

SRI Y.N.COLLEGE (AUTONOMOUS)-NARSAPUR
DEPARTMENT OF PHYSICS
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STUDENT STUDY PROJECTS

SRI Y N COLLEGE (AUTONOMOUS), NARSAPUR
DEPARTMENT OF PHYSICS



STUDENT MINOR RESEARCH PROJECT
ACADEMIC YEAR 2019-2020

**CARNOT ENGINE-CARNOT'S CYCLE &
EFFICIENCY**

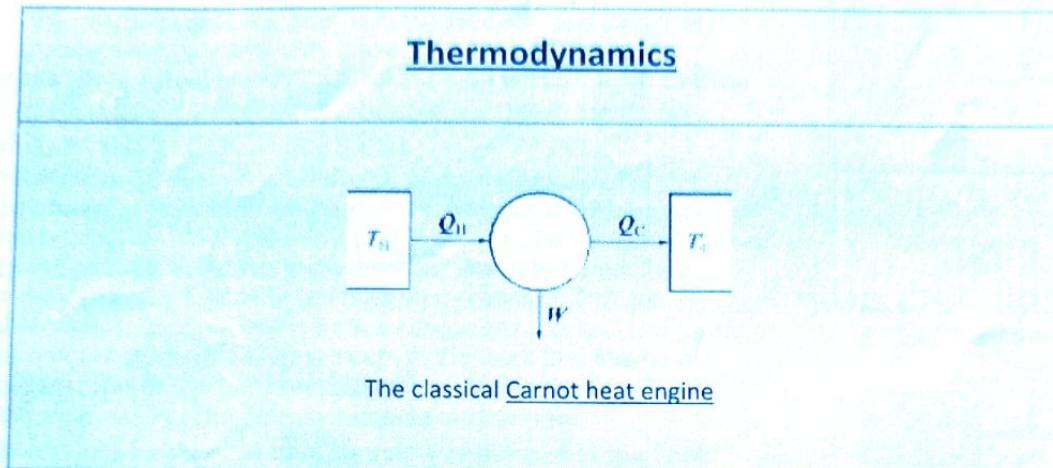
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Carnot cycle



The **Carnot cycle** is a theoretical thermodynamic cycle proposed by French physicist Sadi Carnot in 1824 and expanded upon by others in the 1830s and 1840s. It provides an upper limit on the efficiency that any classical thermodynamic engine can achieve during the conversion of heat into work, or conversely, the efficiency of a refrigeration system in creating a temperature difference (e.g. refrigeration) by the application of work to the system. It is not an actual thermodynamic cycle but is a theoretical construct.

Every single thermodynamic system exists in a particular state. When a system is taken through a series of different states and finally returned to its initial state, a thermodynamic cycle is said to have occurred. In the process of going through this cycle, the system may perform work on its surroundings, thereby acting as a heat engine. A system undergoing a Carnot cycle is called a Carnot heat engine, although such a "perfect" engine is only a theoretical construct and cannot be built in practice.^[1] However, a microscopic Carnot heat engine has been designed and run.^[2]

Essentially, there are two systems at temperatures T_h and T_c (hot and cold respectively), which are so large that their temperatures are practically unaffected by a single cycle. As such, they are called "heat reservoirs". Since the cycle is reversible, there is no generation of entropy during the cycle; entropy is conserved. During the cycle, an arbitrary amount of entropy ΔS is extracted from the hot reservoir, and deposited in the cold reservoir. Since there is no volume change in either reservoir, they do no work, and during the cycle, an amount of energy $T_h \Delta S$ is extracted from the hot reservoir and a smaller amount of energy $T_c \Delta S$ is deposited in the cold reservoir. The difference in the two energies $(T_h - T_c) \Delta S$ is equal to the work done by the engine.

Stages [edit]

The Carnot cycle when acting as a heat engine consists of the following steps:

- 1. Reversible isothermal expansion of the gas at the "hot" temperature, T_1 (isothermal heat addition or absorption).** During this step (1 to 2 on Figure 1, A to B in Figure 2) the gas is allowed to expand and it does work on the surroundings. The temperature of the gas does not change during the process, and thus the expansion is isothermal. The gas expansion is propelled by absorption of heat energy Q_1 from the high temperature reservoir and results in an increase of entropy of the gas in the amount $\Delta S_1 = Q_1/T_1$.
- 2. Isentropic ([Reversible adiabatic process|reversible adiabatic]) expansion of the gas (isentropic work output).** For this step (2 to 3 on Figure 1, B to C in Figure 2) the mechanisms of the engine are assumed to be thermally insulated, thus they neither gain nor lose heat (an adiabatic process). The gas continues to expand, doing work on the surroundings, and losing an amount of internal energy equal to the work that leaves the system. The gas expansion causes it to cool to the "cold" temperature, T_2 . The entropy remains unchanged.
- 3. Reversible isothermal compression of the gas at the "cold" temperature, T_2 . (isothermal heat rejection)** (3 to 4 on Figure 1, C to D on Figure 2) Now the surroundings do work on the gas, causing an amount of heat energy Q_2 to leave the system to the low temperature reservoir and the entropy of the system decreases in the amount $\Delta S_2 = Q_2/T_2$. (This is the same amount of entropy absorbed in step 1, as can be seen from the **Clausius inequality**.)
- 4. Isentropic compression of the gas (isentropic work input).** (4 to 1 on Figure 1, D to A on Figure 2) Once again the mechanisms of the engine are assumed to be thermally insulated, and frictionless, hence reversible. During this step, the surroundings do work on the gas, increasing its internal energy and compressing it, causing the temperature to rise to T_1 due solely to the work added to the system, but the entropy remains unchanged. At this point the gas is in the same state as at the start of step 1.

In this case,

$$\Delta S_1 = \Delta S_2,$$

or,

$$Q_1/T_1 = Q_2/T_2.$$

This is true as Q_2 and T_2 are both lower and in fact are in the same ratio as Q_1/T_1 .

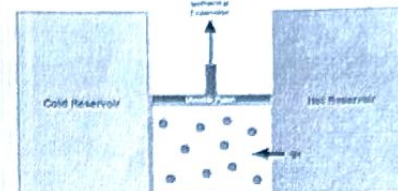
The pressure-volume graph [edit]

When the Carnot cycle is plotted on a pressure volume diagram, the isothermal stages follow the isotherm lines for the working fluid, adiabatic stages move between isotherms and the area bounded by the complete cycle path represents the total work that can be done during one cycle.

Properties and significance [edit]

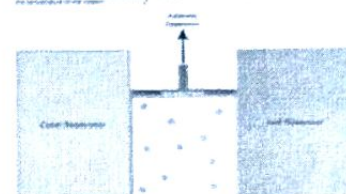
Stage One:

At this stage heat is added from the hot reservoir and is absorbed by the gas, causing it to expand. The temperature of the gas remains constant. The expansion causes the gas to do work on the surroundings.



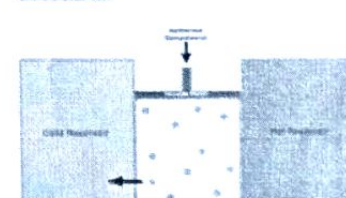
Stage Two:

At this stage the cylinder is insulated from both reservoirs. The gas continues to expand, doing work on the surroundings, and losing internal energy. The temperature of the gas decreases.



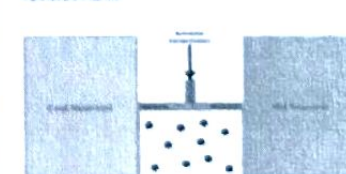
Stage Three:

At this stage the cylinder is connected to the cold reservoir. Heat is rejected from the gas to the cold reservoir, causing it to compress. The temperature of the gas remains constant.



Stage Four:

At this stage the cylinder is insulated from both reservoirs. The gas continues to compress, and internal energy is added to the gas. The temperature of the gas increases.



The temperature-entropy diagram

The behaviour of a Carnot engine or refrigerator is best understood by using a temperature-entropy diagram (TS diagram), in which the thermodynamic state is specified by a point on a graph with entropy (S) as the horizontal axis and temperature (T) as the vertical axis. For a simple closed system (control mass analysis), any point on the graph will represent a particular state of the system. A thermodynamic process will consist of a curve connecting an initial state (A) and a final state (B). The area under the curve will be:

$$Q = \int_A^B T dS \quad (1)$$

which is the amount of thermal energy transferred in the process. If the process moves to greater entropy, the area under the curve will be the amount of heat absorbed by the system in that process. If the process moves towards lesser entropy, it will be the amount of heat removed. For any cyclic process, there will be an upper portion of the cycle and a lower portion. For a clockwise cycle, the area under the upper portion will be the thermal energy absorbed during the cycle, while the area under the lower portion will be the thermal energy removed during the cycle. The area inside the cycle will then be the difference between the two, but since the internal energy of the system must have returned to its initial value, this difference must be the amount of work done by the system over the cycle. Referring to figure 1, mathematically, for a reversible process we may write the amount of work done over a cyclic process as:

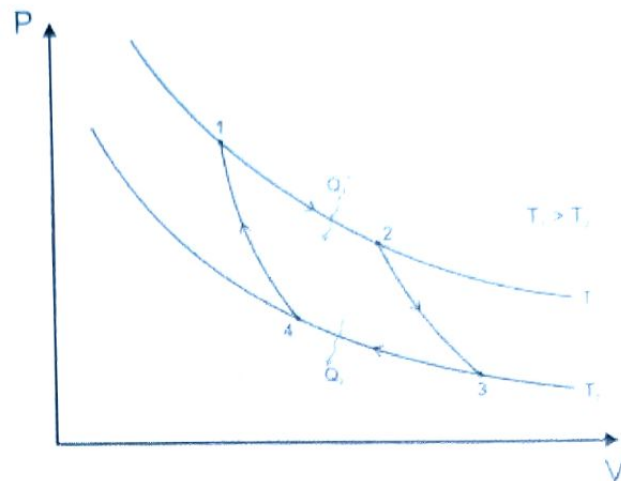


Figure 1: A Carnot cycle illustrated on a PV diagram to illustrate the work done.

