Middle Technical University

College of Electrical & Electronic
Engineering Techniques

Department of Electrical Power
Engineering Techniques

Engineering Mechanics

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A-Thermodynamics

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Thermodynamics

***“Thermodynamics*”** is derived from the Greek words *threme*, meaning “ heat” and *dynamics* meaning “ strength” particularly applied to motion. Then thermodynamics would mean the heat liberated by the burning of wood, coal or oil .

Applied thermodynamics is the science that deal with energy transformation; the conversion of heat into work, or chemical energy into electrical energy, both of these are energy transformations, and thermodynamics is the science that provides the tools to analyze them. It is concerned with the means necessary to convert heat energy from available sources such as chemical fuels or nuclear piles into mechanical work.

Heat Engine: is the name given to a system which by operating in a cyclic manner produces network from a supply of heat.

Heat: is a form of energy which transferred from one body to another body at a lower temperature, by virtue of the temperature difference between the bodies. When the temperature of the bodies are equal no heat transfer takes place between them.

Work: is define as the product of a force and the distance moved in the direction of the force.

When a boundary of the closed system moves in the direction of the force acting on it, then the system dose work on its surrounding, then the force is positive **(+).**

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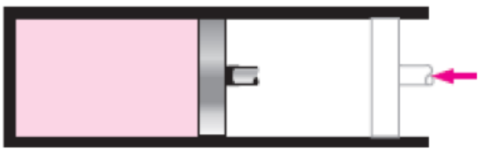
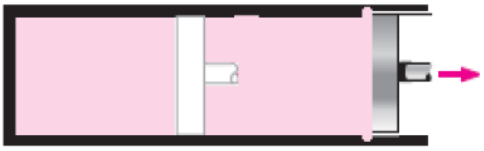
And the boundary is moved inwards the work is done on the system by its surroundings, then the force is negative **(-).** The units of work is N-m or Joule Work is observed to be energy in transition. It is never contained in a body or passed by a body.



Negative work



Positive work

Relation between Work and Heat:

Heat and work are both transitory energies and must not be confused with the intrinsic energy possessed a system. For example when a gas is contained in a well lagged cylinder (fig. 2) is compressed by moving the piston to the left, the pressure and temperature of the gas are increase, and hence the intrinsic energy of the gas increase and its caused by the work done by the piston on the gas.

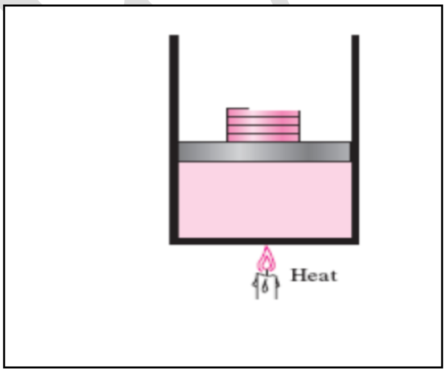


Figure 2

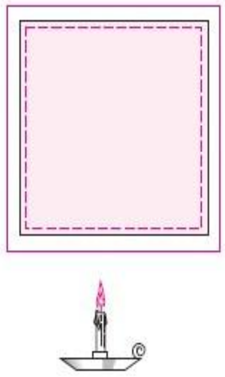


Figure 3

As another example, consider a gas contained in a rigid container and heated (fig. 3). Since the boundaries of the system are rigidly fixed then no work is done or by the system. The pressure and the temperature of the gas are observed to increase, and hence the intrinsic energy of the gas will increase.

The increase in intrinsic energy has been caused by the heat added to the system.

The conclusion from this must therefore be that there is a relationship between heat and work.

Definitions

Force: The ability of accelerated a body of a given mass, the unit of the force is the Newton (N)

Newton(N): The force required to give a mass of I kg an acceleration of 1 m/s^2

Power: The rate of working done, the unit of the power is Watt (J/s)

System: is a collection of matter prescribed and identifiable. The boundaries are not necessarily inflexible; the system may divided into:

1- **Closed system:** In which there is no transfer of mass across the boundaries of the system**:** example the fluid in the cylinder of a reciprocating engine (fig.4).

