p-v diagram



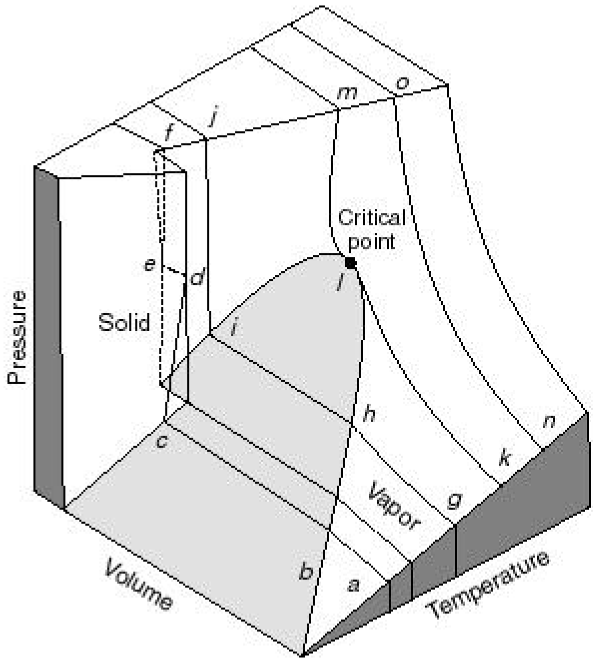
2. p-T diagram

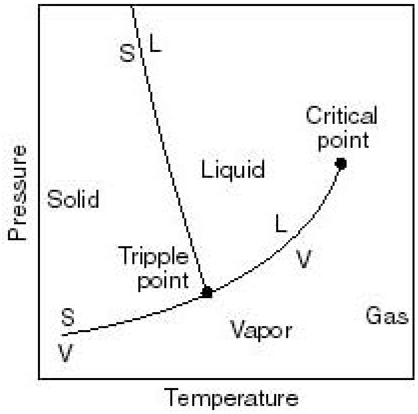


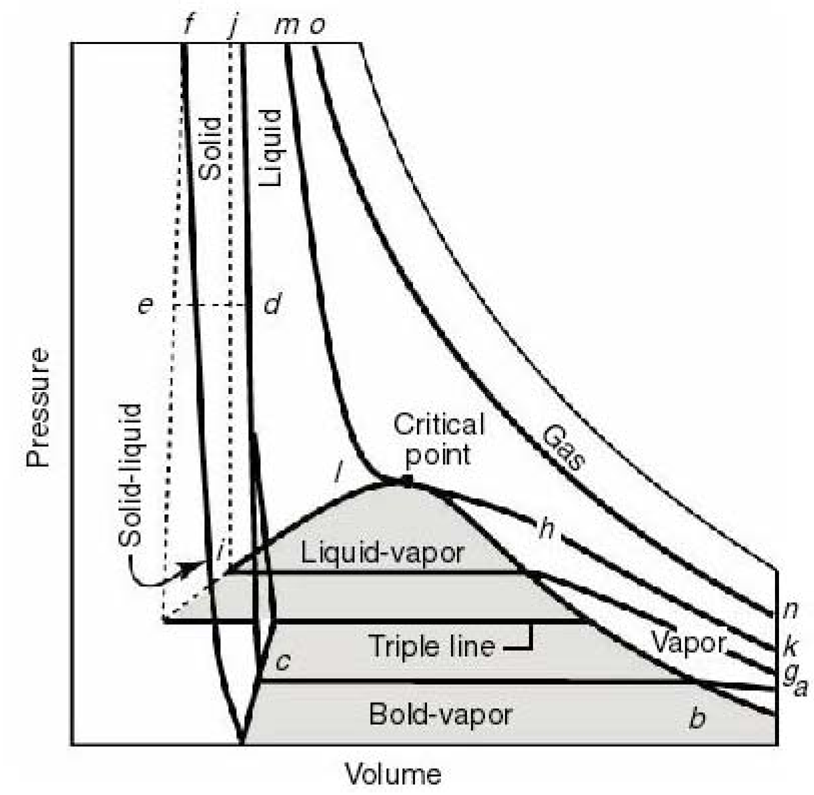
3. T-v diagram

G. **Note that real substances may have phase changes (water to water vapor, or water to ice, for example). Many thermodynamic devices rely on these phase changes (liquid-vapor power cycles are used in many power generation schemes, for example). You will learn more about these in**

16.050. In this course we will deal only with single-phase thermodynamic systems.







Pressure-temperature-volume surface for a substance that expands on freezing

(from*VW, S & B: 3.7*)