Contents (Sontag textbook)

Contents

Introduction & Definition

- Therme – heat
  Dynamis – force

- Thermodynamics is the engineering science of the relations between *heat*, *work* and the *properties of substances*

- Thermodynamics is the engineering science of the changes in energy in terms of heat and work and their relations with the properties of systems

- Engineers are interested in studying *systems* and how they interact with their *surroundings*

Fig. 1 Steam Engines

The Industrial Revolution depended on heat engines, most of which (like these steam engines) were of very low efficiency. The development of physical theories, and mathematical tools, to analyse these systems led to rapid improvements in technology

Introduction

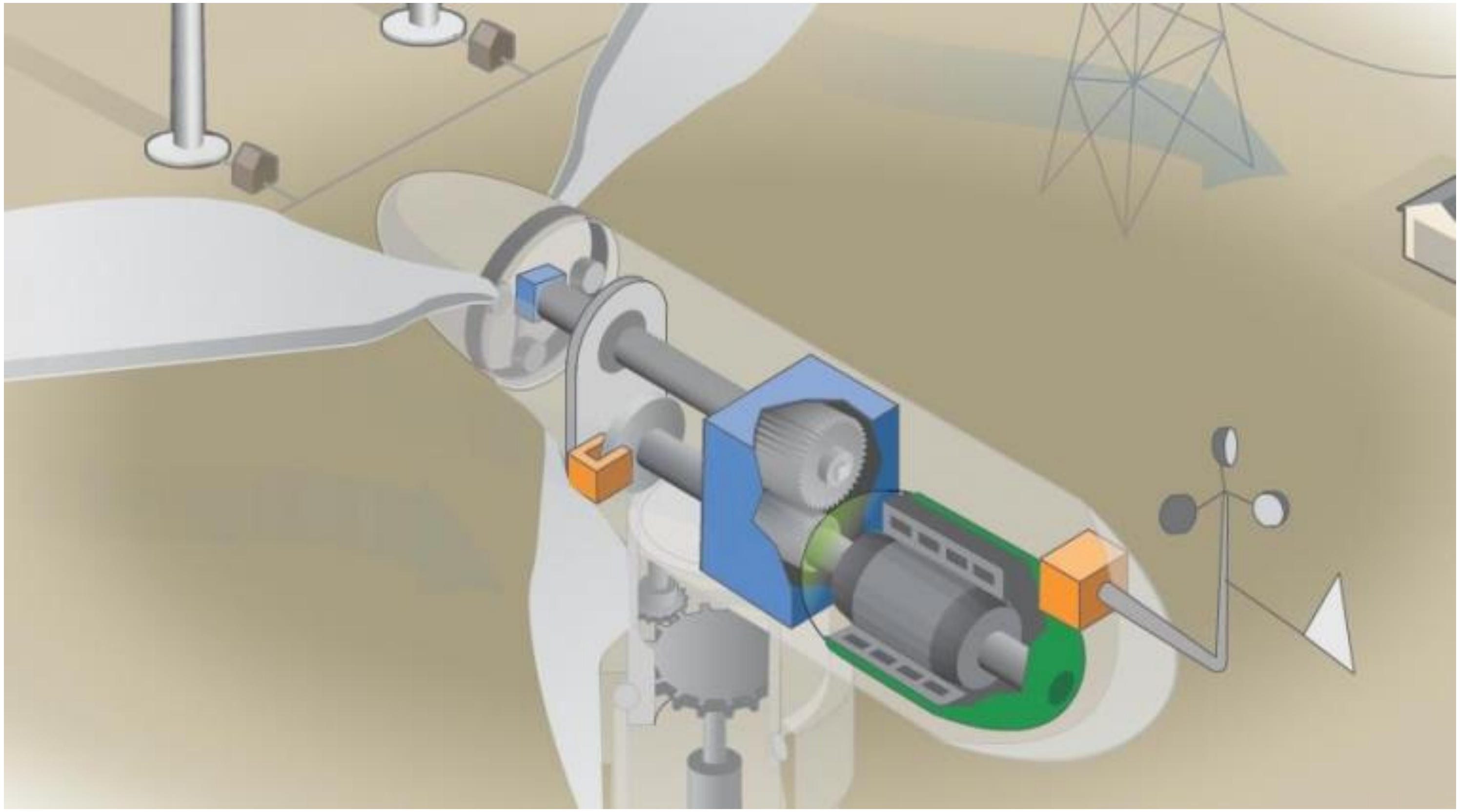
Areas of Application of Engineering Thermodynamics

- Car engines
- Turbines
- Compressors, Pumps
- Fossil - Nuclear - Fueled power stations
- Propulsion systems for aircraft and rockets
- Combustion systems

