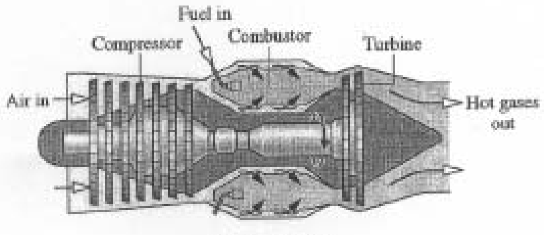
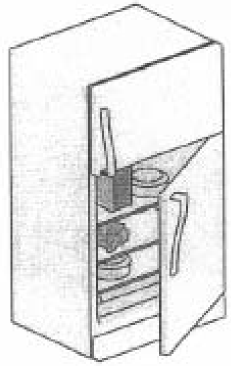
Why do we need to study thermodynamics?

Knowledge of thermodynamics is required to design any device involving the interchange between heat and work, or the conversion of material to produce heat (combustion).

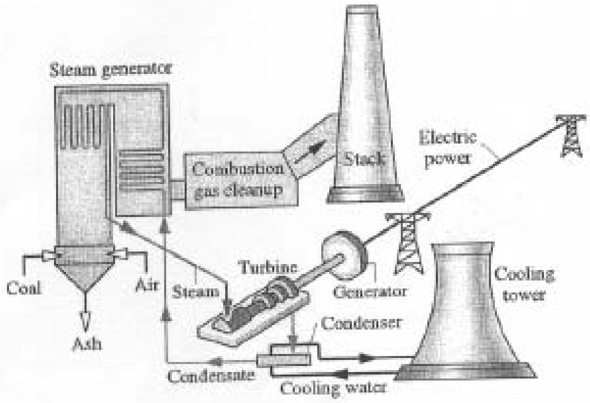
Examples of practical thermodynamic devices:



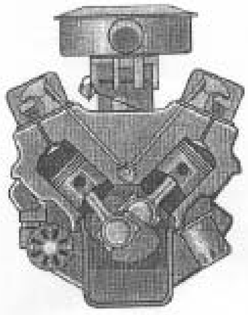
Turbojet engine



Refrigerator



Electrical power plant



Automobile engine

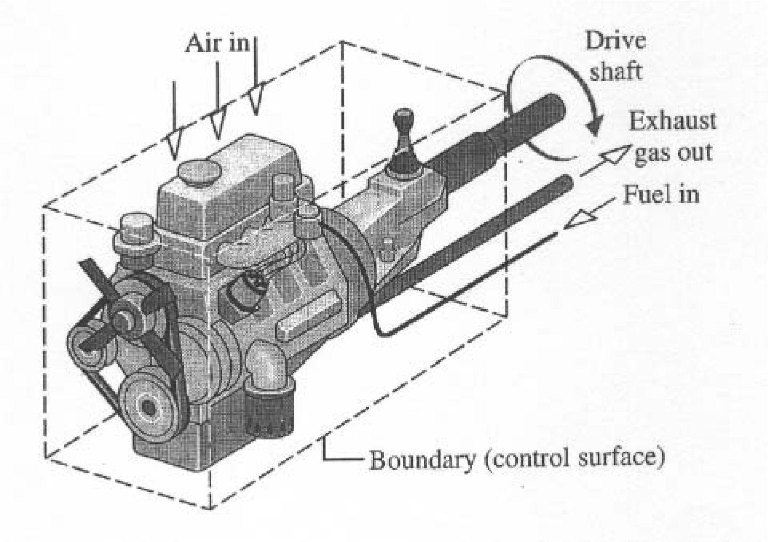
What is thermodynamics?

