Course Title

PHS101 / PHYSICS

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LEARNING MANAGEMENT SYSTEM
LMS

Summary of Thermodynamics

- First law of thermodynamics: $\Delta U = Q - W$
- Isothermal process: temperature is constant.
- Adiabatic process: no heat is exchanged.
- Work done by gas at constant pressure:

$$W = P\,\Delta V. \qquad \text{[constant pressure]}$$

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An isothermal process is one where the temperature does not change.

In order for an isothermal process to take place, we assume the system is in contact with a heat reservoir.

In general, we assume that the system remains in equilibrium throughout all processes.

An adiabatic process is one where there is no heat flow into or out of the system.

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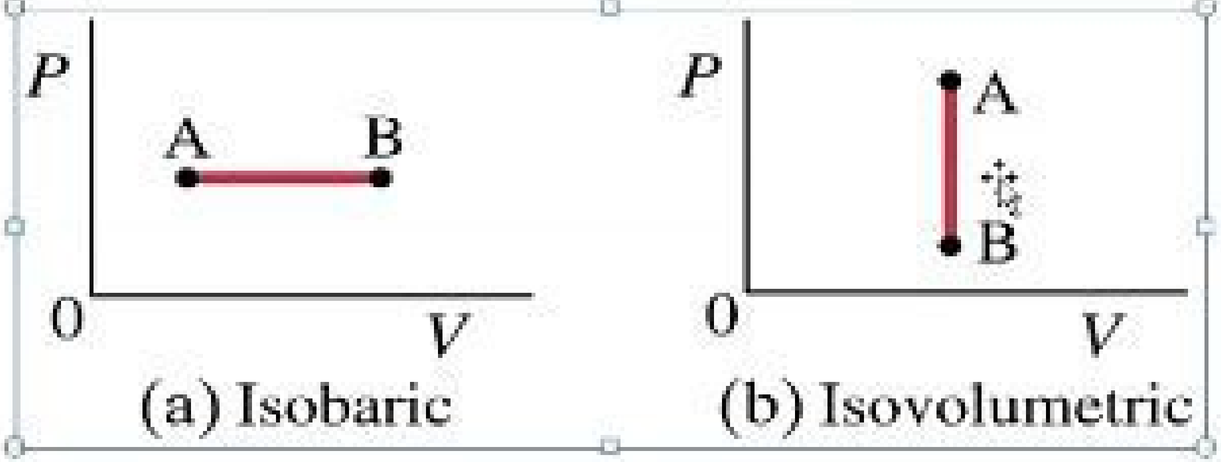
- An isobaric process (a) occurs at constant pressure; an isovolumetric one (b) at constant volume.



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The second law of thermodynamics is a statement about which processes occur and which do not. There are many ways to state the second law; here is one:

Heat can flow spontaneously from a hot object to a cold object; it will not flow spontaneously from a cold object to a hot object.

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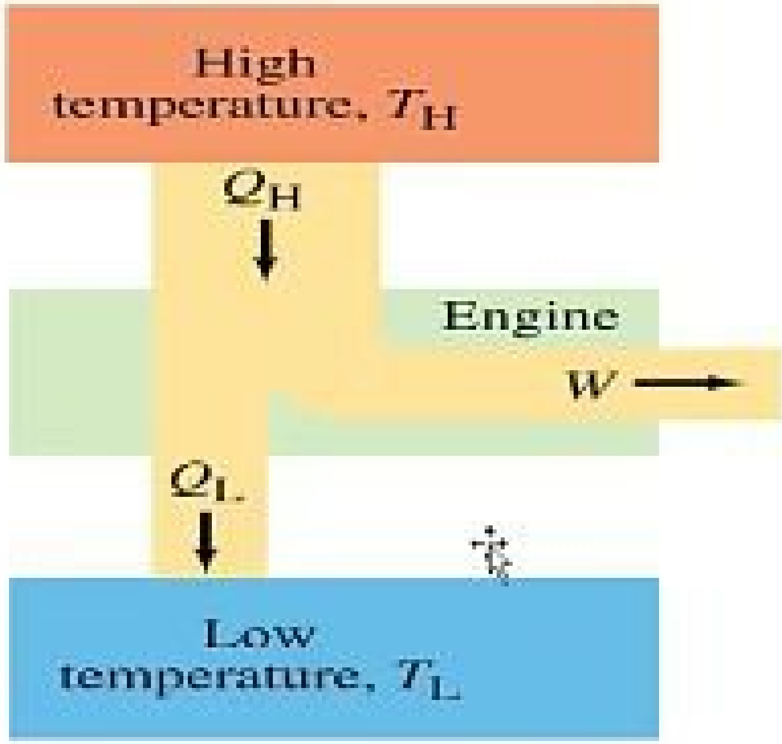
It is easy to produce thermal energy using work, but how does one produce work using thermal energy?

This is a heat engine; mechanical energy can be obtained from thermal energy only when heat can flow from a higher temperature to a lower temperature.



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The efficiency of the heat engine is the ratio of the work done to the heat input:

$$e = \frac{W}{Q_{\mathrm{H}}}.$$

Using conservation of energy to eliminate W, we find:

$$e = \frac{W}{Q_{\mathrm{H}}} = \frac{Q_{\mathrm{H}} - Q_{\mathrm{L}}}{Q_{\mathrm{H}}}$$

or

$$e = 1 - \frac{Q_{\mathrm{L}}}{Q_{\mathrm{H}}}.$$

Summary contd

Refrigerator performance is measured by the coefficient of performance (COP):

$$\text{COP} = \frac{Q_L}{W}. \qquad \begin{bmatrix}\text{refrigerator and}\\ \text{air conditioner}\end{bmatrix}$$

Substituting:

$$\text{COP} = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}. \qquad \begin{bmatrix}\text{refrigerator and}\\ \text{air conditioner}\end{bmatrix}$$

Summary contd

- Second law of thermodynamics:
    - heat flows spontaneously from a hot object to a cold one, but not the reverse
    - a given amount of heat cannot be changed entirely to work
    - natural processes tend to increase entropy.
- Change in entropy: $\Delta S = \frac{Q}{T}$,
- Entropy is a measure of disorder.
- As time goes on, less and less energy is available to do useful work.