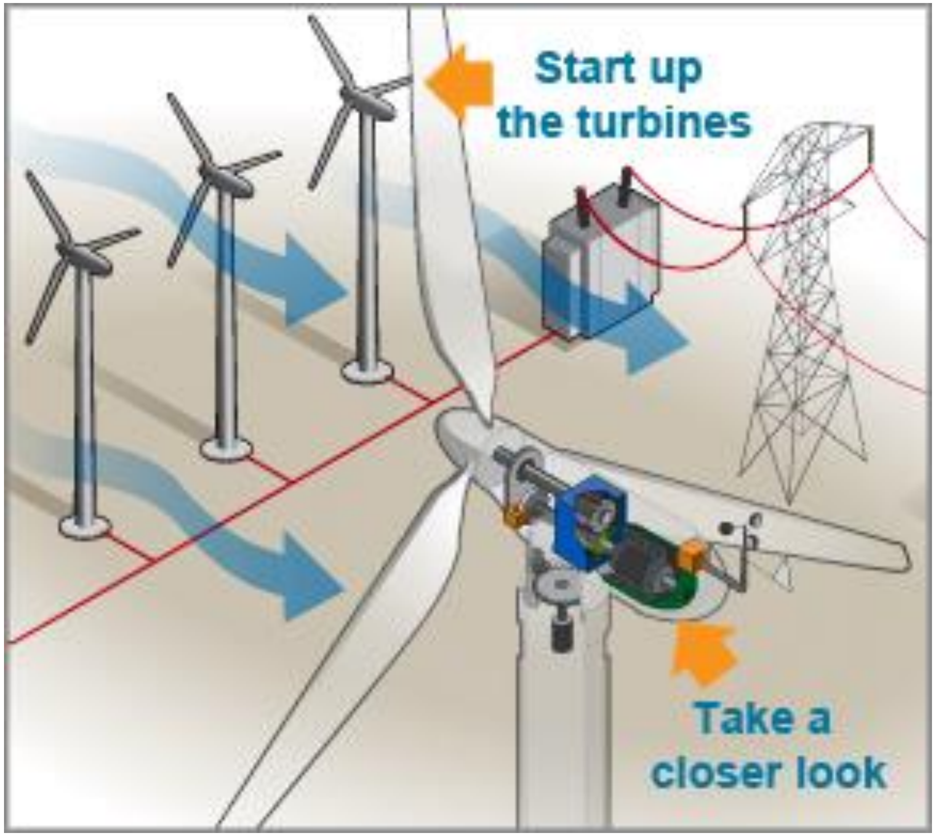
- Heating, Ventilation, Air-Conditioning systems
  - Vapor compression and absorption refrigeration
  - Heat pumps
- Alternative energy systems
  - Fuel cells
  - Geothermal systems
  - Wind power
- Biomedical applications
  - Life-support systems
  - Artificial organs

Thermodynamic application

Thermodynamic application – wind turbines

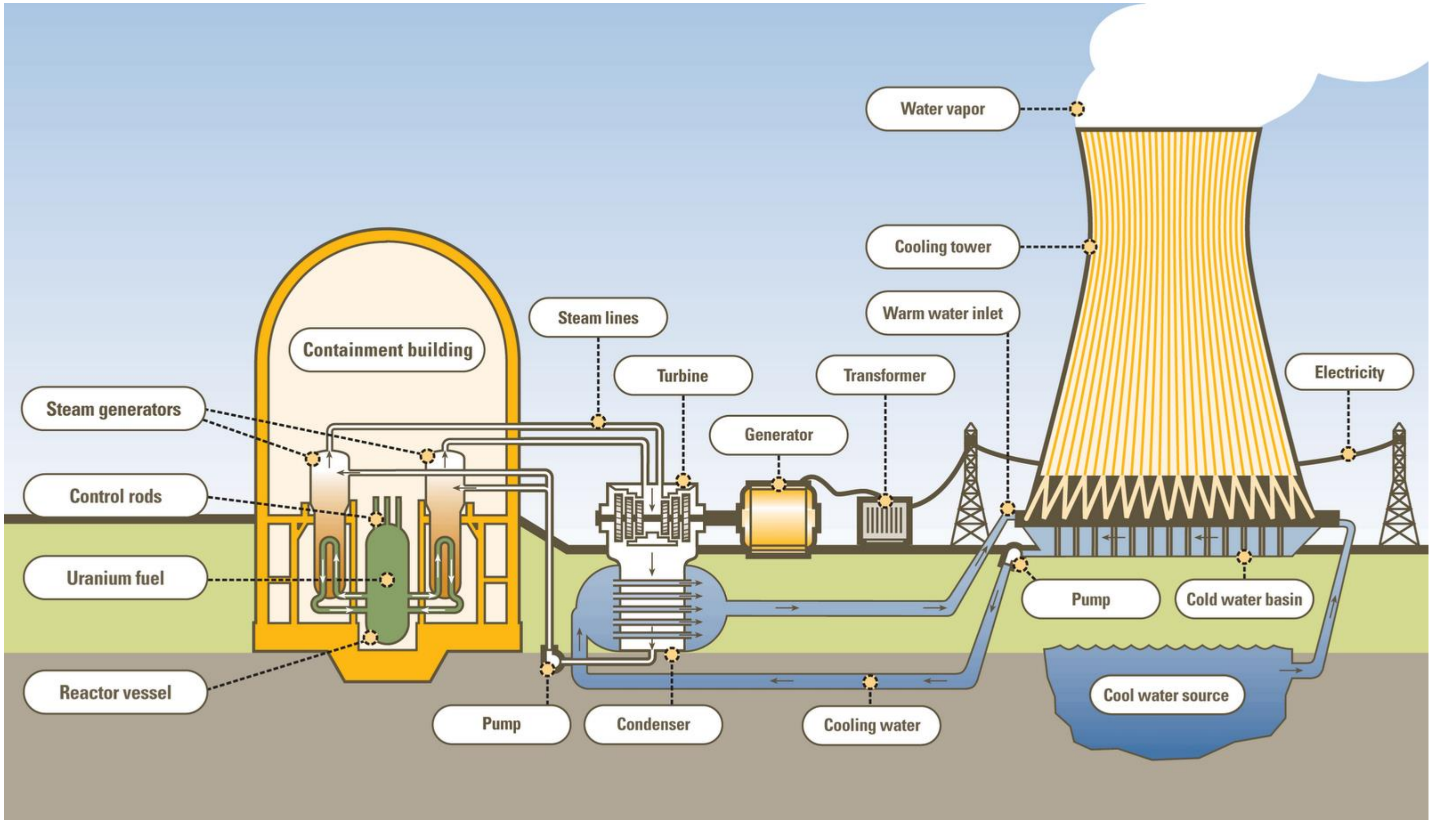


Thermodynamic application



Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity.

