SYNERGY INSTITUTE OF ENGINEERING & TECHNOLOGY
Department of Mechanical Engineering
LECTURE NOTE (Academic Session 2023-2024)

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Subject Code: RME4C002 **Subject Credit: 3**

Name of Subject: Engineering Thermodynamics

ENGINEERING THERMODYNAMICS

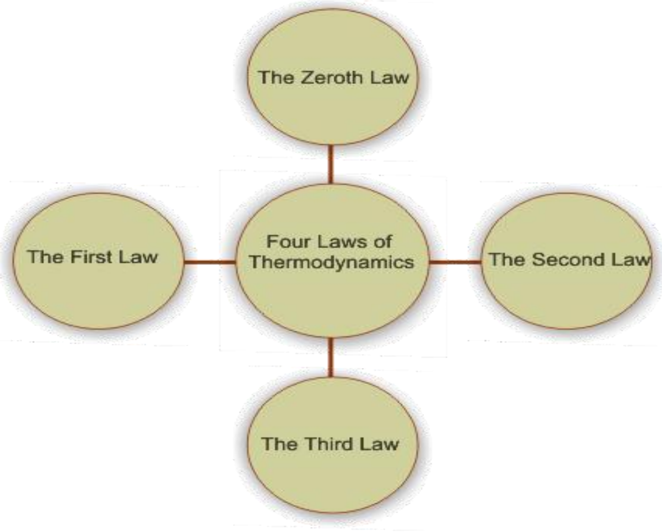
Whatis Thermodynamics?

- Thermodynamics is asciencedealingwith Energyand its transformation and its effect on the physical properties of substances.
- Itdealswith equilibriumand feasibilityofa process.
- Dealswiththerelationshipbetweenheatand work andthepropertiesofsystemsin equilibrium.

ScopeofThermodynamics:

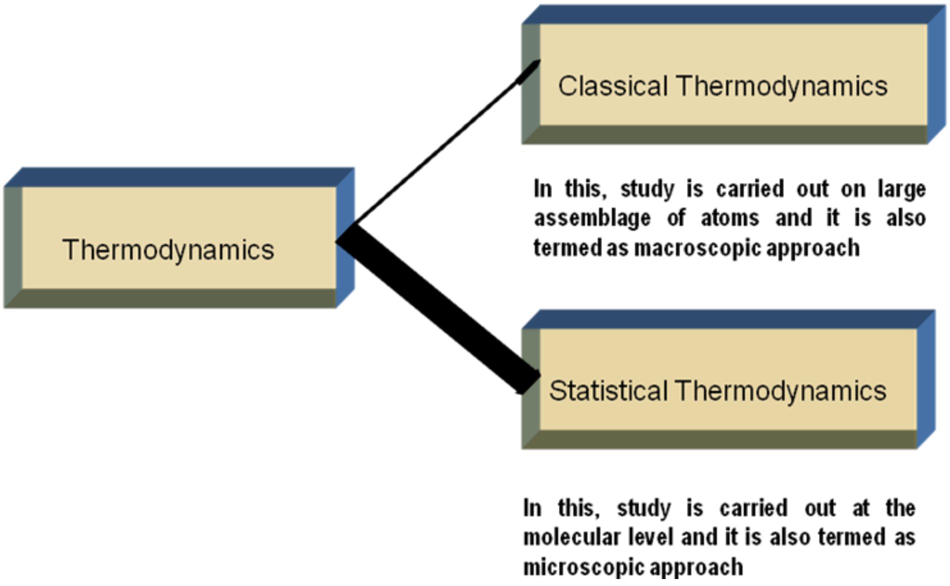
- Steampowerplant
- SeparationandLiquification Plant
- Refrigeration
- Air-conditioningandHeatingDevices.
- Internalcombustionengine
- Chemicalpower plants
- Turbines
- Compressors,etc

Theprinciplesofthermodynamicsaresummarizedintheformoffourthermodynamic laws:



- **TheZerothLaw** dealswiththermalequilibriumandprovidesameansformeasuring temperatures.
- **TheFirstLaw**dealswiththeconservationofenergyandintroducestheconceptof internal energy.
- **TheSecondLaw**ofthermodynamicsprovideswiththeguidelinesontheconversionof internal energy of matter into work. It also introduces the concept of entropy.
- **TheThirdLaw** ofthermodynamicsdefinestheabsolutezeroofentropy.Theentropyof a pure crystalline substance at absolute zero temperature is zero.

DifferentApproachesofThermodynamics:



In this, study is carried out on large assemblage of atoms and it is also termed as macroscopic approach

In this, study is carried out at the molecular level and it is also termed as microscopic approach

WritethedifferencebetweenMacroscopicandMicroscopicapproachof Thermodynamics:

Macroscopic Approach	**MicroscopicApproach**
1.MacroscopicapproachisknownasClassical Thermodynamics.	1. Microscopic approach is known asStatistical Thermodynamics
2.Attentionisfocussedonacertainquantityof matter without taking into account the events occuring at molecular level.	2.Aknowledgeofthestructureofmatter under consideration is essential.

3.Onlyafewvariablesareusedtodescribethe state of the matter under consideration.	3.Alargeno.ofvariablesarerequiredfora completespecificationofthestateofmatter under consideration.
4.Thevaluesofthevariablesusedtodescribe the state of the matter are easily measurable.	4. The variables used to describe the state of mattercannotbemeasuredeasilyandprecisely

DefineThermodynamicSystem?

Athermodynamicsystemisdefinedasadefinitequantityofmatteroraregionofspacewithina prescribed boundary upon which attention is focussed in the analysis of a problem.

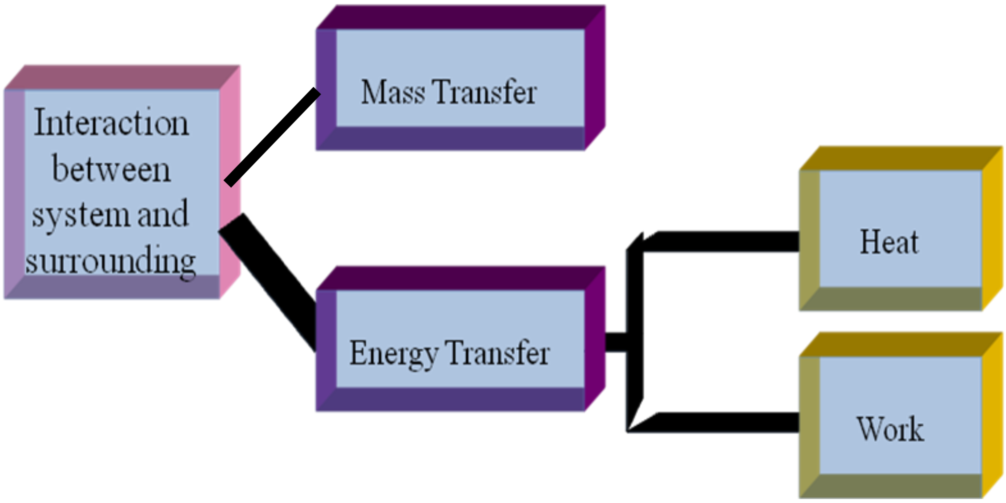
Surrounding: Everythingexternaltothesystemis Surroundings.

Boundary:

- Thesurfacewhichseparates thesystemfrom the surrounding.
- Systemandsurroundinginteractthrough boundaryintheformofHeatandWork.
- Boundarycan bereal (or) imaginary.
- Boundarycan befixed (or) moving.

SystemandSurroundingputtogetheris knownas **Universe**

Interaction Between System and Surrounding

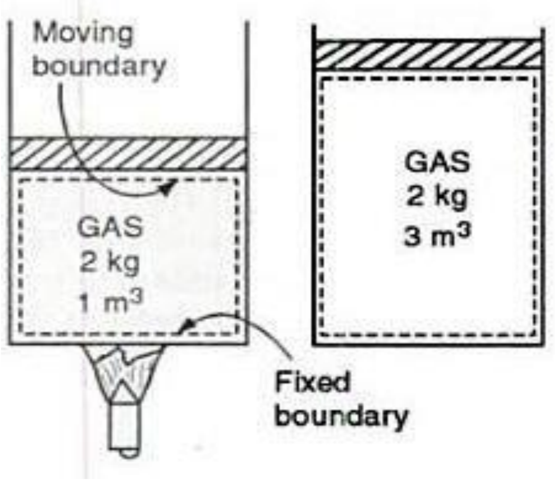


Basedonthetypeof interaction,thesystems areclassified as

- **CLOSED SYSTEM**
- **OPENSYSTEM**
- **ISOLATED SYSTEM**

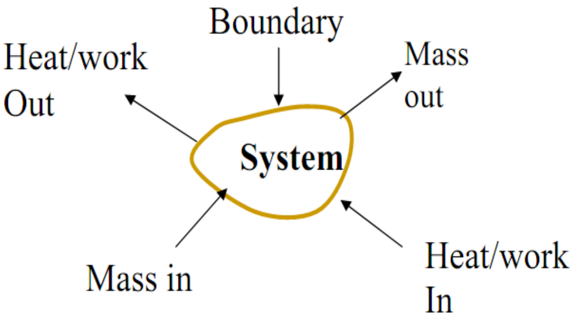
CLOSEDSYSTEM(ControlMass): Itisalso termedascontrolmassor fixedmassanalysis.

There is no mass transfer across the system boundarybut energy in theform of Heat or Work can cross the system boundary.



