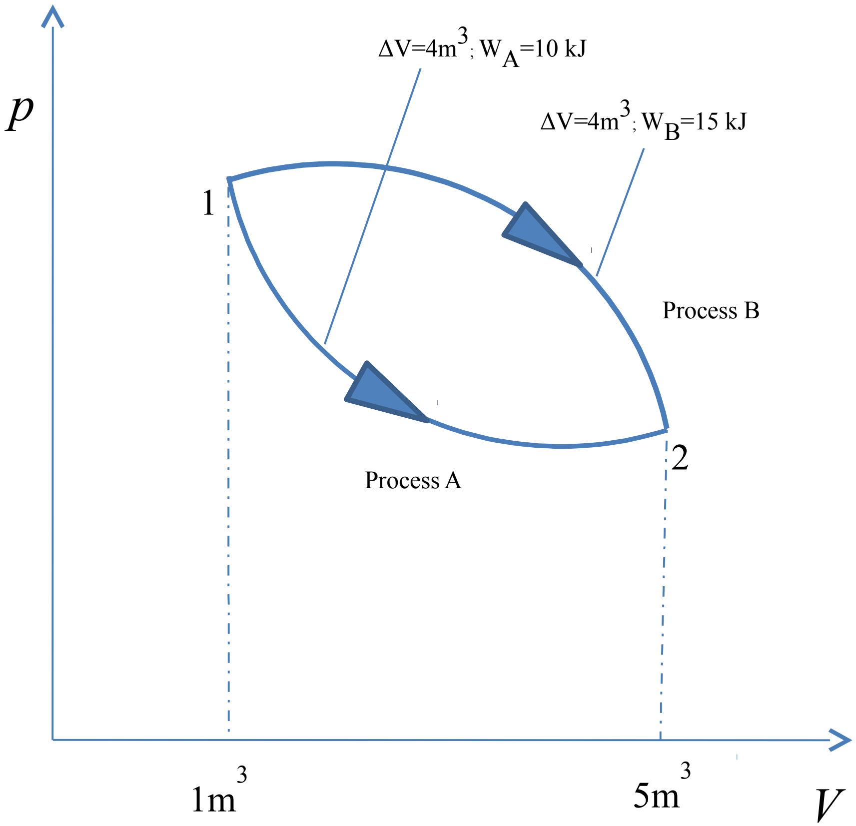
- Recap: Lecture 4: 13th January 2014, 1130-1230 hrs.
  - Energy transfer mechanisms
    - Heat transfer, adiabatic process
    - Work
    - Path and point functions

Path and Point functions

- Path functions
  - Have inexact differentials, sometimes designated by symbol, δ or $đ$
  - Eg. δQ or $đQ$ and δW or $đW$ instead of dQ and dW
- Point functions
  - Have exact differentials, designated by symbol, d
  - Eg. dP, dV, dT

Path and Point functions



$$\int_1^2 dV = V_2 - V_1 \text{ but, } \int_1^2 \delta W \neq W_2 - W_1$$

$\oint$ of a property is zero

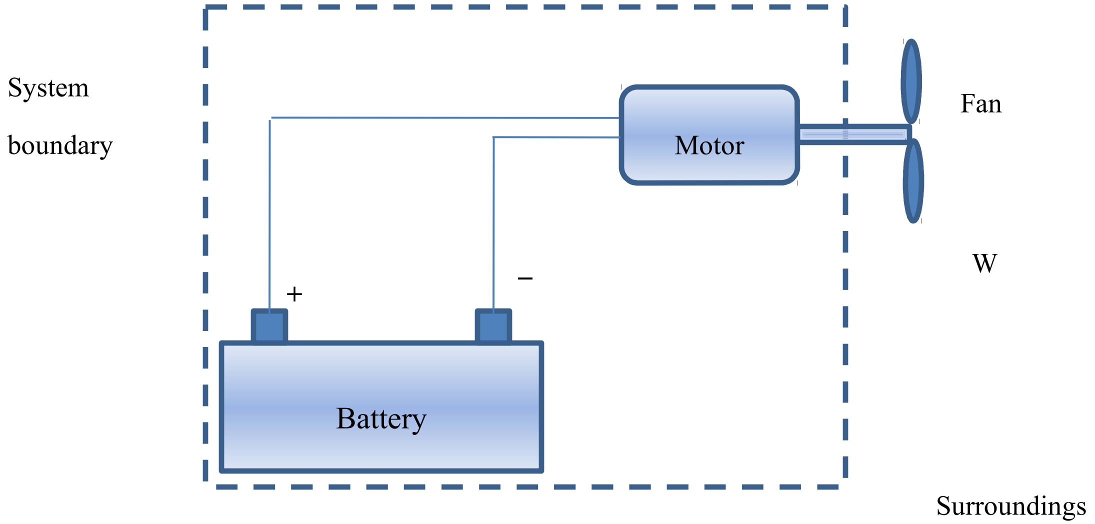
Properties are point functions,

eg. P, T, v, h (enthalpy), s (entropy), c_p,c_v etc.