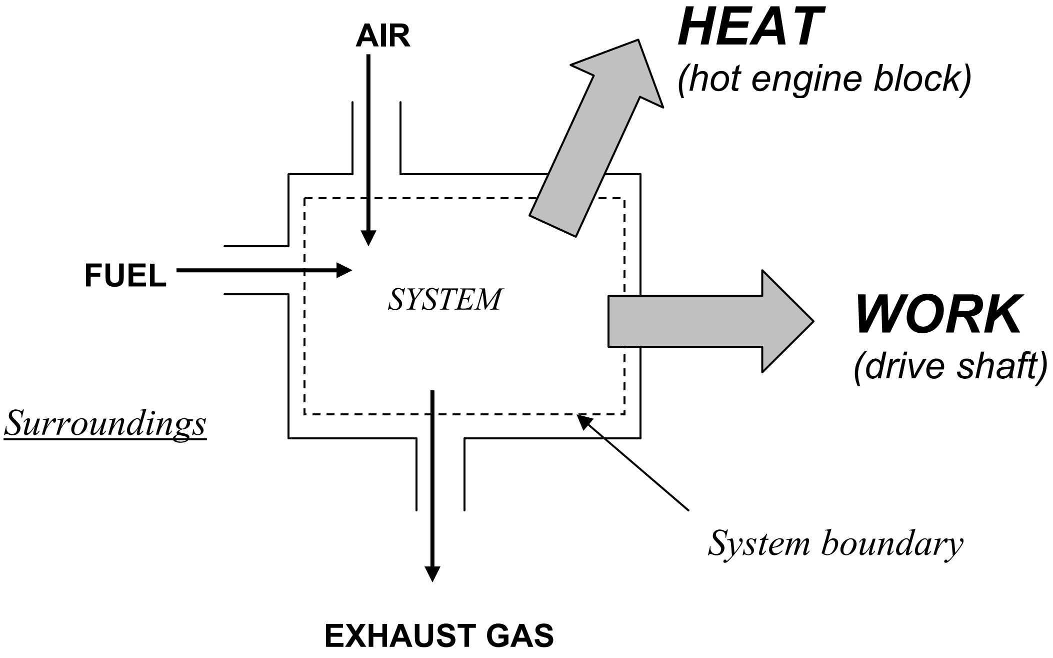
- The study of the relationship between work, heat, and energy.
- Deals with the conversion of energy from one form to another.
- Deals with the interaction of a system and it surroundings.

System - identifies the subject of the analysis by defining a boundary

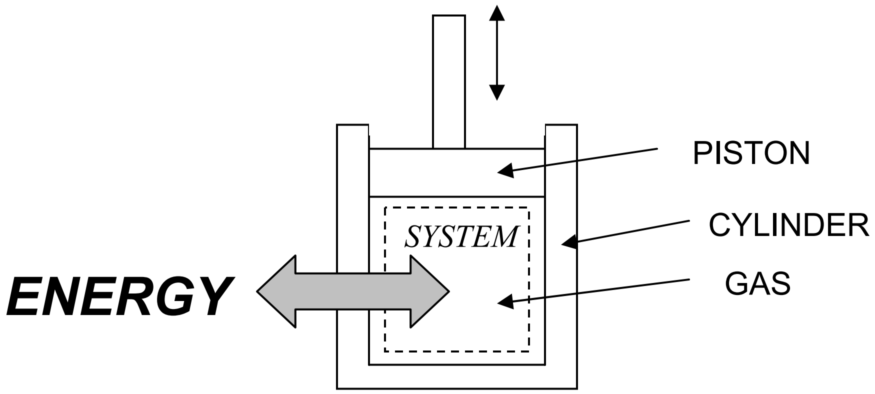
Surroundings - everything outside the system boundary.