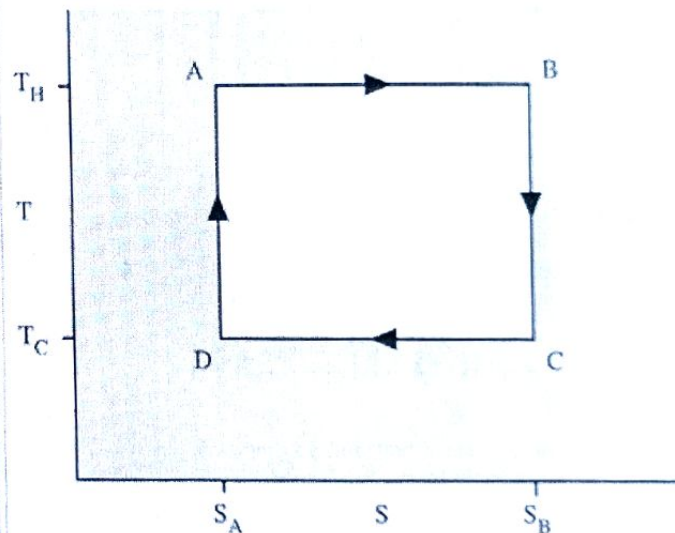
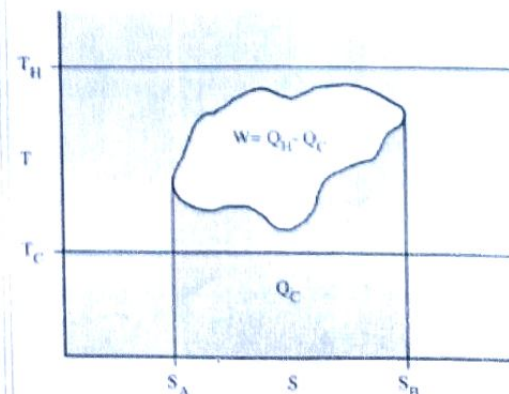


Figure 2: A Carnot cycle acting as a heat engine, illustrated on a temperature-entropy diagram. The cycle takes place between a hot reservoir at temperature T_H and a cold reservoir at temperature T_C . The vertical axis is temperature, the horizontal axis is entropy.

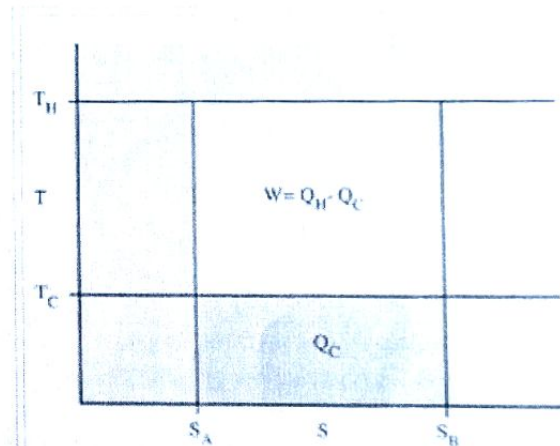


A generalized thermodynamic cycle taking place between a hot reservoir at temperature T_H and a cold reservoir at temperature T_C . By the second law of thermodynamics, the cycle cannot extend outside the temperature band from T_C to T_H . The area in red Q_C is the amount of energy exchanged between the system and the cold reservoir. The area in white W is the amount of work energy exchanged by the system with its surroundings. The amount of heat exchanged with the hot reservoir is the sum of the two. If the system is behaving as an engine, the process moves clockwise around the loop, and moves counter-clockwise if it is behaving as a refrigerator. The efficiency to the cycle is the ratio of the white area (work) divided by the sum of the white and red areas (heat absorbed from the hot reservoir).

$$W = \oint PdV = \oint (dQ - dU) = \oint (TdS - dU) = \oint TdS - \oint dU = \oint TdS \quad (2)$$

Since dU is an exact differential, its integral over any closed loop is zero and it follows that the area inside the loop on a T - S diagram is equal to the total work performed if the loop is traversed in a clockwise direction, and is equal to the total work done on the system as the loop is traversed in a counterclockwise direction.

Evaluation of the above integral is particularly simple for the Carnot cycle. The amount of energy transferred as work is



A Carnot cycle taking place between a hot reservoir at temperature T_H and a cold reservoir at temperature T_C .

$$W = \oint PdV = \oint TdS = (T_H - T_C)(S_B - S_A)$$

The total amount of thermal energy transferred from the hot reservoir to the system will be

$$Q_H = T_H(S_B - S_A)$$

and the total amount of thermal energy transferred from the system to the cold reservoir will be

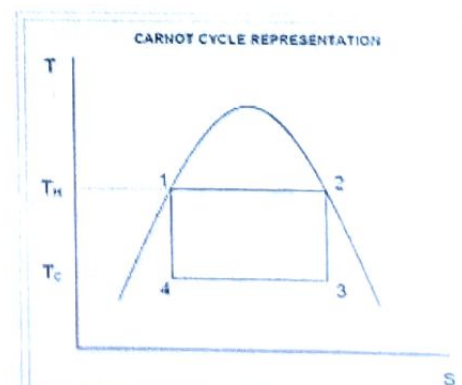
$$Q_C = T_C(S_B - S_A)$$

The efficiency η is defined to be:

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H} \quad (3)$$

where

W is the work done by the system (energy exiting the system as work),
 Q_C is the heat taken from the system (heat energy leaving the system),
 Q_H is the heat put into the system (heat energy entering the system),



A visualization of the Carnot cycle

T_C is the absolute temperature of the cold reservoir, and

T_H is the absolute temperature of the hot reservoir.

S_B is the maximum system entropy

S_A is the minimum system entropy

This definition of efficiency makes sense for a heat engine, since it is the fraction of the heat energy extracted from the hot reservoir and converted to mechanical work. A Rankine cycle is usually the practical approximation.

Reversed Carnot cycle [edit]

The Carnot heat-engine cycle described is a totally reversible cycle. That is, all the processes that comprise it can be reversed, in which case it becomes the Carnot refrigeration cycle. This time, the cycle remains exactly the same except that the directions of any heat and work interactions are reversed. Heat is absorbed from the low-temperature reservoir, heat is rejected to a high-temperature reservoir, and a work input is required to accomplish all this. The P-V diagram of the reversed Carnot cycle is the same as for the Carnot cycle except that the directions of the processes are reversed.^[3]

Carnot's theorem [edit]

Main article: Carnot's theorem (thermodynamics)

It can be seen from the above diagram, that for any cycle operating between temperatures T_H and T_C , none can exceed the efficiency of a Carnot cycle.

Carnot's theorem is a formal statement of this fact: *No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between those same reservoirs.* Thus, Equation 3 gives the maximum efficiency possible for any engine using the corresponding temperatures. A corollary to Carnot's theorem states that: *All reversible engines operating between the same heat reservoirs are equally efficient.* Rearranging the right side of the equation gives what may be a more

easily understood form of the equation. Namely that the theoretical maximum efficiency of a heat engine equals the difference in temperature between the hot and cold reservoir divided by the absolute temperature of the hot reservoir. Looking at this formula an interesting fact becomes apparent; Lowering the temperature of the cold reservoir will have more effect on the ceiling efficiency of a heat engine than raising the temperature of the hot reservoir by the same amount. In the real world, this may be difficult to achieve since the cold reservoir is often an existing ambient temperature.

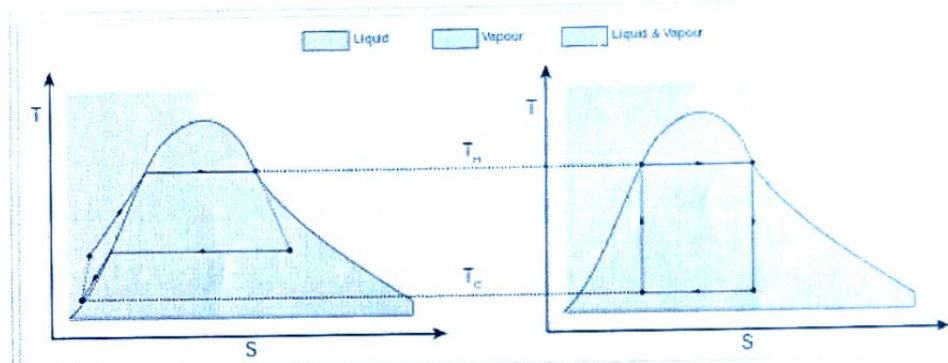
In other words, maximum efficiency is achieved if and only if no new entropy is created in the cycle, which would be the case if e.g. friction leads to dissipation of work into heat. In that case the cycle is not reversible and the Clausius theorem becomes an inequality rather than an equality. Otherwise, since entropy is a state function, the required dumping of heat into the environment to dispose of excess entropy leads to a (minimal) reduction in efficiency. So Equation 3 gives the efficiency of any reversible heat engine.

In mesoscopic heat engines, work per cycle of operation fluctuates due to thermal noise. For the case when work and heat fluctuations are counted, there is exact equality that relates average of exponents of work performed by any heat engine and the heat transfer from the hotter heat bath.^[4]

Efficiency of real heat engines [edit]

See also: Heat engine efficiency and other performance criteria

Carnot realized that in reality it is not possible to build a thermodynamically reversible engine, so real heat engines are even less efficient than indicated by Equation 3. In addition, real engines that operate along this cycle are rare



A real engine (left) compared to the Carnot cycle (right). The entropy of a real material changes with temperature. This change is indicated by the curve on a T-S diagram. For this figure, the curve indicates a vapor-liquid equilibrium (See Rankine cycle). Irreversible systems and losses of energy (for example, work due to friction and heat losses) prevent the ideal from taking place at every step.

Nevertheless, Equation 3 is extremely useful for determining the maximum efficiency that could ever be expected for a given set of thermal reservoirs.

