Introduction to Aerospace Propulsion

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Lecture No - 8

In this lecture ...

- First law of thermodynamics for closed systems
  - Energy balance
  - Energy change for a system
  - Energy transfer mechanisms
  - First law for a cycle
  - First law for a system undergoing change of state
  - Perpetual motion machines of the first kind

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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.

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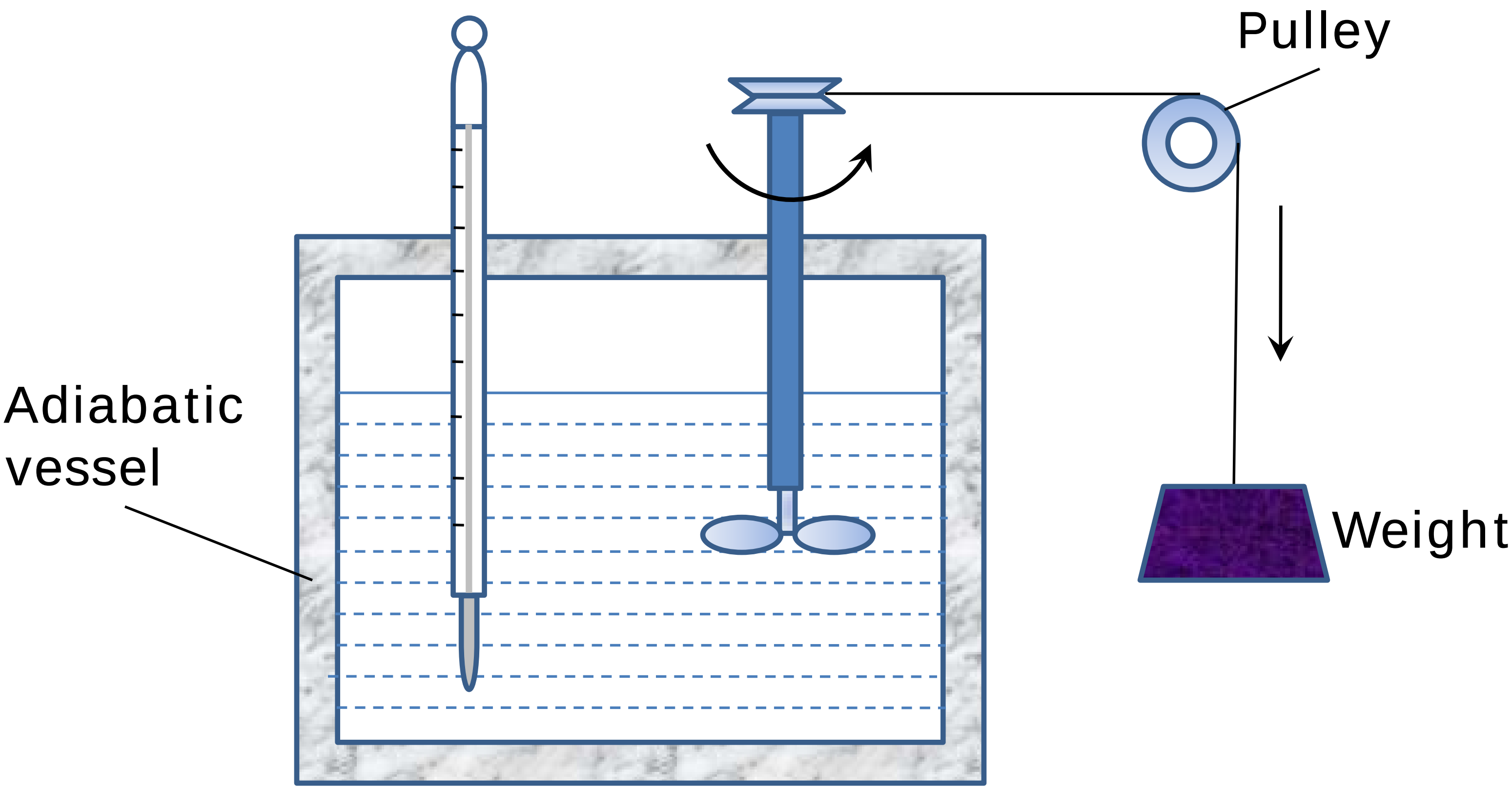
Joule's experiment



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.