As an example, consider an Internal Combustion (IC) Engine

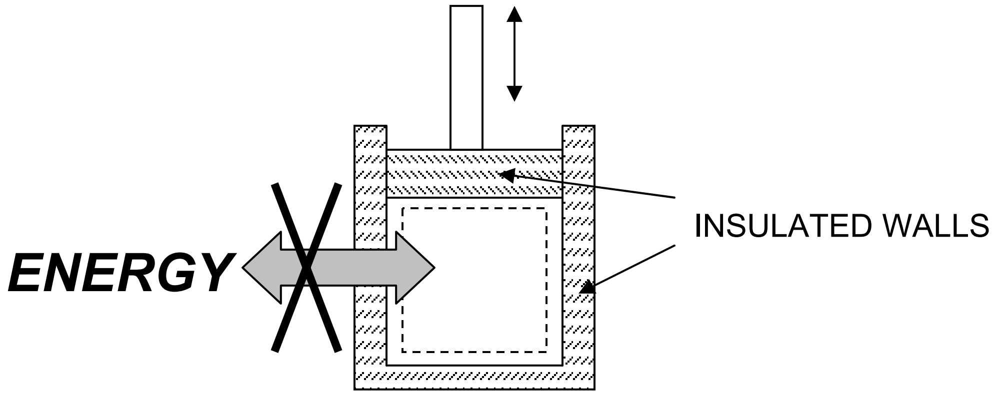




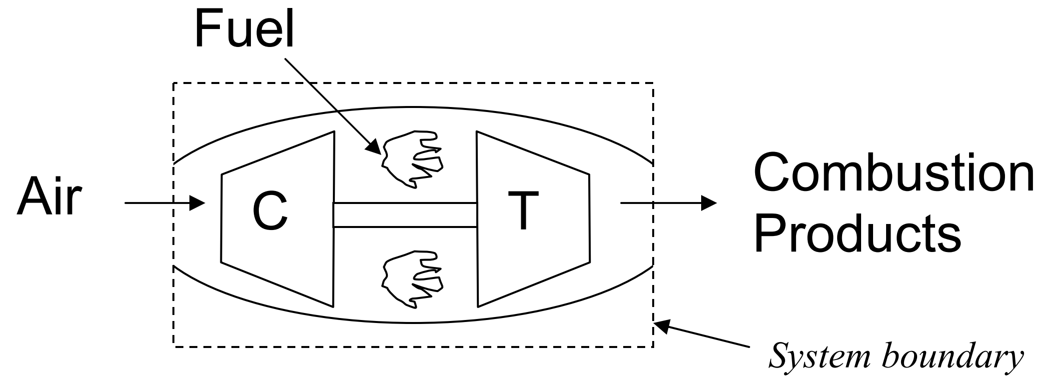
Closed System - fixed non-changing mass of fluid within the system, i.e., no mass transfer across the system boundary but can have energy exchange with the surroundings. Example: piston-cylinder assembly



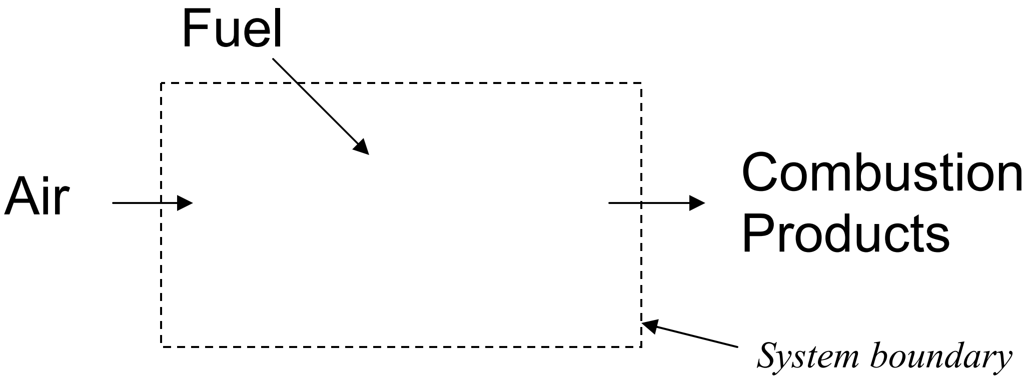
Isolated System - a system that does not interact at all with the surroundings, e.g., no heat transfer across system boundary



Open System (Control Volume) - fixed volume in space, mass and energy exchange permitted across the system boundary. Example: jet engine