2- **Open system :** in which there is a transfer of mass across the boundaries: open system may sub divided into:

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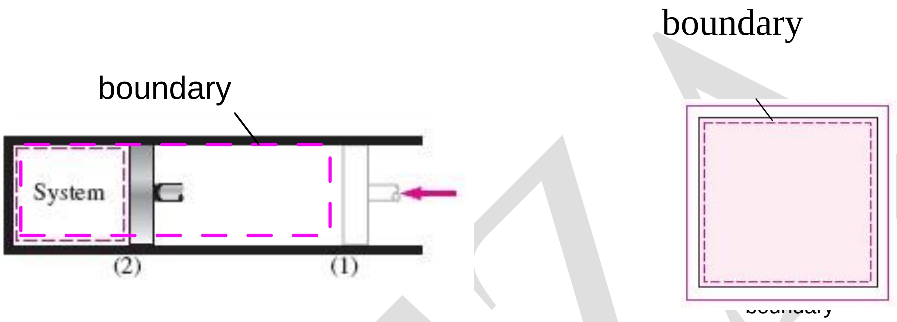
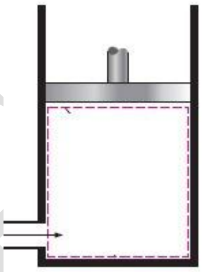
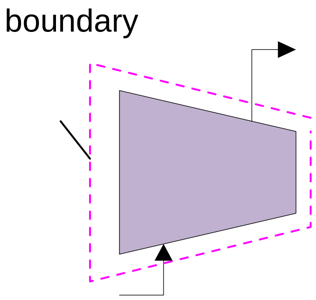
- **A- One flow system:** in which the mass is transfer in one direction, either flow into the system or flow out of the system. (Fig.5)
- **B- Two flow system:** in which the mass transfer into and out of the system at constant mass flow rate. (Fig. 6)



(Fig. 4)



(Fig.5) one flow system



(Fig. 6) two flow system

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Temperature: Temperature is not possible to define.

There are four temperature scales, they are

1- **Fahrenheit**: (Daniel Fahrenheit 1686-1736)

The scales temperature having been fixed by body temperature (96 ^oF) and an ice-saltwater mixture, the triple point become 32 ^oF and water boiled at 212 ^oF.

2- **Celsius**: (Anders Celsius 1701-1744)

Celsius devised a scale that started at 0 ^oC (triple point) and went to 100(boiling point of water)

3- **Kelvin:** (Lord Kelvin 1851)

Kelvin first proposed that there was an absolute temperature, which is equal to 0 K

4- **Rankin:** is the second absolute temperature scale.

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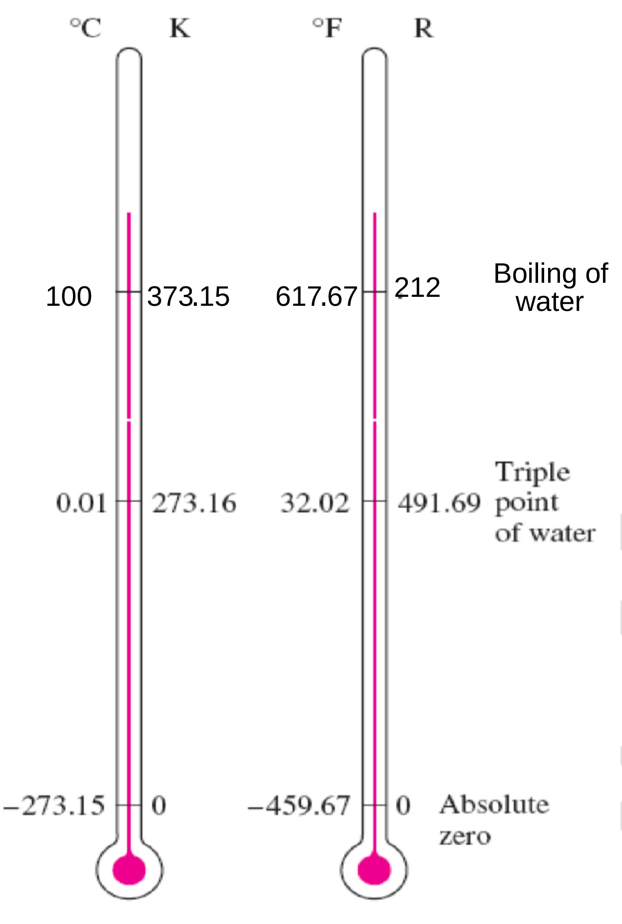

