Introduction to Aerospace Propulsion

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Lecture No - 6

In this lecture ...

- Specific heat
  - At constant pressure and constant volume
- Heat transfer
  - Meaning of heat transfer
  - Types of heat transfer
- Work
  - Thermodynamic meaning of work
  - Different types of work

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Specific heats

- It takes different amounts of energy to raise the temperature of identical masses of different substances by one degree.
- Therefore, it is desirable to have a property that will enable us to compare the energy storage capabilities of various substances.
- This property is the specific heat.

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Specific heats

- Specific heat is defined as the energy required to raise the temperature of a unit mass of a substance by one degree.
- In general, this energy depends on how the process is executed.
- There are two kinds of specific heats: specific heat at constant volume, *cv* and specific heat at constant pressure, *cp.*

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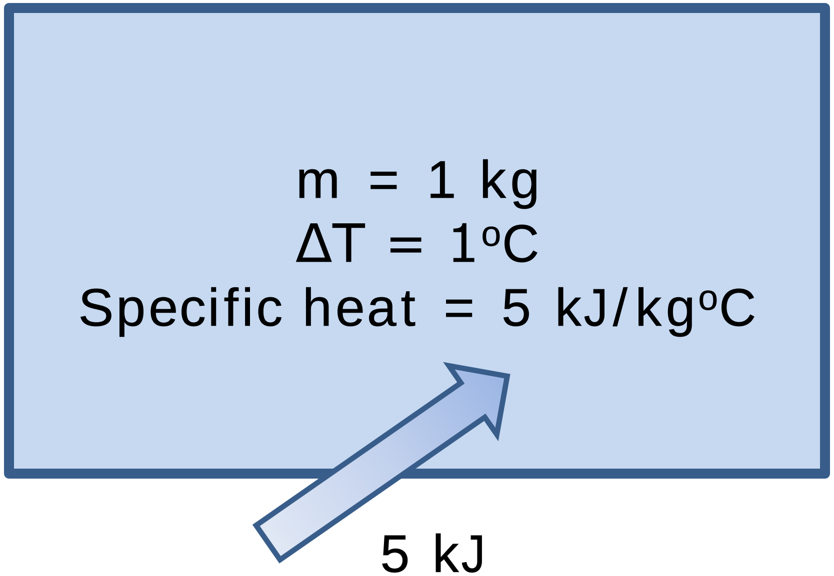
Specific heats



Specific heat is the energy required to raise the temperature of a unit mass of a substance by one degree in a specified way.

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Specific heat at constant volume

- Consider a fixed mass in a stationary closed system undergoing a constant-volume process
- The conservation of energy principle for this process can be expressed in the differential form as

$$\delta e_{in} - \delta e_{out} = du$$

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Specific heat at constant volume

- The left-hand side of this equation represents the net amount of energy transferred to the system.
- Thus,

$$c_v dT = du \quad \text{at constant volume}$$

$$\text{or, } c_v = \left(\frac{\partial u}{\partial T}\right)_v$$

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Specific heat at constant pressure

- Similarly, an expression for the specific heat at constant pressure, c_p can be obtained by considering a constant-pressure expansion or compression process.
- It yields,

$$c_p dT = dh \quad \text{at constant pressure}$$

$$\text{or, } c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

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Specific heats

- c_p and c_v are properties of a system.
- Are valid for any processes
- c_p is always > c_v
  - Because at constant pressure the system is allowed to expand and the energy for the expansion must also be supplied
- Specific heat of a substance change with temperature.

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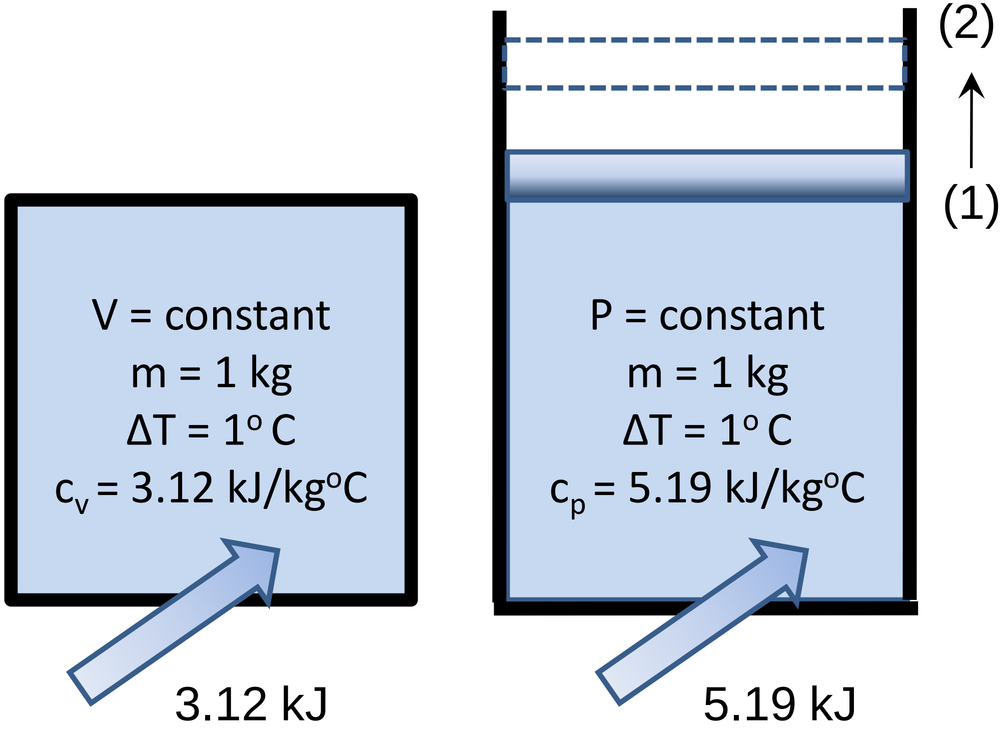
Specific heats