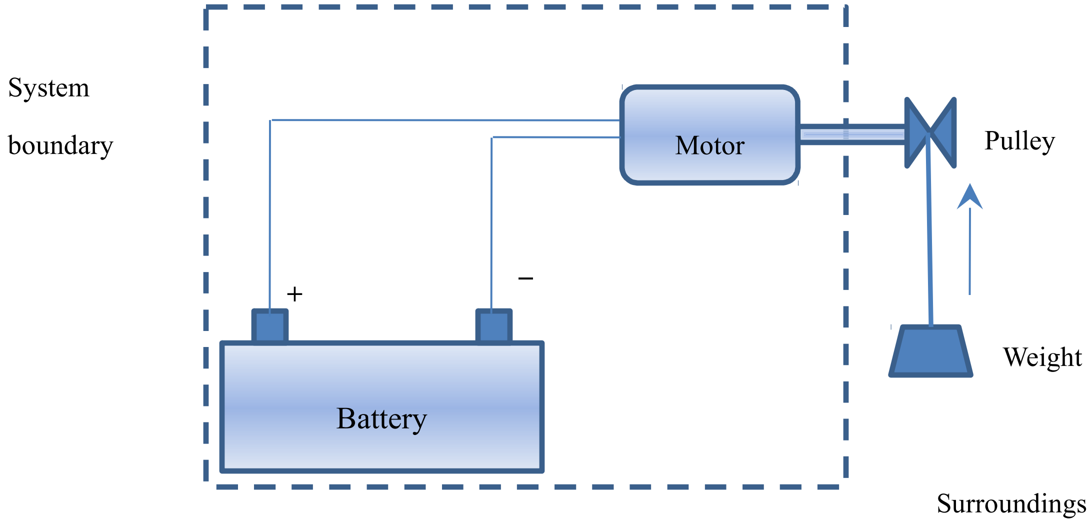
Work

- Work done by a system on its surroundings during a process is defined as that interaction whose sole effect external to the system could be viewed as the raising of a mass through a distance against gravity.

Work



Work

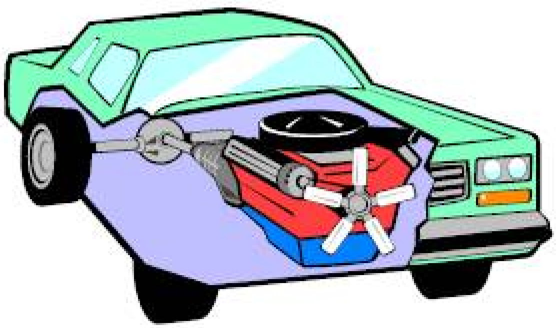


System
boundary
Motor
Pulley
+
−
Weight
Battery
Surroundings

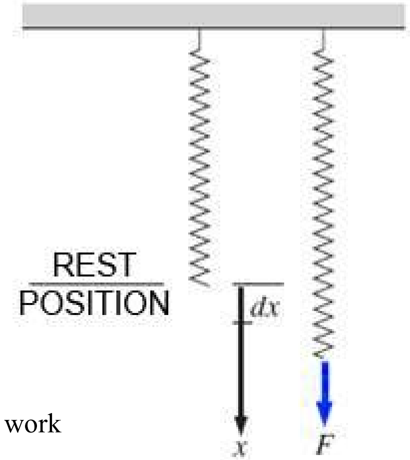
Work

- Examples:
- PdV: displacement work
- Electrical work: heating of a resistor
- Shaft work: rotation of a shaft
- Paddle wheel work
- Spring work
- Stretching of a liquid film

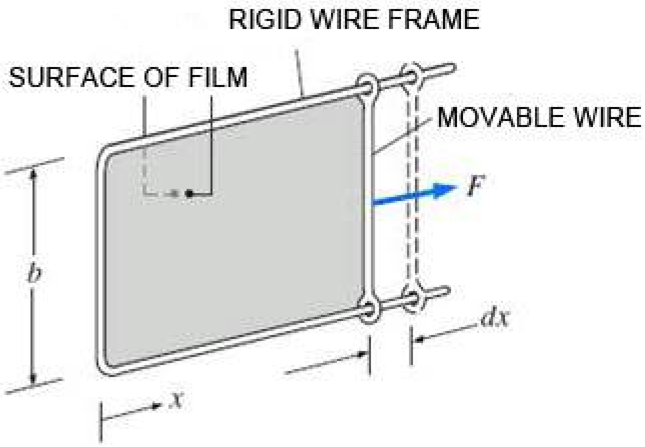
Work



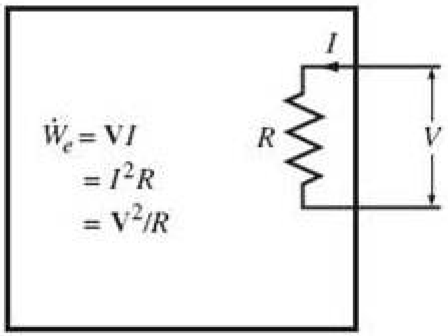
Shaft work: rotation of a shaft



Spring work



Stretching of a liquid film

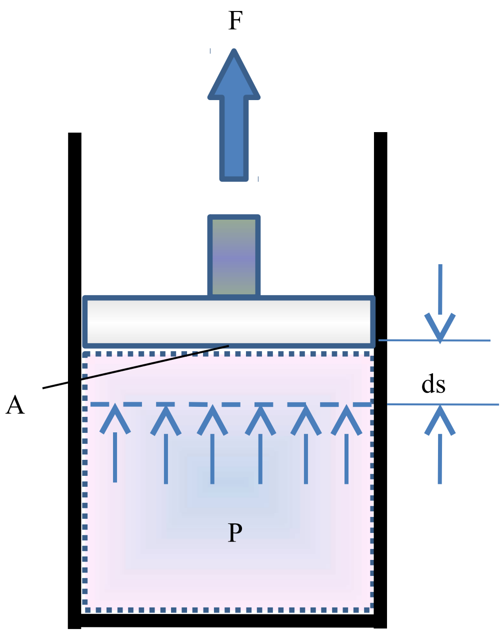


Electrical work: heating of a resistor

Displacement work

- Moving boundary or displacement work is of significant interest to engineers.
- Many engineering systems generate useful work output by this mode.
- Examples: automobile engines, steam engines, pumps etc.

