Some notes on the First Law of Thermodynamics for a closed system

The first law of thermodynamics is a statement of the conservation of energy.

For a closed system we have:

$$\Delta E = \Sigma Q - \Sigma W$$

Let's discuss in some detail each term of the above equation:

Energy Change:

ΔE : represents the change in energy experienced by the system. If the system experience a change from state 1 to state 2, we have:

$$\Delta E = E_2 - E_1$$

In general we can write the energy change of a system as:

$$E_2 - E_1 = \underbrace{U_2 - U_1}_{\text{change-internal-energy}} + (\Delta E_{\text{kinetic}}) + (\Delta E_{\text{potential}}) + (\Delta E_{\text{other}})$$

In many cases in thermodynamic analysis the changes in kinetic, potential and other forms of energy storage are negligible compared with the change in internal energy. In those cases,

$$\Delta E \approx \Delta U$$
$$E_2 - E_1 \approx U_2 - U_1$$

You (the analyst) should decide when the assumption of negligible kinetic and potential energy changes is a valid one.

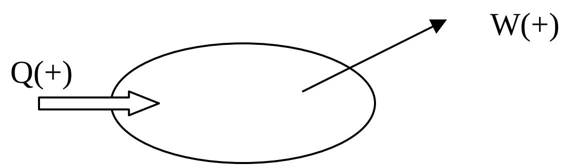
HEAT interactions:

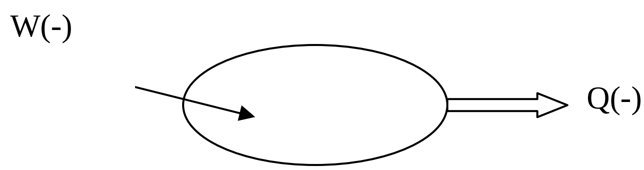
$\sum Q$: represents the net heat interactions.

WORK interactions:

$\sum W$: represents the net work interaction.

As we mentioned in class, there is a sign convention for the work and heat interactions. We will consider that work done BY the system to be positive and heat entering the system to be positive:





Some notation:

Q: denotes heat, it has units of energy (it is an energy interaction): Joules (J) or kJ (kilo-Joules).

W: denotes work interaction, it has units of energy (it is also an energy interaction): Joules (J) or kilo-Joules (kJ).

Energy is a property (i.e. it is path independent), but heat and work are NOT properties, so in the first law we have:

$$\Delta E = \Sigma Q - \Sigma W$$

Energy Change

Change in a property (path independent)

Net heat interaction

Net work interaction

Q and W are not properties, they are interactions and depend upon the process (i.e. they are path dependent)

There are several ways to write the first law for a closed system:

1.

$$\Delta E = \Sigma Q - \Sigma W$$

2. differential form

$$dE = \delta Q - \delta W$$

Note, that since E represents a state variable its differential quantity is indicated by the letter d (representing an exact differential) instead of the Greek symbol δ (representing an inexact differential whose integral represents a path function).

3. Per unit mass:

$$\Delta e = \Sigma q - \Sigma w$$

here:

e, energy per unit mass (specific energy)(kJ/kg)
q, heat interaction per unit mass (kJ/kg)
w, work interaction per unit mass (kJ/kg)

Notice that :

$$E = m \cdot e$$
$$Q = m \cdot q$$
$$W = m \cdot w$$

4. Per unit time:

$$\frac{dE}{dt} = \sum \dot{Q} - \sum \dot{W}$$

here,

$\frac{dE}{dt}$ represents the change in the energy of the system per unit time (the rate of energy change)

$\dot{Q}$ represents the heat interaction per unit time (also called heat transfer rate). It has unit of Joules/second = Watt

$$1\frac{J}{s} = 1W(\text{Watt})$$

it is common to use kW (kilowatt) ; 1kW = 1kJ/s

$\dot{W}$ represents the work interaction per unit time (also called power). Units: W, kW (Watts, kilowatts)

In all the above forms if we neglect the change in kinetic, potential and other forms of energy storage we can replace the Energy by the internal energy U:

	Accounting for changes in kinetic, potential and other forms of energy storage	Kinetic, potential and other forms of energy storage changes negligible	Units
"general"	$\Delta E = \Sigma Q - \Sigma W$	$\Delta U = \Sigma Q - \Sigma W$	J, kJ
"differential form"	$dE = \delta Q - \delta W$	$dU = \delta Q - \delta W$	J, kJ
"per unit time"	$\frac{dE}{dt} = \sum \dot{Q} - \sum \dot{W}$	$\frac{dU}{dt} = \sum \dot{Q} - \sum \dot{W}$	W (Watts) KW (kilowatts)
"per unit mass"	$\Delta e = \Sigma q - \Sigma w$	$\Delta u = \Sigma q - \Sigma w$	J/kg kJ/kg
"per units mass and per unit time"	$\frac{de}{dt} = \sum \dot{q} - \sum \dot{w}$	$\frac{du}{dt} = \sum \dot{q} - \sum \dot{w}$	J/(kg s) W/kg kJ/(kg s) kW/kg

Important words used in problems and some remarks:

- A ***perfect INSULATION*** blocks the **heat** interactions between the system and its environment:

$$\longrightarrow \quad Q = 0$$

It does NOT mean that the temperature is constant.

- An **ISOLATED system** is one whose boundary is impermeable to both energy and mass interactions (do not confuse insulation with ISOLATION).

-A system for which the changes in kinetic and potential energy are zero or negligible is sometimes called a **STATIONARY SYSTEM**, ($\Delta E_p = 0$, and $\Delta E_k = 0$.

So for a Closed Stationary system the first law can be written as:

$$\Delta U = \sum Q - \sum W$$

-Sometimes you will find in the literature:

$$\boldsymbol{\Delta U = Q - W}$$

here Q and W represent the net interactions (what we are representing with the summation, $\sum$ sign).

E ⟶ Energy contained by the system (stored energy), property of the system.

W ⟶ energy in transit due to mechanical interaction between the system and its surroundings

Q ⟶ energy in transit due to the thermal interaction (temperature difference between the system and its surroundings)

Related ideas contained in the FIRST LAW:

1. CONSERVATION OF ENERGY

2. THE EXISTANCE OF AN ENERGY FUNCTION, A STATE VARIABLE CALLED ENERGY

3. DEFINITION OF HEAT AS ENERGY IN TRANSIT

For a Closed stationary system, $\Delta E_{potential} = 0$ and $\Delta E_{kinetic} = 0$ and the first law is written as:

$$\Delta U = Q - W$$

or

$$\Delta U = \sum Q - \sum W$$