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2nd Law of Thermodynamics

Topic:

Second Law of Thermodynamics: 2nd Law of Thermodynamics, Reversible and Irreversible process with examples. Conversion of Work into Heat and Heat into Work. Kelvin-Planck and Clausius Statements and their Equivalence.

Frequently Asked Numerical:

Solved Problems and Problems in exercise of Heat & Thermodynamics, Author A. B. Gupta, H.P Roy, and Published by: Books & Allied Pvt. Ltd. (2018).

References:

i. *Heat & Thermodynamics, Author A. B. Gupta, H.P Roy, Published by: Books & Allied Pvt. Ltd. (2018)*

ii. *Theory & Experiment on Thermal Physics, Author-P. K. Chakraborty, Published by: Central*

This study material is only class-note. This class-note is prepared by following the reference books. Students should read the reference books for better knowledge.

Link to E-Lectures given by different Professors of Indian & Foreign Universities

(i) https://www.youtube.com/watch?v=lvy8h-yWhRQ
(ii) https://nptel.ac.in/courses/112105266/
(iii) https://nptel.ac.in/courses/112104113/
(iv) https://nptel.ac.in/courses/112105220/
(v) https://nptel.ac.in/courses/112108148/
(vi) https://nptel.ac.in/courses/101104063/
(vii) https://www.youtube.com/watch?v=IHIVf5xMfAE
(viii) https://www.youtube.com/watch?v=7WUA9SAAEnI

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Second law of Thermodynamics.

Limitations of 1st law.

From the 1st law of thermodynamics we know that the equivalence of mechanical work and heat, when one is completely converted into other. ~~Thef~~ Therefore 1st law of thermodynamics states the principle of conservation of energy of a thermodynamic system.

If we want to extract a certain amount of heat from a body and want to complete convert into work is found impossible. In actual practice complete conversion work into heat is possible but complete conversion of heat into work is not possible.

Reversible process

A reversible process is that which can be retraced in the opposite direction, so that the working substance passes through exactly the same condition as it does in the direct process.

Conditions for reversibility

i) The process must be quasistatic and slow.

ii) Dissipative forces such that friction viscosity, inelasticity, electrical resistant must be completely absent.

A reversible engine can not be realised in practice.

i) We know that for a reversible engine $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

If $T_2 = 0$ then $Q_2 = 0$. Therefore, no heat can be rejected into sink

ii) In reversible engine the working substance is an ideal gas. However, in practice no gas is ideal.

iii) for a reversible engine, the engine must be free from friction.

iv) for a reversible engine the states should be quasistatic ie, the pressure and temperature of the working substance never differ appreciably from its surroundings at any stage of cycle

These condition are not ~~maintained~~ maintained in practicle. Therefore, a reversible engine can not be realised in practice.

Example (i) Slow ~~adiabatic~~ isothermal expansion of gas
(ii) Slow adiabatic compression of gas
(iii) Small extension and compression of spring.

IRReversible process.

An irreversible process is that which cannot be retraced in the opposite direction so that the working substance does not pass through the same intermediate states through which it passes during the direct process.

Example. → (i) work done against friction.
(ii) Joule-Kelvin effect
(iii) Joule-Thomson effect.
(iv) Joule expansion (free expansion) of a perfect gas.

Reversible process.	Irreversible process.
i) Reversible process is quasistatic	ii) Irreversible process is non-static
ii) Reversible process is non-dissipative	iii) Irreversible process is dissipative.
iii) In reversible process Entropy remains Constant.	iii) In irreversible process entropy increases.

Entropy.

Entropy and its physical significance

If a substance takes an amount of heat Q in a reversible process at a constant temperature T, then the ratio of heat and temperature $\frac{Q}{T}$ is called the increase in entropy of the substance i.e. ΔS.

$\therefore$ Change in entropy $(\Delta S) = \frac{Q}{T}$

or $\boxed{\Delta S = \int \frac{dQ}{T}}$

According to statistical defination entropy is the product of Boltzmann's constant (K) and natural log of thermodynamic probability W.

i.e. $\boxed{S = K \ln W}$

Physical Significance.

i) Entropy is a state function.

ii) The entropy of the universe is continuously increasing.

iii) Like internal energy U and temperature T, the entropy S of a system is a physical property that can be measured.

Kelvin - Plank statement of 2nd law:

"It is impossible to construct a device operating a cycle will take heat from a body and convert it completely into work without leaving any change anywhere".

Clausius Statement

"It is impossible to construct a device, operating in a cycle, will transfer heat from a cold body to hot body without expenditure of work by an external energy source".

formulation of 2nd law of thermodynamics

If S_1 & S_2 be the net entropies of a system in initial and final state.

Change in entropy $(\Delta S) = S_2 - S_1 = \int_i^f \frac{dQ}{T}$

In reversible path if the two states are infinitesimally close to each other then.

$$dS = \frac{dQ}{T}$$

$$\boxed{dQ = T\,dS} \longrightarrow \text{Mathematical expression of 2nd law.}$$

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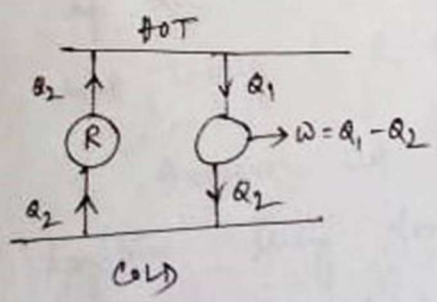
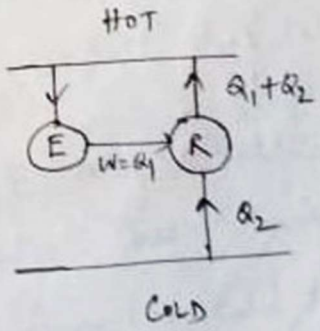
Equivalence of Kelvin - Plank & Clausius statement

Taking a refrigerator (R) which transfer an amount of heat Q_2 from a cold body to hot body without any internal supply of energy is against the Clausius statement.

Now, we take an engine (E) working between same hot and cold bodies, takes Q_1 heat from hot body and convert $(Q_1 - Q_2)$ into work, finally rejects Q_2 into cold body. The engine alongs with clausius law.





However, if the engine E & refrigerator R are combined together, they from a device that takes $Q_1 - Q_2$ heat from the hot bod

and converts all into work without giving up any amount of heat to the cold body. It is clearly against the Kelvin-Plank Statement

Similarly, let us suppose an engine E takes an amount of heat Q_1 from the hot body and converts completely into work $W = (Q_1)$ without giving up any heat to the cold body, against the Kelvin-Plank Statement.

A refrigerator R working between same two temperature takes heat Q_2 from the cold body and converts work $W(=Q_1)$ giving up an amount of heat $Q_1 + Q_2$ to the hot body. R does not violate the law.

However, if R and E are combined together, they from a device - that transfer an amount of heat Q_2 from a cold body to hot body without any external energy source is against the Clausius-Statement.

Thus the two statements are equivalent.