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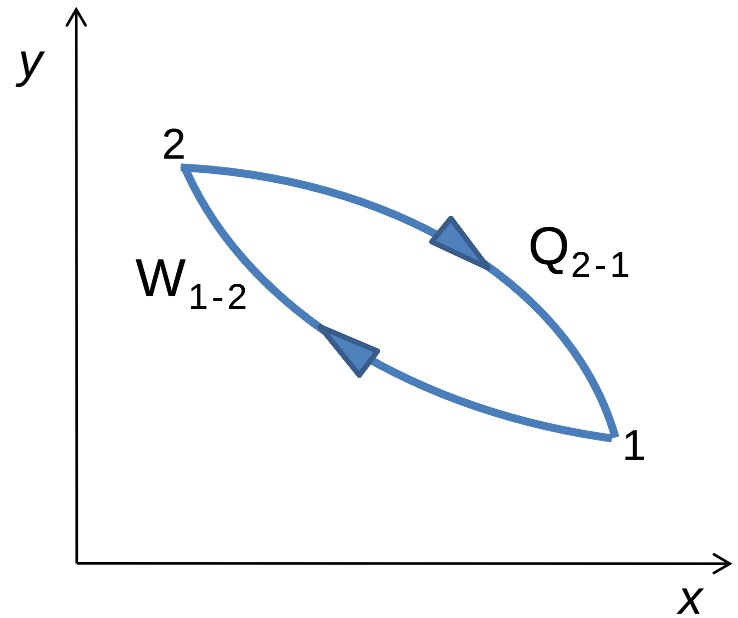
Joule's experiment



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

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

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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.

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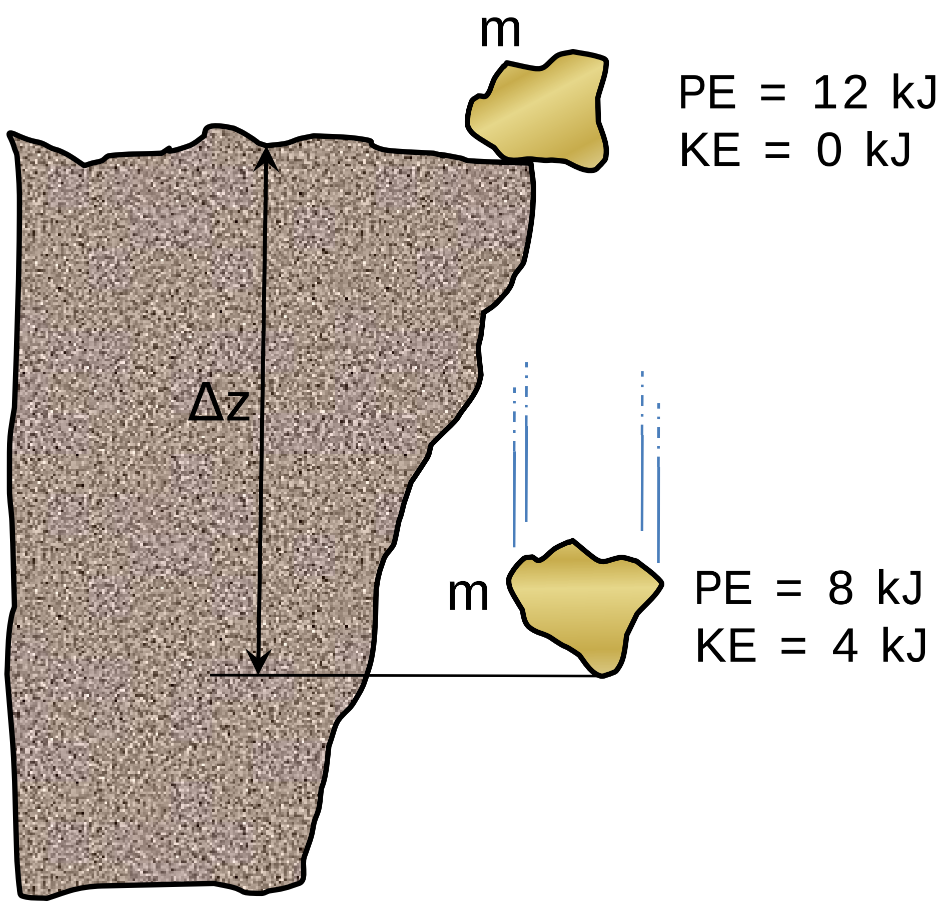
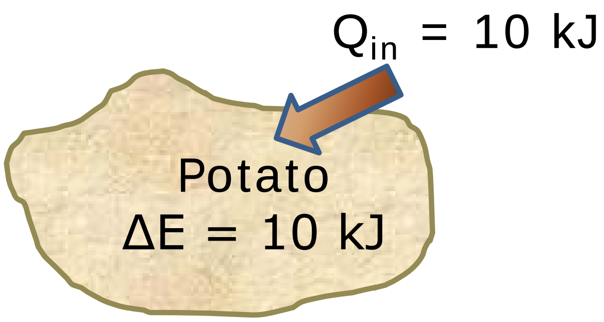
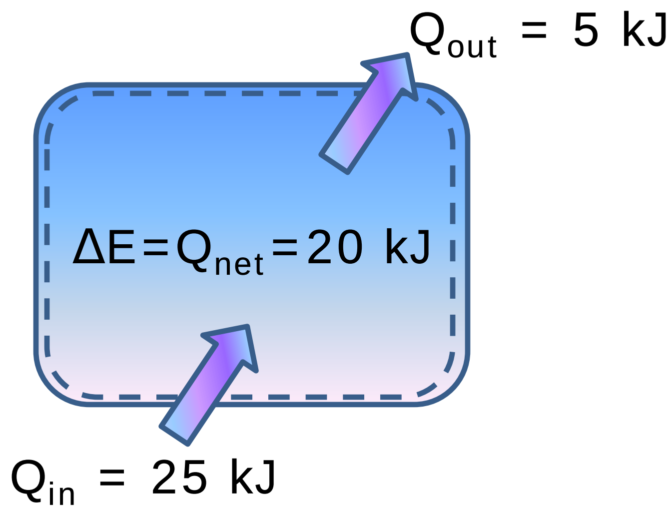
First law of thermodynamics