Thermodynamic application-nuclear plant



In a **nuclear**-fueled **power plant** – much like a fossil-fueled **power plant**– water is turned into steam, which in turn drives turbine generators to **produce electricity**. The difference is the source of heat. At **nuclear power plants**, the heat to make the steam is created when uranium atoms split – called fission.

Introduction & Definition

- Therme – heat
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- Thermodynamics is the engineering science of the relations between *heat*, *work* and the *properties of substances*

- **Thermodynamics is the engineering science of the changes in energy in terms of heat and work and their relations with the properties of systems**

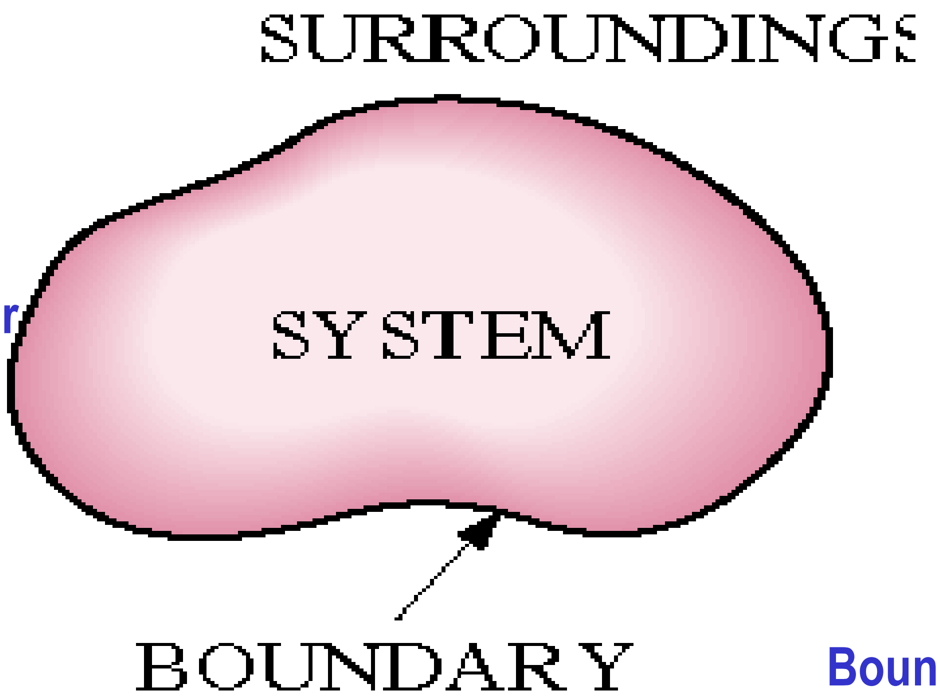
- **Engineers are interested in studying *systems* and how they interact with their *surroundings***

Thermodynamic Systems

A thermodynamic system, or simply system, is defined as a quantity of matter or a region in space chosen for study.

The region outside the system is called the surroundings. The real or imaginary surface that separates the system from its surroundings is called the boundary. The boundary of a system may be fixed or movable.

Surroudings : Region outside of the system



System : area chosen for study

Boundry: Separate system from its surroundings

Systems may be considered to be **closed** or **open**, depending on whether a fixed mass or a fixed volume in space is chosen for study.

Thermodynamic Systems

Open system

- Open system refers to a control volume which mass may flow/ cross the boundary of the **control volume**
- e.g. A car engine

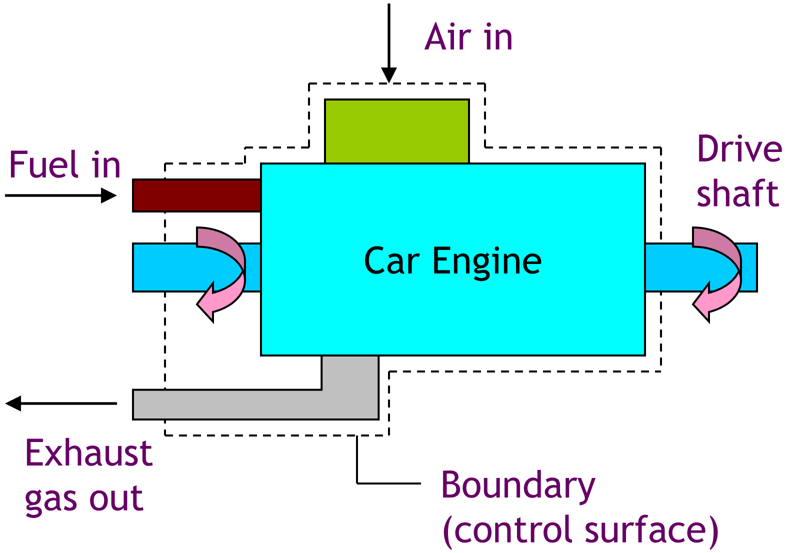


Fig. 7 A car engine

Closed system

- A closed system refers to a fixed quantity of mass – control mass
- No transfer of mass across its boundary
- e.g. A gas in a piston-cylinder assembly