Displacement work

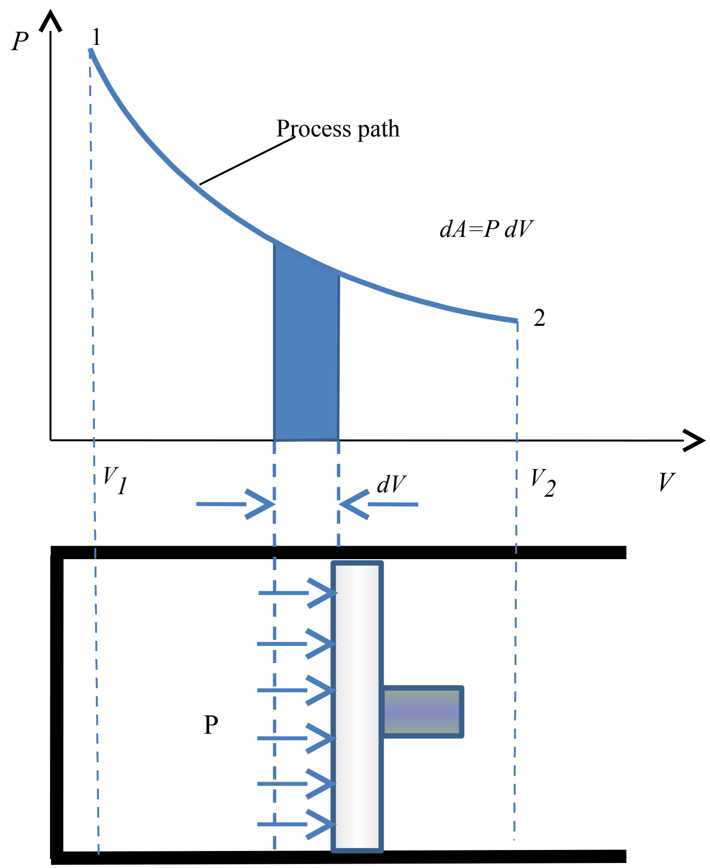


A gas does a differential amount of work δW_b as it forces the piston to move by a differential amount ds