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.

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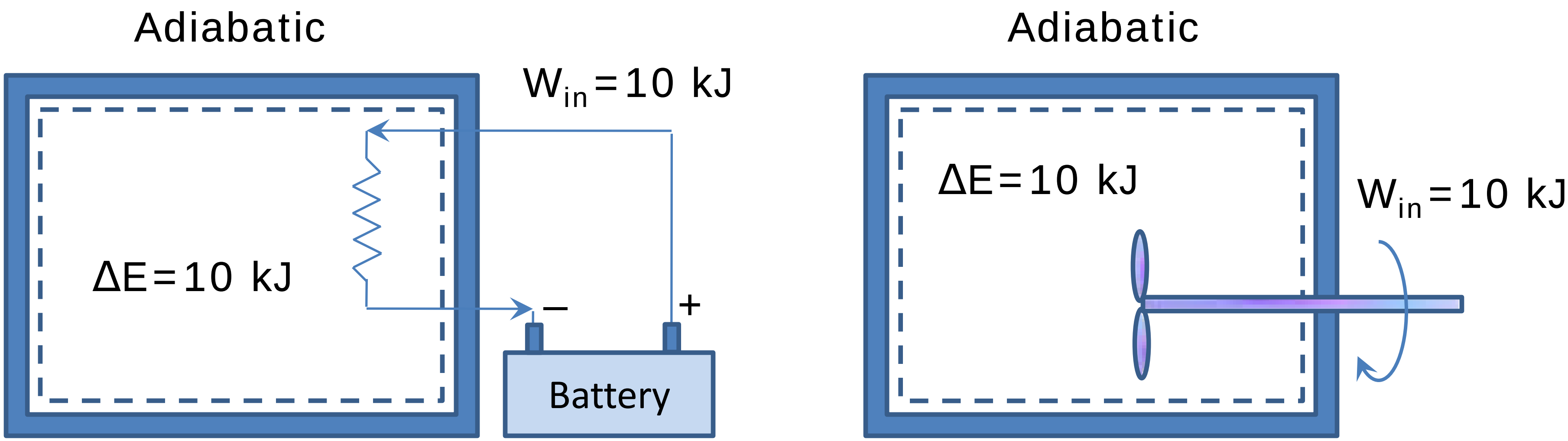
First law of thermodynamics



- 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.