Although **Carnot's cycle** is an idealisation, the expression of Carnot efficiency is still useful. Consider the average temperatures,

$$\langle T_H \rangle = \frac{1}{\Delta S} \int_{Q_{in}} T dS$$

$$\langle T_C \rangle = \frac{1}{\Delta S} \int_{Q_{out}} T dS$$

at which heat is input and output, respectively. Replace T_H and T_C in Equation (3) by $\langle T_H \rangle$ and $\langle T_C \rangle$ respectively.

For the Carnot cycle, or its equivalent, the average value $\langle T_H \rangle$ will equal the highest temperature available, namely T_H , and $\langle T_C \rangle$ the lowest, namely T_C . For other less efficient cycles, $\langle T_H \rangle$ will be lower than T_H , and $\langle T_C \rangle$ will be higher than T_C . This can help illustrate, for example, why a reheater or a regenerator can improve the thermal efficiency of steam power plants—and why the thermal efficiency of combined-cycle power plants (which incorporate gas turbines operating at even higher temperatures) exceeds that of conventional steam plants. The first prototype of the diesel engine was based on the Carnot cycle.

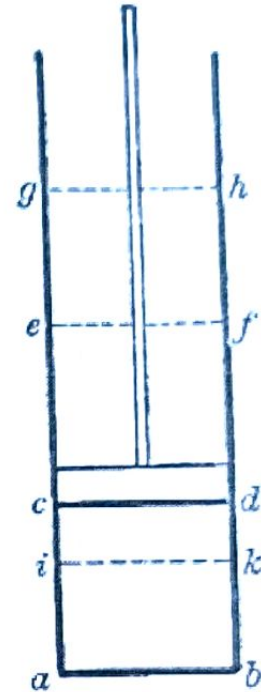
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Carnot heat engine

A **Carnot heat engine**^[2] is an engine that operates on the reversible Carnot cycle. The basic model for this engine was developed by Nicolas Léonard Sadi Carnot in 1824. The Carnot engine model was graphically expanded upon by Benoît Paul Émile Clapeyron in 1834 and mathematically explored by Rudolf Clausius in 1857 from which the concept of entropy emerged.

Every thermodynamic system exists in a particular state. A thermodynamic cycle occurs when a system is taken through a series of different states, and finally returned to its initial state. In the process of going through this cycle, the system may perform work on its surroundings, thereby acting as a heat engine.

A heat engine acts by transferring energy from a warm region to a cool region of space and, in the process, converting some of that energy to mechanical work. The cycle may also be reversed. The system may be worked upon by an external force, and in the process, it can transfer thermal energy from a cooler system to a warmer one, thereby acting as a refrigerator or heat pump rather than a heat engine.



Axial cross section of Carnot's heat engine. In this diagram, *abcd* is a cylindrical vessel, *cd* is a movable piston, and *A* and *B* are constant-temperature bodies. The vessel may be placed in contact with either body or removed from both (as it is here).^[1]

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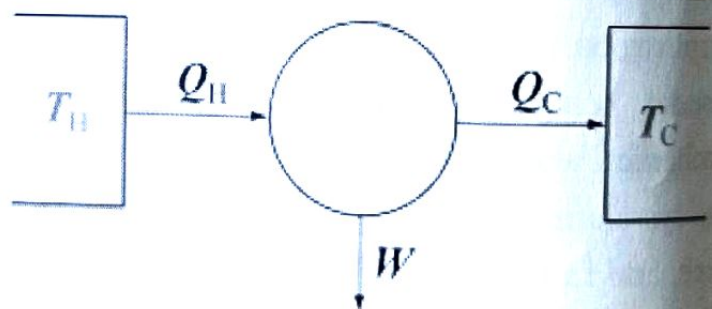
References

Carnot's diagram

In the adjacent diagram, from Carnot's 1824 work, *Reflections on the Motive Power of Fire*,^[3] there are "two bodies A and B , kept each at a constant temperature, that A being higher than that of B . These two bodies to which we can give, or from which we can remove the heat without causing their temperatures to vary, exercise the functions of two unlimited reservoirs of caloric. We will call the first the furnace and the second the refrigerator."^[4] Carnot then explains how we can obtain motive power i.e., "work", by carrying a certain quantity of heat from body A to body B . It also acts as a cooler and hence can also act as a Refrigerator.

Modern diagram

The previous image shows the original piston-and-cylinder diagram used by Carnot in discussing his ideal engines. The figure at right shows a block diagram of a generic heat engine, such as the Carnot engine. In the diagram, the "working body" (system), a term introduced by Clausius in 1850, can be any fluid or vapor body through which heat Q can be introduced or transmitted to produce



Carnot engine diagram (modern) - where an amount of heat Q_H flows from a high temperature T_H furnace through the fluid of the "working body" (working substance) and the remaining heat Q_C flows into the cold sink T_C , thus forcing the working substance to do mechanical work W on the surroundings, via cycles of contractions and expansions.

work. Carnot had postulated that the fluid body could be any substance capable of expansion, such as vapor of water, vapor of alcohol, vapor of mercury, a permanent gas, or air, etc. Although, in these early years, engines came in a number of configurations, typically Q_H was supplied by a boiler, wherein water was boiled over a furnace; Q_C was typically supplied by a stream of cold flowing water in the form of a condenser located on a separate part of the engine. The output work W here is the movement of the piston as it is used to turn a crank-arm, which was then typically used to turn a pulley so to lift water out of flooded salt mines. Carnot defined work as "weight lifted through a height".

Carnot cycle

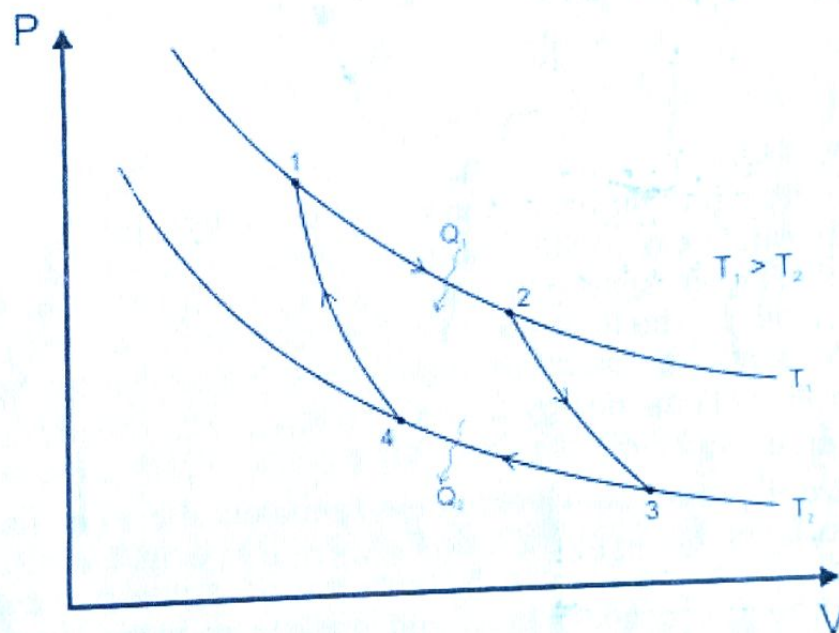


Figure 1: A Carnot cycle illustrated on a PV diagram to illustrate the work done.

The **Carnot cycle** when acting as a heat engine consists of the following steps:

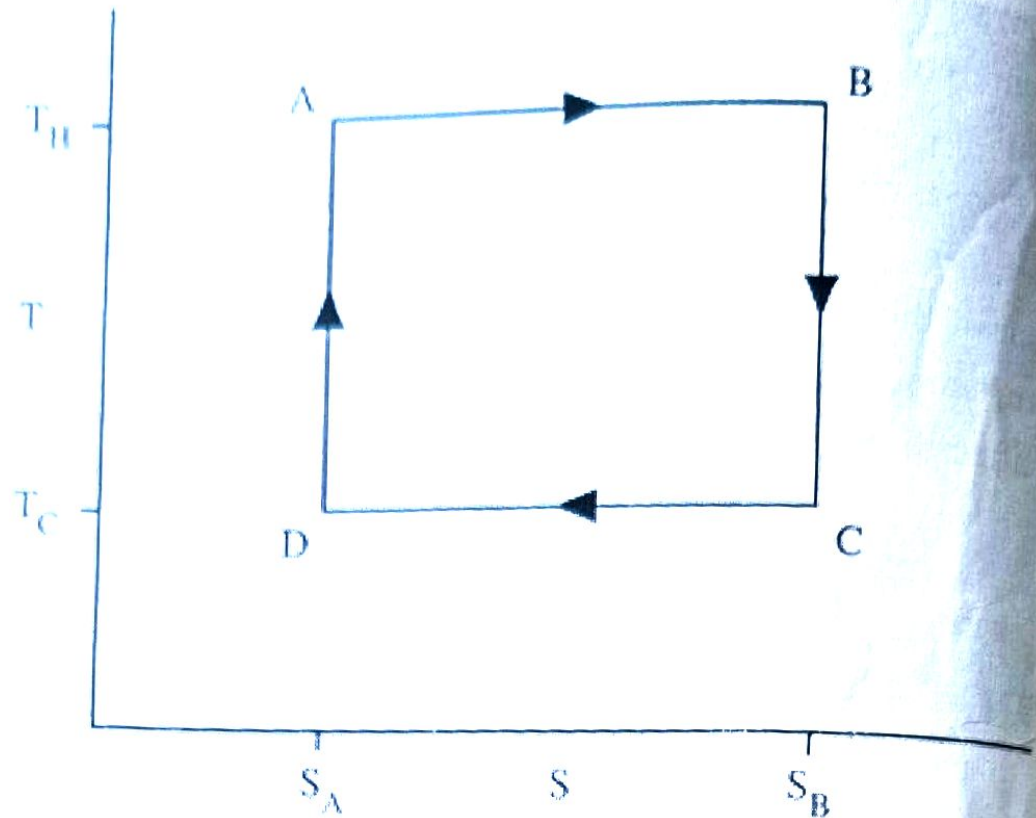


Figure 2: A Carnot cycle acting as a heat engine, illustrated on a temperature-entropy diagram. The cycle takes place between a hot reservoir at temperature T_H and a cold reservoir at temperature T_C . The vertical axis is temperature, the horizontal axis is entropy.