$$K = 273.12 + (\qquad)^{o}C$$

$$R = 459.67 + (\qquad)^{o}F$$

$$°\mathrm{F} = \frac{9}{5}\,(\qquad\quad)°\mathrm{C} + 32$$

$$°\mathrm{C} = \frac{5}{9}\,[(\qquad)°\mathrm{F} - 32]$$

Pressure

Pressure: is the force exerted by the system on unit area.

Units of pressure are N/m^2 (Pa) or bar, 1 bar = 10^5 N/m^2, Atmospheric pressure is

1.0132 bar or 101.325 kPa.

Gage pressure: A gauge for measuring pressure records the pressure above atmospheric pressure.

Absolute pressure: is the gauge pressure plus atmospheric pressure.

Vacuum pressure: it is the pressure of the system below atmospheric pressure.

Specific volume: it is the volume occupied by unit mass, the unite of specific volume is m^3/kg.

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Unites:

SI units will be used throughout our lectures: The **international system of units** was adopted by General Conference of Weight and Measuring in 1960. In SI units six physical quantities are arbitrarily assigned unit value and hence all other physical quantities are derived from these. The six quantities are as follows:

Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	I
Temperature	Kelvin	K
Luminous intensity	Candela	cd

Then for example, velocity = length/time has units m/s, acceleration = velocity/time has units m/s^2 , volume = length x length x length has units of m^3 and so on.

Working Substance: it is a matter contained within a the boundaries of the system can be liquid, vapour or gas.

At any instant the state of the working substance may be define by certain characteristics called properties such as temperature (T), pressure (p), specific volume (ν), internal energy (E), enthalpy (h) and entropy (s). It has been found that, for any pure working substance, only two independent properties suffice to define completely the state of the fluid.

Reversibility: When a fluid undergoes a reversible process, both the fluid and its surroundings can always be restored to their original state.

The criteria of reversibility are as follows:

a- *The process must be frictionless:*

The fluid itself must have no internal friction and there must be no mechanical friction between the cylinder and piston.

b- *The different in pressure between the fluid and its surroundings during the process must be infinitely small.*

This means that the process must take place infinitely slowly.

c- *The different in temperature between the fluid and its surroundings during the process must be infinitely small.*

This mean that heat supplied or rejected to or from the fluid must be transferred infinitely slowly.

It is obvious from the above criteria that no process in practice is truly reversible.

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However, in many practical process a very close approximation to an **internal reversibility,** In an internal reversible process, although the *surroundings* can never be restored to their original state, the *fluid* itself is at all times in an equilibrium state and the bath of the process can be exactly retraced to the initial state.

Reversible Work

Consider an ideal frictionless fluid contain in a cylinder behind a piston. Assume that:

The pressure and the temperature of the fluid are uniform.