c_p is always > c_v

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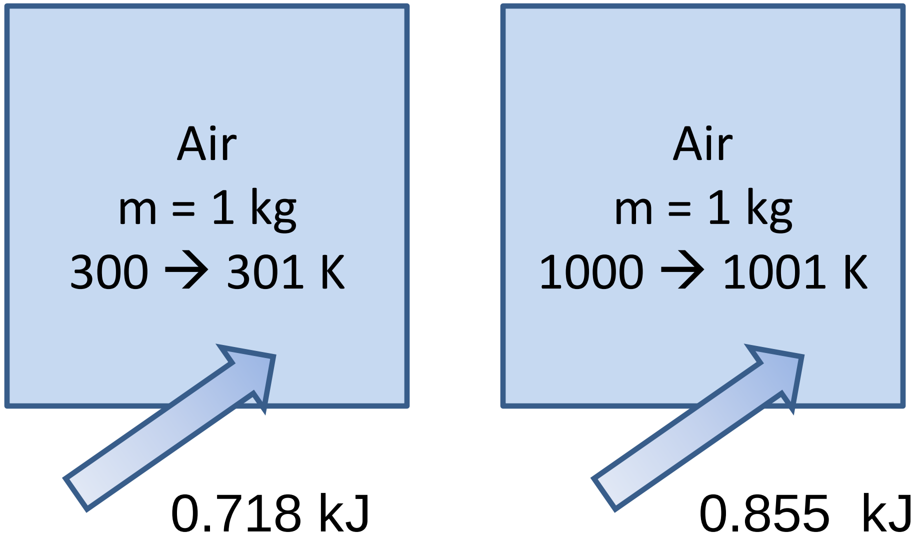
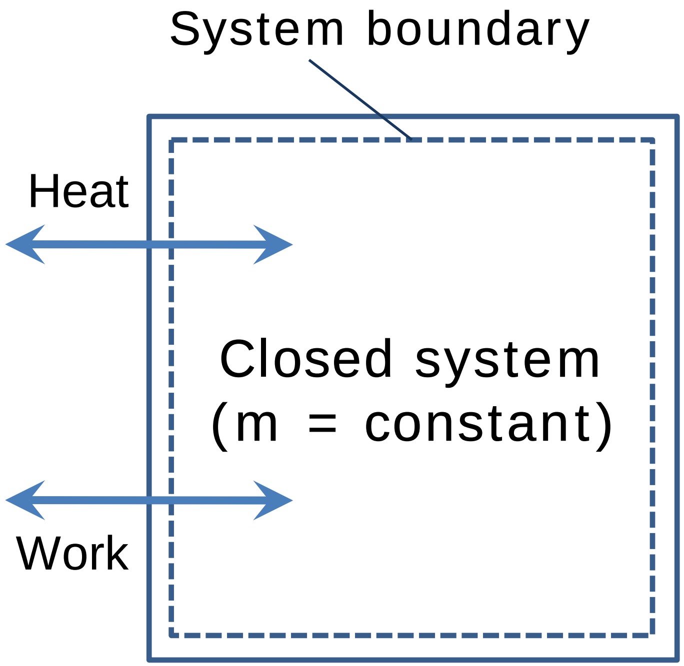
Specific heats



The specific heat of a substance changes with temperature.

Energy transfer mechanisms



Energy can cross the system boundaries of a closed system: heat and work

Energy transfer by heat

- Heat: the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference.
- Energy interaction is heat only if it takes place by virtue of temperature difference.
- Heat is energy in transition; it is recognised only as it crosses the system boundary.