Eg.A certainamountof gasenclosedina cylinderpistonarrangement.

OpenSystem(ControlVolume): Theopensystemisoneinwhichbothmassandenergy can cross the boundary of the system.



Opensystemisalsotermedascontrolvolumeanalysis.

WritedowntheconceptofControlVolume:

A large engineering problems involve mass flow in and out ofa system and therefore, are modeled as control volumes.

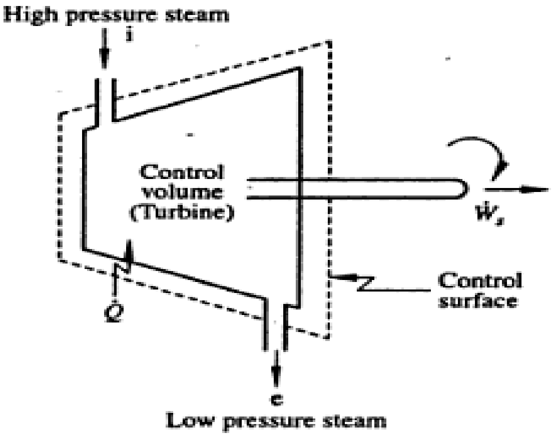
Controlvolume referstoadefinitevolumeonwhich attentionis focussedforenergyanalysis.

Examples:Nozzles,Diffusers,Turbines,Compressors,

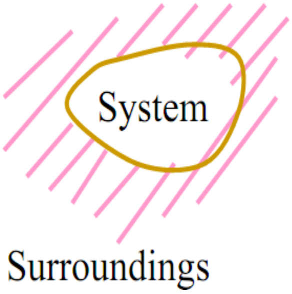
Heat Exchanger, De-superheater, Throttling valves,

I.Cengineetc.

Control Surface: The closed surface that surrounds the control volume is called **CONTROL SURFACE.** Mass as well as energy crosses the control surface. Control surface can be real or imaginary.



Isolated System: The isolated system is one in which there is no interaction between the system and the surroundings thatneither the mass nor the energy interactions. Therefore it is of fixed mass and energy.

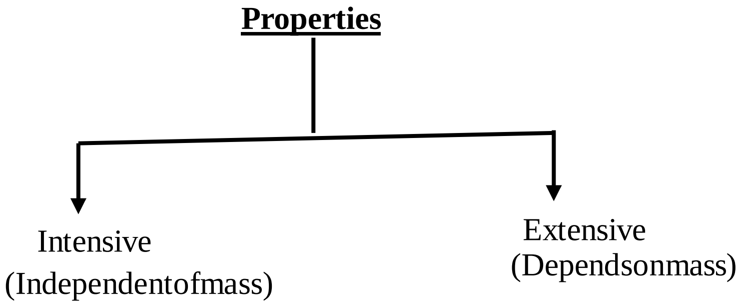


Note:

MassTransfer	**Energy Transfer**	**TypeofSystem**
No	**Yes**	**ClosedSystem**
Yes	**Yes**	**Open System**
No	**No**	**Isolated System**
Yes	**No**	**Impossible**

WhatdoyoumeanbyProperty?

Any observable characteristics required to describe the conditions or state of a system is known as Thermodynamic property of a system.



DifferentiateIntensiveandExtensiveProperty?

Extensive Property	**Intensive Property**
1.Extensivepropertiesaredependentonthemass of a system.	1.Intensivepropertiesareindependentof the mass of a system.
2.Extensivepropertiesareadditive.	2. Intensivepropertiesarenotadditive.

3.Itsvalueforanoverallsystemisthesumofits values for the parts into which the system is divided.	3.Itsvalueremainsthesamewhetherone considers the whole system or onlya part of it.
4.Example:mass(m),volume(V),Energy(E),Enthalpy(H) etc.	4.Example:Pressure(P),Temperature(T),Density etc.
5.Uppercaselettersareusedforextensive properties except mass.	5.Lowercaselettersareusedforintensive propertiesexceptpressure(P)andtemp.(T)

Specific property= Extensive property/mass.

Example:Specificvolume(**v**)=Volume(**V**)/mass(**m**)

Specificenthalpy(**h**)=Enthalpy(**H**)/mass(**m**) Specific entropy (**s**) = Entropy(**S**)/mass(**m**)

State:

- Itisthecondition ofasystemasdefinedbythevaluesofall it'sproperties.
- It givesacompletedescriptionofthe system.
- Any operationinwhich oneormorepropertiesofasystemchangeiscalled***changeof state*** .

Pathand Process:

- Theseries ofstate through asystem passes duringachangeof state is***Path of thesystem***.
- Ifthepathfollowedbythesystemduringchangeofstateisspecifiedordefined completely, then it is called a process.

Wecan allow oneof thepropertiesto remain aconstant duringaprocess.

Isothermal ⟹ ConstantTemperature(**T**)

Isobaric ⟹ ConstantPressure(**P**)

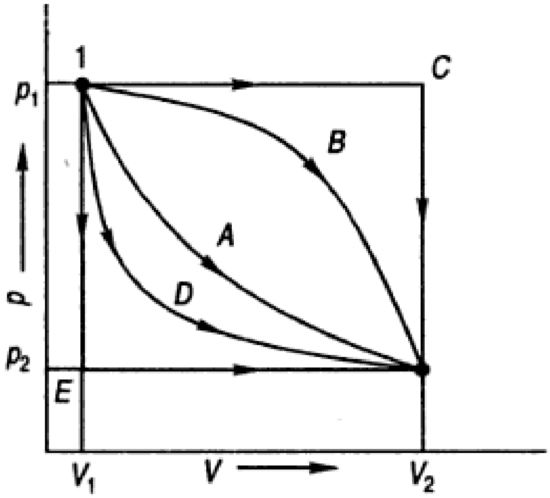
Isochoric ⟹ ConstantVolume(**V**)

Isentropic ⟹ Constant Entropy (**s**)

Isenthalpic ⟹ ConstantEnthalpy (**h**)

Cycle: When a system in a given initial state undergoes a series of processesand returns to initialstateattheendofprocess,thenthesystemissaidtohaveundergoneathermodynamic cycle.

DIFFERENTIATEBETWEENPOINTFUNCTIONVSPATHFUNCTION



PointFunction	**Path Function**
1.Anyquantitywhosechangeisindependentof the path is known as point function.	1. Any quantity, the value of which depends on the path followed during a change of state is known as path function.
2.Themagnitudeofsuchquantityinaprocess depends on the state.	2.Themagnitudeof suchquantityin a process isequaltotheareaunderthecurveona property diagram.
3.Theseareexact differential.	3.Theseareinexactdifferential.Inexact differential is denoted byδ
4.Propertiesaretheexamplesofpointfunction like pressure(P), volume(V),Temp.(T),Energy etc.	4.Ex: Heat and work

ThermodynamicEquilibrium

AsystemissaidtoexistinastateofThermodynamicEquilibriumwhennochangesin macroscopic property is observed if the system is isolated from its surrounding.

At the state of equilibrium, the properties of the system are uniform andonly one value can beassigned to it.

Asystemwillbeinastateofthermodynamicequilibrium,iftheconditionforfollowingthree types of equilibrium are satisfied.

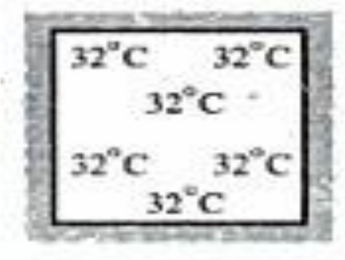
Thermal Equilibrium

Mechanical Equilibrium

Chemical Equilibrium

ThermalEquilibrium(EqualityofTemperature):

Astateofthermalequilibriumcanbedescribedasoneinwhichthetemperatureofthesystemis uniform.



MechanicalEquilibrium(Equalityof Pressure):

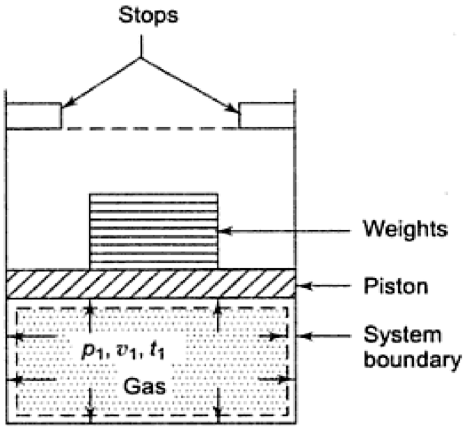
Intheabsenceofanyunbalancedforcewithinthesystemitselfandalsobetweenthesystemand the surroundings, the system is said to be in a state of mechanical equilibrium.

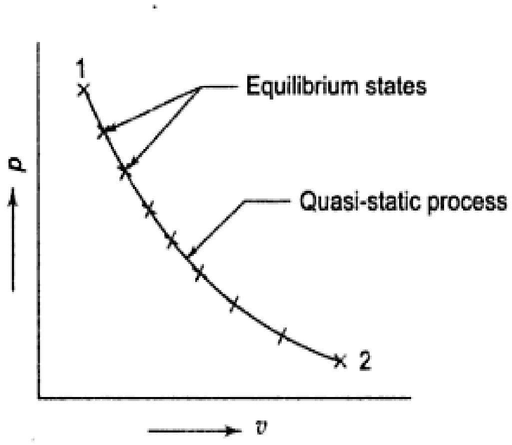
- Mechanicalequilibriumisrelatedtopressure.
- Asystemisinmechanicalequilibriumifthereisnochangeinpressureatanypointof the system .

