Reversible process: is defined as a process that can be reversed without leaving any trace on the surroundings as shown in figure (22).

That is, both the system and the surroundings are returned to their initial states at the end of the reverse process. This is possible only if the net heat and net work exchange between the system and the surroundings is zero for the combined (original and reverse) process.

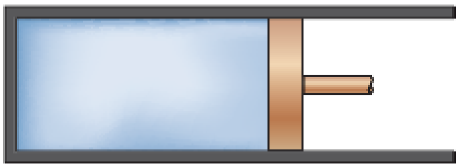


Figure (22) Quasi-equilibrium expansion and compression of a gas (reversible processes)

Irreversible processes: Processes that are not reversible are called irreversible processes.

Energy:

Energy is an important part of most aspects of daily life, energy can cross the boundary of a closed system in two distinct forms: **heat** and **work** as shown in figure (23).

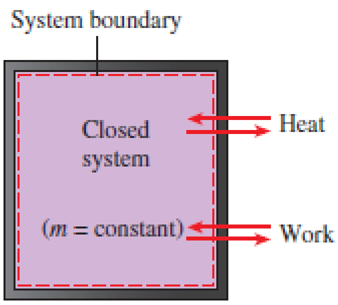


Figure (23) Energy can cross the boundaries of a closed system in the form of heat and work.

Forms of Energy:

Energy can exist in numerous forms such as **thermal**, **mechanical**, **kinetic**, **potential**, **electric**, **magnetic**, **chemical**, and **nuclear**, and their sum constitutes **the total energy** (E) of a system. *The total energy of a system on a unit mass basis is denoted by* **(e)** *and is expressed as*:

$$\boxed{e = \frac{E}{m}} \quad \text{(kJ/kg)}$$

In thermodynamic analysis, it is often helpful to consider the various forms of energy that make up the total energy of a system in two groups: ***macroscopic*** and ***microscopic***. The macroscopic forms of energy are those a system possesses as a whole with respect to some outside reference frame, such as kinetic and potential energies. The microscopic forms of energy are those related to the molecular structure of a system and the degree of the molecular activity, and they are independent of outside reference frames.

Internal energy (U): The sum of all the microscopic forms of energy is called *the internal energy* of a system and is denoted by U.

Kinetic energy (KE): The energy that a system possesses as a result of its motion relative to some reference frame is called *kinetic energy* (KE).

When all parts of a system move with the same velocity, the kinetic energy is expressed as:

$$\boxed{KE = m\frac{V^2}{2}} \quad \text{(kJ)}$$

or, *on a unit mass basis*:

$$\boxed{ke = \frac{V^2}{2}} \quad \text{(kJ/kg)}$$

Where:

V: Denotes the (*velocity*) of the system relative to some fixed reference.

Potential energy (PE): The energy that a system possesses as a result of its elevation in a gravitational field is called potential energy (PE) and is expressed as:

$$\boxed{PE = mgz} \quad \text{(kJ)}$$

or, *on a unit mass basis*:

$$\boxed{pe = gz} \quad \text{(kJ/kg)}$$

where:
g: The gravitational acceleration.
z: The elevation of the center of gravity of a system relative to some reference level.

The magnetic, electric, and surface tension effects are significant in some specialized cases only and are usually ignored.
In the absence of such effects, the total energy of a system consists of the kinetic, potential, and internal energies and is expressed as:

$$\boxed{E = U + KE + PE} \quad \text{(kJ)}$$

$$\boxed{E = U + m\frac{V^2}{2} + mgz} \quad \text{(kJ)}$$

or, *on a unit mass basis*:

$$\boxed{e = u + ke + pe} \quad \text{(kJ/kg)}$$

$$\boxed{e = u + \frac{V^2}{2} + gz} \quad \text{(kJ/kg)}$$

Heat and Work:

Heat: defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.

That is, an energy interaction is heat only if it takes place because of a temperature difference. Then it follows that there cannot be any heat transfer between two systems that are at the same temperature.

As a form of energy, heat has energy units, kJ (or Btu) being the most common one. The amount of heat transferred during the process between two states (states 1 and 2) is denoted by $\mathbf{Q_{12}}$, or just $\mathbf{Q}$. Heat transfer per unit mass of a system is denoted $\mathbf{q}$ and is determined from

$$\boxed{q = \frac{Q}{m}} \quad \text{(kJ/kg)}$$

also:

$$\boxed{Q = \int_1^2 T dS}$$

Where:
T: Temperature
S: Entropy

Work: an energy interaction between a system and its surroundings.