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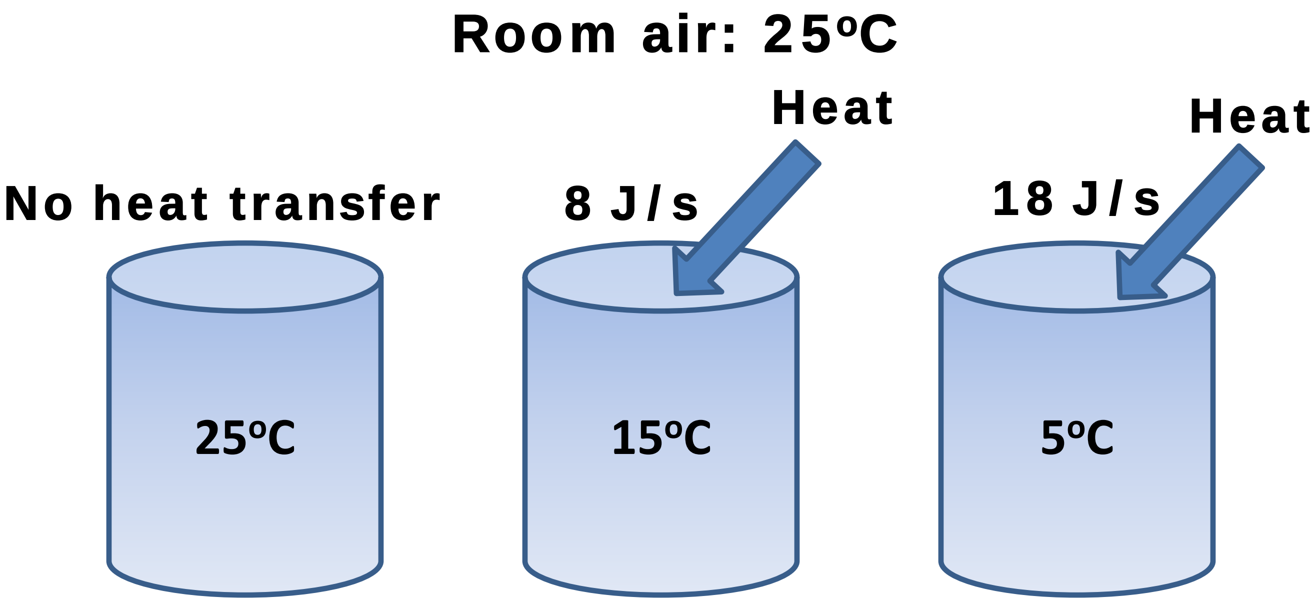
Energy transfer by heat



Temperature difference is the driving force for heat transfer. The larger the temperature difference, the higher is the rate of heat transfer.

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Energy transfer by heat

- In thermodynamics, heat refers to heat transfer.
- A process during which there is no heat transfer is called Adiabatic process.
- Heat transfer mechanisms:
  - Conduction
  - Convection
  - Radiation

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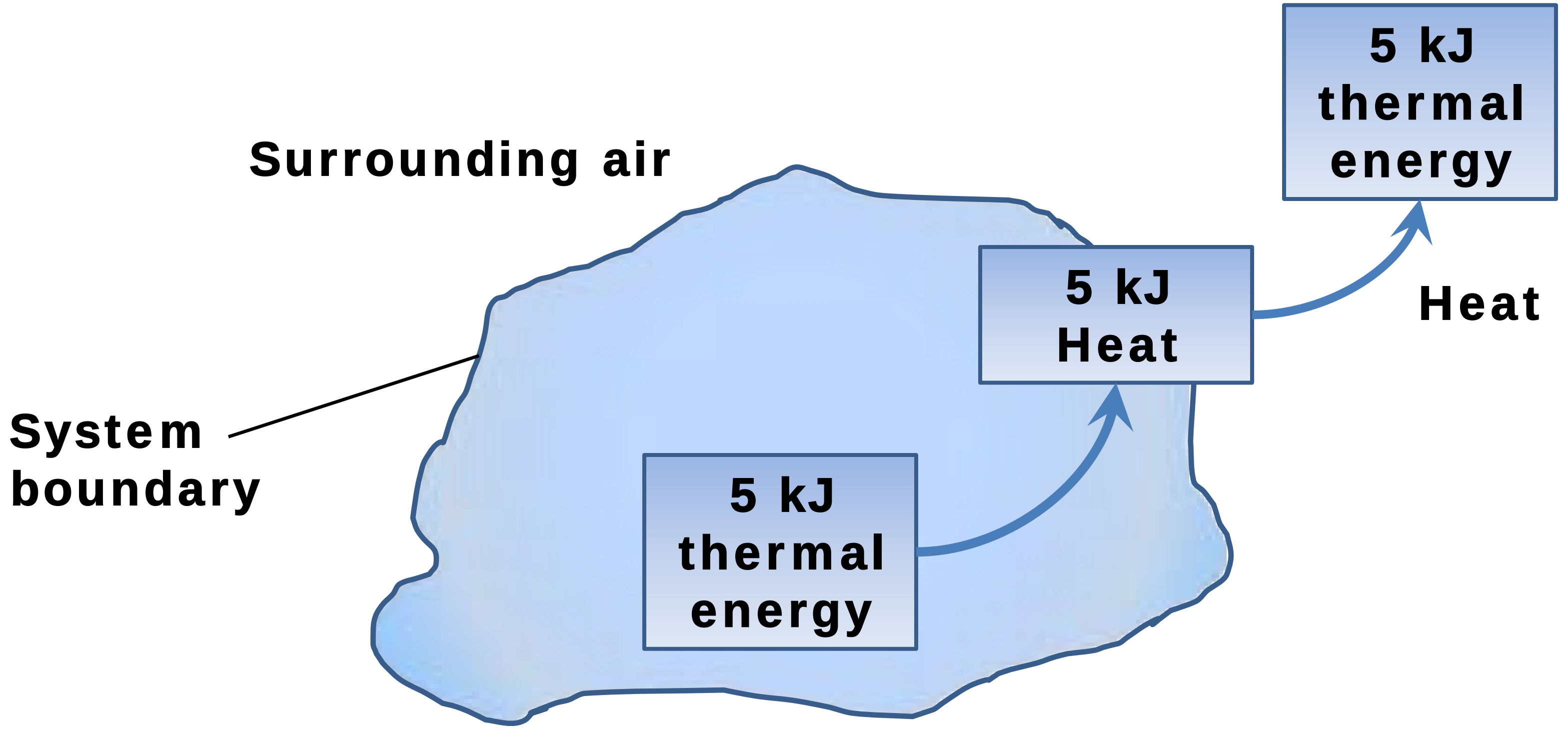
Energy transfer by heat



Energy is recognized as heat transfer only as it crosses the system boundary.