1. **Reversible isothermal expansion of the gas at the "hot" temperature, T_H (isothermal heat addition or absorption).** During this step (1 to 2 on Figure 1, A to B in Figure 2) the gas is allowed to expand and it does work on the surroundings. The temperature of the gas does not change during the process, and thus the expansion is isothermic. The gas expansion is propelled by absorption of heat energy Q_1 and of entropy $\Delta S_H = Q_H/T_H$ from the high temperature reservoir.
2. **Isentropic (reversible adiabatic) expansion of the gas (isentropic work output).** For this step (2 to 3 on Figure 1, B to C in Figure 2) the piston and cylinder are assumed to be thermally insulated, thus they neither gain nor lose heat. The gas continues to expand, doing work on the surroundings, and losing an equivalent amount of internal energy. The gas expansion causes it to cool to the "cold" temperature, T_C . The entropy remains unchanged.

TEMPERATURE ENTROPY DIAGRAM (T-S DIAGRAM)

What is entropy temperature diagram (T-S) . What are its uses obtain the expression for the efficiency of the carnot engine using entropy temperature diagram.

A graph plotted between temperature and entropy is known as temperature entropy diagram. Consider a carnot cycle the working substance undergoes the following operations.

- Isothermal expansion at temperature T_1 .
- Adiabatic expansion where the temperature falls from T_1 to T_2 .
- Isothermal compression at temperature T_2 of the sink.
- Adiabatic compression temperature raises from T_2 to T_1 .

In T-S diagram during isothermal expansion temperature T_1 remains constant. The entropy of the working substance increases from S_1 to S_2 . Shown by the line AB.

During adiabatic expansion BC entropy remains constant at S_2 but temperature falls from T_1 to T_2 .

During isothermal compression CD temperature remains constant at T_2 entropy decreases from S_2 to S_1 .

Finally during adiabatic compression DA entropy remains constant at S_1 temperature raises from T_2 to T_1 .

The area of the cycle of T-S diagram gives the available thermal energy for useful work.

Let S_1 and S_2 be the entropy's at A and B respectively.

During isothermal change AB increase an entropy = $S_2 - S_1$.

Let Q_1 be the amount of heat absorbed by the working substance in isothermal expansion AB and Q_2 be the heat rejected in isothermal compression CD.

We know that $dQ = TdS$

$$\begin{aligned} Q_1 &= T_1 (S_2 - S_1) \\ &= \text{AF. AB} \\ &= \text{Area ABEF} \text{ ----- (1)} \end{aligned}$$

$$\begin{aligned} \text{Similarly, } Q_2 &= T_2 (S_2 - S_1) \\ &= \text{DF. DC} \\ &= \text{Area DCEF} \text{ ----- (2)} \end{aligned}$$

Available energy per cycle converted into useful work

$$\begin{aligned} &= Q_1 - Q_2 \\ &= \text{Area ABEF} - \text{Area DCEF} \\ &= \text{Area ABCD} \text{ ----- (3)} \end{aligned}$$

The area of the cycle on T-S diagram gives the available thermal energy that can be converted into useful work.

$$\begin{aligned}\text{Efficiency} &= \frac{Q_1 - Q_2}{Q_1} \\ &= \frac{\text{Area } ABCD}{\text{Area } ABEF} \\ &= \frac{AB \cdot AD}{AB \cdot AF} \\ &= \frac{AD}{AF} \\ &= \frac{T_1 - T_2}{T_1} \\ &= 1 - \frac{T_2}{T_1}\end{aligned}$$

The ratio of AD/AF gives the efficiency of carnot engine.

USES OF T-S DIAGRAM:

- They are used in metrology.
- They are a great use in predicting defects in the performance of the engine.
- To check the efficiency of the heat engine.
- To obtain the work value of the fuel use.
- It is used in NASA programs.

CARNOT'S THEOREM

According to this theorem no engine can be more efficient than reversible engine working between the same two temperatures.

(OR)

All reversible engines working between the same two temperatures of same efficiency.

Hot source

I W

W' R

Cold sink

Let us consider reversible engine R and irreversible engine I working with the same source and sink. Here I works in the forward direction while R works in the backward direction. Let engine I absorb an amount of heat Q from the source convert a part W into work and transfer the balance ' $Q-W$ ' to the sink.

Similarly, R absorb Q' from the sink, W' is the work done. Transfer the net amount ' $Q'+W=Q$ ' to the source.

$$W'=Q-Q'$$

If possible efficiency of I > efficiency of R

$$W/Q > W'/Q$$

$$W > W' \text{ ----- (1)}$$

Imagine two engines are coupled by belt. The compound engine $Q-W'$ from the sink and gives an amount of heat Q to the source.

The net amount of heat from the sink

$$(Q-W') - (Q-W) = W-W' \text{ ----- (2)}$$

This is positive according to equation (1)

The above fact shows that coupling engine the heat absorbed from the sink " $Q-W'$ " is greater than heat given back to the sink ' $Q-W$ ' while the source is unaffected.

In this way any amount of heat may be taken from the sink work done and no change may be left with source. This is impossible according to second law of thermodynamics that it is impossible for any device to extant heat from a source converting the whole into work.

Our assumption that the I engine is more efficient than R engine is wrong. Thus, no engine working between a source and sink can be more efficient than R engine.

To prove the second part of the theorem consider two R engines A and B between same source and sink if we consider that A drives B in the backward direction than B. If suppose B drives A in backward direction B cannot more efficient than A. So, two engines are equally efficient. So, the efficiency of reversible engine completely independent of working substance.

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PROJECT WORK
ACADEMIC YEAR 2019-2020

SUBMITTED TO

DEPARTMENT OF PHYSICS

TOPIC: Thermodynamics

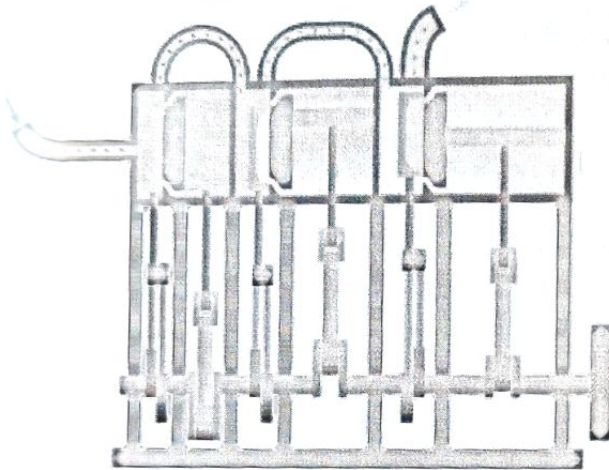
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Thermodynamics

In physics, thermodynamics (from the Greek θερμη therme, meaning "heat"^[1] and δυναμις, dynamis, meaning "power") is the study of energy conversion between heat and mechanical work, and subsequently the macroscopic variables such as temperature, volume and pressure. Its progenitor, based on statistical predictions of the collective motion of particles from their microscopic behavior, is the field of statistical thermodynamics (or statistical mechanics), a branch of statistical physics.^{[2][3][4]} Historically, thermodynamics developed out of need to increase the efficiency of early steam engines.^[5]



Typical thermodynamic system, showing input from a heat source (boiler) on the left and output to a heat sink (condenser) on the right. Work is extracted, in this case by a series of pistons.

INTRODUCTION:

The starting point for most thermodynamic considerations are the laws of thermodynamics, which postulate that energy can be exchanged between physical systems as heat or work.^[6] They also postulate the existence of a quantity named entropy, which can be defined for any isolated system that is in thermodynamic equilibrium.^[7] In thermodynamics, interactions between large ensembles of objects are studied and categorized. Central to this are the concepts of system and surroundings. A system is composed of

particles, whose average motions define its properties, which in turn are related to one another through equations of state. Properties can be combined to express internal energy and thermodynamic potentials, which are useful for determining conditions for equilibrium and spontaneous processes.

With these tools, the usage of thermodynamics describes how systems respond to changes in their surroundings. This can be applied to a wide variety of topics in science and engineering, such as engines, phase transitions, chemical reactions, transport phenomena, and even black holes. The results of thermodynamics are essential for other fields of physics and for chemistry, chemical engineering, aerospace engineering, mechanical engineering, cell biology, biomedical engineering, materials science, and economics to name a few.^{[8][9]}

Developments



Sadi Carnot (1796-1832), the father of thermodynamics

Main article: History of thermodynamics

The history of thermodynamics as a scientific discipline generally begins with Otto von Guericke who, in 1650, built and designed the world's first vacuum pump and demonstrated a vacuum using his Magdeburg hemispheres. Guericke was driven to make a vacuum in order to disprove Aristotle's long-held supposition that 'nature abhors a vacuum'. Shortly after Guericke, the Irish physicist and chemist Robert Boyle had learned of

Guericke's designs and, in 1656, in coordination with English scientist Robert Hooke, built an air pump.^[10] Using this pump, Boyle and Hooke noticed a correlation between pressure, temperature, and volume. In time, Boyle's Law was formulated, which states that pressure and volume are inversely proportional. Then, in 1679, based on these concepts, an associate of Boyle's named Denis Papin built a bone digester, which was a closed vessel with a tightly fitting lid that confined steam until a high pressure was generated.

Later designs implemented a steam release valve that kept the machine from exploding. By watching the valve rhythmically move up and down, Papin conceived of the idea of a piston and a cylinder engine. He did not, however, follow through with his design. Nevertheless, in 1697, based on Papin's designs, engineer Thomas Savery built the first engine. Although these early engines were crude and inefficient, they attracted the attention of the leading scientists of the time. Their work led 127 years later to Sadi Carnot, the "father of thermodynamics", who, in 1824, published Reflections on the Motive Power of Fire, a discourse on heat, power, and engine efficiency. The paper outlined the basic energetic relations between the Carnot engine, the Carnot cycle, and Motive power. It marked the start of thermodynamics as a modern science.^[3] The term thermodynamics was coined by James Joule in 1849 to designate the science of relations between heat and power.^[3] By 1858, "thermo-dynamics", as a functional term, was used in William Thomson's paper An Account of Carnot's Theory of the Motive Power of Heat.^[11] The first thermodynamic textbook was written in 1859 by William Rankine, originally trained as a physicist and a civil and mechanical engineering professor at the University of Glasgow.^[12]

Classical thermodynamics is the early 1800s variation of the original thermodynamics, concerned with thermodynamic states and properties, such as energy, work and heat, and with the laws of thermodynamics, all lacking an atomic interpretation.