As far as the surroundings are concerned the control volume is:

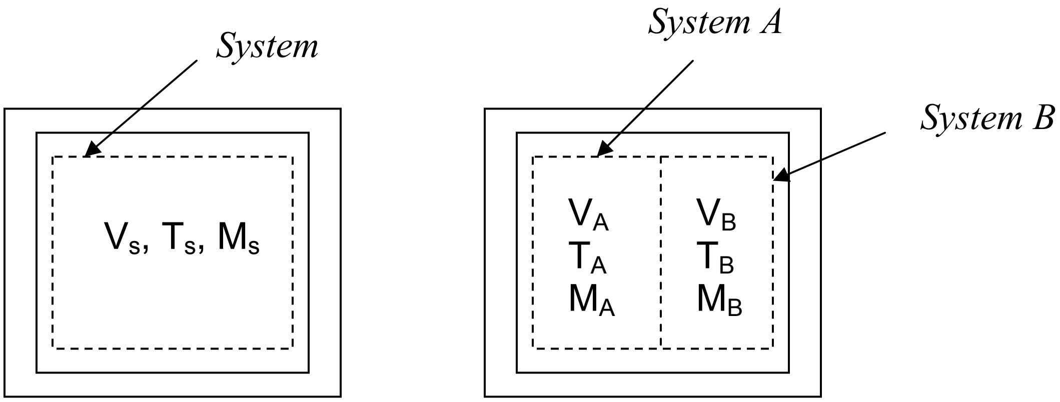


System Properties – macroscopic characteristics of a system to which a numerical value can be assigned at a given time without knowledge of the history of the system, e.g., mass, volume, pressure

There are two types of properties:

Extensive – the property value for the system is the sum of the values of the parts into which the system is divided (depends on the system size) e.g., mass, volume, energy

Intensive – the property is independent of system size (value may vary throughout the system), e.g., pressure, temperature



$V_S = V_A + V_B$ extensive

$M_S = M_A + M_B$ extensive

$T_S \neq T_A + T_B$ intensive

Units – SI used exclusively

Fundamental units:

Mass	kilograms	kg
Length	meter	m
Time	seconds	s
Temperature	Celcius/Kelvin	$^{o}C/^{o}K$

Derived units:

Force (F)	Newton	N
Pressure (P)	Pascal	Pa
Energy (E)	Joule	J

Newton's Law states: Force = mass x acceleration

$$F = m \cdot a$$
$$[N] = [kg] \quad [m/s^2] \qquad \rightarrow 1\ N = 1\ kg\cdot m/s^2$$

$$P = F\ /\ A$$
$$[Pa] \quad [kg\cdot m/s^2] \quad [m^2] \qquad \rightarrow 1\ Pa = 1\ kg/m\cdot s^2$$

$$E = F \cdot x$$
$$[J] = [kg\cdot m/s^2] \quad [m] \qquad \rightarrow 1\ J = 1\ kg\cdot m^2/s^2$$

Property Definitions

In order to speak of an intrinsic property “at a point” we must treat matter as a continuum, i.e., matter is distributed continuously in space

- In classical thermodynamics a point represents the smallest volume V’ for which matter can be considered a continuum.

- The value of the property represents an average over this volume V’.

At any instant the *density*, ρ, at a point is defined as

$$\rho = \lim_{V \to V'} \left(\frac{M}{V} \right) \qquad \text{units: kg/m}^3$$

Mass, M, of the system with volume, V, is

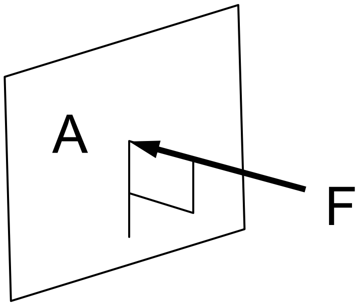
$$\rho = \frac{dM}{dV} \;\rightarrow\; M = \int dM = \int_V \rho dV$$

