Work & Heat

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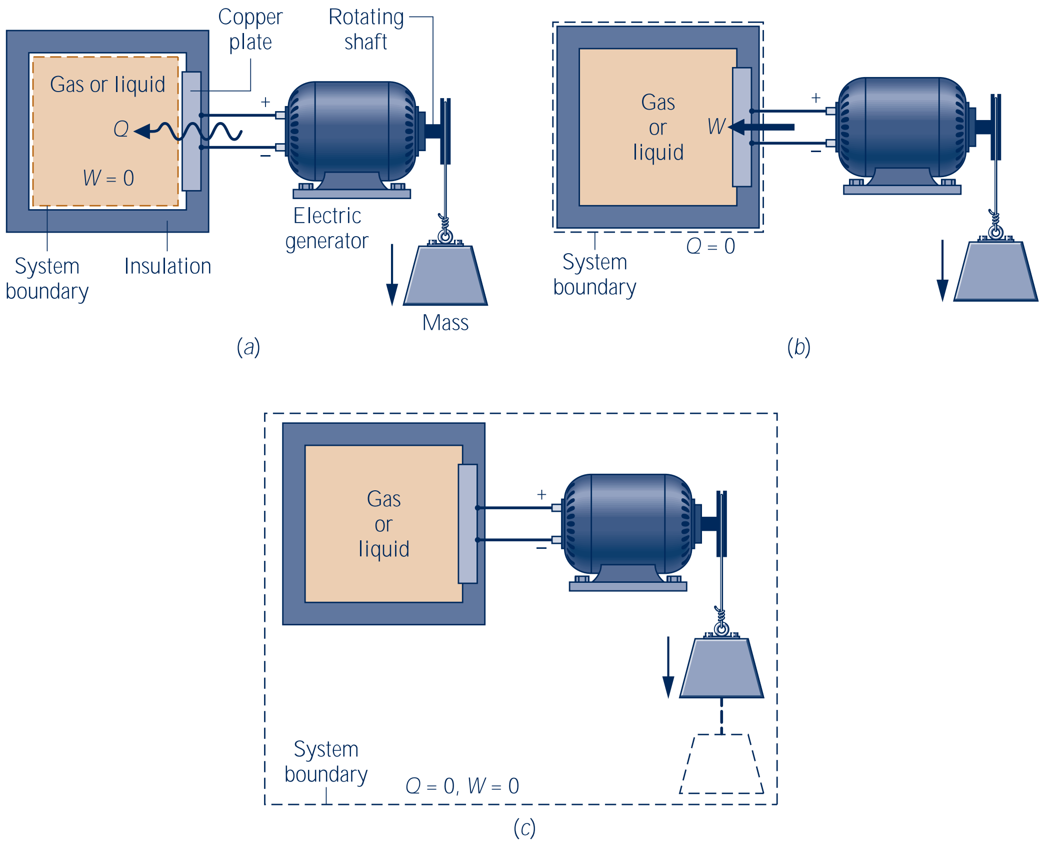
Thermodynamic Work & Heat

Work
is performed by a system on its surroundings during a process if the only effect external to the system could be the raising of a weight.

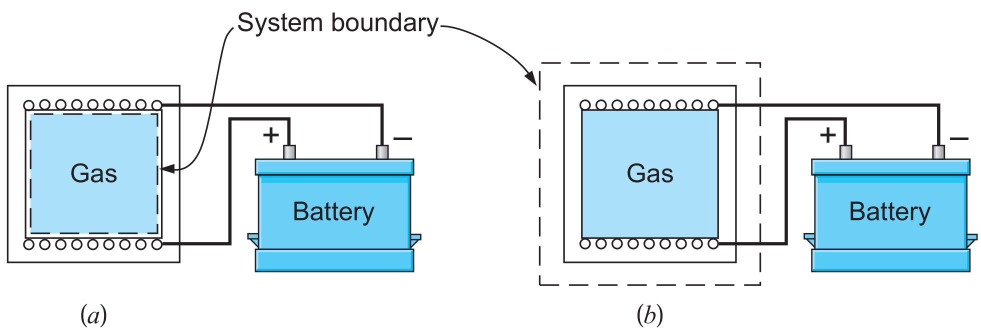
Heat
is energy in transition from one body or system to another solely because of a temperature difference between the systems.