In precursory form, classical thermodynamics derives from chemist Robert Boyle's 1662 postulate that the pressure P of a given quantity of gas varies inversely as its volume V at constant temperature; i.e. in equation form: $PV = k$, a constant. From here, a semblance of a thermo-science began to develop with the construction of the first successful atmospheric steam engines in England by Thomas Savery in 1697 and Thomas Newcomen in 1712. The first and second laws of thermodynamics emerged simultaneously in the 1850s, primarily out of the works of William Rankine, Rudolf Clausius, and William Thomson (Lord Kelvin).

With the development of atomic and molecular theories in the late 1800s and early 1900s, thermodynamics was given a molecular interpretation. This field, called statistical mechanics or statistical thermodynamics, relates the microscopic properties of individual atoms and molecules to the macroscopic or bulk properties of materials that can be observed in everyday life, thereby explaining thermodynamics as a natural result of statistics and mechanics (classical and quantum) at the microscopic level. The statistical approach is in contrast to classical thermodynamics, which is a more phenomenological approach that does not include microscopic details. The foundations of statistical thermodynamics were set out by physicists such as James Clerk Maxwell, Ludwig Boltzmann, Max Planck, Rudolf Clausius and J. Willard Gibbs.

Chemical thermodynamics is the study of the interrelation of energy with chemical reactions or with a physical change of state within the confines of the laws of thermodynamics. During the years 1873-76 the American mathematical physicist Josiah Willard Gibbs published a series of three papers, the most famous being On the Equilibrium of Heterogeneous Substances, in which he showed how thermodynamic processes could be graphically analyzed, by studying the energy, entropy, volume, temperature and pressure of the thermodynamic system in such a manner, one can determine if a process would occur spontaneously.^[13] During the early 20th century, chemists such as Gilbert N. Lewis, Merle Randall, and E. A.

Guggenheim began to apply the mathematical methods of Gibbs to the analysis of chemical processes.^[14]

The Four Laws

Main article: Laws of thermodynamics

The present article is focused on classical thermodynamics, which is focused on systems in thermodynamic equilibrium. It is wise to distinguish classical thermodynamics from non-equilibrium thermodynamics, which is concerned with systems that are not in thermodynamic equilibrium.

In thermodynamics, there are four laws that do not depend on the details of the systems under study or how they interact. Hence these laws are very generally valid, can be applied to systems about which one knows nothing other than the balance of energy and matter transfer. Examples of such systems include Einstein's prediction, around the turn of the 20th century, of spontaneous emission, and ongoing research into the thermodynamics of black holes.

These four laws are:

- Zeroth law of thermodynamics, about thermal equilibrium:

If two thermodynamic systems are separately in thermal equilibrium with a third, they are also in thermal equilibrium with each other.

If we grant that all systems are (trivially) in thermal equilibrium with themselves, the Zeroth law implies that thermal equilibrium is an equivalence relation on the set of thermodynamic systems. This law is tacitly assumed in every measurement of temperature. Thus, if we want to know if two bodies are at the same temperature, it is not necessary to bring them into contact and to watch whether their observable properties change with time.^[15]

- This law was considered so obvious it was added as a virtual after thought, hence the designation Zeroth, rather than Fourth. In

short, if the heat energy of material A is equal to the heat energy of material B, and B is equal to the heat energy of material C. then A and C must also be equal.

- First law of thermodynamics, about the conservation of energy:

The change in the internal energy of a closed thermodynamic system is equal to the sum of the amount of heat energy supplied to or removed from the system and the work done on or by the system or we can say " In an isolated system the heat is constant".

- Second law of thermodynamics, about entropy:

The total entropy of any isolated thermodynamic system always increases over time, approaching a maximum value or we can say " in an isolated system, the entropy never decreases". Another way to phrase this: Heat cannot spontaneously flow from a colder location to a hotter area - work is required to achieve this.

- Third law of thermodynamics, about the absolute zero of temperature:

As a system asymptotically approaches absolute zero of temperature all processes virtually cease and the entropy of the system asymptotically approaches a minimum value; also stated as: "the entropy of all systems and of all states of a system is zero at absolute zero" or equivalently "it is impossible to reach the absolute zero of temperature by any finite number of processes". Absolute zero, at which all activity would stop if it were possible to happen, is -273.15°C (degrees Celsius), or -459.67°F (degrees Fahrenheit) or 0 K (kelvins, formerly sometimes degrees absolute).

SRI Y N COLLEGE (AUTONOMOUS), NARSAPUR
DEPARTMENT OF PHYSICS



PROJECT WORK
ACADEMIC YEAR 2019-2020

SUBMITTED TO

DEPARTMENT OF PHYSICS

TOPIC: RAYLEIGH CRITERION

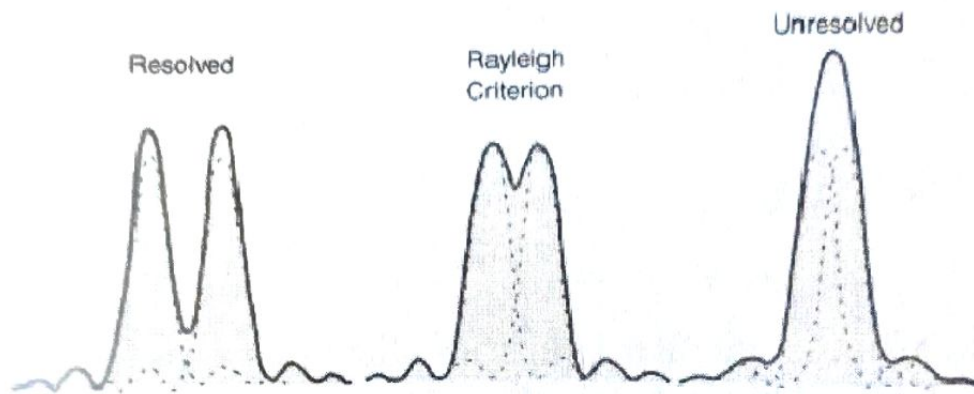
T Rohoini-MPC EM
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The Rayleigh Criterion

The Rayleigh criterion is the generally accepted criterion for the minimum resolvable detail - the imaging process is said to be diffraction-limited when the first diffraction minimum of the image of one source point coincides with the maximum of another.



$$\sin \theta_R = \frac{\lambda}{d}$$

Single slit

$$\sin \theta_R = 1.22 \frac{\lambda}{d}$$

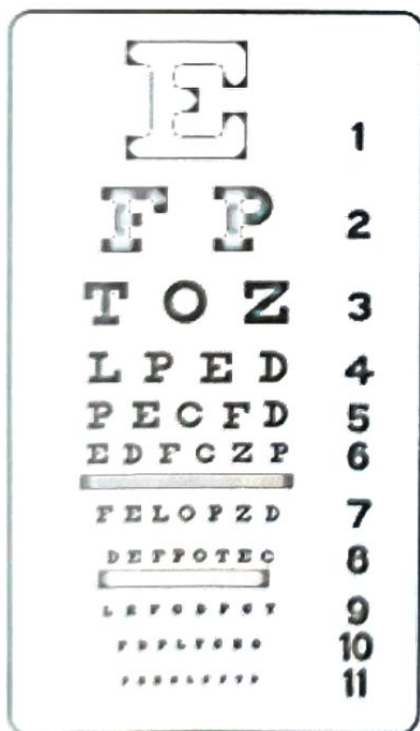
Circular aperture

Application to vision

If all parts of an imaging system are considered to be perfect, then the resolution of any imaging process will be limited by diffraction. Considering the single slit expression above, then when the wavelength is equal to the slit width, the angle for the first diffraction minimum is 90° . This means that the wave is spread all the way to the plane of the slit and will not contain resolvable information about the source of the wave. This leads to the simplified statement that the limit of resolution of any imaging process is going to be on the order of the

wavelength of the wave used to image it.

Visual acuity is typically measured with the use of a standard eye chart called the Snellen chart. It was devised by Dr. Hermann Snellen, a Dutch Ophthalmologist, in 1862. It was originally used at a standard distance of 6 meters, which in U.S. common units is about 20 feet.



Where such units are used, normal vision came to be characterized by the fraction 20/20, which corresponded to being able to distinguish the letters on the fourth line up from the bottom at a distance of 20 feet. The E on the chart has a standard height of 88 mm and the other letters are scaled accordingly. The basic scheme is that the letters two rows down are half the size, and two rows up twice the size. The nominal designations of visual acuity as a number ratio could be based on

Snellen Chart from
Wikipedia

which lines you could read. If you could just resolve the letters two rows up from the normal vision line at 20 feet, your acuity would be labeled 20/40 and if you could resolve two lines down it would be labeled 20/10.

Another way of saying it is that if your vision is 20/40, you can just resolve at 20 feet what a person with normal vision could resolve at 40 feet. A visual acuity of 20/200 with the best possible correction with lenses is a nominal condition for being considered legally blind.

If the above describes the standard for normal vision, what are the factors which limit the resolution of human vision? To examine whether diffraction is the limiting factor, it is interesting to compare this standard of resolution with the limits imposed by diffraction. If the E on the chart (20/200) is 88mm high, then the 20/20 line would have letters of height 8.8 mm.

$$\tan \theta \approx \sin \theta \approx \theta \approx \frac{y}{D} \quad \theta = \frac{0.0088}{6} = 1.47 \times 10^{-3} \text{ rad}$$

The Rayleigh criterion for diffraction-limited vision for an iris diameter of 5 mm and a wavelength of 500 nm is:

$$\theta_R = 1.22 \frac{\lambda}{d} = \frac{1.22 \times 5 \times 10^{-5} \text{ cm}}{0.5 \text{ cm}} = 1.22 \times 10^{-4} \text{ rad}$$

So 20/20 is about 12x the Rayleigh criterion. Ackerman reports that the data show:

$\theta = 5 \times 10^{-4} \text{ rad}$ Resolution limit for most persons

$\theta = 2 \times 10^{-4} \text{ rad}$ Most acute vision, optimum circumstances

This is another example of the remarkable nature of human senses: the most acute vision is within about a factor of two of the physical limits imposed by diffraction!