<u>ChemicalEquilibrium</u>(Equalityofchemicalpotential):

- Asystemisinchemicalequilibriumwhenitschemicalcompositiondoesnotchangewith time, that is no chemical reaction occurs .
- Itisrelatedtochemicalpotential.

QUASI-STATICPROCESS





Aquasi-staticprocessisoneinwhichthedeviationfromthermodynamicequilibriumis infinitesimal.

Characteristics:

- Infiniteslownessisthecharacteristicfeatureofthis process.
- Aquasi-static processis thusa *successionof equilibrium states.*
- Itcanbe represented asa continuouslineonthepropertydiagram.
- Itisalsoknownasareversible process.

REVERSIBLE PROCESS

Reversible process is one which is performed in such a way that at the end of the process both thesystemandsurroundingmayberestoredtotheirinitialstatewithoutproducinganychanges in rest of the Universe.

ReasonsforstudyingReversible Process:

1. Theyare easytoanalyze.

2. Theyservedasan idealizedprocesstowhich actualprocesscanbecompared.

3. They are taken for consideration because work producing devices such as steam turbine, automobile enginesetc delivers the max. work and work consuming devices like compressors, pumps etc consumes the least work.

Characteristicsof ReversibleProcess

- ✓ AReversibleprocessiscarriedoutinfinitelyslowlywithaninfinitesimalgradientsothat every state pass through by the system is in equilibrium.
- ✓ Itis possibleto execute theprocess ineitherofthedirection.
- ✓ Nodissipativeeffectsuchasfriction,loss inaresistor,etcare present.
- ✓ Heatandworkinteractionsofthesystemandthesurroundingsinthereverseprocessareequal and opposite in direction to the same in the forward process.

Examples:

1. Frictionlessisothermalexpansionorcompressionofa fluid.
2. Frictionlessadiabaticexpansionorcompressionof a fluid.
3. Elastic stretchingof a solid.
4. Electriccurrentwithzero resistance.

IRREVERSIBLEPROCESS

An irreversible process is one that is carried out in such a way that the system and surrounding cannotbeexactlyrestoredtotheirrespectiveinitialstateattheendofthereverseprocess,thata net change occurs in the Universe.

Note:Inanirreversiblethesurroundingwouldalwaysbeaffectedbylossofworkandgainof low temperature heat, which can be considered as waste heat for the surrounding.

Causesofan Irreversibility:

Theirreversibilityofaprocessmaybe duetoeitherone or bothof thefollowing.

(i) LackofEquilibrium.

(ii) InvolvementofDissipative effects.

LackofEquilibrium(Mechanical,Thermal,Chemical)

Thelackofequilibriumbetweenthesystemandthesurroundingsorbetweenthetwosystems causes a spontaneous change which makes the process irreversible.

Examples:

1. Heattransferthroughafinitetemperaturedifference.
2. CompressionorExpansionthroughafinitepressuredifferencebetweenthesystemand the surroundings.
3. FreeexpansionorUnrestrainedexpansion.
4. Mixingof substances.

DissipativeEffects:

Dissipationresults inthetransformation ofwork into molecularenergyof thesystem.

Examples:

1. Friction.
2. Flowofelectricitythrough aresistor.
3. Paddlewheelworktransfer.etc

Characteristicsof anIrreversibleProcess:

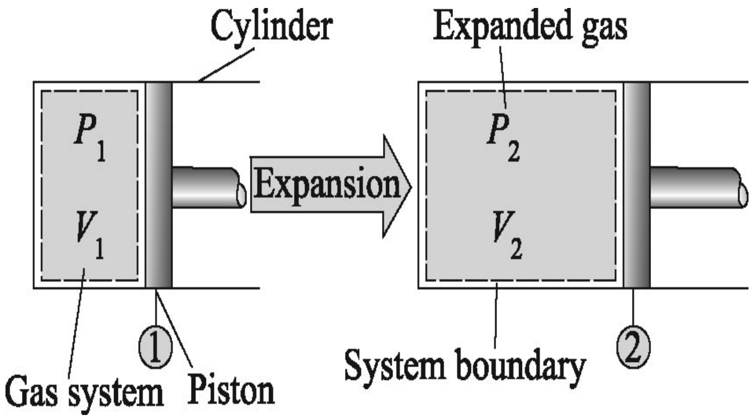
1. Itcanbe carriedoutinonedirectiononly.
2. Itoccursat afiniterate.
3. Duringanirreversibleprocess,thesystemisnotin equilibrium.

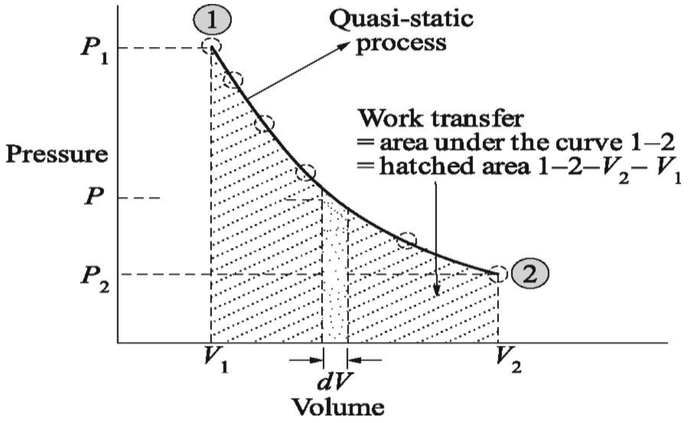
Anirreversibleprocesscannotbereversedwithoutcausingpermanentchangesinthe surroundings.

Heat&Work Transfer

ThermodynamicWork: Workissaidtobedonebyasystemifthesoleeffectonthings external to the system can be reduced to the raising of a weight.

Displacement(or)pdVWork:





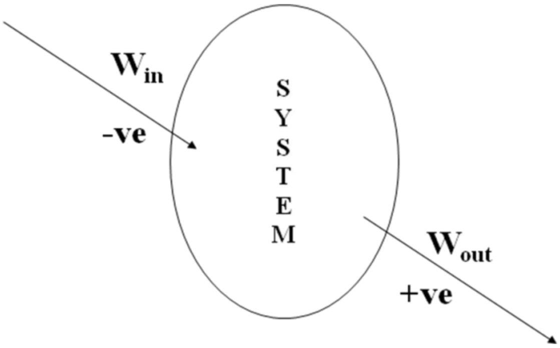
ExpressionforpdVWork:

$$\begin{aligned} W &= \int dW \\ &= \int (p * \text{pistonarea} * displacement) \\ &= \int p * A * dL \\ &= \int pdV \end{aligned}$$

$$W_{12} = \int_1^2 pdV$$

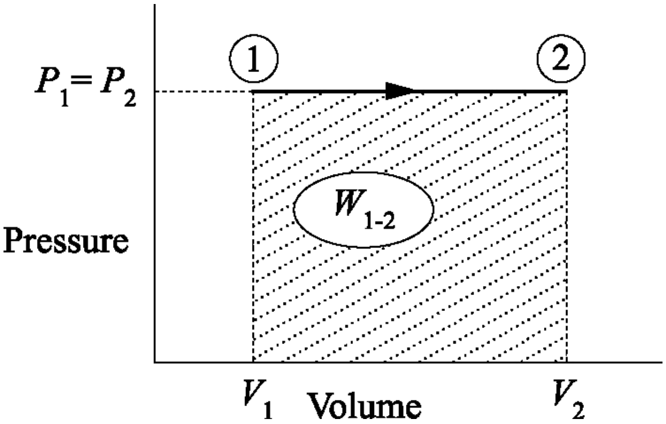
Sign Conventionforwork transfer:

Workdonebythe systemis**positiveand**Workdoneon thesystem is**negative.**



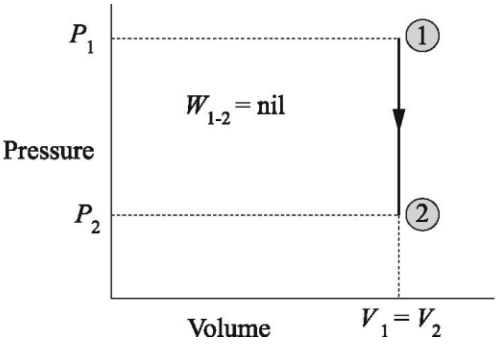
WorkdoneduringvariousQuasi-staticProcesses:

ConstantPressure Proces:



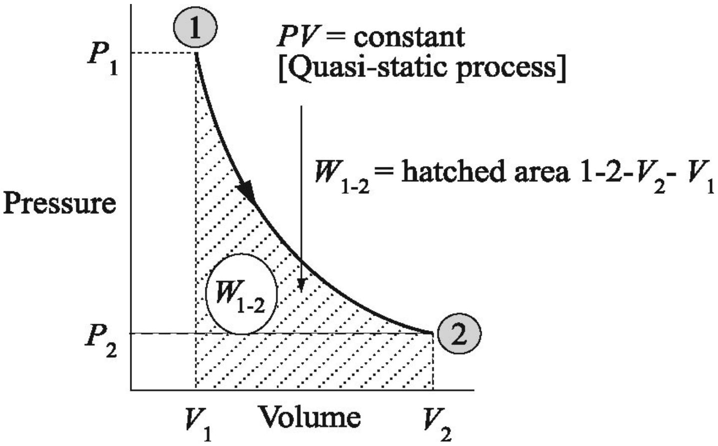
$$W_{1-2} = \int_{V_1}^{V_2} p dV = p(V_2 - V_1)$$