$$\delta W_b = F\,ds = PA\,ds = P\,dV$$

$$W_b = \int_1^2 P dV \qquad (kJ)$$

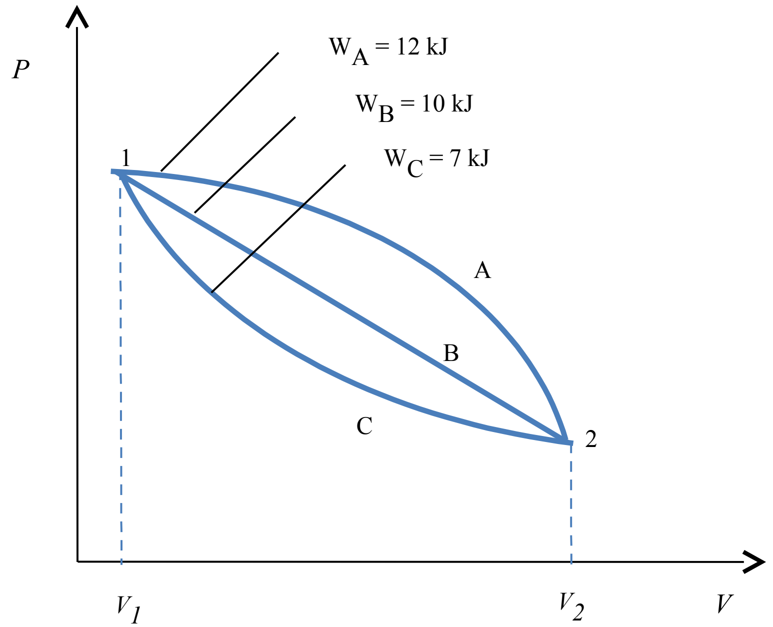
Displacement work



$$Area = A = \int_{1}^{2} dA = \int_{1}^{2} P dV$$

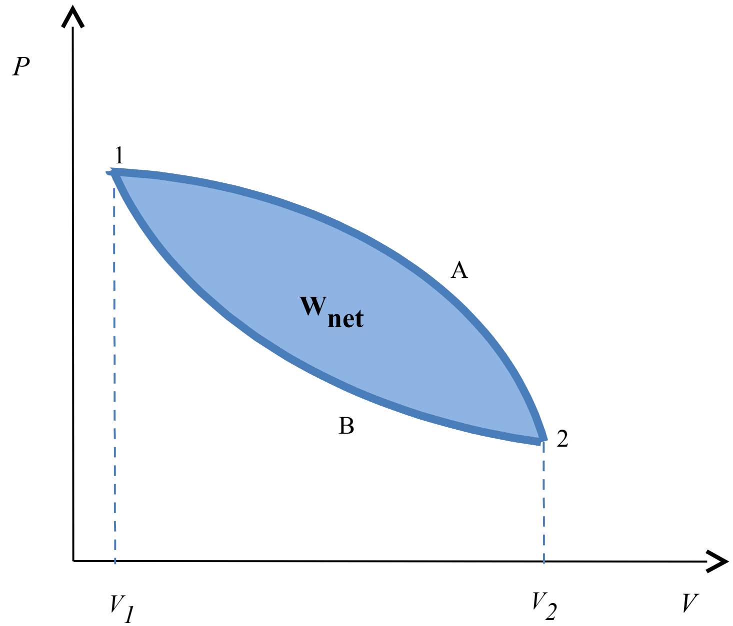
The area under the process curve on a P-V diagram is equal, in magnitude, to the work done during a quasi-equilibrium expansion or compression process of a closed system.

Displacement work



The boundary work done during a process depends on the path followed as well as the end states.

Displacement work



The net work done during a cycle is the difference between the work done by the system and the work done on the system.

Displacement work

- Displacement work during various processes:

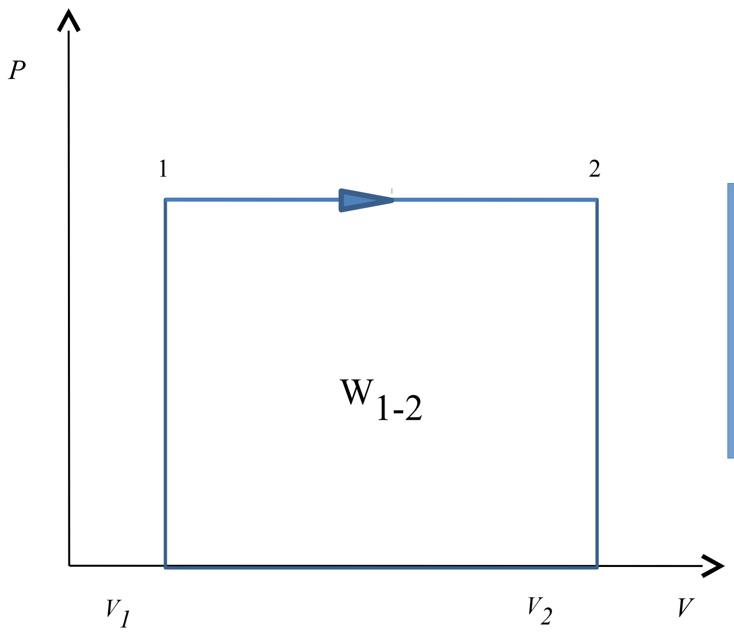
  Constant pressure process

  Constant volume process

  PV= constant

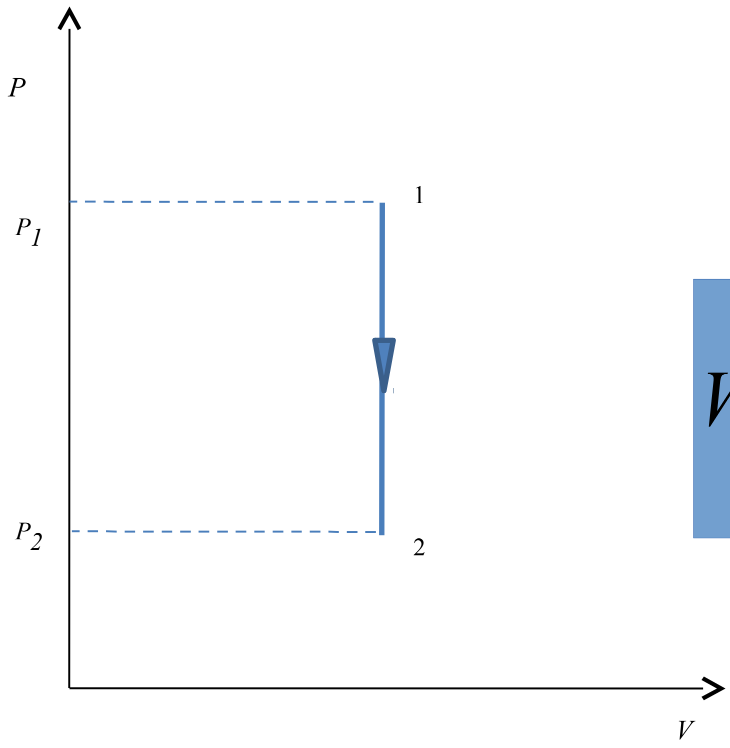
  Polytropic process, PV^n = constant

Constant pressure process



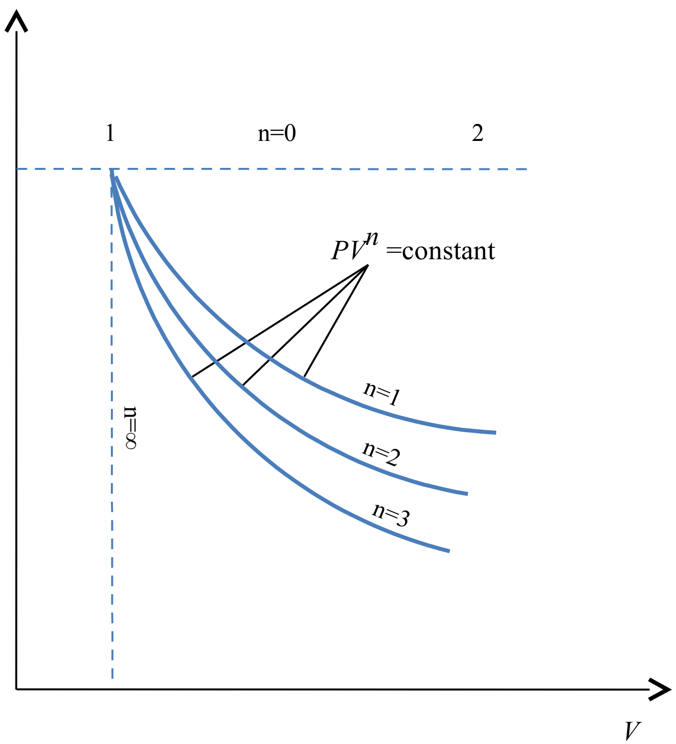
$$W_{1-2} = \int_{V_1}^{V_2} p\,dV = p(V_2 - V_1)$$

Constant volume process



$$W_{1-2} = \int_{V_1}^{V_2} p\,dV = p(V_2 - V_1) = 0$$

PV^n = constant (Polytropic processes)



$$W_{1-2} = \int_1^2 P\,dV = \int_1^2 C V^{-n}\,dV$$

$$(\because PV^n = C)$$

Now, $P_1 V_1^{\,n} = P_2 V_2^{\,n} = C$

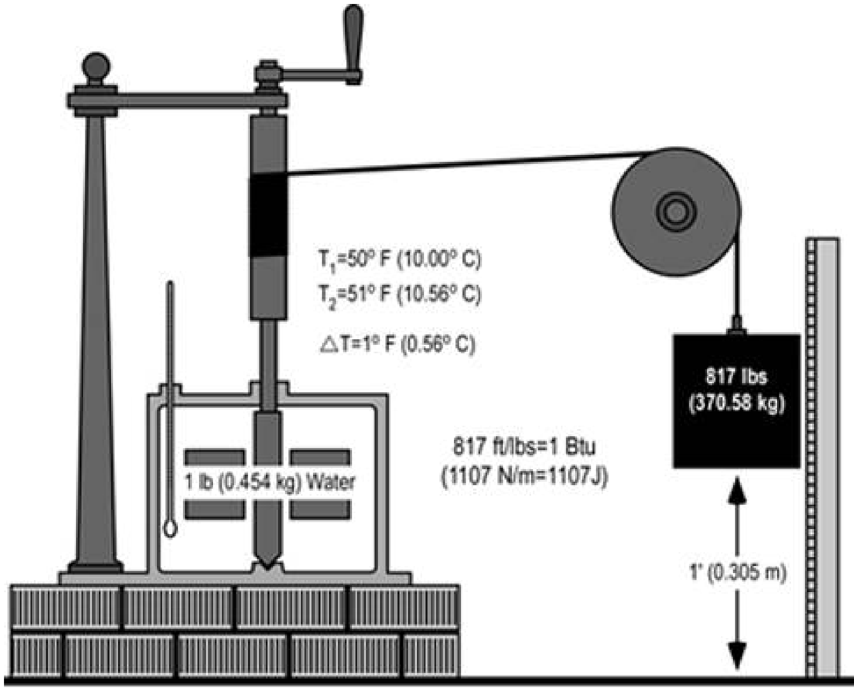
$$W_{1-2} = C\,\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1} = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

Joule’s experiment

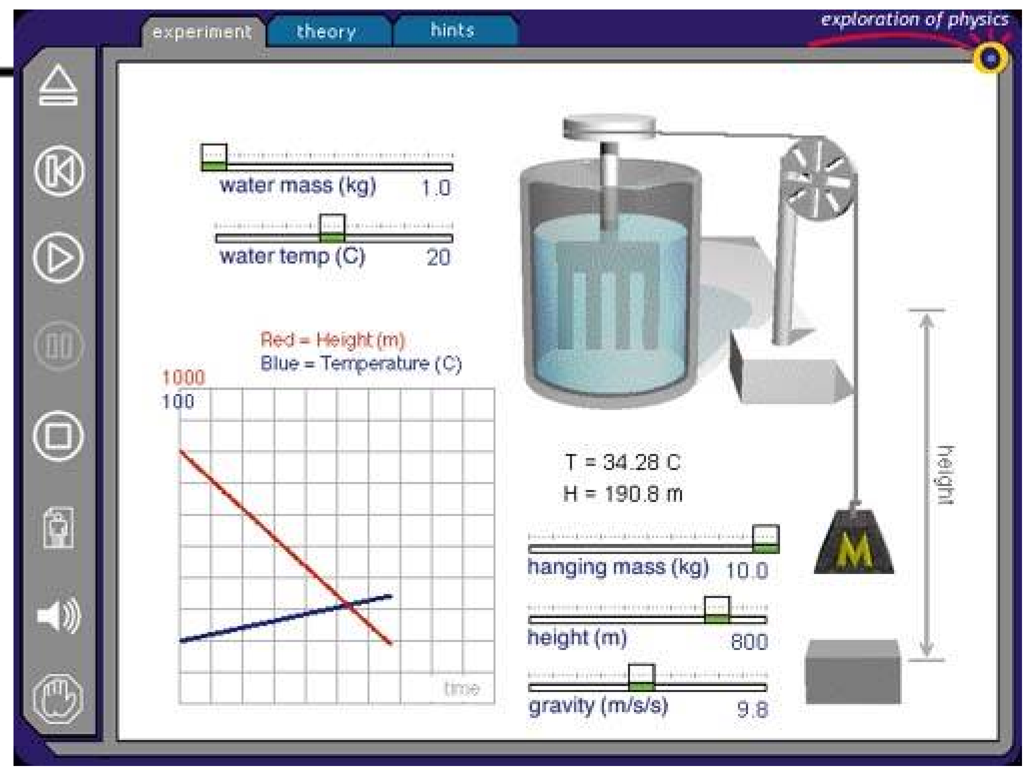
- Joule’s experiment (1840-1849) to investigate the equivalence of heat and work.
- Prior to Joule, heat was considered to be a invisible fluid known as caloric and flows from a body of higher caloric to one with a lower caloric.
- Caloric theory of heat
- Joule’s experiment laid the foundation of the first law of thermodynamics.