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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,

$$\Delta E = \Delta U$$

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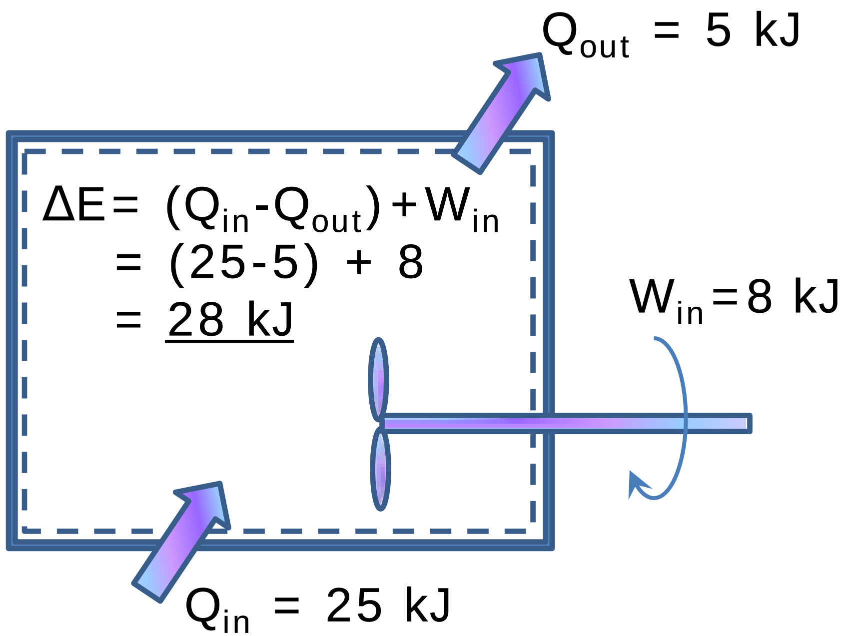
Energy change of a system



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

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Energy transfer mechanisms

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

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

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Energy transfer mechanisms

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

or, in the rate form, as

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

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

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

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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

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

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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

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

- That is, the net work output during a cycle is equal to net heat input

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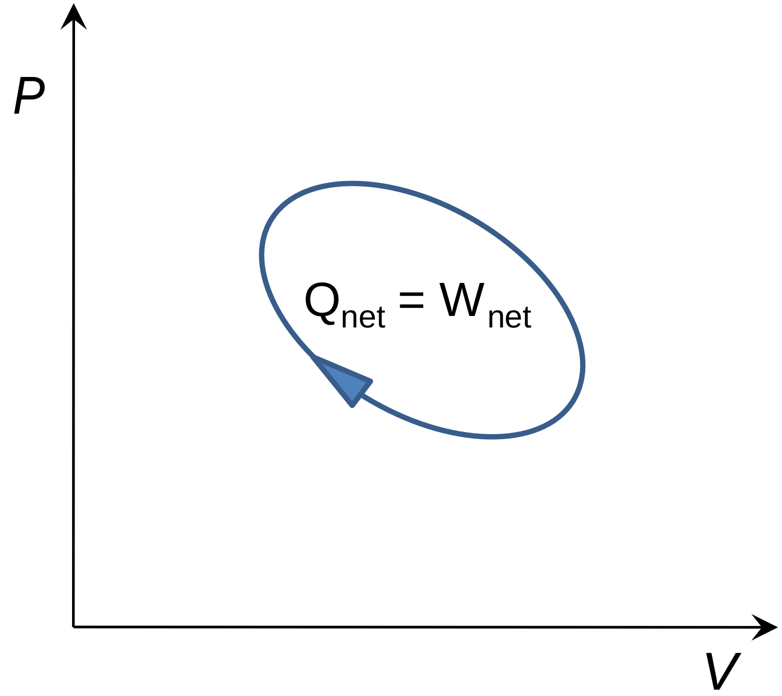
First law for a cycle



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

First law for a system undergoing a change of state

- In processes involving a change of state, heat and work interactions may be unknown.
- It is a usual practice to assume the direction of heat and work interactions.
- It is usually assumed that heat to be transferred into the system (heat input) in the amount of Q and work to be done by the system (work output) in the amount of W.

