The first law of thermodynamics:

The first law of thermodynamics, also known as the conservation of energy principle, provides a basis for studying the relationships among the various forms of energy and energy interactions.

The first law of thermodynamics states that energy can be neither created nor destroyed during a process; it can only change forms. Therefore, every bit of energy should be accounted for during a process.

Energy Balance:

The conservation of energy principle can be expressed as follows:

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

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

Where:

E_{in} : Total energy entering the system

E_{out} : Total energy leaving the system

ΔE_{system} : Change in the total energy of the system

$$\boxed{\Delta E_{system} = \Delta U + \Delta KE + \Delta PE}$$

$$\Delta U = U_2 - U_1$$

$$\Delta KE = \frac{1}{2} m(V_2^2 - V_1^2)$$

$$\Delta PE = mg(z_2 - z_1)$$

For stationary systems:

$z_1 = z_2 \Rightarrow \Delta PE = 0$

$V_1 = V_2 \Rightarrow \Delta KE = 0$

thus:

$$\Delta E_{system} = \Delta U$$

Mechanisms of Energy Transfer (E_{in}) and (E_{out}):

Energy can be transferred to or from a system in three forms: **heat**, **work**, and **mass flow**.

The only two forms of energy interactions associated with a **fixed mass or closed system are heat transfer and work.**

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

Thus:

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

Where the subscripts "in" and "out" denote quantities that enter and leave the system, respectively.

- The heat transfer (**Q**) is zero for adiabatic systems.
- The work transfer (**W**) is zero for systems that involve no work interactions.
- The energy transport with mass (**E_{mass}**) is zero for systems that involve no mass flow across their boundaries (i.e., closed systems).

For a closed system undergoing a **cycle**, the initial and final states are identical, and thus:

$$\Delta E_{system} = E_2 - E_1 = 0.$$

Then the energy balance for a cycle simplifies to:

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

Noting that 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:

$$W_{net,out} = Q_{net,in} \quad \text{or} \quad \dot{W}_{net,out} = \dot{Q}_{net,in} \qquad (\textit{for a cycle})$$

That is, the net work output during a cycle is equal to net heat input as shown in figure (28)

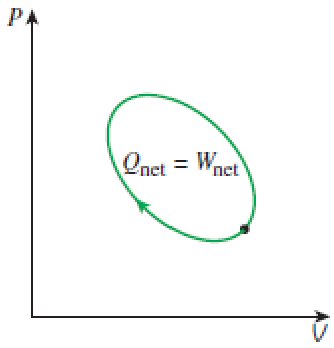


Figure (28) for a cycle $\Delta E = 0$, thus $Q = W$

or, in the rate form:

$$\dot{E}_{in} - \dot{E}_{out} = \Delta E_{system} / dt \qquad \text{(kW)}$$

Rate of net energy transfer by heat, work, and mass ($\dot{E}_{in} - \dot{E}_{out}$)

Rate of change in internal, kinetic, potential, etc., energies ($\Delta E_{system} / dt$)

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

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

The energy balance can be expressed on a *per unit mass basis* as:

$$e_{in} - e_{out} = \Delta e_{system} \qquad \text{(kJ/kg)}$$

Energy balance can also be expressed in the differential form as:

$$\delta E_{in} - \delta E_{out} = dE_{system} \qquad \text{or} \qquad \delta e_{in} - \delta e_{out} = de_{system}$$

$$\Delta E_{system} = E_{final} - E_{initial} = E_2 - E_1$$

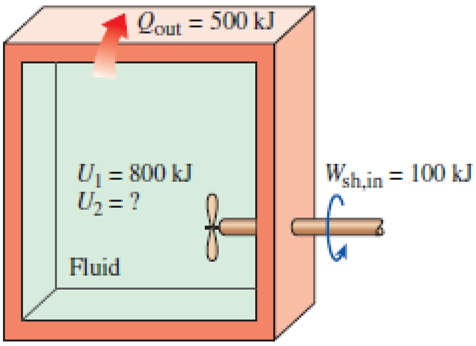
Where:

$E_{initial}$: Energy at initial state

E_{final}: Energy at final state

Note that energy is a property, and the value of a property does not change unless the state of the system changes. Therefore, the energy change of a system is zero if the state of the system does not change during the process.

Example: A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is (800 kJ). During the cooling process, the fluid loses (500 kJ) of heat, and the paddle wheel does (100 kJ) of work on the fluid. **Determine the final internal energy of the fluid.** Neglect the energy stored in the paddle wheel.