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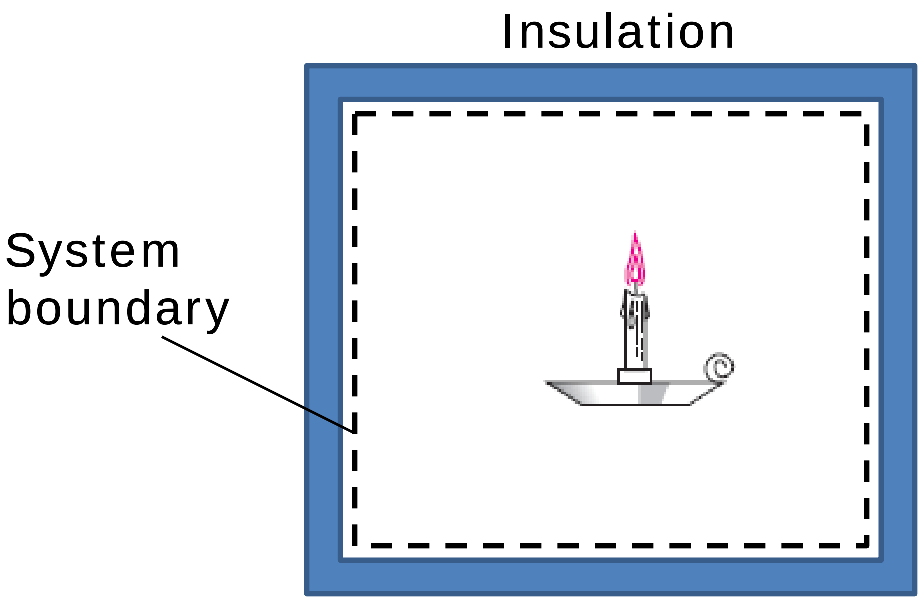
Energy transfer by heat



Qn. Is there is any heat transfer during this burning process?
Qn. Is there is any change in the internal energy of the system?

Energy transfer by work

- Any energy interaction of a closed system other than heat is work.
- An energy interaction that is not caused by a temperature difference between a system and its surroundings is work.
- Work is the energy transfer associated with a force acting through a distance.

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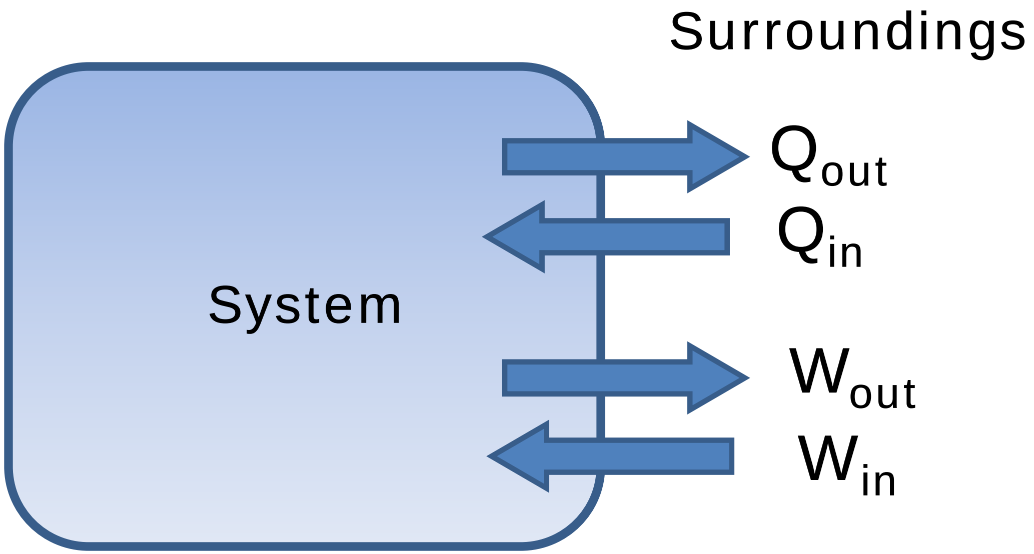
Sign conventions



- 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.

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Energy transfer by heat and work

- Both heat and work are boundary phenomena.
- Systems possess energy, but not heat or work.
- Both are associated with a process, not a state. Unlike properties, heat or work has no meaning at a state.
- Both are path functions (i.e., their magnitudes depend on the path followed during a process as well as the end states).

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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