Joule's experiment

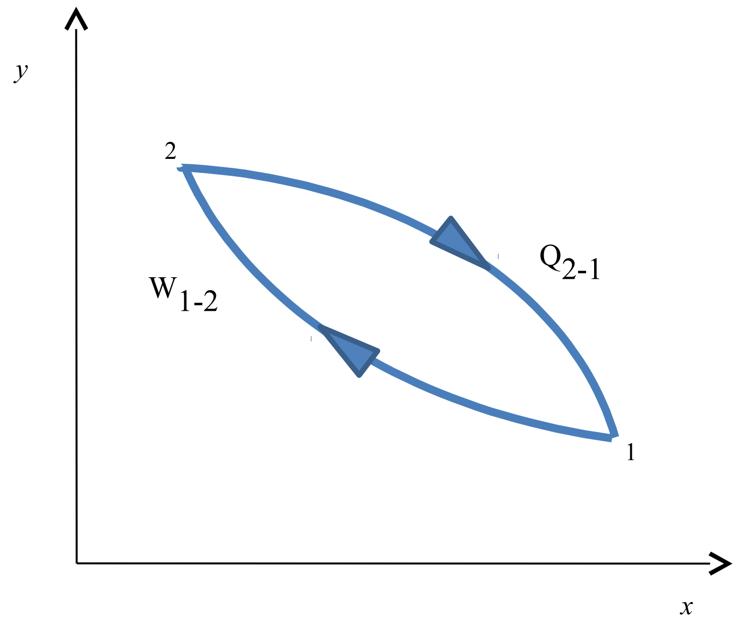
- Work, W_{1-2} done on the system can be measured by the fall of the weight.
- The system temperature rises as work is done on the system.
- Let the insulation now be removed.
- The system reaches its initial state by heat transfer across the system boundaries.
- Therefore the work done is proportional to the heat transfer.
- The constant of proportionality is the Joule's equivalent.



1107 J is quite close to the currently accepted conversion value of 1 Btu=1055 J



Joule's experiment



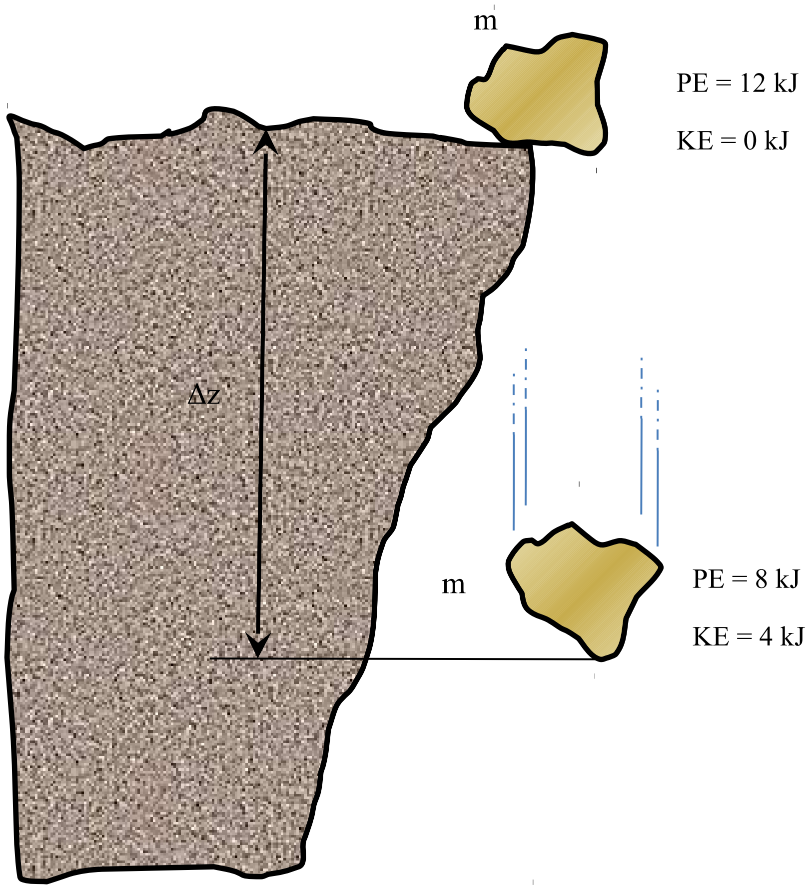
The cycle consists of two processes, one an adiabatic work transfer followed by heat transfer

$$\left(\sum W\right)_{cycle} = J\left(\sum Q\right)_{cycle} \quad or \quad \oint dW = J\oint dQ$$