According to a British standard quoted by Wikipedia, the minimum illumination for Snellen charts should be 480 lux. If the illumination is increased, the iris will constrict more and the diffraction at the smaller aperture would tend to diminish the acuity. However, the smaller aperture also reduces the effects of any aberrations in the lens, which would act to increase visual acuity. The conventional wisdom is that persons see better in bright light, suggesting that the gain in overcoming aberrations is greater than the loss from diffraction.

Fundamental Resolution Measure (FREM).

Our approach to the derivation of the resolution measure is to obtain a bound/limit to the accuracy with which the distance between two point sources can be estimated based on the acquired data (see *Materials and Methods*). Analogous to Rayleigh's criterion, we consider an optical microscope setup that images two identical, self-luminous, in-focus point sources emitting unpolarized, incoherent light. The analytical expression of the FREM for this imaging condition is given by

$$\delta_d := \frac{1}{\sqrt{4\pi \Lambda_0 \cdot (t - t_0) \cdot \Gamma_0(d)}} \cdot \frac{\lambda}{n_a}, \quad [1]$$

where λ denotes the emission wavelength of the detected photons, n_a denotes the numerical aperture of the objective lens, Λ_0 denotes the photon detection rate (intensity) per point source, $[t_0, t]$ denotes the acquisition time interval, and $\Gamma_0(d)$ is given by

$$\Gamma_0(d) := \int_{\mathbb{R}^2} \frac{1}{\frac{J_1^2(\alpha r_{01})}{r_{01}^2} + \frac{J_1^2(\alpha r_{02})}{r_{02}^2}} \left(\left(x + \frac{d}{2} \right) \frac{J_1(\alpha r_{01}) J_2(\alpha r_{01})}{r_{01}^3} - \left(x - \frac{d}{2} \right) \frac{J_1(\alpha r_{02}) J_2(\alpha r_{02})}{r_{02}^3} \right)^2 dx dy, \quad [2]$$

with J_n denoting the n th order Bessel function of the first kind, $\alpha = 2\pi n_a/\lambda$; $r_{01} = \sqrt{(x + d/2)^2 + y^2}$, and $r_{02} = \sqrt{(x - d/2)^2 + y^2}$.

According to Rayleigh's criterion, the minimum resolvable distance between two point sources is given by $0.61 \lambda/n_a$. The FREM, on the other hand, provides a more complex expression, which, in addition to the dependence on the ratio λ/n_a , exhibits an inverse square root dependence on other factors, i.e., the expected number of detected photons $[\Lambda_0 \cdot (t - t_0)]$ and the term $\Gamma_0(d)$ given by Eq. 2. Note that the FREM depends on the distance of separation d through the term $\Gamma_0(d)$. Moreover, the presence of the ratio λ/n_a in $\Gamma_0(d)$ through the term $\alpha (= 2\pi n_a/\lambda)$ shows that the FREM exhibits a nonlinear dependence on λ/n_a .

The stochastic framework used to obtain the FREM models the photon emission (detection) process as a random process (shot noise process). The spatial locations at which the photons hit the detector are assumed to be randomly distributed according to the image profiles of the point sources/single molecules. This framework considers an optical microscope setup in which the detector provides the time points and the spatial coordinates of every detected photon without adding any extraneous noise. For any imaging condition, this setup can be thought of as an idealization of current imaging detectors in which the presence of finite-sized pixels and measurement noise deteriorates the acquired data. Thus the resolution measure derived within this framework provides a result that is fundamental for the given imaging condition. In the present context, the FREM is obtained for imaging conditions analogous to those of Rayleigh's criterion.

Hence the spatial distribution of the detected photons from each point source is described by the Airy profile (1). The FREM predicts how accurately the distance d between two point sources can be resolved. A small numerical value for the FREM predicts a high accuracy in determining d , whereas a large numerical value of the FREM predicts a low accuracy in determining d . Fig. 1A shows the behavior of the FREM as a function of the distance of separation between a pair of GFP molecules ($\lambda=520$ nm) and for a pair of Cy5 molecules ($\lambda=690$ nm) that are imaged with an objective lens of numerical aperture 1.45. In Fig. 1A, it is assumed that the expected photon count is the same for both fluorophores. For the GFP molecules, Rayleigh's criterion predicts the smallest resolvable distance to be ≈ 220 nm ($\approx 0.61 \lambda/n_a$). In contrast, Fig. 1A shows that the FREM has a small numerical value for distances ranging from 50 to 220 nm, which are well below Rayleigh's criterion. For distances < 50 nm, however, the FREM deteriorates (i.e., increases) significantly with decreasing distance of separation (see Fig. 1A Inset). In particular, as the distance of separation decreases to zero, the FREM becomes infinitely large, because the term $\Gamma_0(d)$ (Eq. 2), which appears in the denominator of the FREM, tends to zero. An analogous behavior of the FREM is also seen for the Cy5 molecules. Note that the numerical value of the FREM for the Cy5 molecules is consistently larger than that of the GFP molecules for the same expected photon count per fluorophore. For example, the FREM predicts that a distance of 10 nm between two GFP molecules can be determined with an accuracy not better than ± 5.7 nm when the expected photon count per GFP molecule is 3,000. On the other hand, for the same distance of separation and photon count per molecule, the FREM predicts an accuracy not better than ± 9.1 nm for the Cy5 molecules. In the case of the Cy5 molecules, however, the numerical value of the FREM is comparable to the distance of separation itself. Because the FREM exhibits an inverse square root dependence on the expected number of detected photons, this deterioration can be compensated for by increasing the expected

number of detected photons, as shown in Fig. 1B. Thus in the above example, if we increase the expected photon count per Cy5 dye molecule to 10^4 , then the FREM predicts that a distance of 10 nm can be determined with an accuracy not better than ± 5 nm.

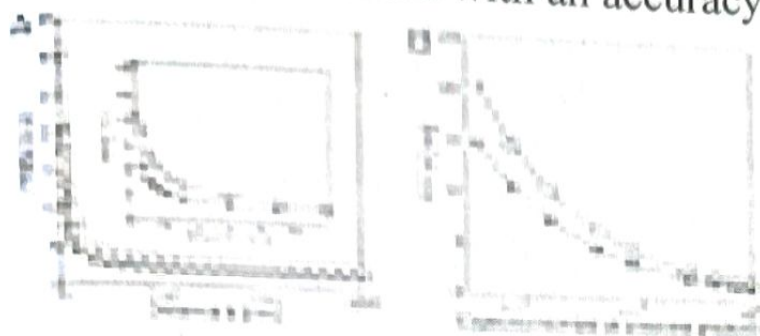


Fig. 1.

Dependence of the FREM on distance and photon count. (A) The FREM as a function of the distance of separation between two point sources/single molecules. (Inset) The same for a distance range of 1–50 nm. (B) The FREM as a function of the expected (more ...)

Practical Resolution Measure (PREM).

The FREM provides the best-case scenario for a microscope setup, where experimental factors that potentially deteriorate the acquired data were not taken into account. We next investigate how the resolution measure is affected by such experimental factors. Here we obtain an analytical expression for the resolution measure that takes into account these experimental factors. We refer to this result as the PREM. The PREM can be thought of as an extension to the FREM. For instance, the PREM takes into account the presence of additive noise sources, namely Poisson and Gaussian noise. Poisson noise is used to model spurious photons in the acquired image, which, for example, arise because of the autofluorescence of the sample and dark current of the detector (6). Gaussian noise is used to model measurement noise in the acquired data, which, for example, arise during the readout process in the detector (6). The additive Poisson noise considered here is distinct from the shot noise, which describes the statistics of the photon-detection process from the single molecules and is already accounted for by the FREM. Aside from these extraneous noise sources, the PREM also takes into account the effect of pixelation of the detector.

Fig. 2A shows the behavior of the PREM as a function of the distance between two Cy5 molecules in the presence and absence of noise sources for a pixelated detector. Fig. 2A also shows the FREM for reference. Note that even in the absence of extraneous noise sources the numerical value of the PREM is consistently greater than that of the FREM because of the pixelation of the detector. Moreover, in the presence of noise sources this behavior of the PREM becomes more pronounced. In particular, for very small distances (≤ 50 nm), the numerical value of the PREM is at least three to five times greater than that of the FREM (see Fig. 2A Inset). Analogous to Fig. 1B, the deterioration of the PREM at very small distances can be compensated for by collecting more photons from the point sources (Fig. 2B). In contrast, for distances ranging from 100 to 250 nm, which are below Rayleigh's criterion ($\approx 0.61 \lambda/n_a \approx 290$ nm), the numerical value of the PREM approaches that of the FREM even in the presence of noise, as shown in Fig. 2A. As an application of these results, consider a practical scenario in which we require distances ranging from 50 to 200 nm to be resolved between two Cy5 molecules with an accuracy of at least 5 nm. From Fig. 2B, we know that to estimate a distance of 50 nm with an accuracy not better than 5 nm the PREM predicts the expected number of detected photons per single molecule to be at least 15,000. On the other hand, from Fig. 2A we see that to estimate a distance of 200 nm with similar accuracy the PREM predicts the expected number of detected photons per single molecule to be at least 2,500. Hence to resolve distances ranging from 50 to 200 nm between two Cy5 molecules with an accuracy not better than 5 nm on average at least 15,000 photons must be collected per single molecule.