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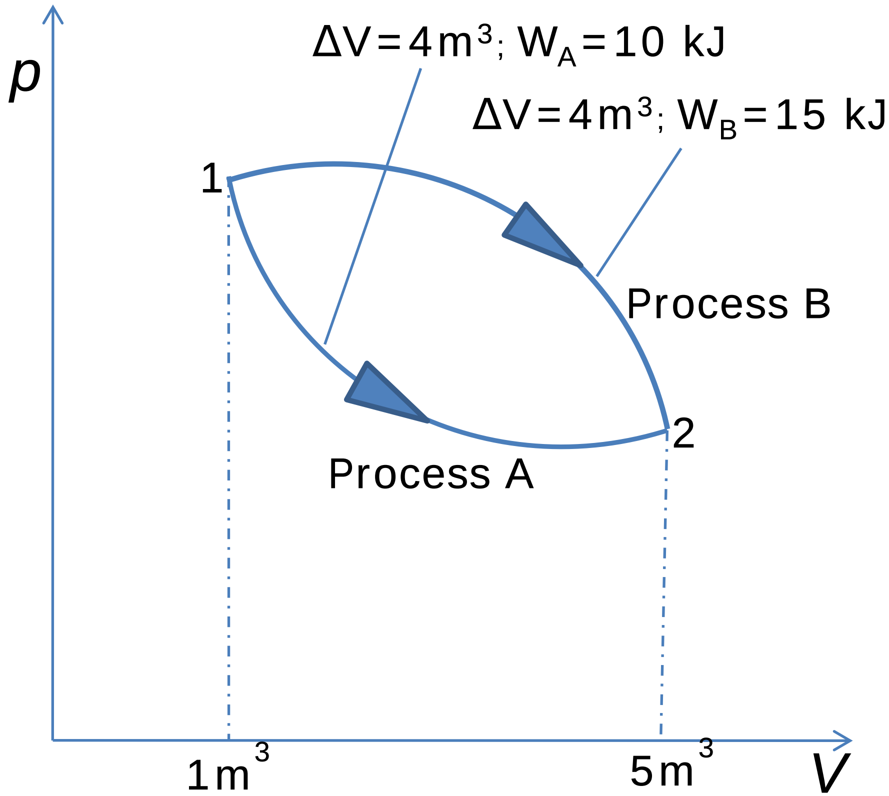
Path and Point functions



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

$\oint$ of a property is zero

Properties are point functions; but heat and work are path functions.

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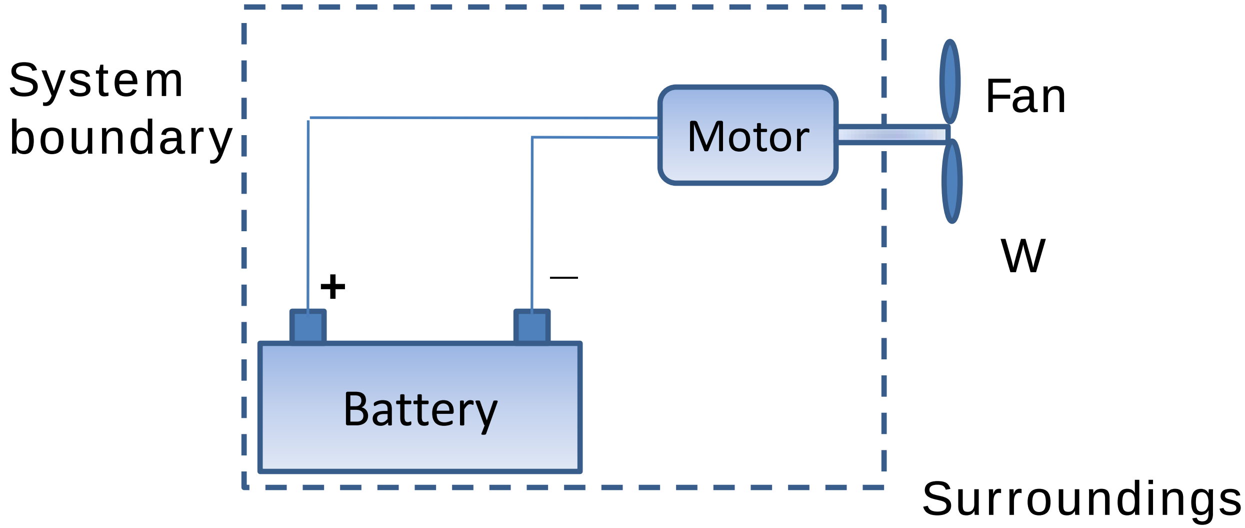
Work

- 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



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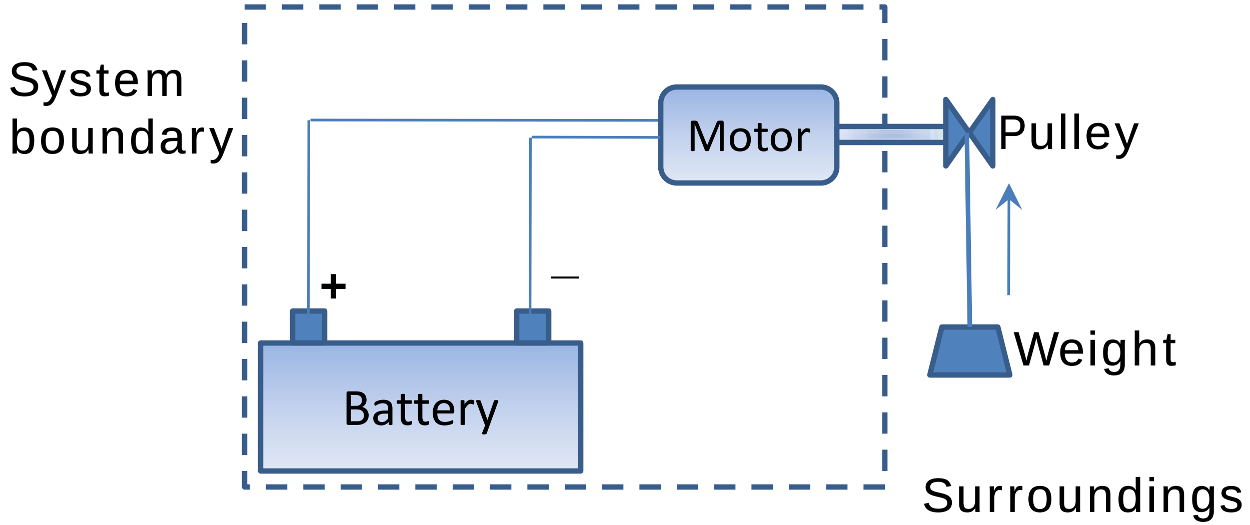
Work