- The magnitudes of heat and work depend on the arbitrary selection of boundaries between interacting systems. These are not properties, and it is improper to speak of heat or work 'contained' in a system.
- Heat and work transfers are the only mechanisms by which energy can be transferred across the boundary of a closed system.



T010

Comparison of Heat & Work

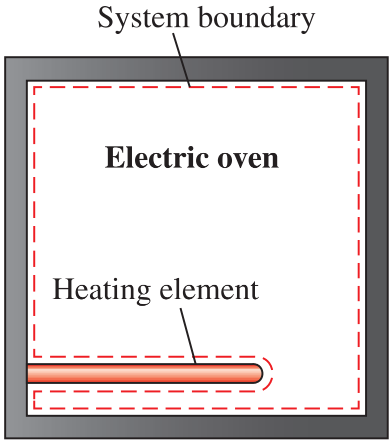


T023

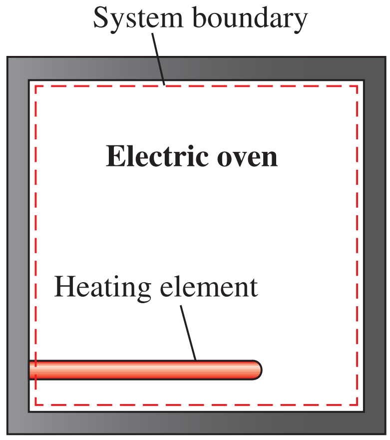
An example of the difference between heat and work.

- Heat and work are both transient phenomena. Systems never possess heat or work.
- Both heat and work are boundary phenomena. Both are observed only at the boundary of the system, and both represent energy crossing the boundary.
- Both heat and work are path functions and inexact differentials.

An energy transfer can be heat or work, depending on system selection.



T081

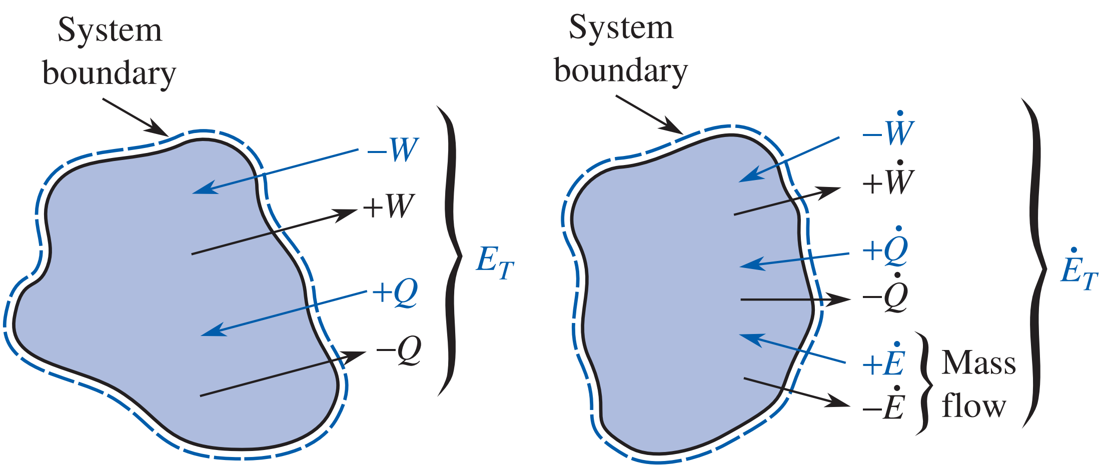


T080

Energy generated in the heating element is transferred due to temperature difference between the heating element and the air inside oven ⇝ heat interaction

Energy transfer is not caused by temperature difference between the oven and the surroundings, rather is caused by electrons crossing boundary ⇝ work interaction

Work & Heat: Sign-Convention



T004 (a) Closed system (b) Open system

General Work Expressions

- Thermodynamic work is generalized to include all forms of work, and a generalized force F_k and generalized displacement $d\delta_k$ can be identified:

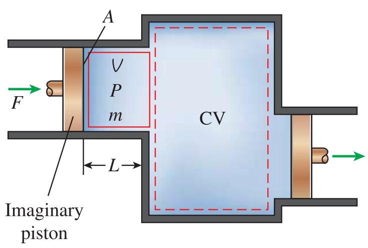
$$W_k = \int F_k \, d\delta_k$$

- A general system could have many possible work modes, so a general work expression is:

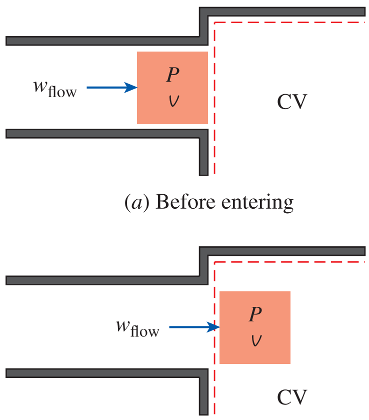
$$W = W_s + W_b + W_f + \cdots = \sum W_k$$

  - $W_s \equiv$ shaft work: rotary useful work
  - $W_b \equiv$ boundary work: due to expansion/compression of system
  - $W_f \equiv$ flow work: interaction required for the mass to cross CS
  - $W_I \equiv$ electrical work
  - . . .

Flow Work



T1360



(a) Before entering

(b) After entering

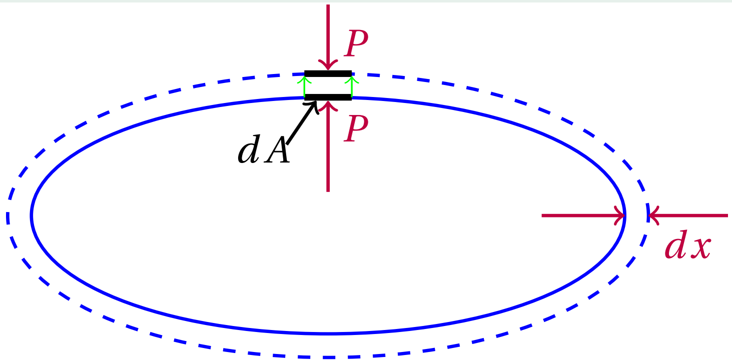
T1361

Flow work, W_f is associated with mass crossing the CS, and represents the work that must be done by fluid outside the control volume to push $\dot{m}$ across the control volume boundary.

- $W_{f,i} = -(PA_i)L_i$: as displacement against PA_i
- $W_{f,e} = +(PA_e)L_e$: as displacement along PA_e

$\Rightarrow$ $W_f = W_{f,i} + W_{f,e} = -P(V_i - V_e)$

Moving System Boundary Work



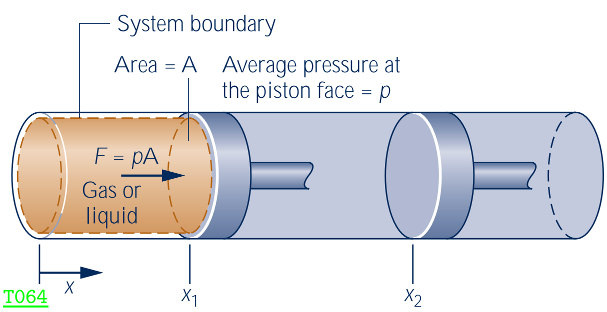
T1362

- Force acting on an element dA of CS $= PdA$
- Work performed as dA recedes by a distance $dx = (PdA)dx$
- Work done $= \delta W_b = \int\int_A PdAdx = P\int\int_A dAdx = PdV$