Examples

Example 1

How much work is done on 1 mole of an ideal gas kept at 0^0C during an expansion from 3.0L to 10.0L.

Solution:

$$Workdone = -nRT\ln\left(\frac{V_f}{V_i}\right), where\ n = 1, R = \frac{8.314J}{molK}, V_f = 10L,\ V_i = 3L$$

$$Workdone = -1\ x\ 8.31\ x\ 273\ \ln\left(\frac{10}{3}\right)$$

$$= -2268.63\ \ln(3.3) = -2.709\ x\ 10^3 J$$

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Example 2

Find the change in internal energy of 6kg of water at 100^0C and atmospheric pressure that is converted at constant temperature and pressure to 3kg of steam, if the volume in the vapour phase is 1670 times that of the liquid state. ($L_v = 2256KJ/kg$).

Solution:

At atmospheric pressure and at 100^0C, the water changes to vapour, therefore, heat is added.

$$The\ amount\ of\ added\ heat\ Q = mL_v$$

$$= 6\,x\,2256KJ/kg \quad = 13536KJ.$$

Example 2

Since this process occurs at constant pressure. The density of water is very nearly 1000kg/m^3 over the whole range from 0^{o}C to 100^{o}C, therefore, from

$$Density = \frac{Mass}{Volume}, \qquad Volume = \frac{Mass}{density}$$

$$V_a = \frac{6}{1000kg/m^3} = 6 \: x \: 10^{-3} m^3$$

$$Similarly, the\ vapour\ volume = 1670\ x\ volume\ of\ liquid\ water$$

$$i.e\ V_b = 1670 V_a = 1670\ x\ 6\ x\ 10^{-3} = 10.02 m^3$$

$$V_b = 10.02 m^3$$

$$Workdone = P\Delta V = atm.pressure\ x\ \Delta V$$

$$Workdone = 1.0\ x\ 10^5 Pa\ x\ (10.02 - 6\ x\ 10^{-3}) m^3$$

$$= 1\ x\ 10^5\ x\ 10.014 = 1001.4KJ$$

$$\therefore\ \Delta u = Q - W = (13536 - 1001.4)KJ$$

$$= 12534.6KJ$$

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Example 3:

(a) Calculate the work done by 0.6 mole of oxygen as it is heated from $t_1 = -50^oC \ to \ t_2 = 80^oC$ at constant pressure. (b) Find the change in internal energy of 0.6mol of Oxygen as it is heated from $t_1 = -50^oC \ to \ t_2 = 80^oC$ at constant volume.

Solution:

(a) At constant pressure, the process is Isobaric

$$\therefore, from \ \Delta u = Q - W$$

$$\Delta u = nC_p\Delta T - P\Delta V$$

$$n = 0.6, \Delta T = (353 - 223)K = 130K, \Delta u = ?$$

At constant volume, $P\Delta V = workdone = 0$

$$\therefore, \Delta u = Q - W \ becomes \ \Delta U = Q.$$

$$\therefore, \Delta u = nC_v\Delta T = nC_v\Delta(T_f - T_i) = nC_v(130)$$

$$Remember \ that \ C_v = \frac{3}{2}R. \ for \ monoatomic \ gas \ while \ C_v \ for \ Oxygen \ is \ 21.1J/mol \ K.$$

$$\therefore, \Delta u = nC_v\Delta T = 0.6 \ x \ 21.1 \ x \ 130 = 1645.8J$$

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Example 4:

Calculate the work done and heat entering the gas if 2 mole of an ideal gas expands along a 300K isotherm until the volume doubles.

Solution:

At Isothermal process, $\Delta u = 0, \therefore \ \Delta u = Q - W$ *becomes* $0 = Q - W$

$$\therefore Q = W$$

$$Workdone\ by\ the\ system = nRT \ln\left(\frac{V_f}{V_i}\right)$$

$$Workdone = 2\ x\ 8.31\ x\ 300 \ln\left(\frac{2V_i}{V_i}\right)$$

$$= 2\ x\ 8.31\ x\ 300 \ln 2$$

$$= 4950\ x\ 0.69314$$

$$Workdone = 3.45KJ$$

(b) $Since\ Q = W$

$$\therefore heat\ entering\ the\ gas = 3.45KJ$$

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Example 5

Calculate the change in internal energy if 3 moles of a mono atomic ideal gas undergoes an adiabatic expansion and temperature drops from 400K to 180K during the expansion.

Solution: From mono atomic gas, $C_v = \frac{3}{2}R$.

$$For\ an\ adiabatic\ expansion, Q = 0, \therefore \Delta u = Q - W$$

$$becomes\ \Delta u = 0 - W$$

$$\therefore\ \Delta u = -W$$

$$\Delta u = -W = -nC_v\Delta T = -3\ x\ \frac{3}{2}R\Delta T$$

$$\Delta u = \frac{-3\ x\ 3\ x\ 8.314\ x\ (300 - 180)}{2}$$

$$\Delta u = -4.487KJ$$