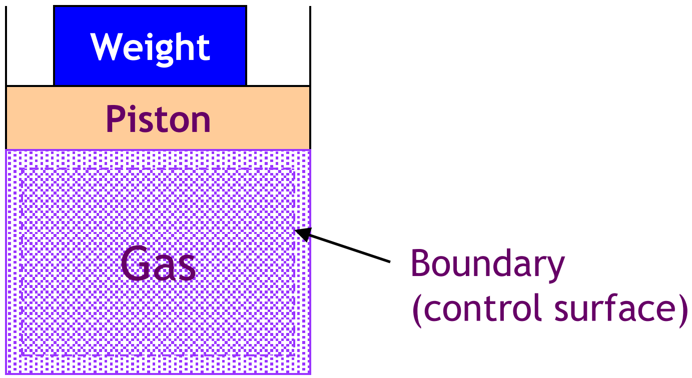
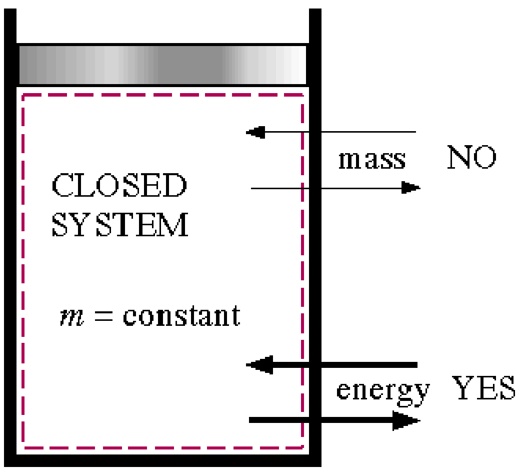
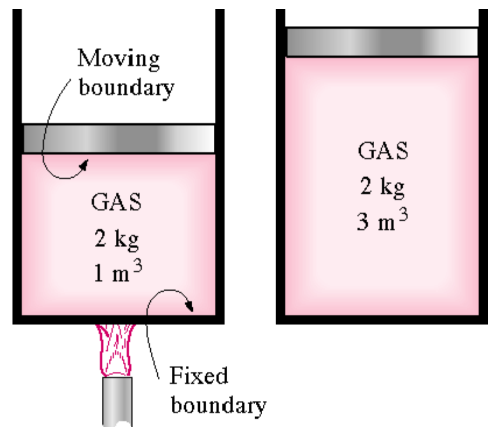


Fig. 8 A gas in a piston-cylinder assembly

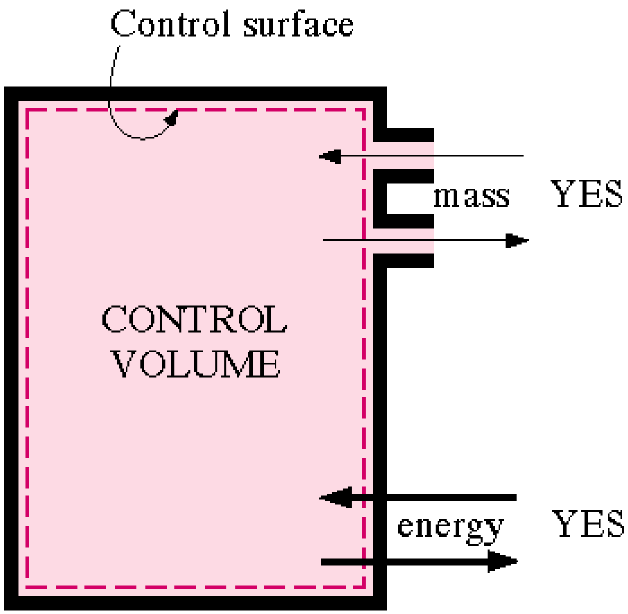
A **closed system** consists of a **fixed amount of mass** and **no mass may cross the system boundary**. The closed system boundary may move.

Examples of closed systems are sealed tanks and piston cylinder devices (note the volume does not have to be fixed). However, energy in the form of heat and work may cross the boundaries of a closed system.





An **open system**, or **control volume**, has **mass** as well as **energy crossing the boundary**, called a control surface. Examples of open systems are pumps, compressors, turbines, valves, and heat exchangers.



Properties of a System

Any characteristic of a system in equilibrium is called a **property**. The property is independent of the path used to arrive at the system condition.

Some thermodynamic properties are pressure P, temperature T, volume V, and mass m.

Properties may be **extensive** or **intensive**.

Extensive properties are those that vary directly with size--or extent--of the system.

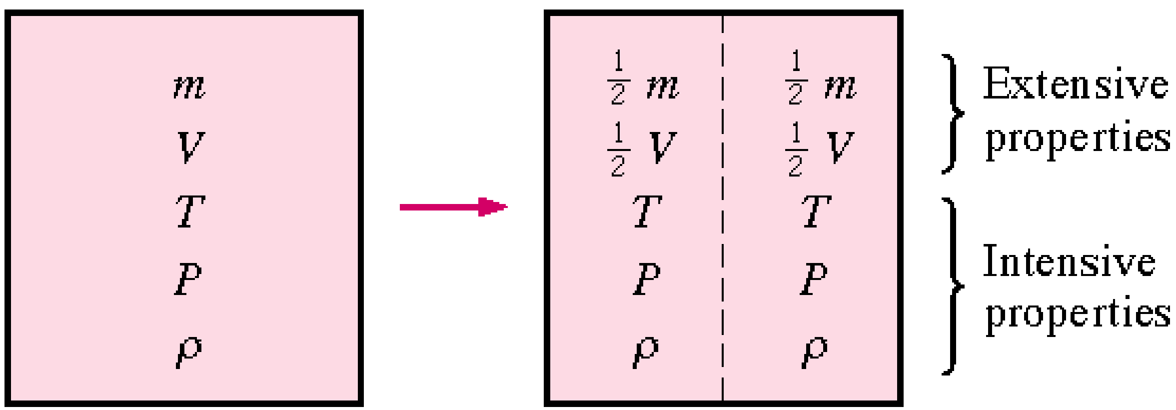
Some Extensive Properties

a. mass
b. volume
c. total energy
d. mass dependent property

Intensive properties are those that are independent of size.