Note: if ρ is uniform over the volume $M = \rho V$

Specific volume, υ, defined as

$$\upsilon = \frac{1}{\rho} \qquad \text{units: m}^3\text{/kg}$$

Consider a small area *A* passing through a point in a fluid at rest. Fluid on one side of the area exerts a compressive force *F* normal to the area



The *pressure*, *P*, at a point is defined as

$$P = \lim_{A \to A'} \left(\frac{F}{A} \right)$$

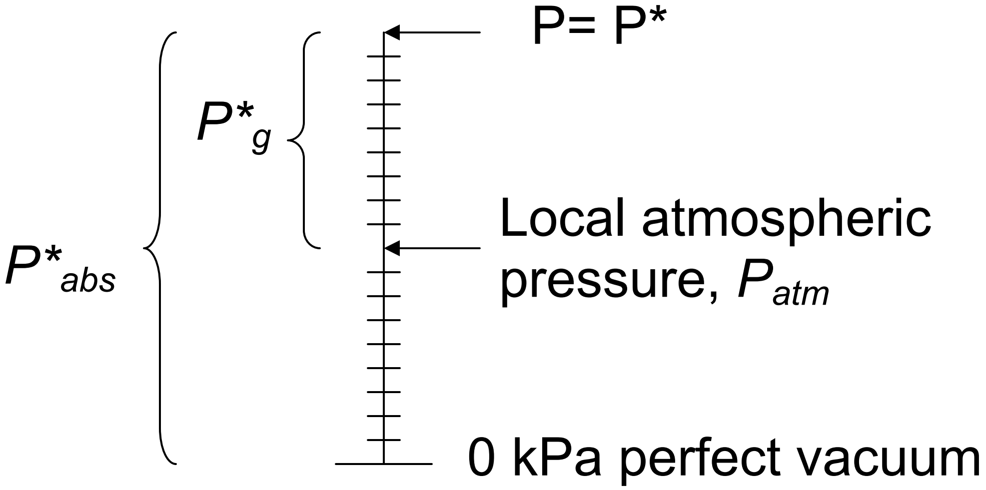
units: $1 \text{ Pa} = 1 \text{ N/m}^2$

1 standard atmosphere = 101,325 Pa

1 bar = 100,000 Pa = 100 kPa = 0.1 MPa

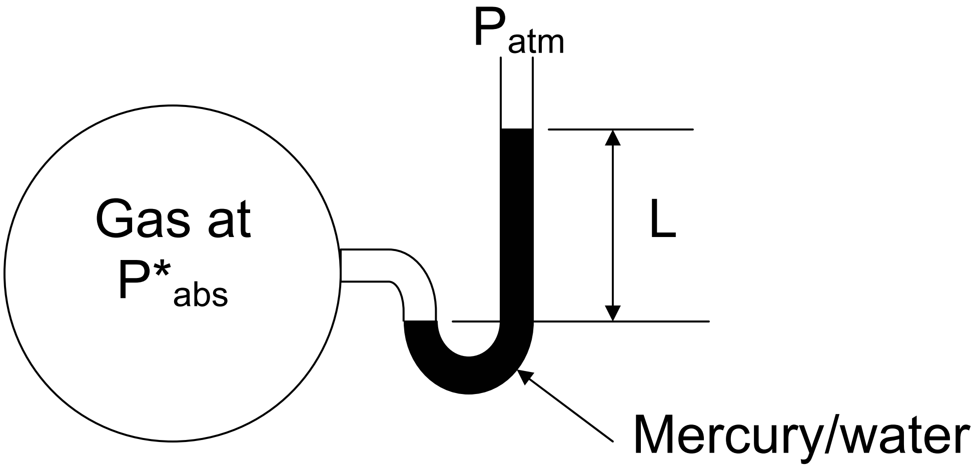
Absolute pressure , P_{abs}, measured relative to a perfect vacuum

Gauge pressure , P_g, measured relative to the local atmospheric pressure, P_{atm}.