Solution:

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

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

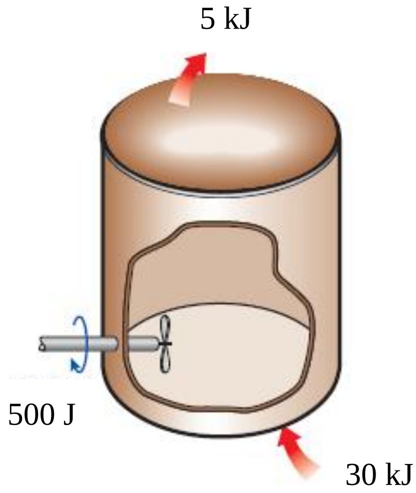
$$W_{sh,in} - Q_{out} = U_2 - U_1$$

$$100 - 500 = U_2 - 800$$

$$U_2 = 800 + 100 - 500$$

$$U_2 = 400 \text{ kJ}$$

Example: Water is being heated in a closed pan on top of a range while being stirred by a paddle wheel. During the process, (30 kJ) of heat is transferred to the water, and (5 kJ) of heat is lost to the surrounding air. The paddle-wheel work amounts to (500 J). **Determine the final internal energy of the system** if its initial internal energy is (10 kJ).



Solution:

$W_{in} = 500 \text{ J} \Rightarrow W_{in} = 0.5 \text{ kJ}$

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

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

$$Q_{in} + W_{in} - Q_{out} = U_2 - U_1$$

$$30 + 0.5 - 5 = U_2 - 10$$

$$U_2 = 25.5 + 10$$

$$U_2 = 35.5 \text{ kJ}$$

H.W: A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. During the cooling process, the fluid loses (233 kJ) of heat, and the paddle wheel does (382 kJ) of work on the fluid. **Determine the change in internal energy of the fluid**. Neglect the energy stored in the paddle wheel.

Answer: ΔU= 149 kJ

The ideal gas:

An ideal gas is a theoretical gas composed of many randomly moving particles that are not subject to interparticle interactions.

The ideal gas equation of state:

Property tables provide very accurate information about the properties, but they are bulky and vulnerable to typographical errors. A more practical and desirable approach would be to have some simple relations among the properties that are sufficiently general and accurate.

Any equation that relates the pressure, temperature, and specific volume of a substance is called an equation of state. **Property relations that involve other properties of a substance at equilibrium states are also referred to as equations of state**. There are several equations of state, some simple and others very complex. The simplest and best-known equation of state for substances in the gas phase is **the ideal-gas equation of state**. This equation predicts the (P-V-T) behavior of a gas quite accurately within some properly selected region.

Gas and *vapor* are often used as synonymous words. The vapor phase of a substance is customarily called a gas when it is above the critical temperature. Vapor usually implies a gas that is not far from a state of condensation.

Boyle's Law ⟹ $V \alpha \frac{1}{P}$

Charles Law: ⟹ $V \alpha\, T$

That is, $Pv = RT$ — the ideal-gas equation of state, or simply the ideal-gas relation

Where:
R: The gas constant
P: The absolute pressure
T: The absolute temperature
v: The specific volume

or $V = mv$ ⟹ $PV = mRT$

<u>a gas that obeys this relation is called an **ideal gas**</u>

The gas constant R is different for each gas as shown in figure (29), and is determined from:

$$R = \frac{R_u}{M} \quad \text{(kJ/kg.K)}$$

And

$$m = nM \quad \text{(kg)}$$

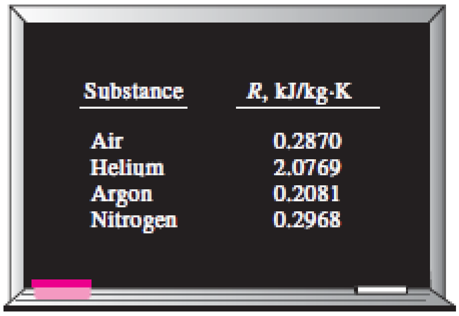


Figure (29) Different substances have different gas constants.

From Avogadro's Law ⟹ $V \alpha\ n$

Where:

R_u: The universal gas constant.

M: the molar mass (also called molecular weight) of the gas.

n: The mole number.

The constant (R_u) is the same for all substances, and its value is:

$$R_u = 8.31447 \ \text{(kJ/kmol.K)}$$

By writing the equation $PV = mRT$ for a fixed mass and simplifying, the properties of an ideal gas at two different states are related to each other by:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$