Some Intensive Properties

a. Temperature
b. Pressure
c. Density



Extensive properties per unit mass are intensive properties. For example, the specific volume *v*, defined as

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

and density ρ, defined as

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

are intensive properties.

Specific volume, υ

$$\upsilon = \frac{volume}{mass}$$

$$\rho = \frac{1}{v} \equiv \frac{mass}{volume} \equiv density$$

$$\overline{v} = \frac{volume}{mol} = \text{molal specific volume}$$

•For gas, specific volume is a very dependent on pressure and temperature

•Specific volume could be estimated using Equation of State. Example: Ideal gas equation of state

Try out problem 2 and 3 on page 6

Units

An important component to the solution of any engineering thermodynamic problem requires the proper use of units.

The system of units selected for this course is the SI System, also known as the International System (sometimes called the metric system).

In SI, the units of mass, length, and time are the kilogram (kg), meter (m), and second (s), respectively.

We consider force to be a derived unit from Newton's second law, i.e.,

$$Force = (mass)(acceleration)$$

$$F = ma$$

In SI, the force unit is the newton (N), and it is defined as the force required to accelerate a mass of 1 kg at a rate of 1 m/s^2. That is,

$$1N = (1kg)(1\frac{m}{s^2})$$

This definition of the newton is used as the basis of the conversion factor to convert mass-acceleration units to force units.

Oftentimes, the engineer must work in other systems of units. Comparison of the United States Customary System (USCS), or English System, and the slug system of units with the SI system is shown below.

	SI	USCS
Mass	Kilogram (kg)	Pound-mass (lbm)
Time	Second (s)	Second (s)
Length	Meter (m)	Foot (ft)
Force	Newton (N)	Pound-force (lbf)

Weight

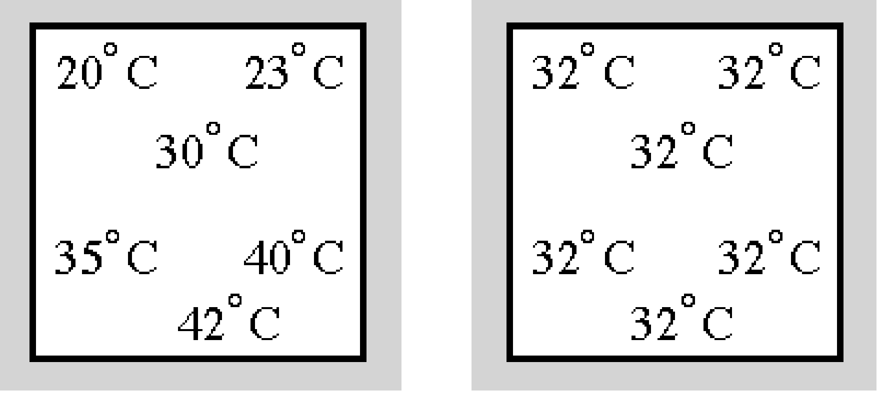
- A force of gravity acted on the body(mass)

  W = F= $\frac{mg}{g_c}$

- <u>Mass</u> remains the same regardless of location.
- Weight is dependent on local gravitational force (or elevation)
- Example: 1 kg mass has a weight of 9.8N on the earth and 1.67N on the moon.

Equilibrium

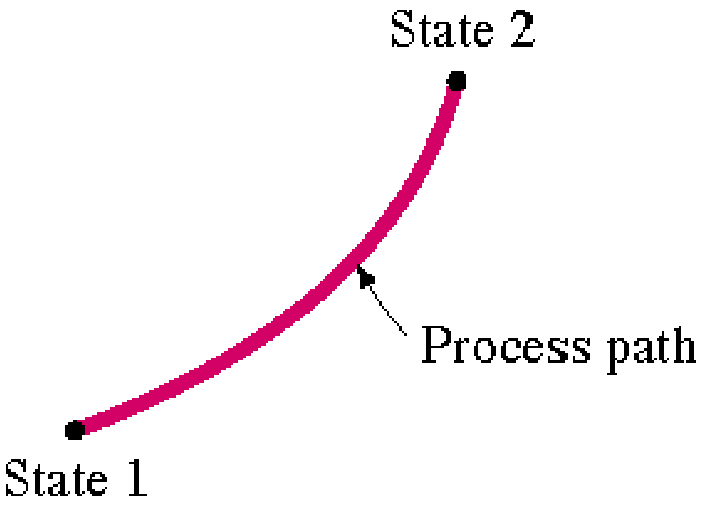
A system is said to be in thermodynamic equilibrium if it maintains thermal (uniform temperature), mechanical (uniform pressure), phase (the mass of two phases, e.g., ice and liquid water, in equilibrium) and chemical equilibrium.



(a) Before (b) After

Process

Any change from one state to another is called a process.



In most of the processes that we will study, **<u>one</u>** thermodynamic property is **<u>held constant</u>** → **iso**

Some of these processes are

Process	Property held constant
isobaric	pressure
isothermal	temperature
isochoric	volume
isentropic	entropy (see Chapter 7)

Steady-Flow Process

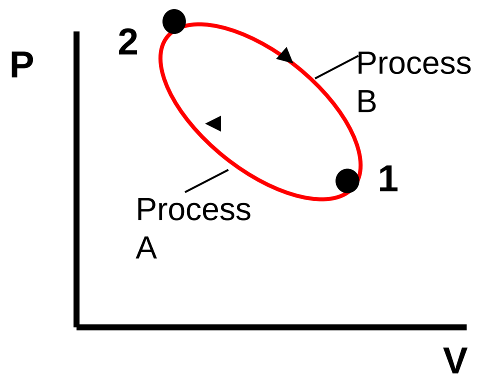
Consider a fluid flowing through an open system or control volume such as a water heater. The flow is often defined by the terms steady and uniform. The term **steady** implies that there are no changes with time.