Note: $P^*_g = P^*_{abs} - P_{atm}$

Gauge pressure measurement via a manometer



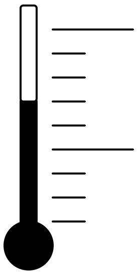
$$P^*_g = P^*_{abs} - P_{atm} = \rho g L \qquad g = 9.81\ m/s^2$$

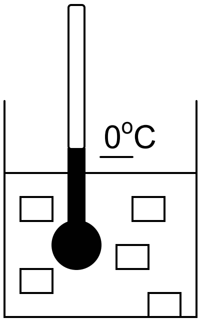
The density of mercury is 13.5 times the density of water

Note: 1 standard atmosphere = 760 mm (29.9 in.) mercury
= 10,260 mm water

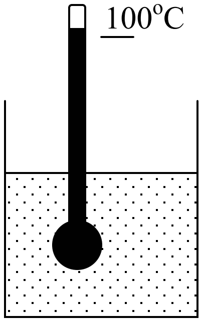
Temperature, *T*, in units of degrees celcius, ^{o}C, is a measure of “hotness” relative to the freezing and boiling point of water

A thermometer is based on the thermal expansion of mercury





ICE BATH



BOILING
WATER

Microscopic point of view:

Temperature is a measure of the internal molecular motion, e.g., average molecule kinetic energy

At a temperature of –273.15^{o}C molecular motion ceases

Temperature in units of degrees kelvin, ^{o}K, is measured relative to this absolute zero temperature, so

$$0^{o}K = -273^{o}C$$

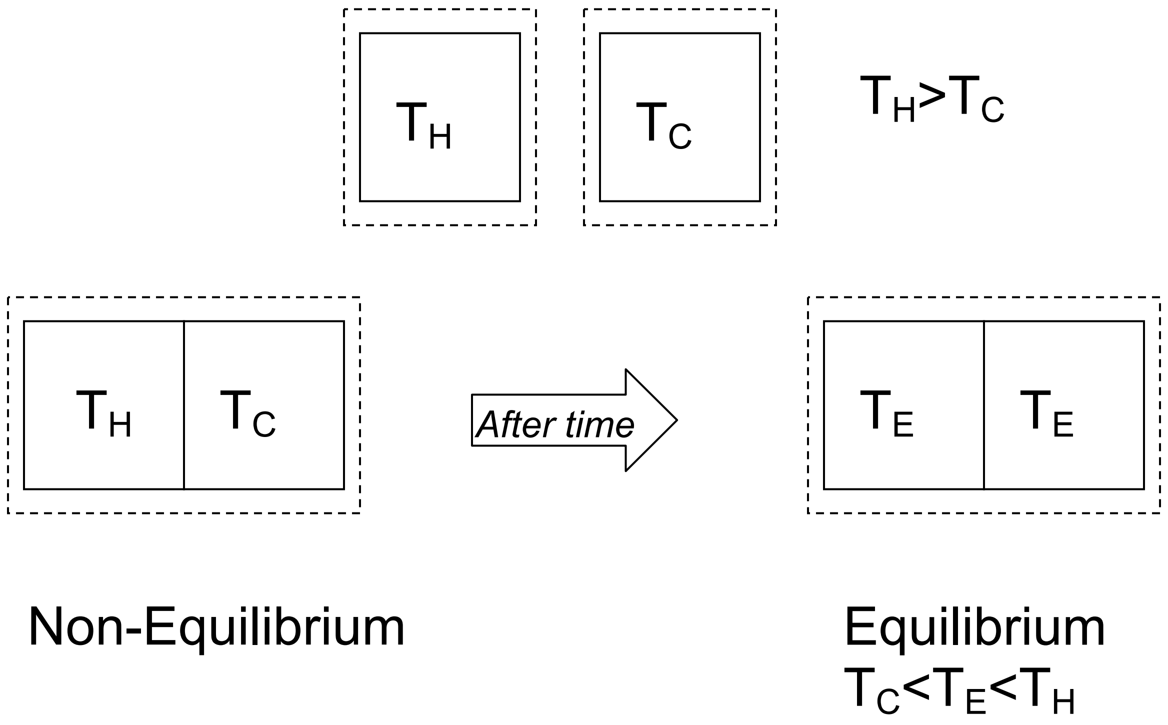
in general, $$T \text{ in } ^{o}K = T \text{ in } ^{o}C + 273.13$$

System state – condition of the thermodynamic system as described by its properties (P_1,T_1,….)