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First law for a system undergoing a change of state

- The energy balance would be:

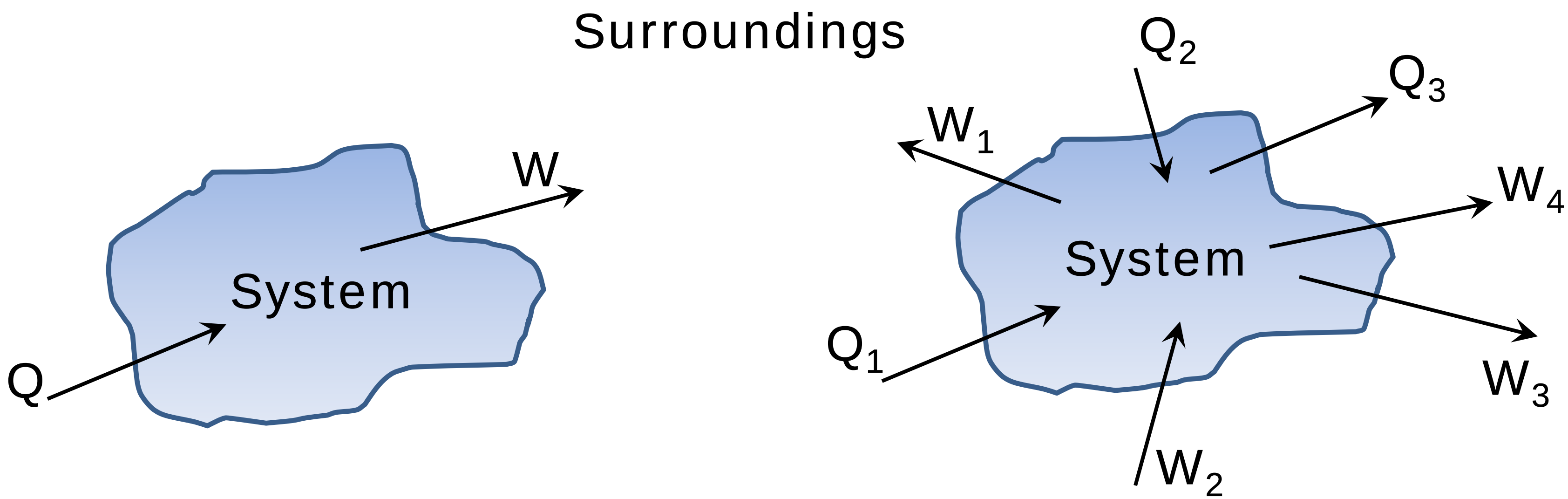
$$Q_{net,in} - W_{net,out} = \Delta E_{system} \quad or \quad Q - W = \Delta E$$

where, $Q = Q_{net,in} = Q_{in} - Q_{out}$ is the net heat input

and $W = W_{net,out} = W_{out} - W_{in}$ is the net work output.

- Obtaining a negative quantity for *Q* or *W* simply means that the assumed direction for that quantity is wrong and should be reversed.

First law for a system undergoing a change of state



$$Q - W = \Delta E$$

$$\left(Q_1 + Q_2 - Q_3\right) - \left(W_1 - W_2 + W_3 + W_4\right) = \Delta E$$

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First law for closed systems

$$\text{General}: \; Q - W = \Delta E$$

$$\text{Stationary systems}: Q - W = \Delta U$$

$$\text{Per unit mass}: q - w = \Delta e$$

$$\text{Differential form}: \delta q - \delta w = de$$

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First law: isolated system

- An isolated system has no interaction between the system and its surroundings
- For an isolated system, $đQ=0$ and $đW=0$
- The first law gives

$$dE=0$$

$$\text{or,} \qquad E=constant$$

- The energy of an isolated system is thus, always a constant.

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First law : some observations

- The first law cannot be proven mathematically, but no process in nature is known to have violated the first law.
- First law of thermodynamics is a fundamental physical law in itself.
- From the first-law point of view, heat and work are not different at all.
- However heat and work are very different from the second law point of view.

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Perpetual Motion Machine of the First Kind (PMM1)

- Any device that violates first law is called a perpetual-motion machine of the first kind (PMM1).
- Such a device will create energy!
- Numerous ideas have been proposed over the years, of devices that generate energy in some way.
- These devices of course violate the first law and hence were never demonstrated.