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DEPARTMENT OF PHYSICS



STUDY PROJECT WORK
ACADEMIC YEAR 2019-2020

SUBMITTED TO

DEPARTMENT OF PHYSICS

TOPIC: RENEWABLE ENERGY

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Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat.^[3] Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services.^[4]

Based on REN21's 2017 report, renewables contributed 19.3% to humans' global energy consumption and 24.5% to their generation of electricity in 2015 and 2016, respectively. This energy consumption is divided as 8.9% coming from traditional biomass, 4.2% as heat energy (modern biomass, geothermal and solar heat), 3.9% hydro electricity and 2.2% is electricity from wind, solar, geothermal, and biomass. Worldwide investments in renewable technologies amounted to more than US\$286 billion in 2015, with countries such as China and the United States heavily investing in wind, hydro, solar and biofuels.^[5] Globally, there are an estimated 7.7 million jobs associated with the renewable energy industries, with solar photovoltaics being the largest renewable employer.^[6] As of 2015 worldwide, more than half of all new electricity capacity installed was renewable.^[7]

Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment^[8] of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits.^[9] The results of a recent review of the literature^[10] concluded that as greenhouse gas (GHG) emitters begin to be held liable for damages resulting from GHG emissions resulting in climate change, a high value for liability mitigation would provide powerful incentives for deployment of renewable energy technologies. In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power.^[11]

At the national level, at least 30 nations around the world already have renewable energy contributing more than 20 percent of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond.^[12] Some places and at least two countries, Iceland and Norway generate all their electricity using renewable energy already, and many other countries have the set a goal to reach 100% renewable energy in the future. For example, in Denmark the government decided to switch the total energy supply (electricity, mobility and heating/cooling) to 100% renewable energy by 2050.^[13] At least 47 nations around the world already have over 50 percent of electricity from renewable resources, with Iceland generating all its electrical power from renewable energy^{[14][15][16]} though this does not include non-electrical energy (e.g. transport and heating).

While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas and developing countries, where energy is often crucial in human development.^[17] Former United Nations Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity.^[18] As most of renewables provide electricity, renewable energy deployment is often applied in conjunction with further electrification, which has several benefits: Electricity can be converted to heat (where necessary generating higher temperatures than fossil fuels), can be converted into mechanical energy with high efficiency and is clean at the point of consumption.^{[19][20]} In addition to that electrification with renewable energy is much more efficient and therefore leads to a significant reduction in primary energy requirements, because most renewables do not have a steam cycle with high losses (fossil power plants usually have losses of 40 to 65%).^[21]

Water pollution is the contamination of **water bodies**, usually as a result of human activities. Water bodies include for example **lakes, rivers, oceans, aquifers and groundwater**. Water pollution results when **contaminants** are introduced into the natural environment. For example, releasing inadequately treated **wastewater** into natural water bodies can lead to degradation of **aquatic ecosystems**. In turn, this can lead to public health problems for people living downstream. They may use the same polluted river water for drinking or bathing or irrigation. Water pollution is the leading worldwide cause of death and disease, e.g. due to water-borne diseases.^{[1][2]}

Water pollution can be grouped into **surface water pollution**. **Marine pollution and nutrient pollution** are subsets of water pollution. Sources of water pollution are either point sources and non-point sources. Point sources have one identifiable cause of the pollution, such as a storm drain, **wastewater treatment plant** or stream. Non-point sources are more diffuse, such as **agricultural runoff**.^[3] Pollution is the result of the cumulative effect over time. All plants and organisms living in or being exposed to polluted water bodies can be impacted. The effects can damage individual **species** and impact the natural biological communities they are part of.

The causes of water pollution include a wide range of **chemicals and pathogens** as well as physical parameters. Contaminants may include organic and inorganic substances. Elevated temperatures can also lead to polluted water. A common cause of thermal pollution is the use of water as a coolant by **power plants** and industrial manufacturers. Elevated water temperatures decrease oxygen levels, which can kill fish and alter food chain composition, reduce species biodiversity, and foster invasion by new thermophilic species.^{[4][5] 375}

Water pollution is measured by analysing water samples. Physical, chemical and biological tests can be done. Control of water pollution requires appropriate infrastructure and management plans. The infrastructure may include **wastewater treatment plants**. **Sewage treatment plants and industrial wastewater treatment plants** are usually required to protect water bodies from untreated wastewater. **Agricultural wastewater treatment for farms, and erosion control from construction sites** can also help prevent water pollution. **Nature-based solutions** are another approach to prevent water pollution.^[6] Effective control of urban runoff includes reducing speed and quantity of flow. In the United States, best management practices for water pollution include approaches to reduce the quantity of water and improve water quality.^[7]

Water is typically referred to as polluted when it is impaired by **anthropogenic contaminants**. Due to these contaminants it either does not support a human use, such as **drinking water**, or undergoes a marked shift in its ability to support its biotic communities, such as fish. Natural phenomena such as **volcanoes, algae blooms, storms, and earthquakes** also cause major changes in water quality and the ecological status of water.

Water pollution is a major global problem. It requires ongoing evaluation and revision of **water resource policy** at all levels (international down to individual aquifers and wells). It has been suggested that water pollution is the leading worldwide cause of death and diseases.^{[2][1]} Water pollution accounted for the deaths of 1.8 million people in 2015.^[8]

India and China are two countries with high levels of water pollution: An estimated 580 people in India die of water pollution related illness (including **waterborne diseases**) every day.^[9] About 90 percent of the water in the cities of China is polluted.^[10] As of 2007, half a billion Chinese had no access to safe drinking water.^[11]

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PROJECT WORK
ACADEMIC YEAR 2019-2020

SUBMITTED TO

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TOPIC: Global Warming

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Global mean surface-temperature change from 1880 to 2018, relative to the 1951–1980 mean. The 1951–1980 mean is 14.19 °C (57.54 °F). [1] The black line is the global annual mean, and the red line is the five-year local regression line. The blue uncertainty bars show a 95% confidence interval. Average global temperatures from 2014 to 2018 compared to a baseline average from 1951 to 1980, according to NASA's Goddard Institute for Space Studies. Global warming is a long-term rise in the average temperature of the Earth's climate system, an aspect of climate change shown by temperature measurements and by multiple effects of the warming. [2] [3] The term commonly refers to the mainly human-caused observed warming since pre-industrial times and its projected continuation, [4] though there were also much earlier periods of global warming. [5] In the modern context the terms global warming and climate change are commonly used interchangeably, [6] but climate change includes both global warming and its effects, such as changes to precipitation and impacts that differ by region. [7] [8] Many of the observed warming changes since the 1950s are unprecedented in the instrumental temperature record, and in historical and paleoclimate proxy records of climate change over thousands to millions of years. [2] In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded, "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." [9] The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) to 2.6 to 4.8 °C (4.7 to 8.6 °F) depending on the rate of greenhouse gas emissions and on climate feedback effects. [10] These findings have been recognized by the national science academies of the major industrialized nations [11] [a] and are not disputed by any scientific body of national or international standing. [13] [14] Future climate change effects are expected to include rising sea levels, ocean acidification, regional changes in precipitation, and expansion of deserts in the subtropics. [15] [16] [17] Surface temperature increases are greatest in the Arctic, with the continuing retreat of glaciers, permafrost, and sea ice. Predicted regional precipitation effects include more frequent extreme weather events such as heat waves, droughts, wildfires, heavy rainfall with floods, and heavy snowfall. [18] Effects directly significant to humans are predicted to include the threat to food security from decreasing crop yields, and the abandonment of populated areas due to rising sea levels. [19] [20] Environmental impacts appear likely to include the extinction or relocation of ecosystems as they adapt to climate change, with coral reefs, [21] mountain ecosystems, and Arctic ecosystems most immediately threatened. [22] Because the climate system has a large "inertia" and greenhouse gases will remain in the atmosphere for a long time, climatic changes and their effects will continue to become more pronounced for many centuries even if further increases to greenhouse gases stop. [23] Possible societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, and possible future climate engineering. Most countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC), [24] whose ultimate objective is to prevent dangerous anthropogenic climate change. [25] Parties to the UNFCCC have agreed that deep cuts in emissions are required [26] and that global warming should be limited to well below 2.0 °C (3.6 °F) compared to pre-industrial levels, [b] with efforts made to limit warming to 1.5 °C (2.7 °F). [28] Some scientists call into question

climate adaptation feasibility, with higher emissions scenarios,[29]or the two degree temperature target.[30]Public reactions to global warming and concern about its effects are also increasing. A global 2015Pew Research Centerreport showed that a medianof 54% of all respondents asked consider it "a very serious problem". Significant regional differences

Global warming, the phenomenon of increasing average air temperatures near the surface of Earth over the past one to two centuries. Climate scientists have since the mid-20th century gathered detailed observations of various weather phenomena (such as temperatures, precipitation and storms) and of related influences on climate (such as ocean currents and the atmosphere's chemical composition). These data indicate that Earth's climate has changed over almost every conceivable timescale since the beginning of geologic time and that the influence of human activities since at least the beginning of the Industrial Revolution has been deeply woven into the very fabric of climate change.

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STUDENT MINOR RESEARCH PROJECT
ACADEMIC YEAR 2019-2020

SOLAR WATER HEATER SYSTEM

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P Rama Krishna Rao

SOLAR WATER HEATER

Solar water heating (SWH) is the conversion of sunlight into heat for water heating using a solar thermal collector. A variety of configurations are available at varying cost to provide solutions in different climates and latitudes. SWHs are widely used for residential and some industrial applications.

A sun-facing collector heats a working fluid that passes into a storage system for later use. SWH are active (pumped) and passive (convection-driven). They use water only, or both water and a working fluid. They are heated directly or via light-concentrating mirrors. They operate independently or as hybrids with electric or gas heaters.^[2] In large-scale installations, mirrors may concentrate sunlight into a smaller collector.

The global solar thermal market is dominated by China, Europe, Japan and India, although Israel was one of the first countries to mandate installation of SWH in 1980, leading to a flourishing industry

Freeze protection

Freeze protection measures prevent damage to the system due to the expansion of freezing transfer fluid. Drainback systems drain the transfer fluid from the system when the pump stops. Many indirect systems use antifreeze (e.g., propylene glycol) in the heat transfer fluid.