A system is at **steady-state** if none of the system properties change with time

A system is in **equilibrium** if when the system is isolated from its surroundings there are no changes in its properties

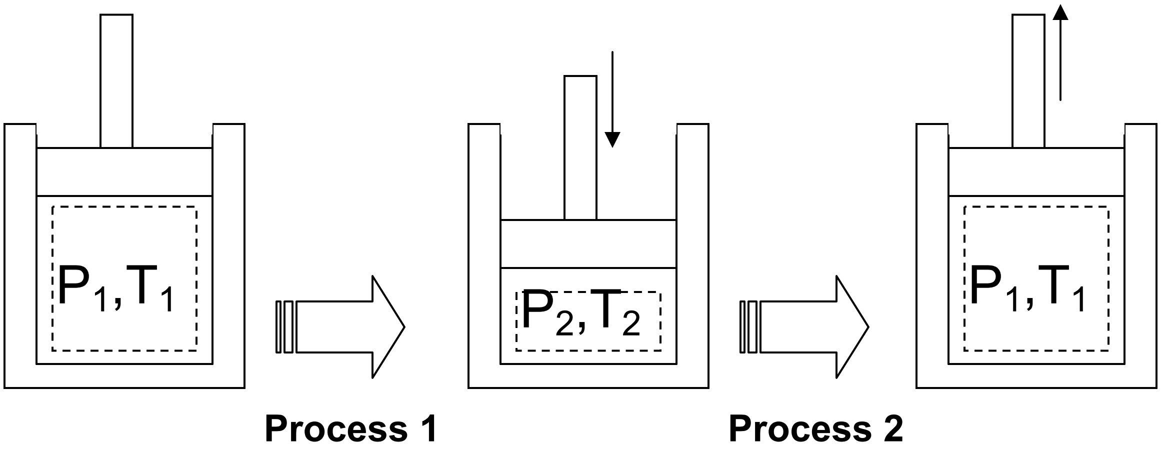
Example: thermal equilibrium

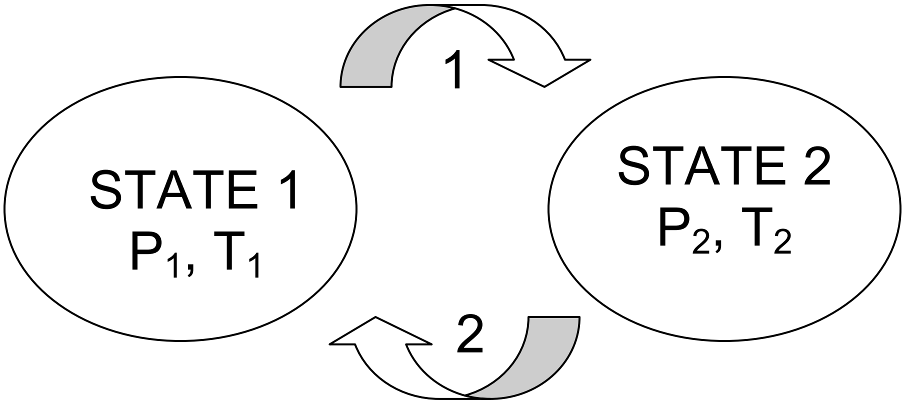


A **process** is the transformation of a system from one state to another state.

A **cycle** is a sequence of processes that begins and ends at the same state.

Example showing a cycle consisting of two processes





CYCLE