$$\delta W_b = PdV \;\Rightarrow\; W_b = \int_1^2 PdV$$

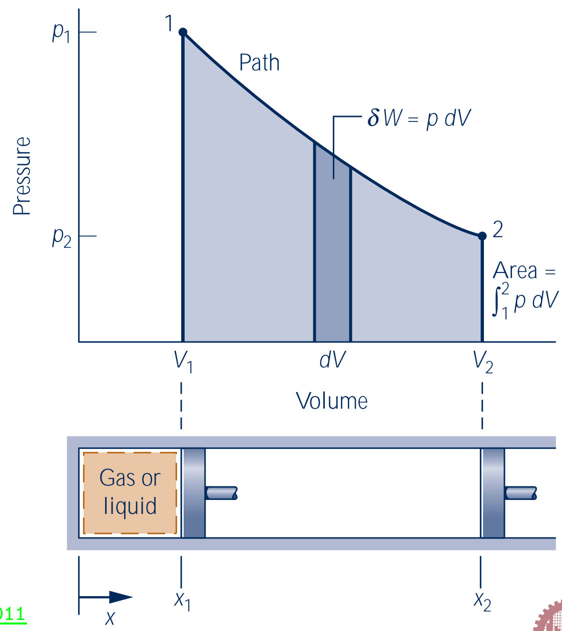
dV is the change in volume represented by the volume enclosed between the full and the broken curves in figure.

Expansion & Compression Work

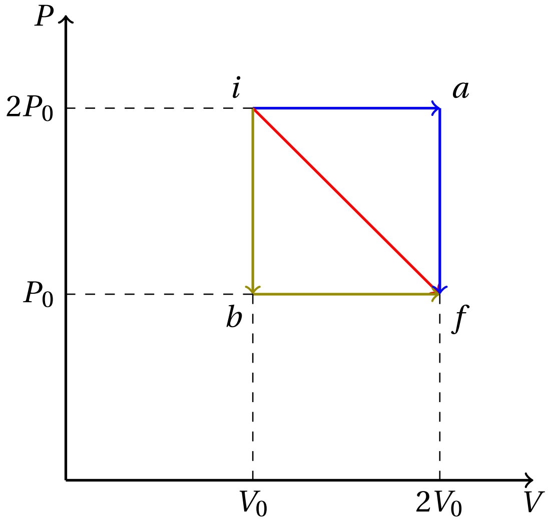


T064

$$\longrightarrow \delta W = Fdx$$
$$= PAdx$$
$$= PdV$$
$$\Longrightarrow W_{12} = \int PdV$$



T011

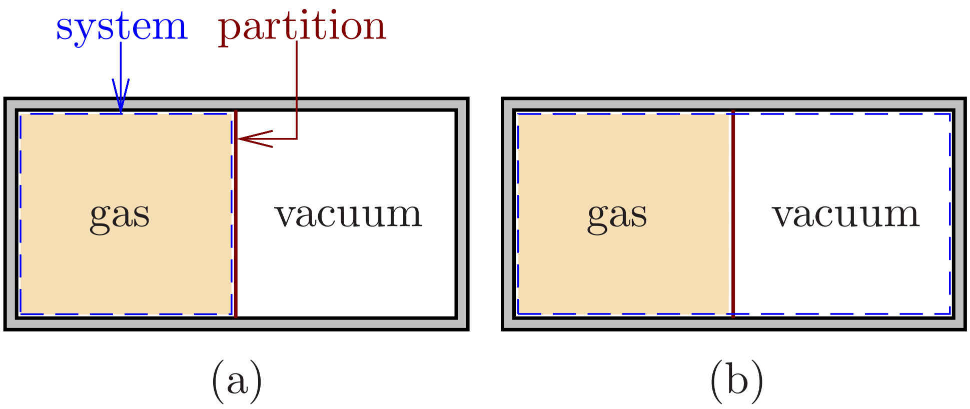


T1363

$$W_{i\to f} = \begin{cases} W_{if} & = \frac{3}{2} P_o V_o \\ W_{ia} + W_{af} & = 2P_o V_o + 0 = 2P_o V_o \\ W_{ib} + W_{bf} & = 0 + P_o V_o = P_o V_o \end{cases}$$

Work done by a system depends not only on the initial and final states but also on the intermediate states $\Longrightarrow$ path function.

Process involving a change in volume with $W = 0$, if partition separating the gas from vacuum is ruptured.



T022

- Work can only be identified at the system boundary.

(a) If the gas is the system: there is a change in volume, but no resistance at the system boundary as the volume increases, and so no work is done in the process of filling the vacuum.

(b) If gas & vacuum space is considered as system: no work is done as no work can be identified at the system boundary.