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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

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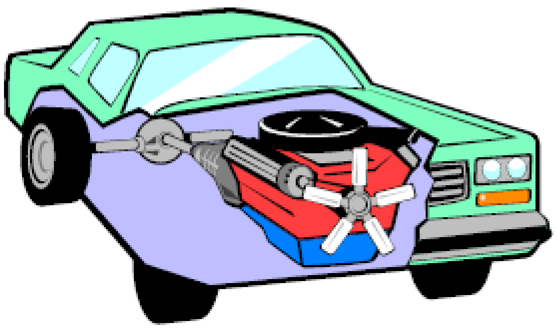
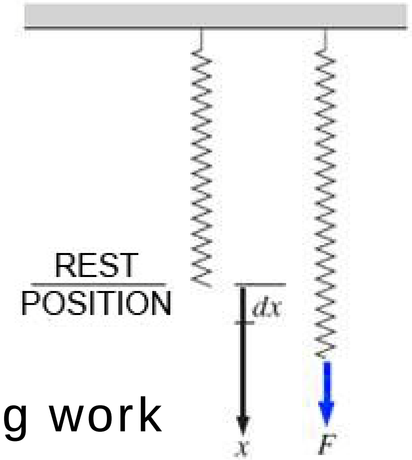
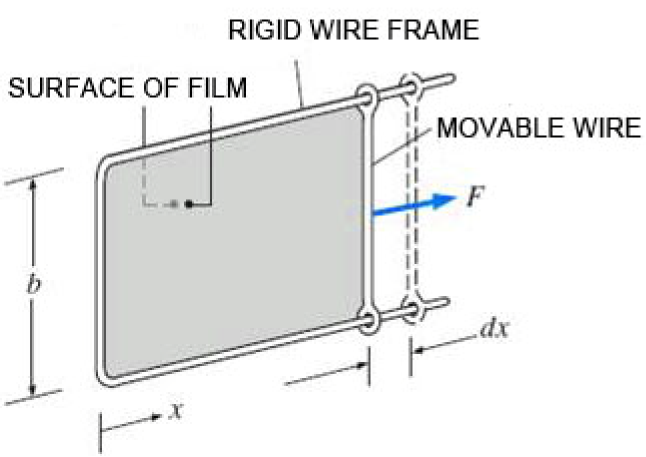
Work



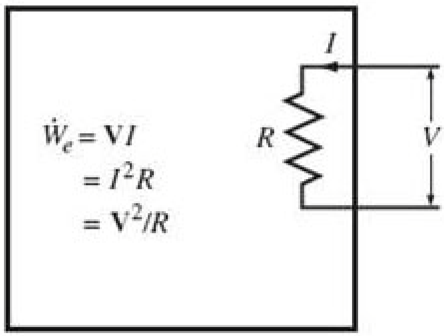
Shaft work: rotation of a shaft



Spring work



Stretching of a liquid film



Electrical work: heating of a resistor

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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.

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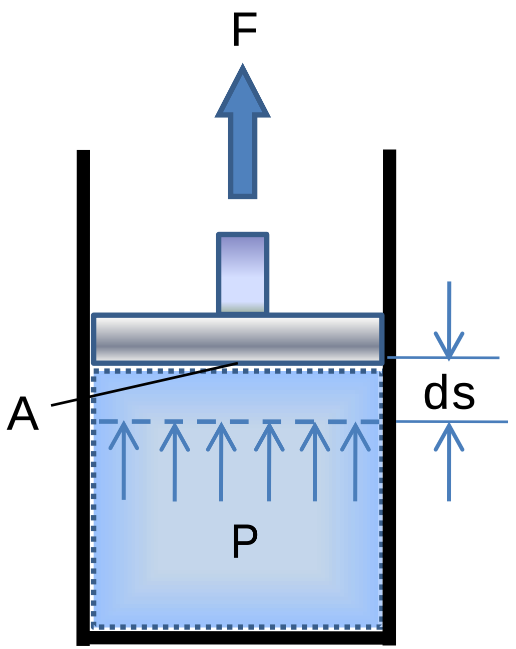
Displacement work