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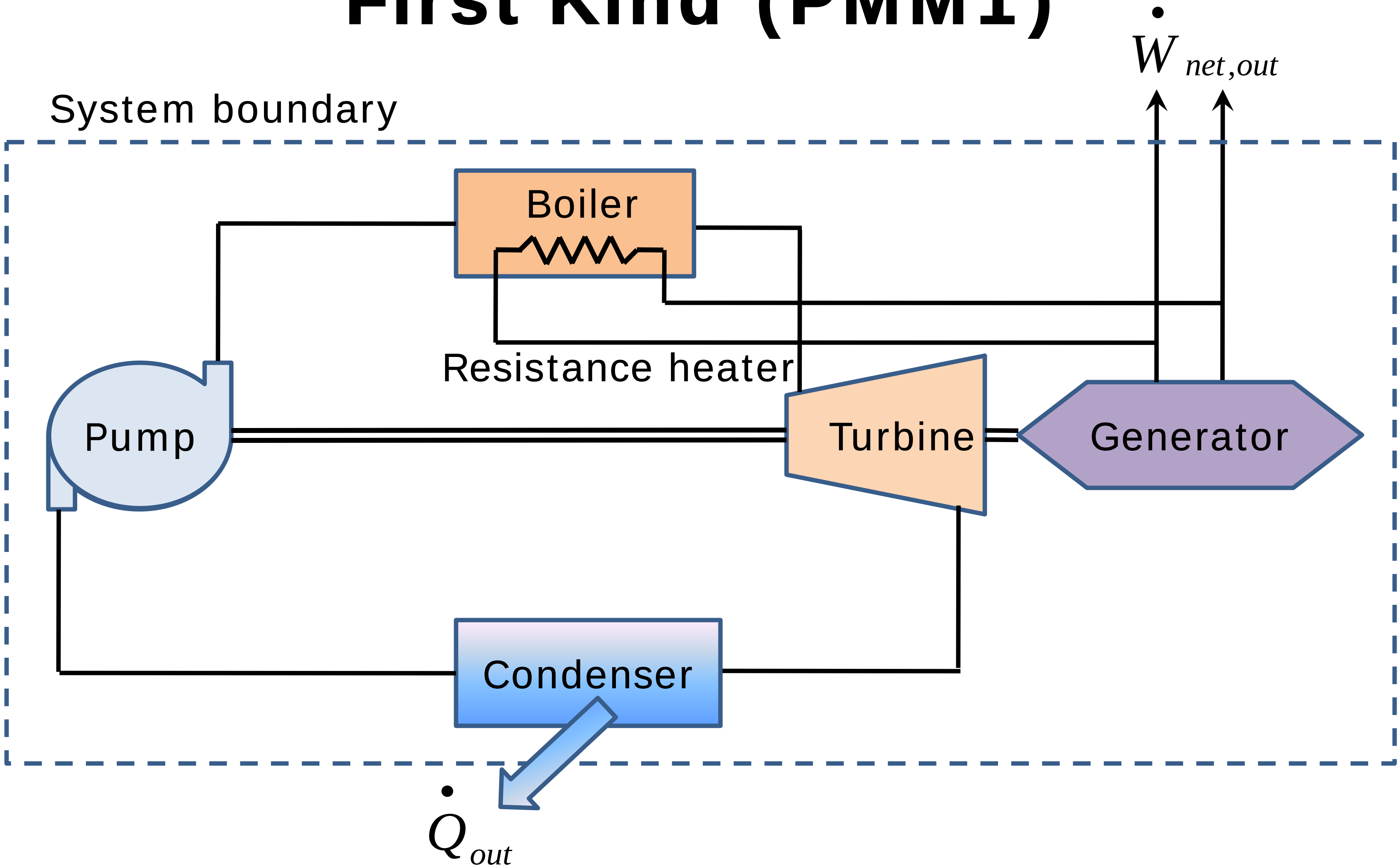
Perpetual Motion Machine of the First Kind (PMM1)



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Perpetual Motion Machine of the First Kind (PMM1)

- The device continuously produces energy at a rate of $\dot{Q}_{out} + \dot{W}_{net,out}$ without receiving any energy.
- This is a clear violation of the first law.
- Converse of a PMM1: there can be no machine which would continuously consume work without some other form of energy appearing simultaneously.

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Recap of this lecture

- First law of thermodynamics for closed systems
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  - First law for a cycle
  - First law for a system undergoing change of state
  - Perpetual Motion Machines of the First Kind

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In the next lecture ...

- First law of thermodynamics for open systems/flow processes
- Flow work and the energy of a flowing fluid
- Total energy of a flowing fluid
- Energy transport by mass
- Energy analysis of steady-flow systems
- Some steady-flow engineering devices

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