As mentioned earlier, energy can cross the boundary of a closed system in the form of heat or work. Therefore, if the energy crossing the boundary of a closed system is not heat, it must be work. Heat is easy to recognize: Its driving force is a temperature difference between the system and its surroundings. Then we can simply say that an energy interaction that is not caused by a temperature difference between a system and its surroundings is work. More specifically, work is the energy transfer associated with a force acting through a distance. A rising piston, a rotating shaft, and an electric wire crossing the system boundaries are all associated with work interactions.

Work is also a form of energy transferred and, therefore, has energy units such as **(kJ)**.

The work done during a process between states 1 and 2 is denoted by **W_{12}**, or simply **W**. The work done per unit mass of a system is denoted by ***w*** and is expressed as

$$\boxed{w = \frac{W}{m}} \quad \text{(kJ/kg)}$$

The work done per unit time is called **power** and is denoted **$\dot{W}$** as shown in figure (24).
The unit of power is **(kJ/s)**, or **kW**

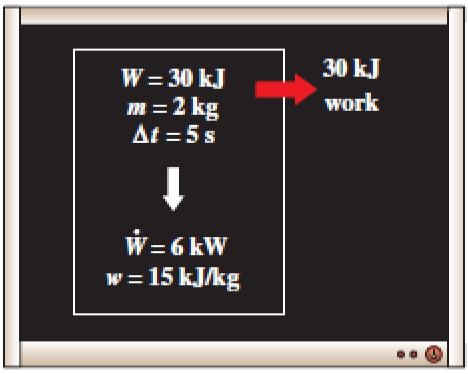


Figure (24) The relationships among w, W, and $\dot{W}$

Heat and **work** are **directional quantities**, and thus the complete description of a heat or work interaction requires the specification of both the magnitude and direction. One way of doing that is to adopt a sign convention. The generally accepted formal sign convention for heat and work interactions is as follows: **heat transfer to a system and work done by a system are positive; heat transfer from a system and work done on a system are negative.** Figure (25) show sign heat and work

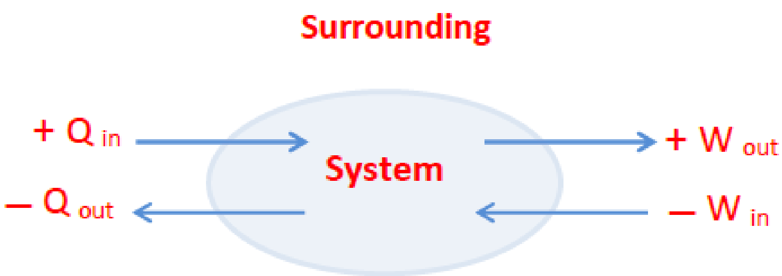


Figure (25) Sign heat and work

Consider the gas enclosed in the piston–cylinder device shown in Figure (26). The initial pressure of the gas is **(P)**, the total volume is **(V)**, and the cross sectional area of the piston is **(A)**. If the piston is allowed to move a distance **(ds)** in a quasi-equilibrium manner, the differential work done during this process is:

$$\boxed{\delta W = Fds = PAds = PdV}$$

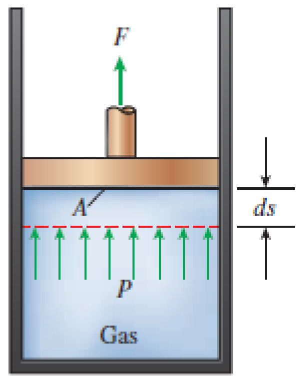


Figure (26) A gas does a differential amount of work δW as it forces the piston to move by a differential amount ds.

The total boundary work done during the entire process as the piston moves is obtained by adding all the differential works from the initial state to the final state, as shown in figure (27):

$$\boxed{W = \int_{1}^{2} PdV} \quad \text{(kJ)}$$

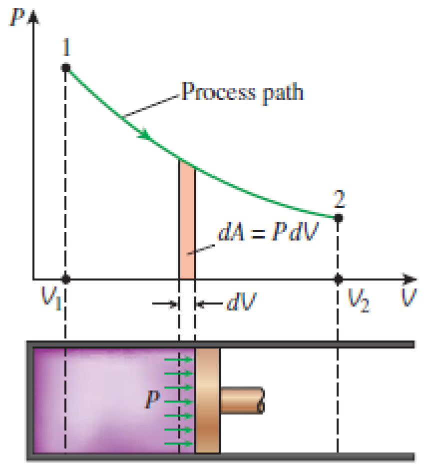


Figure (27) The area under the process curve on a P-V diagram represents the boundary work

Example: A frictionless piston–cylinder device contains (4.54 kg) of steam at (413.685 kPa) and volume (0.47 m^3/kg). Heat is now transferred to the steam at constant pressure until the volume reaches to (0.522 m^3/kg). If the piston is not attached to a shaft and its mass is constant, determine the work done by the steam during this process.