The term **uniform** implies no change with location over a specified region.

Cycle

A process with identical end states is called a **cycle**. Below is a cycle composed of two processes, A and B.

Along process A, the pressure and volume change from state 1 to state 2. Then to complete the cycle, the pressure and volume change from state 2 back to the initial state 1 along process B.



Pressure

Force per unit area is called pressure, and its unit is the pascal, N/m^2, in the SI system and psia, lbf/in^2 absolute, in the English system.

$$P = \frac{Force}{Area} = \frac{F}{A}$$

$$1\ kPa = 10^3\ \frac{N}{m^2}$$

$$1\ MPa = 10^6\ \frac{N}{m^2} = 10^3\ kPa$$

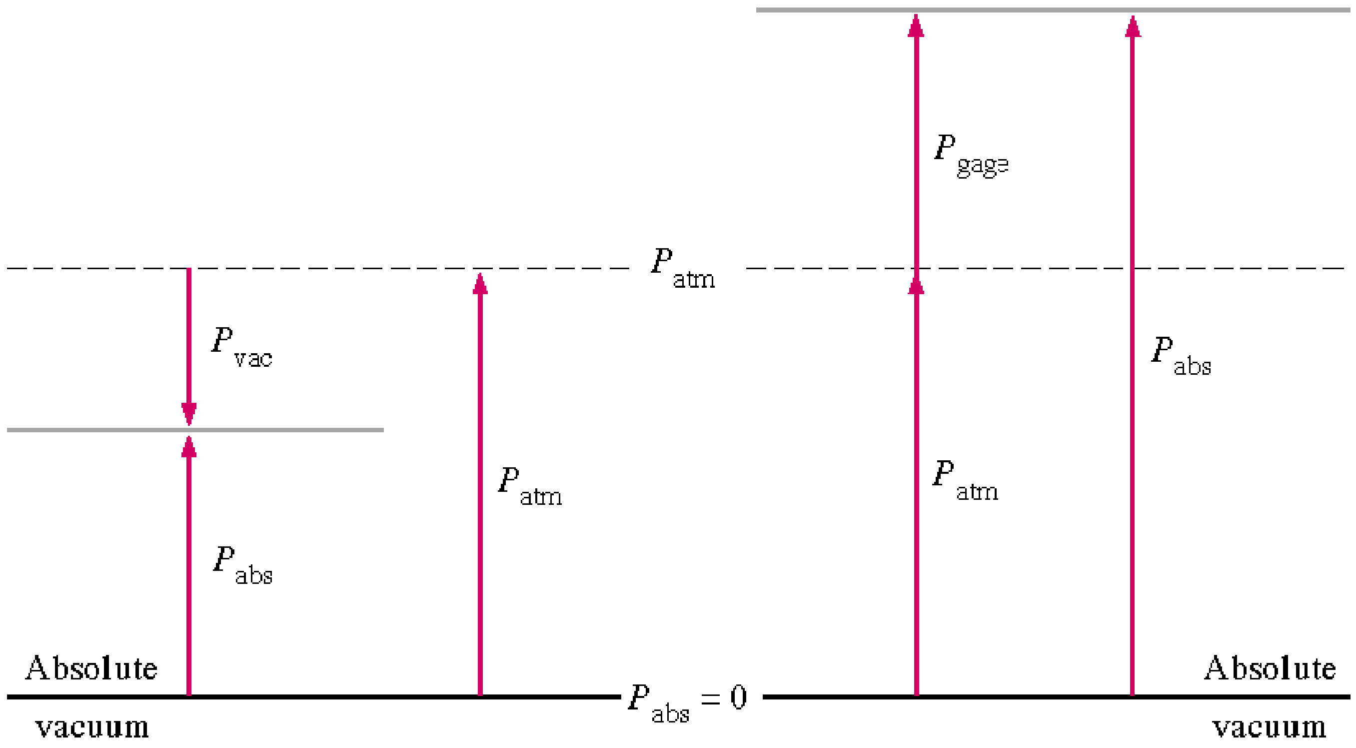
Pressure

Absolute pressure is zero-referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure.

Gauge/gage pressure is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure.

Differential pressure is the difference in pressure between two points.

The relation among atmospheric, gage, and vacuum pressures is shown below.



$$P_{vac} = P_{atm} - P_{abs}$$

$$P_{gage} = P_{abs} - P_{atm}$$

EXERCISES

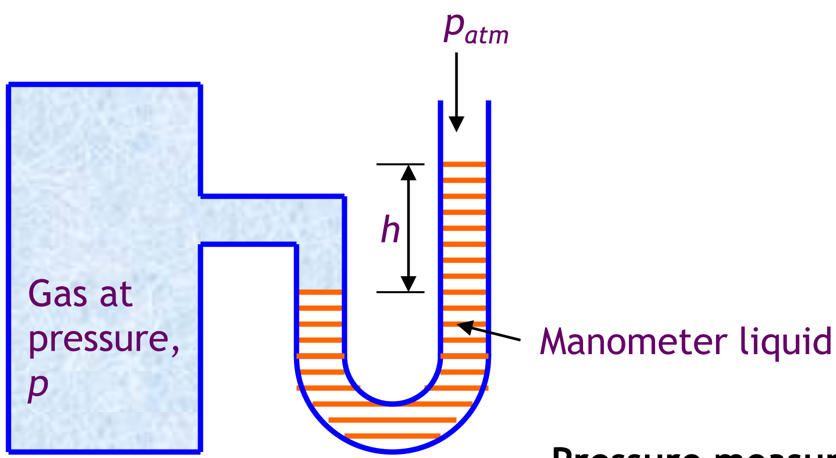
Lets try out tutorial problem 7

Pressure Measurement

Manometer

- Manometer measure pressure differences in terms of the length of a column of liquid such as water, mercury and oil.
- As shown in Fig. 10, the manometer has one end open to atmosphere and the other attached to a closed vessel containing gas at uniform pressure
- The difference between the gas pressure and that of the atmosphere is