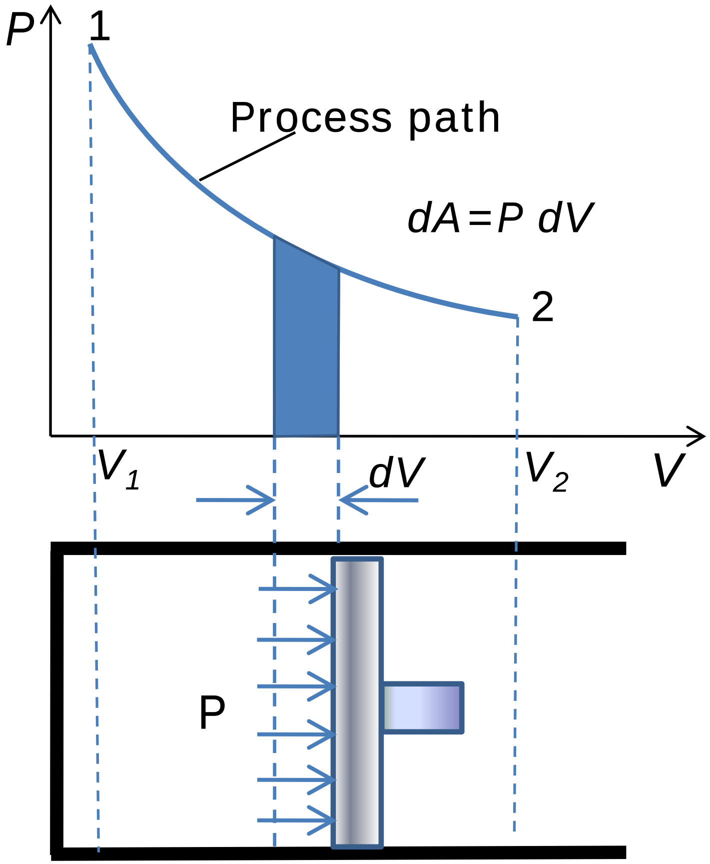


A gas does a differential amount of work δW_b as it forces the piston to move by a differential amount *ds*

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

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

Displacement work



$$Area = A = \int_1^2 dA = \int_1^2 PdV$$

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.

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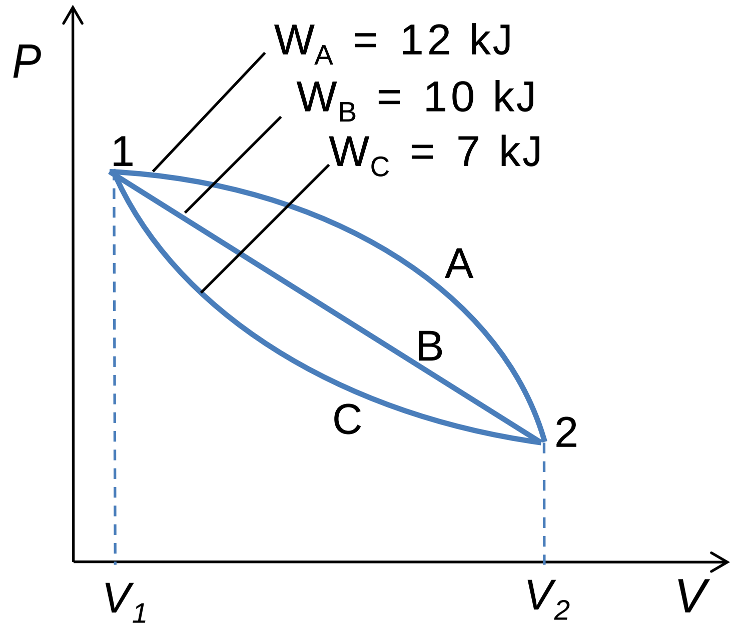
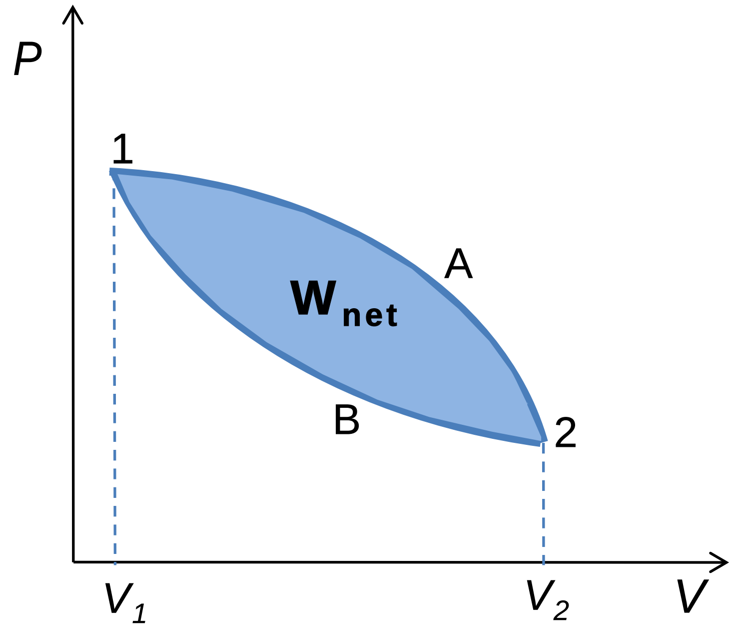
Displacement work



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.