ConstantVolumeProcess:



$$W_{12} = \int_{V_1}^{V_2} p dV = 0$$

ConstantTemperature Process:



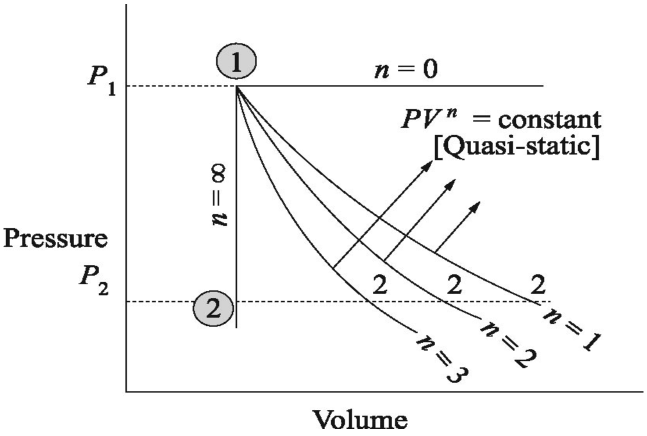
$$W_{12} = \int_{V_1}^{V_2} p dV$$

$$pV = p_1V_1 = C$$

$$p = \frac{p_1V_1}{V}$$

$$W_{1-2} = p_1V_1\int_{V_1}^{V_2}\frac{dV}{V} = p_1V_1\ln\frac{V_2}{V_1}$$

PolytropicProcess $pV^n = C$**,**wherenisaconstant



$$pV^n = p_1V_1^n = p_2V_2^n = C$$

$$p = \frac{(p_1V_1^n)}{V^n}$$

$$W_{12} = \int_{V_1}^{V_2} p\,dV$$

$$= \int_{V_1}^{V_2} \frac{p_1V_1^n}{V^n}\,dV$$

$$= \frac{p_1V_1 - p_2V_2}{n-1}$$

HeatTransfer: Energytransferbyvirtueoftemperaturedifferenceiscalled HeatTransfer. Heat Transfer is also a boundary phenomenon.

SpecificHeat: Itistheamountofheatrequiredtoraisethetemperatureofunitmassofa substance by unit degree.

For**Solids**and**Liquids**

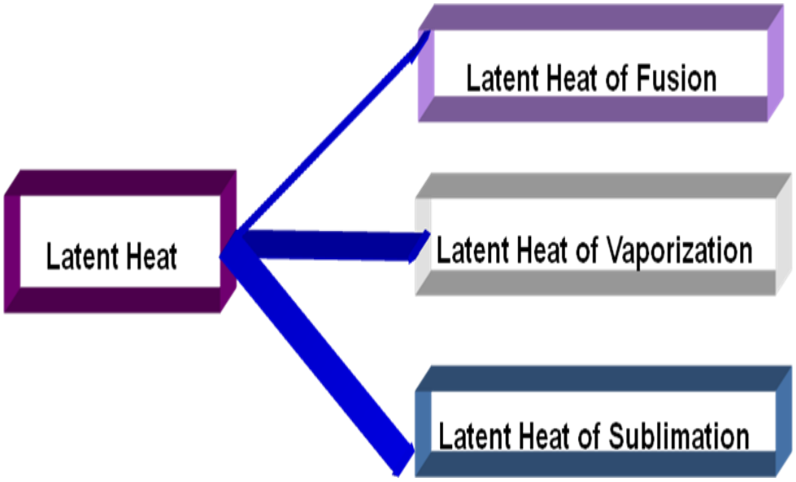
$c_p = c_v = c$

For**Gases**

c_p–specificheatcapacityatconstantpressure c_v–

specific heat capacity at constant volume

LatentHeat: Itistheamountofheattransferredtocauseaphase change.



FIRSTLAWOFTHERMODYNAMICS

- ThisisbasedonLawofConservationof Energy.
- Thisisalso calledasFirst Principle.

Foraclosedsystem,undergoinga cycle

SumofallWorktransfers=SumofallHeatTransfers

$$(W_1+W_2+W_3+\ldots..)=\Sigma(Q_1+Q_2+Q_3+\ldots\ldots\ldots\ldots\ldots)$$

$$\Sigma(W) = \Sigma(Q)$$

$$\oint dW = \oint dQ$$

Fora closedsystem,undergoingaProcess

Wheneverheatisabsorbed byasystemitincreases itsinternalenergyanddoessomework.

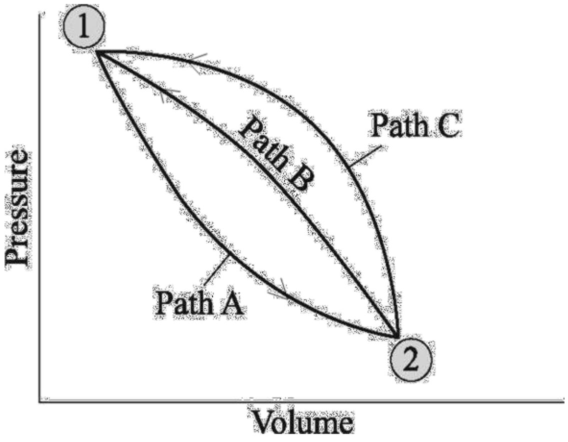
$$Q=\Delta E + W$$

Where Q– heat absorbed by the system

W–Workoutputfromthesystem

ΔE– Changein Stored Energyof the system

ShowthatEnergyisapropertyof the system



ForpathA,

$$Q_A = W_A + \Delta E_A \qquad (1)$$

ForpathB,

$$Q_B = W_B + \Delta E_B \qquad (2)$$

ForpathB,

$$Q_C = W_C + \Delta E_C \qquad (3)$$

ForCycle1-A-2-B-1,

$$W_A + W_B = Q_A + Q_B \qquad (4)$$

$$Q_A - W_A = -(Q_B - W_B)$$

$$\Delta E_A = -\Delta E_B \qquad (A)$$

ForCycle1-A-2-C-1,

$$W_A Q + W_C = Q_A + Q_C$$

$$_A \; - W_A = -(Q_C - W_C)$$

$$\Delta E_A = -\Delta E_C \qquad (C)$$

ComparingA andC

$$\Delta E_B = \Delta E_C$$

Enthalpy:

- Itisthe energycontentof theflowingfluid.
- Itisdefinedbythesummationofinternalenergyandflowwork. H =

U + PV

<u>Note:</u>Foranidealgash =u+Pv.

=u +RT

So,h =f(T)

Define$C_v$with thehelpinternal energyandTemperature:

Theamountofheatrequiredtoraisethetemperatureofunitmassofasubstanceby1°Cina reversible constant volume process.

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

$C_v$isalsodefinedasthechangeofinternalenergyofthesubstanceperunitchangein temperature at constant volume.

Define$C_p$with thehelpenthalpyandTemperature:

Theamountofheatrequiredtoraisethetemperatureofunitmassofasubstanceby1°Cina reversible constant pressure process.

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$C_p$isalsodefinedasthechangeofinternalenergyofthesubstanceperunitchangein temperature at constant pressure.

ApplicationofFirstlawtodifferentThermodynamic process:

Process	**Index=n**	Q	$W=\int PdV$	P-V-TRelation
Rev.Const.Vol.	∞	$Q = \Delta U$ $= mC_v(T_2 - T_1)$	$W=0$	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
Rev.Const.pressure	n=0	$Q = \Delta H$ $= mC_p(T_2 - T_1)$	$W = P(V_2 - V_1)$ $= mR(T_2 - T_1)$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Rev.Isothermal	n=1	$Q = W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1 = P_2V_2$
Rev.Adiabatic	n=γ	$Q=0$	$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$P_1V_1^{\gamma} = P_2V_2^{\gamma}$
Rev.Polytropic	n	$Q = \Delta U + W$	$W = \frac{P_1V_1 - P_2V_2}{n-1}$	$P_1V_1^n = P_2V_2^n$

SECONDLAW OFTHERMODYNAMICS

Statethelimitationsoffirstlawofthermodynamics?

1. FirstLawplacesno restrictiononthedirection ofaprocess.

2. Itdoesnotensurewhethertheprocess isfeasibleor not.

3. Thislawdoesnotdifferentiateheatandwork. It isconcernedwiththequantityofenergyand the transformation of energy from one form to another with no regard to its quality.

Aspectsofthesecondlaw

1. To identifythe directionofprocess.

2. Establishingconditions forequilibrium.

3. Italsoassertsthatenergyhasqualityaswellasquantity.

3. Itisalsousedindeterminingthetheoreticallimitsfortheperformanceofheatenginesand refrigerators.

4. Definingatemperaturescale independent of theproperties of anythermometric substance.

Thermal Energy Reservoir (TER): It is a hypothetical body with a relatively large thermal energycapacity that can supply or absorb finite amount of heat without undergoing any change in temperature. Examples: Oceans, rivers, atmospheric air etc.