$$p = \rho g h + p_{atm}$$



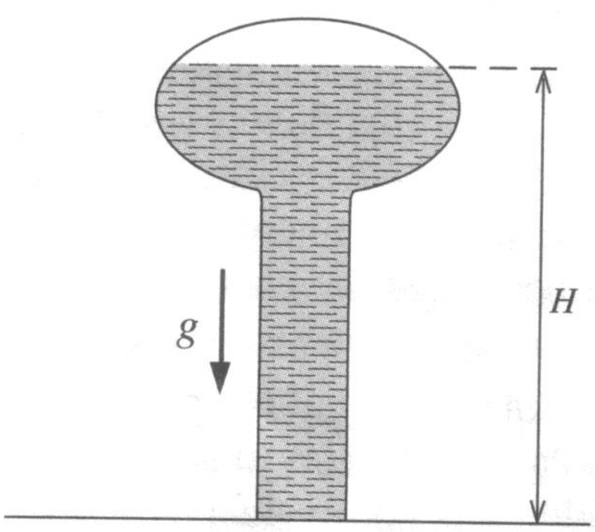
Pressure measurement by a manometer

EXERCISES

Lets try out tutorial problem 11

Problem 11

In the city water tower, water is pumped up to a level 25 m above ground in a pressurized tank with air at 125 kPa over the water surface. This is illustrated in figure below. Assuming the water density is 1000 kg/m3 and standard gravity, find the pressure required to pump more water in at ground level.



Temperature

Temperature is considered as a thermodynamic property that is the measure of the energy content of a mass. When heat energy is transferred to a body, the body's energy content increases and so does its temperature.

Equality of Temperature

If two bodies remain in contact for some time, they will soon have the same level of hotness or coldness. We may say that the two bodies have equality of temperature.

Equality of temperature

Room temperature, $25^{o}C$

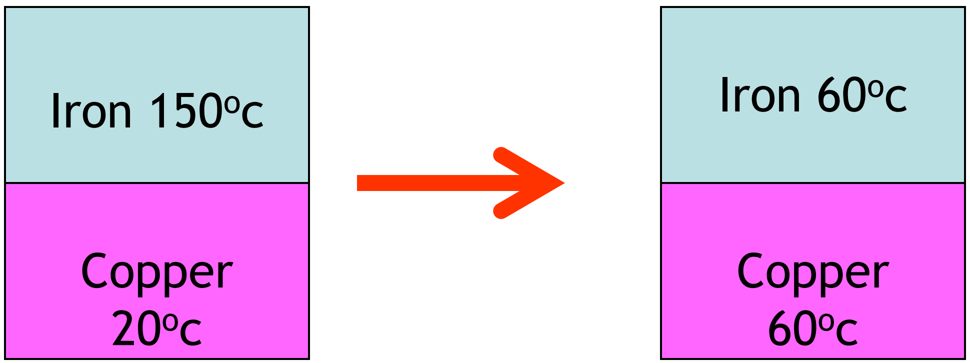
Hot coffee $70^{o}C$

A cup of hot coffee left on the table will cools off to room temperature

COFFEE

More than 400 billion cups of coffee are consumed each year making it second only to oil as a world commodity. It is indeed the world's most popular beverage