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Displacement work

- Displacement work during Various processes:

Constant pressure process
Constant volume process
PV= contant
Polytropic process, PV^n = constant

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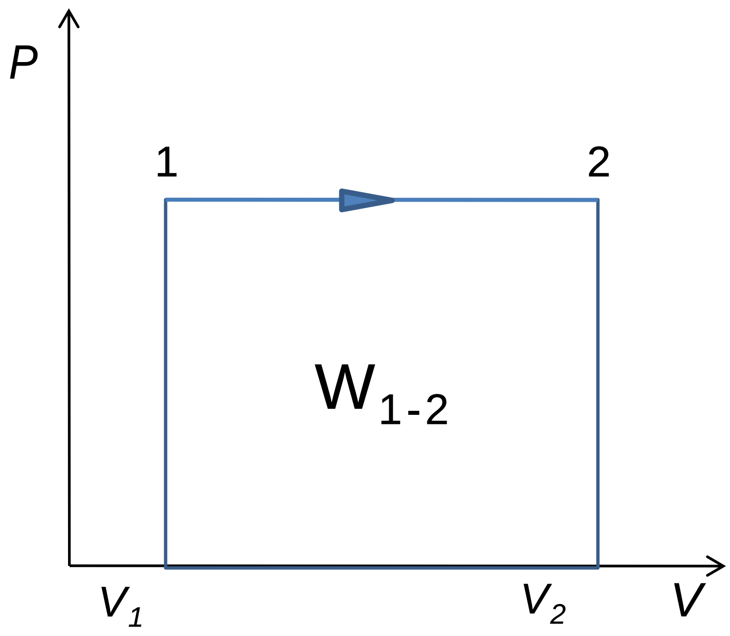
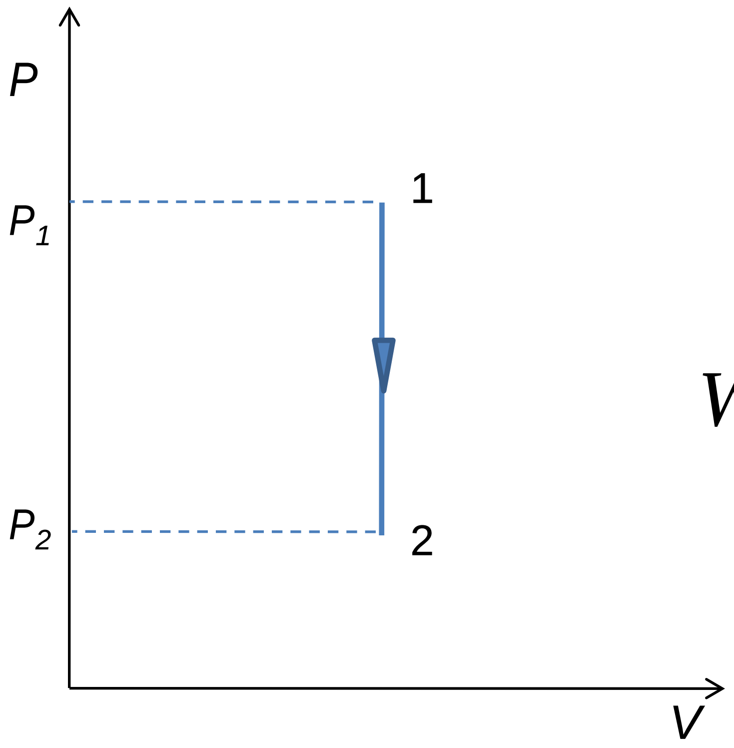
Constant pressure process



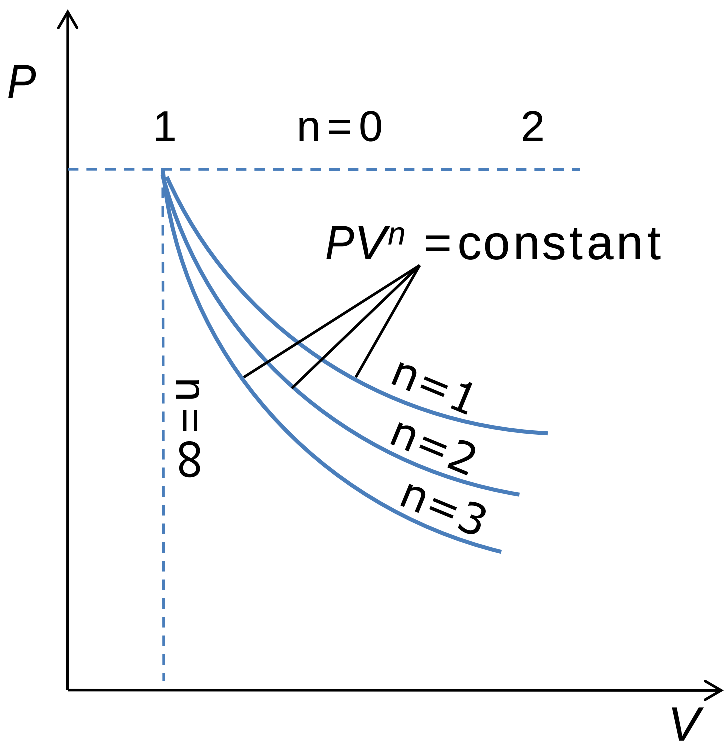
$$W_{1-2} = \int_{V_1}^{V_2} p dV = p(V_2 - V_1)$$

Constant volume process



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

PV^n = constant (Polytropic processes)



$$W_{1-2} = \int_1^2 PdV = \int_1^2 CV^{-n} dV$$

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

$$\text{Now,} \quad P_1V_1^{\,n} = P_2V_2^{\,n} = C$$

$$W_{1-2} = C\,\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1} = \frac{P_2V_2 - P_1V_1}{1-n}$$

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Recap of this lecture

- Specific heat
  - At constant pressure and constant volume
- Heat transfer
  - Meaning of heat transfer
  - Types of heat transfer
- Work
  - Thermodynamic meaning of work
  - Different types of work

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In the next lecture ...

- Solve problems related to calculation of
  - Work done (displacement work)

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