There is no friction between the piston and the cylinder

The cross sectional area of the piston is **A.**

The pressure of the fluid is **p.**

The force that exerted on the piston is **F**

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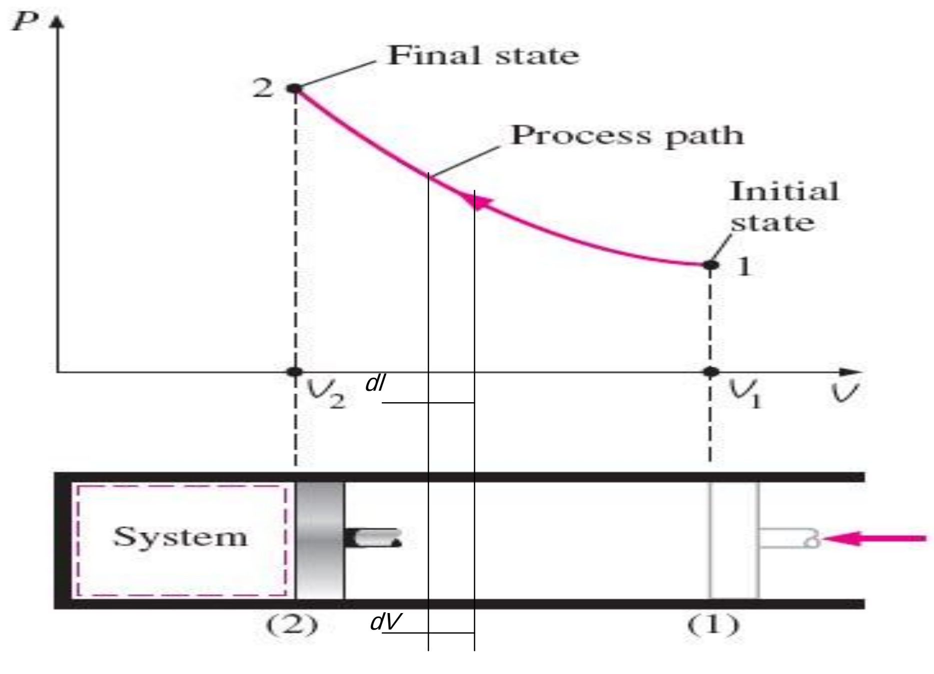

F = P.A

Let the piston move under the action of the force exerted on the fluid a distance *dl to* the right. The work done by the fluid on the piston is given by the force times distance moved

$\delta W = F.dl$

$\delta W = p.A..dl$

Remember that $A.dl = dV$

$\delta W = p.dV$

Total work done is the area (1-2-b-a-1)

Work done = $\int_1^2 P.dv$

When **P** can be expressed in terms of **V** then the integral $\int_1^2 P.dv$ can be evaluated.

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Example 1

A certain fluid at 10 bar is contained in a cylinder behind a piston, the initial volume being 0.05 m^3. Calculate the work done by the fluid when it expands reversibly:

a- at constant pressure to final volume of 0.2 m^3.

b- According to a linear law to final volume of 0.2 m^3 and final V^2 pressure of 2 bar.

c- According to a law PV=C to final volume of 0.1 m^3.

d- According to a law PV^3=C to a final volume 0.06 m^3.

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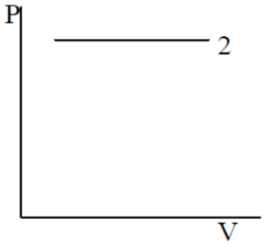
e- According to a law $P = \frac{A}{V^2} - \frac{B}{V}$ to a final volume of 0.1 m^3.and final pressure of 1 bar, where A & B are constants.

a- W=$\int_1^2 p.dV$ p=c

W= p.$\int_1^2 dV$ =p[V_2-V_1] = $10\times10^2[0.2-.05]=150kJ$

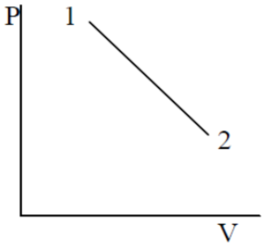


b- linear law $\frac{p-p_1}{V-V_1} = \frac{p_2-p_1}{V_2-V_1} \rightarrow \frac{p-10\times10^2}{V-0.05} = \frac{2\times10^2-10\times10^2}{0.2-0.05}$

0.15p+800V-190=0

$$p = \frac{190-800V}{0.15}$$

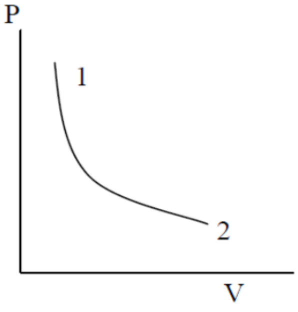
W=$\int_1^2 p.dV = \int_1^2 \frac{190-800V}{0.15}.dV = \left[\frac{190V-400V^2}{0.15}\right]_1^2$ =90kJ