First law of thermodynamics

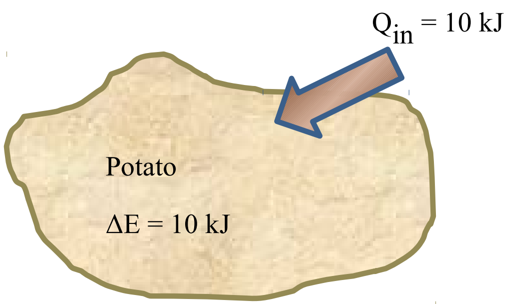
- Conservation of energy principle
- Energy can neither be created nor destroyed, it can only be converted from one form to another.
- For all adiabatic processes between two specified states of a closed system, the net work done is the same regardless of the nature of the closed system and the details of the process.

First law of thermodynamics

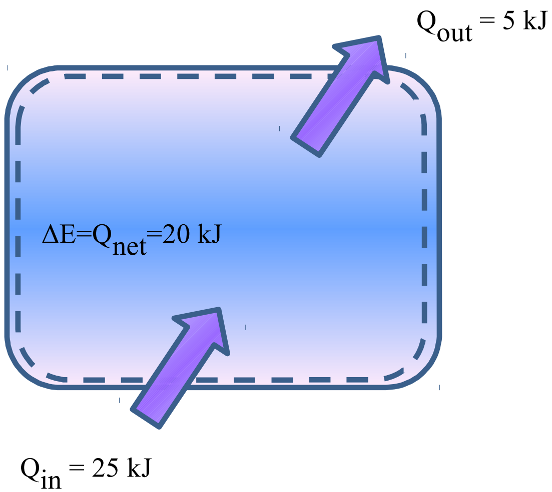


Energy cannot be created or destroyed; it can only change forms

First law of thermodynamics

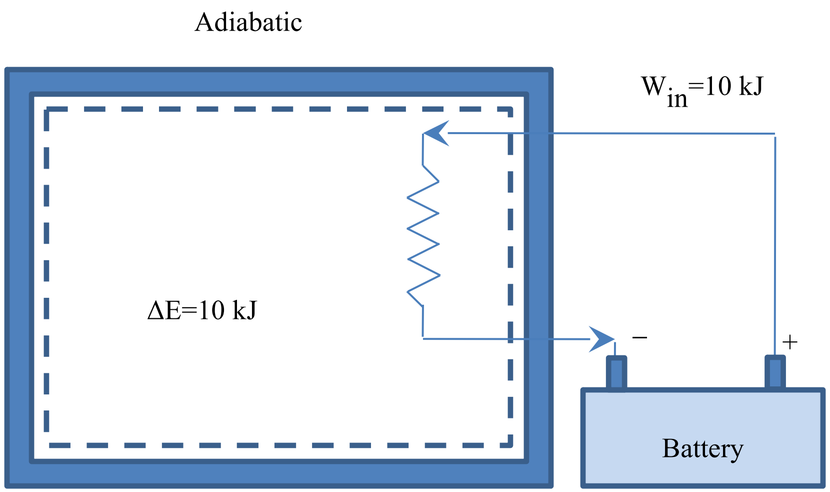


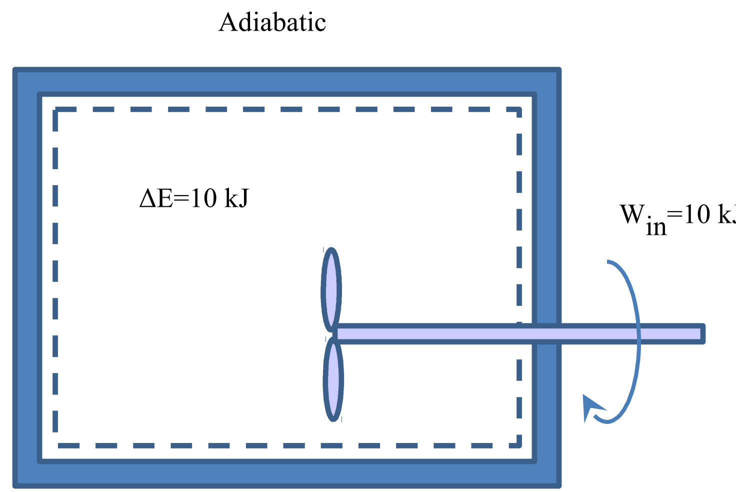
The increase in the energy of a potato in an oven is equal to the amount of heat transferred to it.



In the absence of any work interactions, the energy change of a system is equal to the net heat transfer.

First law of thermodynamics





- The work done on an adiabatic system is equal to the increase in energy of the system.
- Change in total energy during an adiabatic process is equal to the net work done.

Energy balance

- The net change (increase or decrease) in the total energy of a system during a process is equal to the difference between the total energy entering and total energy leaving the system.