Solution:

P_1= 413.685 kPa $\Rightarrow$ P_1= 413.685 $\times$1000 = 413685 Pa

v_1= 0.47 m^3/kg $\Rightarrow$ $V_1 = mv_1$ = 4.54 $\times$ 0.47 $\Rightarrow$ V_1= 2.1338 m^3

v_2= 0.522 m^3/kg $\Rightarrow$ $V_2 = mv_2$ = 4.54 $\times$ 0.522 $\Rightarrow$ V_2= 2.3699 m^3

$$\boxed{W = \int_1^2 PdV} \Rightarrow W = \int_{V1}^{V2} PdV \Rightarrow W = P\int_{V1}^{V2} dV$$

$$W = P[V]_{V1}^{V2} \Rightarrow W = P(V_2 - V_1)$$

$$W = 413685(2.3699 - 2.1338)$$

$$W = 413685(0.2361)$$

$$W = 97671.0285 \text{ J}$$

Example: A gas in a piston–cylinder assembly undergoes an expansion process at constant pressure. The initial pressure is (3 bar), the initial volume is (0.1 m^3), and the final volume is (0.2 m^3). Determine the work for the process.

Solution:

$P_1 = P_2 = 3$ bar $\Rightarrow$ $P_1 = 3\times100000 = 300000$ Pa

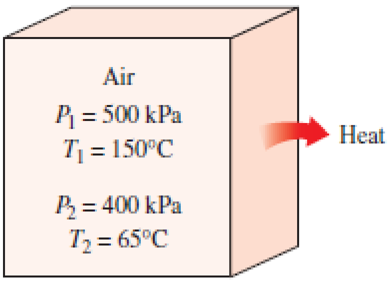
$V_1 = 0.1\ m^3$, $V_2 = 0.2\ m^3$

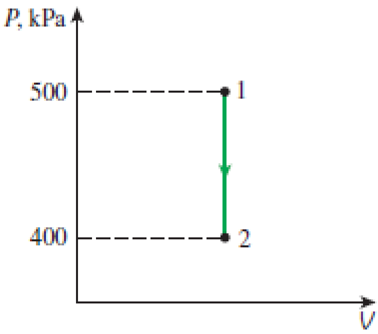
$$\boxed{W = \int_1^2 P dv} \qquad \boxed{W = P\int_{V1}^{V2} dv} \qquad \boxed{W = P\int_{V1}^{V2} dv}$$

$$W = P[V]_{V1}^{V2} \Rightarrow W = P(V_2 - V_1) \Rightarrow W = 300000(0.2-0.1)$$

$$W = (300000)(0.1) \Rightarrow W = 30000\ \text{J}$$

Example: A rigid tank contains air at (500 kPa) and (150 ^oC). As a result of heat transfer to the surroundings, the temperature and pressure inside the tank drop to (65 ^oC) and (400 kPa), respectively. Determine the work done during this process.





Solution:

$$W = \int_1^2 P \cancel{dV}^{\,0} = 0$$

Example: A fluid at a pressure of (3 bar), and with a specific volume of (0.18 m^3/kg), contained in a cylinder behind a piston expands reversibly to a pressure of (0.6 bar) according to a law, $P = C/v^2$, where C is a constant. Calculate the work done by the fluid on the piston.

Solution:

P_1= 3 bar ⇒ P_1= 3×100000=300000 Pa

P_2= 0.6 bar ⇒ P_2= 0.6×100000=60000 Pa

v_1= 0.18 m^3/kg

$$P = \frac{C}{v^2} \Rightarrow C = P_1 v_1^2 \Rightarrow C = (300000)(0.18)^2 = 9720$$

$$v_2^2 = \frac{C}{P_2} \Rightarrow v_2^2 = \frac{C}{P_2} \Rightarrow v_2^2 = \frac{C}{60000} = 0.162 \Rightarrow v_2 = 0.4025\,\mathrm{m^3/kg}$$

$$\boxed{w = \int_1^2 Pdv} \Rightarrow w = \int_{v1}^{v2} \frac{C}{v^2} dv \Rightarrow w = C \int_{v1}^{v2} \frac{dv}{v^2}$$

$$w = 9720 \int_{0.18}^{0.4025} \frac{dv}{v^2} \Rightarrow w = 9720 \left[-\frac{1}{v} \right]_{0.18}^{0.4025} \Rightarrow w = -9720 \left[\frac{1}{v} \right]_{0.18}^{0.4025}$$

$$w = -9720 \left[\frac{1}{0.4025} - \frac{1}{0.18} \right]$$

$$w = 29850.932 \text{ J/kg}$$

$$w = 29.8509 \text{ kJ/kg}$$

H.W: The properties of a closed system change following the relation between pressure and volume as PV=3, where (P) is in bar, (V) is in m^3. Calculate the work done when the pressure increases from (1.5 bar) to (7.5 bar).