C=P_1V_1=10x10^2x0.05 = 50

$$p = \frac{50}{V}$$

$$W = \int_1^2 p.dV = \int_1^2 \frac{50}{V}.dV = 50[\ln V]_1^2 = 50\{\ln(0.1) - \ln\{0.05)\} = 34.65kJ$$



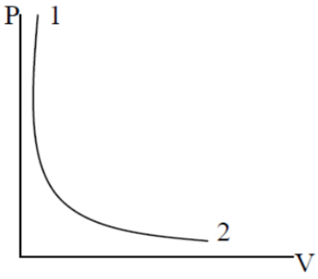
d-PV^3=C

$$10\times10^2(0.05)^3 = 0.125 = C$$

$$P = \frac{0.125}{V^3}$$

$$W = \int_1^2 p.dV = \int_1^2 \frac{0.125}{V^3}.dV = \left[\frac{-0.125}{2V^2}\right]_1^2 = 7.638kJ$$

f-



$$P=\frac{A}{V^2}-\frac{B}{V}$$

$$10\times10^2=\frac{A}{0.1^2}-\frac{B}{0.1} \qquad 1$$

$$1\times10^2=\frac{A}{0.05^2}-\frac{B}{0.05} \qquad 2$$

$$A=4 \quad B=30$$

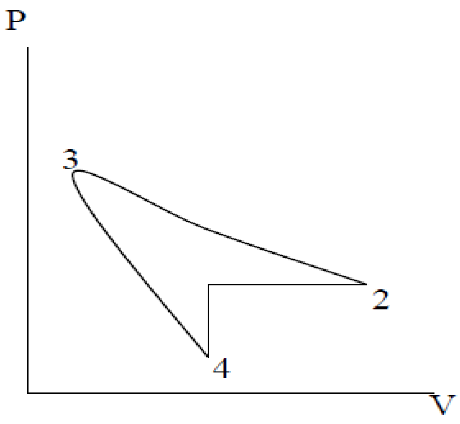
$$P=\frac{4}{V^2}-\frac{30}{V}$$

$$W=\int_1^2 p.dV=\int_1^2\left[\frac{4}{V^2}-\frac{30}{V}\right].dV$$

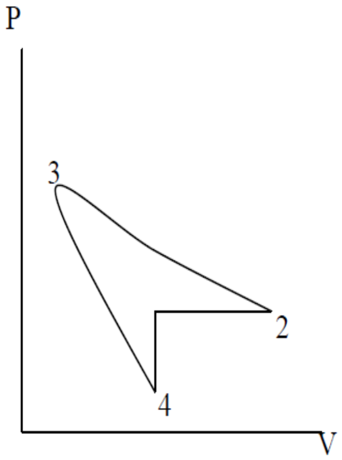
$$W=\left[-\frac{4}{V}-30\ln(V)\right]_1^2=19.2kJ$$

Example 2

A fluid is heated reversibly at constant pressure of 1.05 bar until it has a specific volume of 0.1 m^3/kg. It is then compressed reversibly according to a law PV=C to a pressure 4.2 bar, then allowed to expand reversibly according to a law PV$^{1.3}$=C, and finally heated at constant volume back to initial condition. The work done in the constant pressure process is 515 N-m and the mass of the fluid is 0.2 kg. Calculate the net work done on or by the fluid in the cycle and sketch the cycle on the P-V diagram.



P_1=1.05 bar $\quad$ V_1=?
P_2=P_1=1.05 bar $\quad$ V_2=0.1 m^3/kg
P_3=4.2 bar $\quad$ V_3=?
P_4=? $\quad$ V_4=V1