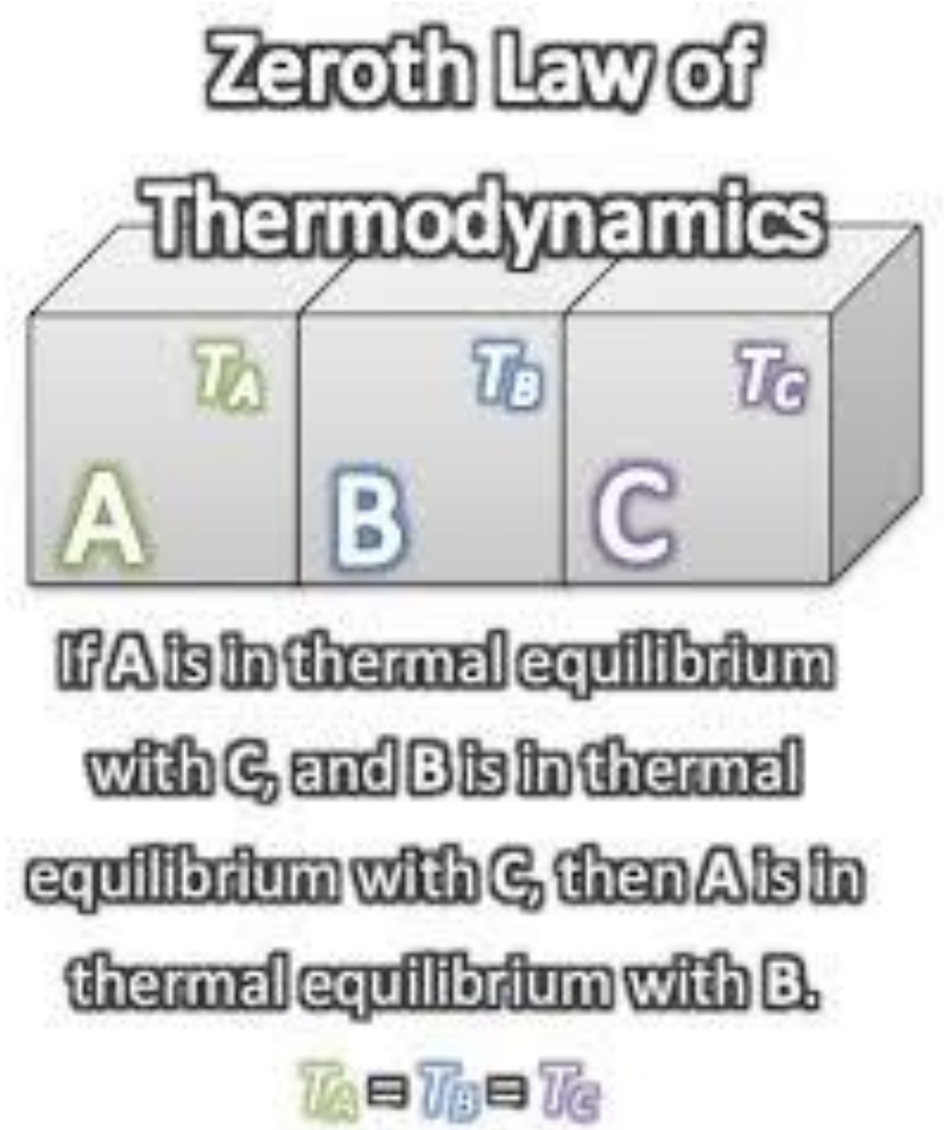
Equality of temperature



Two bodies reaching thermal equilibrium after being brought into contact

Zeroth Law of Thermodynamics

When two bodies have equality of temperature with the third body, they in turn have equality of temperature with each other.


Zeroth Law of Thermodynamics
T_A
T_B
T_C
A
B
C
If A is in thermal equilibrium with C, and B is in thermal equilibrium with C, then A is in thermal equilibrium with B.
$T_A = T_B = T_C$

Temperature Scale.

- Common scale: ^oC or ^oF
- Absolute scale: K and R
- Conversion between temperature scales:

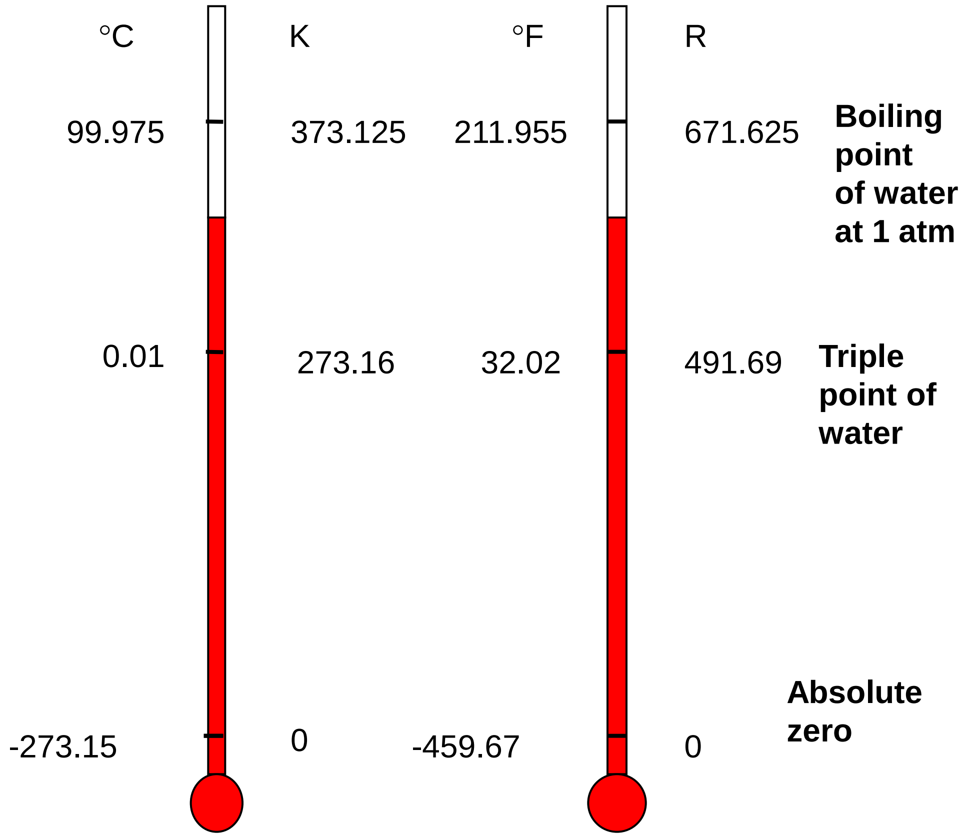
$$T(^oF) = 1.8T(^oC) + 32$$

$$T(K) = T(^oC) + 273.15$$

$$T(R) = T(^oF) + 459.67$$

$$T(R) = 1.8T(K)$$

Below is a comparison of the temperature scales.



EXERCISES

Lets try out tutorial problem 13

Problem 13

Using the freezing and boiling point temperatures for water in both Celcius and Fahrenheit scales, develop a conversion formula between the scales. Find the conversion formula between Kelvin and Rankine temperature scales.

TUTORIAL

Lets try out

problem 5

problem 8

problem 10

problem 14