- TERthat supplies energyintheform of heatis called a**source**
- TERthatabsorbs energyin theformof heatis called a**sink**

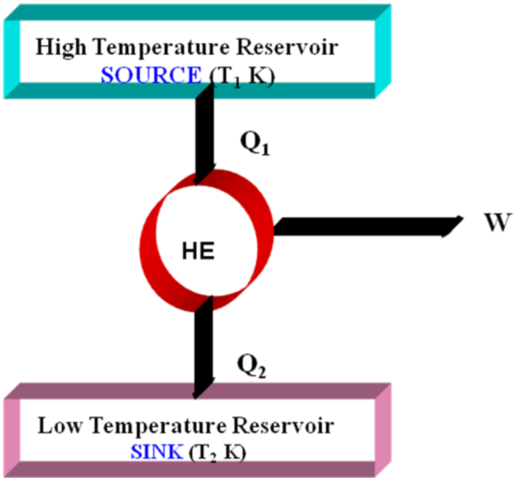
Heat Engines: Heat engine is a cyclic device, used to convert heat to work. Heat engine can be characterized by the following points.

1. Theyreceiveheatfrom ahightemperaturesource(solarenergy,oil-furnaceetc.)

2. Theyconvert part ofthis heat to work(usuallyin the formof a rotatingshaft)

3. Theyrejecttheremainingwaste heatto alowtemperaturesink (theatmosphere,rivers, etc)

4. Theyopertateon a cycle.



Q_1 =amount of heat supplied to steam in boiler from a high-temperaturesource.

Q_2=amountofheatrejectedfromsteamincondensertoalowtemperaturesink. W = net

work output of this heat engine.

Thermal efficiency: The fraction of the heat input that is converted to net work output is a measure of the performance of the heat engine.

$$\mathit{Thermalefficiency}()\eta = \frac{\text{Networkoutput}}{\text{Totalheatinput}}$$

$$\eta_{th} = \frac{W}{Q_1}$$

$$\eta_{th} = 1 - \frac{Q_2}{Q_1}$$

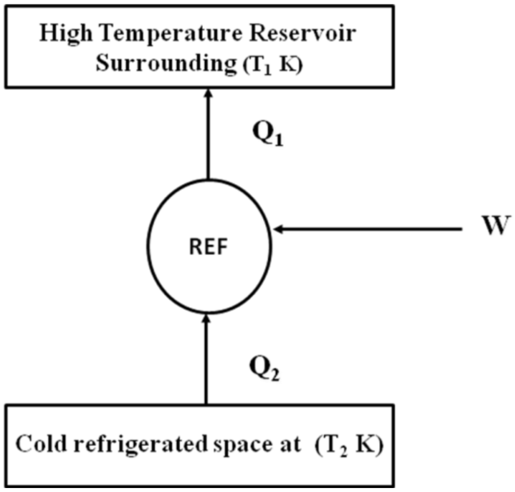
Refrigerator: Refrigeratorsarecyclicdevices,usedtotransferheatfromalowtemperature medium to a high temperature medium.

Theworkingfluid usedin therefrigeration cycleis called arefrigerant. Themost frequentlyused refrigeration cycle is the vapor-compression refrigeration cycle.

CoefficientofPerformance(COP)

$$COP_R = \frac{\text{Desiredoutput}}{\text{Requiredinput}} = \frac{Q_2}{W}$$

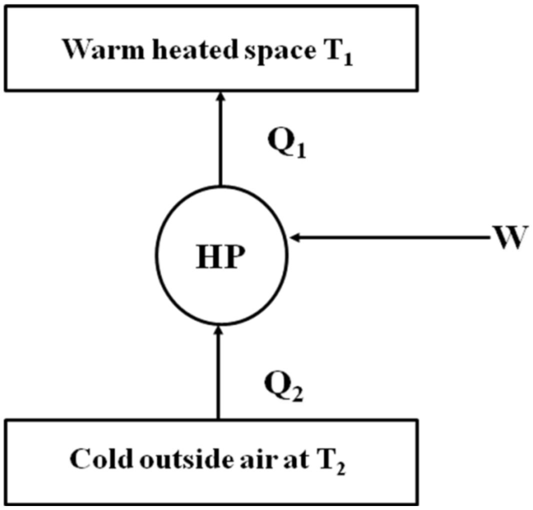
$$COP_R = \frac{Q_2}{Q_1 - Q_2}$$



(Refrigerator)

Heat Pumps: Heat pumps are another cyclic devices, used to transfer heat from a low temperature medium to a high temperature medium.

The objective of a heat pump is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low temperature source, such as cold outside air inwinter and supplying this heat to the high temperature medium such as a house.



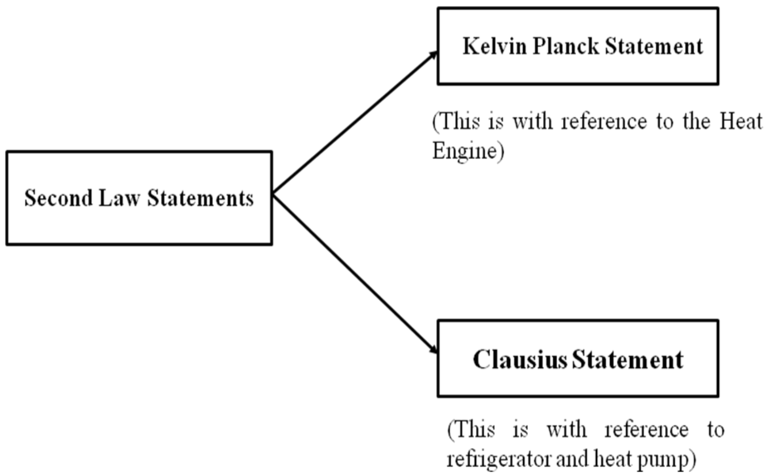
$$COP_{HP} = \frac{\text{Desired output}}{\text{Requiredinput}} = \frac{Q_1}{W}$$

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$

RelationbetweenCOP$_{HP}$andCOP$_{R}$

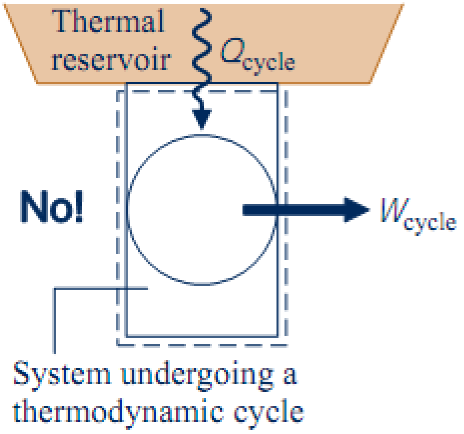
$$COP_{HP} = COP_R + 1$$

StatementsofSecondLaw



Kelvin-PlanckStatementoftheSecondlaw

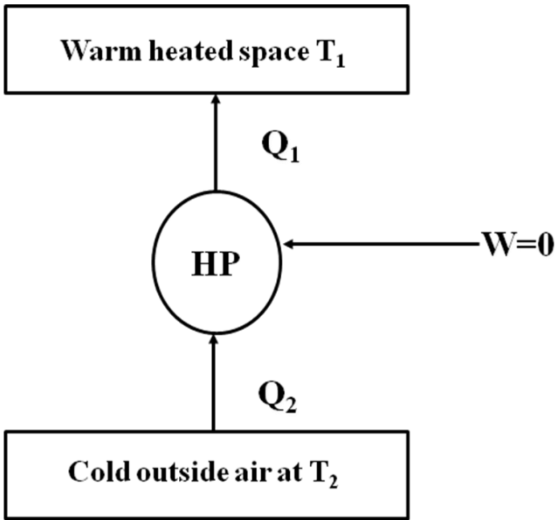
Itisimpossibleforanydevicethatoperatesonacycletoreceiveheatfrom asinglereservoirand produce a net amount of work.



(AheatenginethatviolatestheKelvin-Planck statement)

Clausius Statement:

Itisimpossibletoconstructadevicethatoperatesinacycleandproducenoeffectotherthanthe transfer of heat from a low temperature body to a high temperature body.

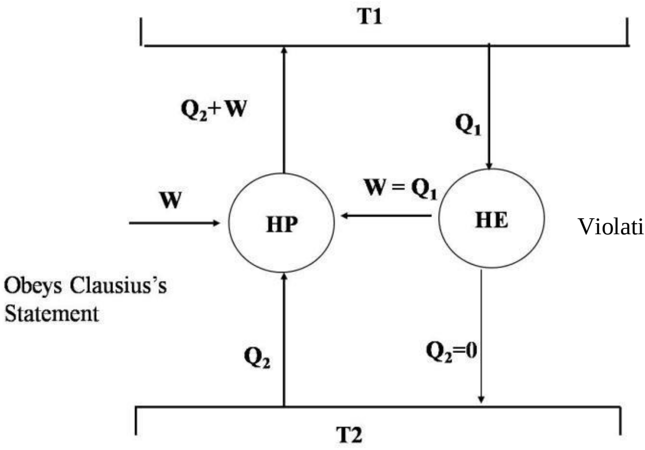


A refrigerator that violates the Clausius statement of the second law

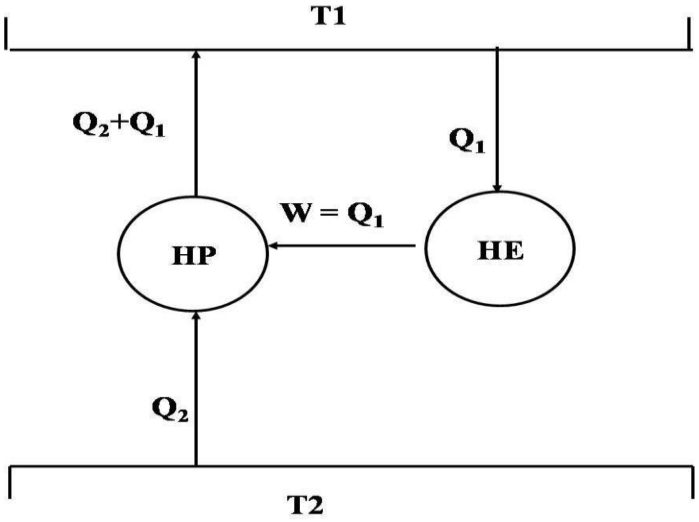
Equivalence of Kelvin Planck and Clausius Statements:

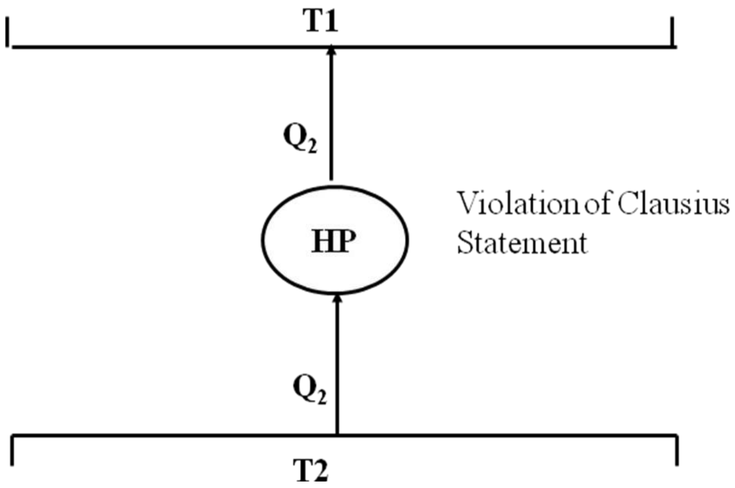
The equivalence of the statement is demonstrated by showing that the violation of each statement implies the violation of other.

CASE-1: Violation of Kelvin-planck statement leads to violation of Clausius statement



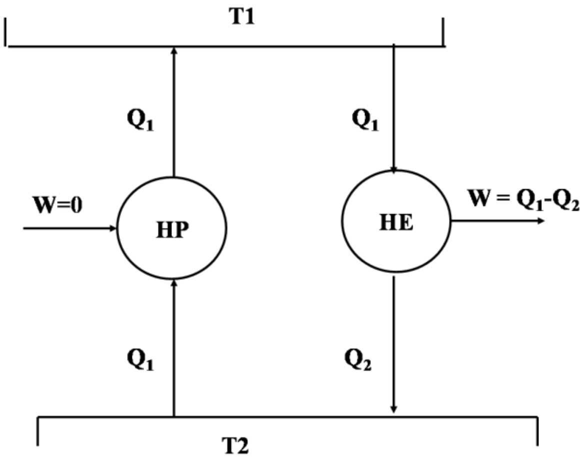
Violation of Kelvin-Planck statement

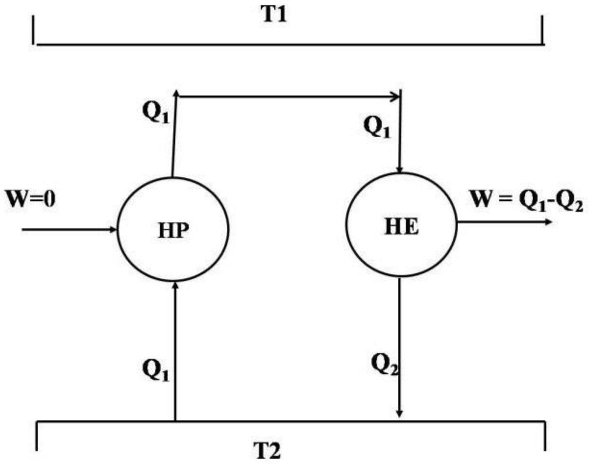


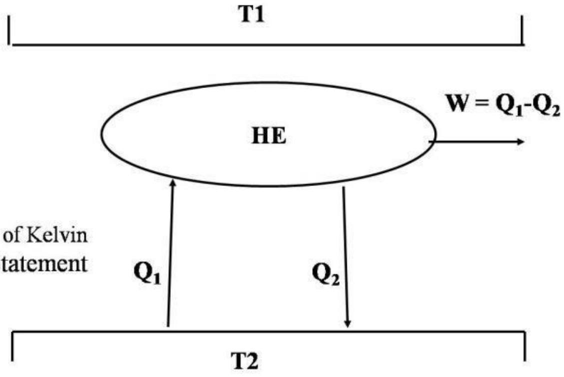


ThusviolationKelvinPlanckStatementhasleadtotheviolationof Clausius Statement

CASE-2:ViolationofClausiusstatementleadstoviolationofKelvin-planckstatement





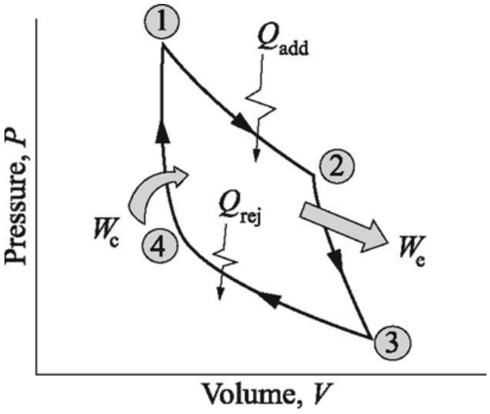


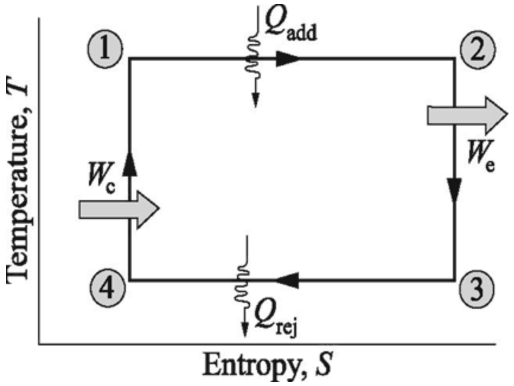
Violation of Kelvin Planck Statement

Thus Violation of Clausius Statement has lead to violation of Kelvin Planck Statements

CarnotCycle: Carnotcycleisareversiblecyclethatiscomposedoffourreversibleprocesses, two isothermal and two adiabatic.

- **Process1-2(ReversibleIsothermalHeatAddition)**
- **Process2–3(ReversibleAdiabatic Expansion)**
- **Process3–4(ReversibleIsothermalHeatRejection)**
- **Process4–1 (RevesibleAdiabatic Compression)**





$\Sigma(Q_{net})_{cycle}=\Sigma(W_{net})_{cycle}Q_{add}-$

$Q_{rej}=W_e - W_c$

$$\eta = \frac{W_{net}}{Q_{add}} = \frac{Q_{add}-Q_{rej}}{Q_{add}}$$

$$\boxed{\eta = 1 - \frac{Q_{rej}}{Q_{add}}}$$

FromT-Sdiagram

$$\eta = 1 - \frac{T_2(\Delta S)}{T_1(\Delta S)}$$

$$\boxed{\eta = 1 - \frac{T_2}{T_1}}$$

Carnot’sTheorem:

1. Theefficiencyofanirreversibleheatengineis alwayslessthanefficiencyofareversibleone operating between the same two reservoirs.

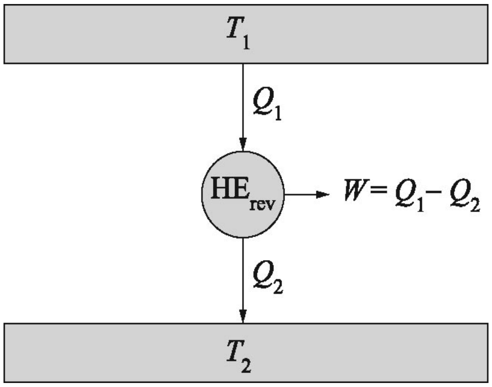
2. Theefficienciesofallreversibleheatenginesoperatingbetweenthesamereservoirsarethe same.

ClausiusInequality

Thecyclcintegralof $\frac{\delta Q}{T}$ isalways less thanorequal to zero.

Mathematicallyit canbeexpressed as $\oint \frac{\delta Q}{T} \le 0$.TheequalityintheClausiusinequalityholds fortotallyor just reversible cycleand the inequalityfor theirreversible ones.