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

or,

$$E_{in} - E_{out} = \Delta E_{system}$$

Energy change of a system

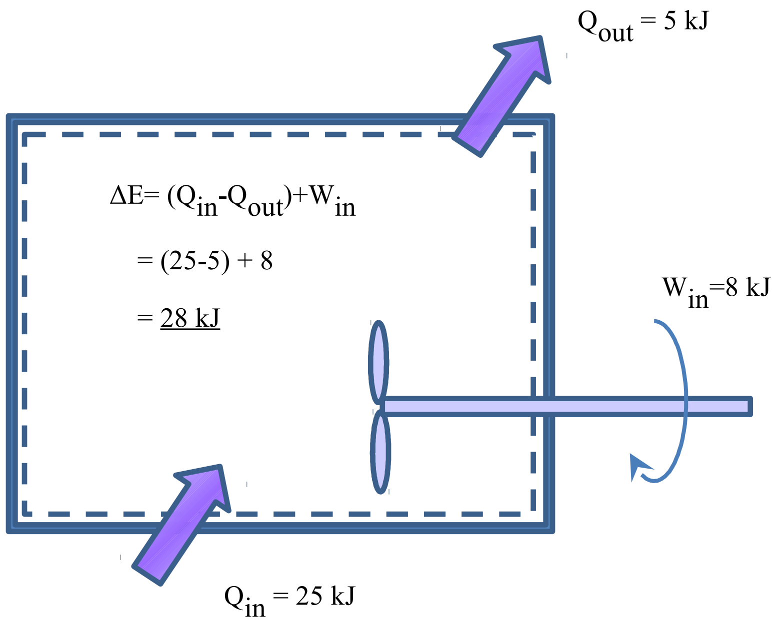
- Energy change = Energy at the final state – Energy at the initial state
- In the absence of electrical, magnetic or surface tension effects,

$$\Delta E = \Delta U + \Delta KE + \Delta PE$$

- Thus, for stationary systems,

$$\Delta E = \Delta U$$

Energy change of a system



The energy change of a system during a process is equal to the net work and heat transfer between the system and its surroundings

Energy transfer mechanisms

- Energy can be transferred to or from a system by three mechanisms
  - Heat
  - Work
  - Mass flow

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,out}) = \Delta E_{system}$$

Energy transfer mechanisms

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic} \\ \text{potential etc. energies}}} \quad \text{(kJ)}$$

or, in the rate form, as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic} \\ \text{potential etc. energies}}} \quad \text{(kW)}$$

For constant rates, the total quantities during a time interval t are related to the quantities per unit time as

$$Q = \dot{Q}\,\Delta t, \quad W = \dot{W}\,\Delta t, \quad \text{and} \quad \Delta E = (dE/dt)\,\Delta t \quad \text{(kJ)}$$

First law for a cycle

- For a closed system undergoing a cycle, the initial and final states are identical.
- Therefore, $\Delta E_{system} = E_2 - E_1 = 0$
- The energy balance for a cycle simplifies to

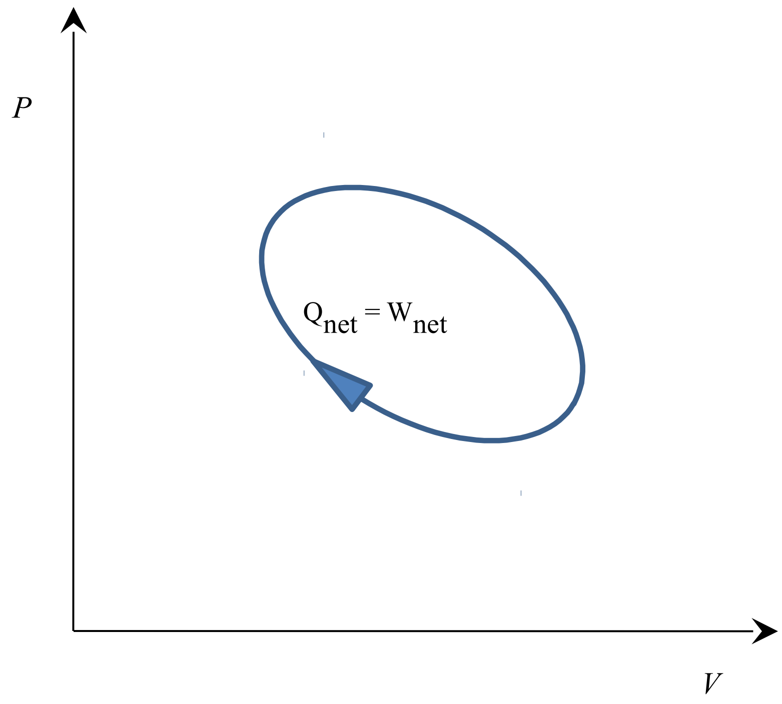
$$E_{in} - E_{out} = 0 \text{ or } E_{in} = E_{out}$$

First law for a cycle

- A closed system does not involve any mass flow across its boundaries, the energy balance for a cycle can be expressed in terms of heat and work interactions as

$$W_{net,out} = Q_{net,in} \quad \text{or} \quad \dot{W}_{net,out} = \dot{Q}_{net,in}$$

First law for a cycle



For a cycle, $\Delta E = 0$, thus $Q_{net} = W_{net}$