<u>Process 1-2</u> P=C $\quad$ W= 515 N-m

$$w=\int_1^2 P.dv = P\int_1^2 dv = P(v_2 - v_1)$$

$$515 = m.p.(v_2 - v_1) = 0.2\times1.05\times10^2(0.1 - v_2)$$

$$v_2 = 0.075 m^3 / kg$$

<u>Process 2-3</u> PV=C

PV=C

$$P=\frac{C}{V}$$

$$w=\int_2^3 pdv = C\int_2^3\frac{dv}{v} = P_2V_2\int_2^3\frac{dv}{v} = 1.05\times10^2\times0.075[\ln v]_2^3 = 1.05\times10^2\times0.075[\ln v_3 - \ln v_2]\rightarrow v3 =$$

$$P_2v_2 = P_3v_3 \rightarrow v_3 = \frac{P_2}{P_3}.v_2 = \frac{1.05}{4.2}\times0.1 = 0.025m^3 / kg$$

$$w = 1.05\times10^2\times0.075[\ln 0.025 - \ln 0.075] = -14556\ J / kg$$

$$W = m.w = 0.2\times(-14556) = -2911.2J$$

<u>Process 3-4</u> $PV^{1.3}$=C

v_4=v_1=0.075 m^3/kg

$$p=\frac{c}{v^{1.3}}$$

$$w=\int_3^4 P.dv = c\int_3^4\frac{dv}{v^{1.3}} = p_3v_3^{1.3}\int_3^4\frac{dv}{v^{1.3}} = p_3v_3^{1.3}\left[-\frac{1}{0.3v^{0.3}}\right]_3^4$$

$$w == 4.2\times10^5(0.025)^{1.3}\left[\frac{1}{-0.3(0.075)^{0.3}} + \frac{1}{0.3(0.025)^{0.3}}\right] = 9827.4J / kg$$

$$W = m.w = 0.2\times9827.4 = 1965.5J$$

<u>Process 4-1</u> V=C

$$w=\int_4^1 p.dv \rightarrow v = c \rightarrow dv = 0 \therefore w = 0$$

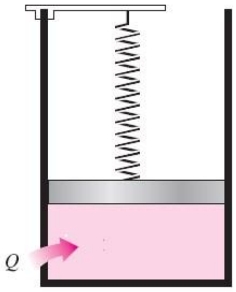
$$W_{net} = \underset{1-2}{W} + \underset{2-3}{W} + \underset{3-4}{W} + \underset{4-1}{W} = 515 + (-2911.2) + 1965.5 + 0 = -430.7J = -0.4307kJ$$

Example 3:

Consider the system shown in figure below. The initial volume inside the cylinder is 0.1 m3. At this state the pressure inside is 100 kPa, which just balance the atmospheric pressure plus the piston weight, the spring is touching but exert no force on the piston at this state. The gas now heated until the volume is doubled. The final pressure of the gas is 300 kPa, and during the process the spring force is proportional to the displacement of the piston from the initial position. Calculate the work done by the system, what percentage of work is done against the spring.

P1=100kPa   V1=0.1m3

P2=300kPa   V2=0.2m3



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$$Force\ \alpha\quad \Delta l$$

$$Force\ \alpha\quad (l-l_1)$$

$$\frac{Fs}{A}\alpha\frac{l-l_1}{A}\frac{A}{A}$$

$$Ps\alpha\frac{(l-l_1)A}{A^2}$$

$$Ps\alpha\frac{(v-v_1)}{A^2}=\frac{C}{A^2}(v-v_1)$$

$$Ps=a(v-v_1)$$

$$Pt=Po+Ps=100+a(v-v_1)$$

$$at\quad Pt=300\quad v=0.2$$

$$300=100+a(0.2-0.1)$$

$$a=2000$$

$$Pt=100+2000(v-0.1)=100+2000v-200$$

$$Pt=2000v-100$$

$$w=\int_1^2 p.dv=\int_1^2(2000v-100).dv=\left[\frac{2000v^2}{2}-100v\right]_1^2$$

S

$$w=\left[\frac{2000(0.2)^2}{2}-100(0.2)\right]-\left[\frac{2000(0.1)^2}{2}-100(0.1)\right]=20kJ$$

if there is no spring the piston will be rise at constant pressure

$$w=\int_1^2 p.dv=\int_1^2 dv=p(v_2-v_1)=100(0.2-0.1)=10kJ$$

$$\text{percentage of work is done against the spring}=\frac{10}{20}=50\%$$