ReversibleEngine



$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

(or)

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

$$\frac{Q_1}{T_1} - \frac{Q_2}{T_2} = 0$$

$$\oint \frac{dQ}{T} = 0$$

For an Irreversible Engine

$$Q_1 - Q_{2I} < Q_1 - Q_{2R}$$

and therefore

$$Q_{2I} > Q_{2R}$$

Consequently, for an irreversible heat engine

$$\oint \delta Q = Q_1 - Q_{2I} > 0$$

$$\oint \frac{\delta Q}{T} = \frac{Q_1}{T_1} - \frac{Q_{2I}}{T_2} < 0$$

So we conclude that for all irreversible heat engine

$$\oint \frac{\delta Q}{T} < 0$$

Entropy:

Entropy is defined as $dS = \left(\frac{\delta Q}{T}\right)_{rev}$

The T ds Relations:

$\delta Q_{rev} = dU + \delta W_{rev}$

But $\delta Q_{rev} = TdS$

and $\delta W_{rev} = PdV$

Thus, The first TdS equation is obtained as

$TdS = dU + PdV$

The second TdS equation is obtained by using the definition of enthalpy h $dH = u + pv.$

$TdS = dH$ $dH = dU + d(PV) = dU + PdV + VdP$

$TdS = dH - VdP$ $(\text{Since } TdS = dU + PdV)$

The TdS equations can be written on unit mass basis as

$Tds = du + Pdv$

$Tds = dh - vdP$

Entropychangeof anidealgas

Theentropychangebetweentwostatesofanidealgascanbeobtainedfromtheidealgas equation and the combined equation of the first first and second laws.

$$Tds=du+Pdv$$

But, $s_2 - s_1 = c_v \ln\left[\frac{T_2}{T_1}\right]$

$du=c_v dT$ and $P=(RT)/v$

Therefore,

$$Tds=c_v dT + \left[\frac{RT}{v}\right] dv$$

or

$$\int_1^2 ds = \int_1^2 c_v \frac{dT}{T} + \int_1^2 R\frac{dv}{v}$$

$$\therefore \quad s_2 - s_1 = c_v \ln\left[\frac{T_2}{T_1}\right] + R\ln\left[\frac{v_2}{v_1}\right]$$

Again, $Tds=dh - vdP$

Now,

$dh=c_p dT$ and $v=(RT)/P$

$$ds=c_p\left[\frac{dT}{T}\right] - \left[\frac{RT}{PT}\right]dP$$

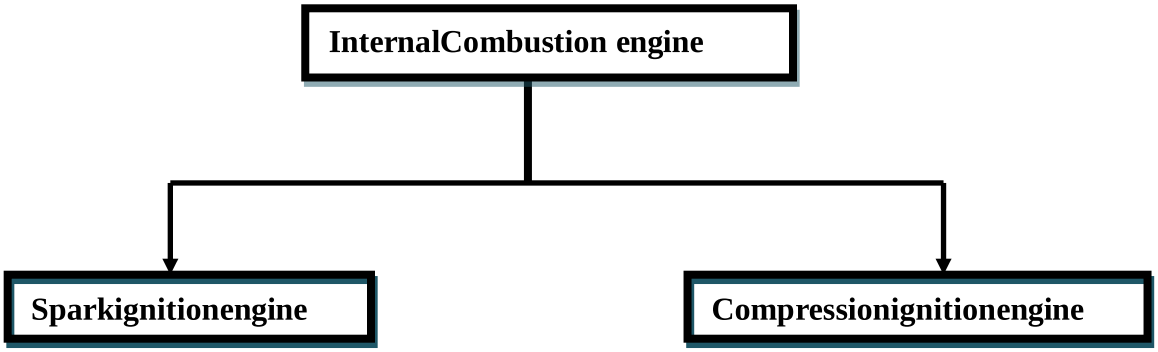
$$\int_1^2 ds = \int_1^2 c_P \frac{dT}{T} - R\int_1^2 \frac{dP}{P}$$

$$\therefore \quad s_2 - s_1 = c_p \ln\left[\frac{T_2}{T_1}\right] - R\ln\left[\frac{P_2}{P_1}\right]$$

Entropychangefordifferent process:

Process	**Entropy change** $s_2 - s_1$
Reversibleconstantvolume process	$s_2 - s_1 = c_v \ln\left[\frac{T_2}{T_1}\right]$
Reversibleconstantpressure process	$s_2 - s_1 = c_p \ln\left[\frac{T_2}{T_1}\right]$

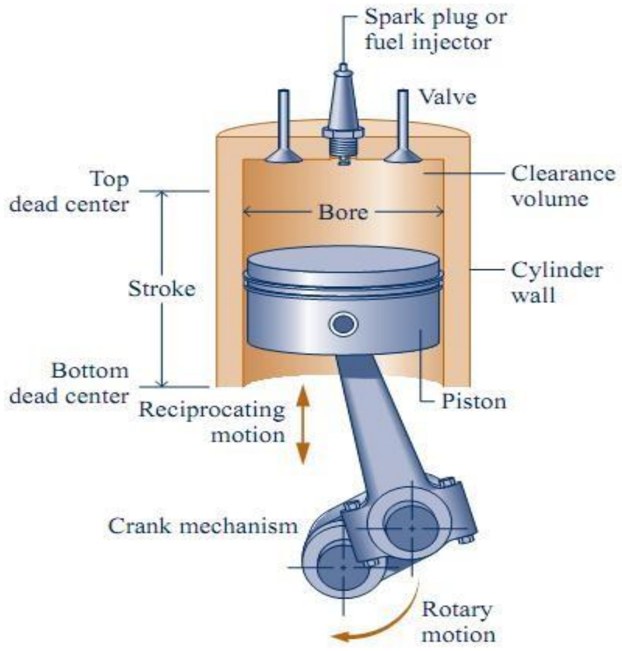
Reversibleisothermal process	$s_2 - s_1 = -R\ln\left[\frac{P_2}{P_1}\right]$ $or s_2 - s_1 = R\ln\left[\frac{v_2}{v_1}\right]$
Reversibleadiabatic process	$s_2 = s_1$
Polytropicprocess	$\int_1^2 ds = \int_1^2 c_v\left[\frac{dT}{T}\right] + \int_1^2 R\left[\frac{dv}{v}\right]$ $or \quad \int_1^2 ds = \int_1^2 c_p\left[\frac{dT}{T}\right] - R\int_1^2\left[\frac{dP}{P}\right]$



Theseenginesarepetrolengineand they work on Otto cycle

Theseenginesaredieselengineand they work on Diesel cycle

BasiccomponentsofICengine



Engine Terminology:

1. Top Dead Center (TDC): Position of the piston when it stops at the furthest point away from the crankshaft.

– Top because this position is at the top of the engines (not always), and dead because the piston stops as this point.

– When the piston is at TDC, the volume in the cylinder is a minimum called the clearance volume.

2. Bottom Dead Center (BDC): Position of the piston when it stops at the point closest to thecrankshaft. Volume of the cylinder is maximum.

3. Stroke: Distancetraveledbythepiston from oneextreme position to theother: TDC to BDC or BDC to TDC.

4. Bore : It is defined as cylinder diameter or piston face diameter; piston face diameter is same as cylinder diameter(minus small clearance).

5. Swept volume/Displacement volume : Volume displaced by the piston as it travels through one stroke.

– Sweptvolumeisdefinedasstroketimes bore.

– Displacementcanbegivenforonecylinderorentireengine(onecylindertimesnumberof cylinders).

Clearance volume : It is the minimum volume of the cylinder available for the charge (air or air fuel mixture) when the piston reaches at its outermost point (top dead center or outer deadcenter) during compression stroke of the cycle.

– Minimumvolume ofcombustion chamberwithpiston at TDC.

Compression ratio : The ratio of total volume to clearance volume of the cylinder is the compression ratio of the engine.

– Typically compression ratio for SI engines varies form8 to 12 and for CI engines it variesfrom 12 to 24

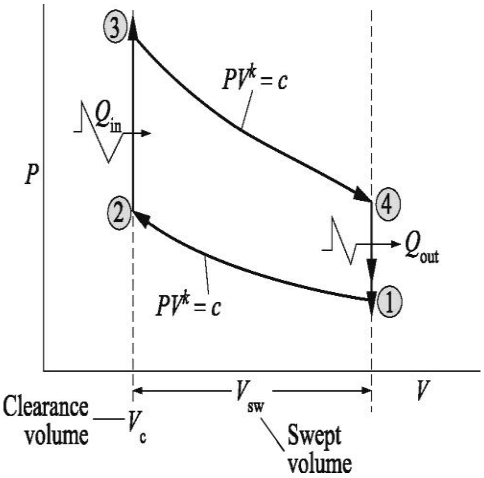
Ottocycle:

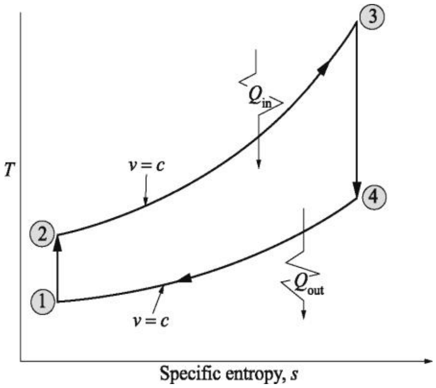
Theprocesses in Ottocycleare

❖ **(1–2)** IsentropicCompression

❖ **(2–3)**Constantvolumeheat addition.

- ❖ **(3–4)** IsentropicExpansion.
- ❖ **(4–1)**Constantvolumeheat rejection.





Efficiencyof OttoCycle

$$\eta_{Otto} = \frac{W_{net}}{HeatSupplied}$$

$$Wnet = W_{34} - W_{21}$$

$$W_{3-4} = C_v(T_3 - T_4) = C_vT_3\left(1 - \frac{1}{r_k^{\gamma-1}}\right)$$

$$W_{2-1} = C_v(T_2 - T_1) = C_vT_1(1 - r_k^{\gamma-1})$$

$$W_{net} = C_p\left(1 - \frac{1}{r_k^{\gamma-1}}\right)T_3 - T_1r_k^{\gamma-1}$$

$$\boxed{\eta_{otto} = \left[1 - \frac{1}{r_k^{\gamma-1}}\right]}$$

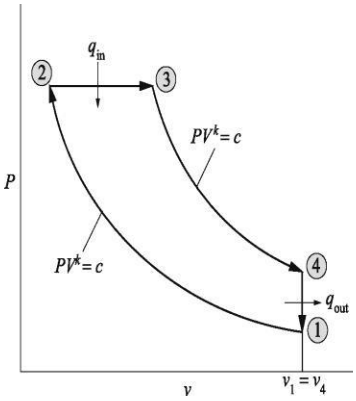
$$\text{Workratio} = \frac{W_{nettu}}{W_{rbine}} = 1 - \left[\frac{T_1}{T_3}\right]r_k^{(\gamma-1)}$$

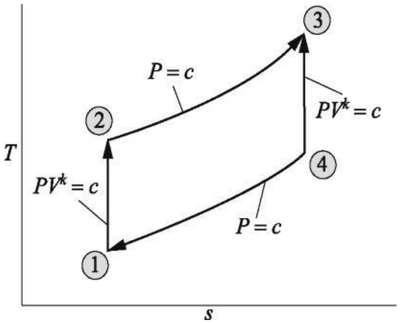
Dieselcycle

TheprocessesinDieselcycleare:

- ❖ **(1–2)** IsentropicCompression
- ❖ **(2–3)**Constantpressureheat addition.
- ❖ **(3–4)** IsentropicExpansion.

- ❖ **(4–1)**Constantvolumeheat rejection.





Efficiencyof Dieselcycle

$$\eta_{Diesel} = \frac{W_{net}}{HeatSupplied} = \frac{q_{in} - q_{out}}{q_{in}}$$

Now$q_{in} = c_p(T_3 - T_2)$and$q_{out} = c_v(T_4 - T_1)$

Hence$\eta_{th} = \dfrac{c_p(T_3 - T_2) - c_v(T_4 - T_1)}{c_p(T_3 - T_2)}$

$$= 1 - \frac{(T_4 - T_1)}{\gamma((T_3 - T_2))} = 1 - \frac{T_1\left[\frac{T_4}{T_1} - 1\right]}{\gamma T_2\left[\frac{T_3}{T_2} - 1\right]}$$

Now $\dfrac{T_1}{T_2} = \left(\dfrac{v_2}{v_1}\right)^{\gamma-1} = \left(\dfrac{1}{r_c}\right)^{\gamma-1}$

Alsosincep_3=p_2,hence $\dfrac{T_3}{T_2} = \dfrac{v_3}{v_2} = \rho$

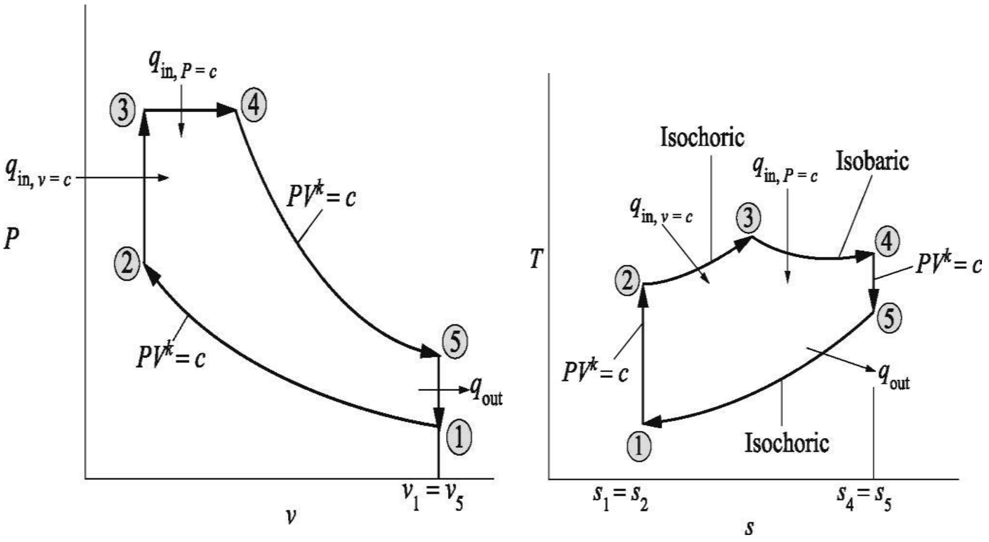
whereρisthecut-offratio. Again

since $v_4 = v_1$, $\dfrac{T_4}{T_1} = \dfrac{p_4}{p_1} = \rho^\gamma$

Substitutingthevaluesof $\dfrac{T_1}{T_2}$, $\dfrac{T_3}{T_2}$,and $\dfrac{T_4}{T_1}$,thevalueofthermalefficiency

$$\eta_{th} = 1 - \left(\frac{1}{r_c}\right)^{\gamma-1}\left[\frac{\rho^\gamma - 1}{\gamma(\rho - 1)}\right]$$

Dual cycle:



ProcessesinDualcycle:

1. (1-2)Isentropic compression

2. (2-3)Constantvolumeheataddition

3. (3-4)Constantpressureheataddition

4. (4-1)Isentropic expansion

5. (5-1)Constantvolumeheatrejection.

Efficiencyof Dual cycle

$$\eta_{dual} = \frac{q_{in} - q_{out}}{q_{in}}$$

$$= \frac{c_v(T_3 - T_2) + c_p(T_4 - T_3) - c_v(T_5 - T_1)}{c_v(T_3 - T_2) + c_p(T_4 - T_3)}$$

$$\eta_{dual} = 1 - \left[\frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma(T_4 - T_3)} \right]$$

Efficiency,

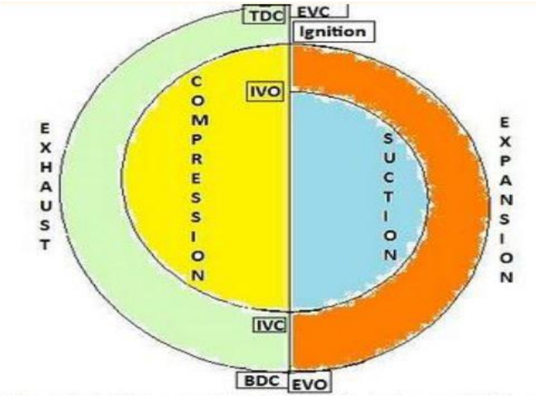
$$\boxed{\eta_{Dual} = 1 - \left[\frac{1}{r_c^{\gamma-1}} \right] \left[\frac{r_p \rho^{\gamma} - 1}{(r_p - 1) + \gamma r_p(\rho - 1)} \right]}$$

ComparisionbetweenSIengineandCIengine

SI engine	CI engine
WorkingcycleisOtto cycle.	Workingcycleisdiesel cycle.
Petrol or gasoline or high octane fuel is used.	Dieselorhighcetanefuelis used.
Highself-ignition temperature.	Lowself-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Useofsparkplugforignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compressionratiois6to 10.5	Compressionratiois14to 22
HighermaximumRPMdueto lower weight	LowermaximumRPM
Maximumefficiencylowerdue to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavierduetohigher pressures

Valvetimingdiagram

The exact moment at which the inlet and outlet valve opens and closes with reference to the position of the piston and crank shown diagrammatically is known as valve timing diagram. It is expressed in terms of degree crank angle. The theoretical valve timing diagram is shown in Fig.



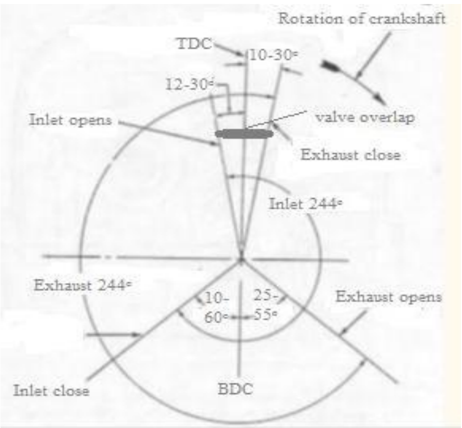
But actual valve timing diagram is different from theoretical due to two factors-mechanical and dynamic factors. Figure 4 shows the actual valve timing diagram for four stroke low speed or high speed engine.

Openingandclosingofinlet valve

➢ Inlet valve opens 12 to 30° CA before TDCto facilitate silent operation of the engine under high speed. It increases the volumetric efficiency.

➢ Inletvalvecloses10-60°CAafterTDCduetoinertiamovementoffreshchargeinto cylinder i.e. ram effect.

Figurerepresentstheactual valve timingdiagramforlowandhighspeed engine.



Openingandclosingofexhaustvalve

Exhaust valve opens 25 to 55° CA before BDC to reduce the work required to expel out the burnt gases from the cylinder. At the end of expansion stroke, the pressure inside the chamber is high, hence work to expel out the gases increases.

Exhaust valve closes 10 to 30° CA after TDC to avoid the compression of burnt gases in next cycle.Kineticenergyoftheburnt gascanassistmaximumexhaustingofthegas. Italsoincreases the volumetric efficiency.

Valveoverlap

During this time both the intake and exhaust valves are open. The intake valve is opened before the exhaust gases have completely left the cylinder, and their considerable velocity assists in drawing in the fresh charge. Engine designers aim to close the exhaust valve just as the fresh charge from the intake valve reaches it, to prevent either loss of fresh charge or unscavenged exhaust gas.