In some direct systems, collectors can be manually drained when freezing is expected. This approach is common in climates where freezing temperatures do not occur often, but can be less reliable than an automatic system as it relies on an operator.

A third type of freeze protection is freeze-tolerance, where low pressure water pipes made of silicone rubber simply expand on freezing. One such collector now has European Solar Keymark accreditation.

Overheat protection

When no hot water has been used for a day or two, the fluid in the collectors and storage can reach high temperatures in all non-drainback systems. When the storage tank in a drainback system reaches its desired temperature, the pumps stop, ending the heating process and thus preventing the storage tank from overheating.

Some active systems deliberately cool the water in the storage tank by circulating hot water through the collector at times when there is little sunlight or at night, losing heat. This is most effective in direct or thermal store plumbing and is virtually ineffective in systems that use evacuated tube collectors, due to their superior insulation. Any collector type may still overheat. High pressure, sealed solar thermal systems ultimately rely on the operation of temperature and pressure relief

valves. Low pressure, open vented heaters have simpler, more reliable safety controls, typically an open vent.

Collector

Solar thermal collectors capture and retain heat from the sun and use it to heat a liquid.^[23] Two important physical principles govern the technology of solar thermal collectors:

- Any hot object ultimately returns to thermal equilibrium with its environment, due to heat loss from conduction, convection and radiation.^[24] Efficiency (the proportion of heat energy retained for a predefined time period) is directly related to heat loss from the collector surface. Convection and radiation are the most important sources of heat loss. Thermal insulation is used to slow heat loss from a hot object. This follows the Second law of thermodynamics (the 'equilibrium effect').
- Heat is lost more rapidly if the temperature difference between a hot object and its environment is larger. Heat loss is predominantly governed by the thermal gradient between the collector surface and the ambient temperatures. Conduction, convection and radiation all occur more rapidly over large thermal gradients^[24] (the ΔT effect).

Flat-plate solar thermal collector, viewed from roof-level

Flat plate

Flat plate collectors are an extension of the idea to place a collector in an 'oven'-like box with glass directly facing the Sun.^[1] Most flat plate collectors have two horizontal pipes at the top and bottom, called headers, and many smaller vertical pipes connecting them, called risers. The risers are welded (or similarly connected) to thin absorber fins. Heat-transfer fluid (water or water/antifreeze mix) is pumped from the hot water storage tank or heat exchanger into the collectors' bottom header, and it travels up the risers, collecting heat from the absorber fins, and then exits the collector out of the top header. Serpentine flat plate collectors differ slightly from this "harp" design, and instead use a single pipe that travels up and down the collector. However, since they cannot be properly drained of water, serpentine flat plate collectors cannot be used in drainback systems.

The type of glass used in flat plate collectors is almost always low-iron, tempered glass. Such glass can withstand significant hail without breaking, which is one of the reasons that flat-plate collectors are considered the most durable collector type.

Unglazed or formed collectors are similar to flat-plate collectors, except they are not thermally insulated nor physically protected by a glass panel. Consequently, these types of collectors are much less efficient when water temperature exceed ambient air temperatures. For pool heating applications, the water to be heated is often colder than the ambient roof temperature, at which point the lack of thermal insulation allows additional heat to be drawn from the surrounding environment.^[25]

Evacuated tube

Evacuated tube collectors (ETC) are a way to reduce the heat loss,^[1] inherent in flat plates. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes.^[26] Since two flat glass sheets are generally not strong enough to

withstand a vacuum, the vacuum is created between two concentric tubes. Typically, the water piping in an ETC is therefore surrounded by two concentric tubes of glass separated by a vacuum that admits heat from the sun (to heat the pipe) but that limits heat loss. The inner tube is coated with a thermal absorber.^[27] Vacuum life varies from collector to collector, from 5 years to 15 years.

Flat plate collectors are generally more efficient than ETC in full sunshine conditions. However, the energy output of flat plate collectors is reduced slightly more than ETCs in cloudy or extremely cold conditions.^[1] Most ETCs are made out of annealed glass, which is susceptible to hail, failing given roughly golf ball-sized particles. ETCs made from "coke glass," which has a green tint, are stronger and less likely to lose their vacuum, but efficiency is slightly reduced due to reduced transparency. ETCs can gather energy from the sun all day long at low angles due to their tubular shape.^[28]

Pump

PV pump

One way to power an active system is via a photovoltaic (PV) panel. To ensure proper pump performance and longevity, the (DC) pump and PV panel must be suitably matched. Although a PV-powered pump does not operate at night, the controller must ensure that the pump does not operate when the sun is out but the collector water is not hot enough.

PV pumps offer the following advantages:

- Simpler/cheaper installation and maintenance
- Excess PV output can be used for household electricity use or put back into the grid.
- Can dehumidify living space.^[29]
- Can operate during a power outage.
- Avoids the carbon consumption from using grid-powered pumps.

Bubble pump

The bubble separator of a bubble-pump system

A bubble pump (also known as geyser pump) is suitable for flat panel as well as vacuum tube systems. In a bubble pump system, the closed HTF circuit is under reduced pressure, which causes the liquid to boil at low temperature as the sun heats it. The steam bubbles form a geyser, causing an upward flow. The bubbles are separated from the hot fluid and condensed at the highest point in the circuit, after which the fluid flows downward toward the heat exchanger caused by the difference in fluid levels. The HTF typically arrives at the heat exchanger at 70 °C and returns to the circulating pump at 50 °C. Pumping typically starts at about 50 °C and increases as the sun rises until equilibrium is reached.

Controller

A *differential controller* senses temperature differences between water leaving the solar collector and the water in the storage tank near the heat exchanger. The controller starts the pump when the water in the collector is sufficiently about 8–10 °C warmer than the water in the tank, and stops it when the temperature difference reaches 3–5 °C. This ensures that stored water always gains heat when the pump operates and prevents the pump from excessive cycling on and off. (In direct systems the pump can be triggered with a difference around 4 °C because they have no heat exchanger.)

Tank

The simplest collector is a water-filled metal tank in a sunny place. The sun heats the tank. This was how the first systems worked.^[4] This setup would be inefficient due to the equilibrium effect: as soon as heating of the tank and water begins, the heat gained is lost to the environment and this continues until the water in the tank reaches ambient temperature. The challenge is to limit the heat loss.

- The storage tank can be situated lower than the collectors, allowing increased freedom in system design and allowing pre-existing storage tanks to be used.
- The storage tank can be hidden from view.
- The storage tank can be placed in conditioned or semi-conditioned space, reducing heat loss.
- Drainback tanks can be used.

Insulated tank

ICS or batch collectors reduce heat loss by thermally insulating the tank.^{[1][33]} This is achieved by encasing the tank in a glass-topped box that allows heat from the sun to reach the water tank.^[34] The other walls of the box are thermally insulated, reducing convection and radiation.^[35] The box can also have a reflective surface on the inside. This reflects heat lost from the tank back towards the tank. In a simple way one could consider an ICS solar water heater as a water tank that has been enclosed in a type of 'oven' that retains heat from the sun as well as heat of the water in the tank. Using a box does not eliminate heat loss from the tank to the environment, but it largely reduces this loss.

Standard ICS collectors have a characteristic that strongly limits the efficiency of the collector: a small surface-to-volume ratio.^[36] Since the amount of heat that a tank can absorb from the sun is largely dependent on the surface of the tank directly exposed to the sun, it follows that the surface size defines the degree to which the water can be heated by the sun. Cylindrical objects such as the tank in an ICS collector have an inherently small surface-to-volume ratio. Collectors attempt to increase this ratio for efficient warming of the water. Variations on this basic design include collectors that combine smaller water containers and evacuated glass tube technology, a type of ICS system known as an Evacuated Tube Batch (ETB) collector.^[1]

Applications

Evacuated tube

ETSCs can be more useful than other solar collectors during winter season. ETCs can be used for heating and cooling purposes in industries like pharmaceutical and drug, paper, leather and textile and also for residential houses, hospitals nursing home, hotels swimming pool etc.

An ETC can operate at a range of temperatures from medium to high for solar hot water, swimming pool, air conditioning and solar cooker.

ETCs higher operational temperature range (up to 200 °C (392 °F)) makes them suitable for industrial applications such as steam generation, heat engine and solar drying.

Swimming pools

Solar Pool Heater

Floating pool covering systems and separate STCs are used for pool heating.

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DEPARTMENT OF PHYSICS



STUDENT MINOR RESEARCH PROJECT
ACADEMIC YEAR 2019-2020

AEROBIC AND ANAEROBIC DIGESTION

Project done by:

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Anaerobic digestion

Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. The process is used for industrial or domestic purposes to manage waste or to produce fuels. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion.

Anaerobic digestion occurs naturally in some soils and in lake and oceanic basin sediments, where it is usually referred to as "anaerobic activity". This is the source of marsh gas methane as discovered by Alessandro Volta in 1776.

The digestion process begins with bacterial hydrolysis of the input materials. Insoluble organic polymers, such as carbohydrates, are broken down to soluble derivatives that become available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. These bacteria convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide. The methanogenic archaea populations play an indispensable role in anaerobic wastewater treatments.

Anaerobic digestion is used as part of the process to treat biodegradable waste and sewage sludge. As part of an integrated waste managementsystem, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digesters can also be fed with purpose-grown energy crops, such as maize.

Anaerobic digestion is widely used as a source of renewable energy. The process produces a biogas, consisting of methane, carbon dioxide, and traces of other 'contaminant' gases.^[1] This biogas can be used directly as fuel, in combined heat and power gas engines^[9] or upgraded to natural gas-quality biomethane. The nutrient-rich digestate also produced can be used as fertilizer.

Process

Many microorganisms affect anaerobic digestion, including acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens). These organisms promote a number of chemical processes in converting the biomass to biogas.

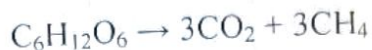
Gaseous oxygen is excluded from the reactions by physical containment. Anaerobes utilize electron acceptors from sources other than oxygen gas. These acceptors can be the organic material itself or may be supplied by inorganic oxides from within the input material. When the oxygen source in an anaerobic system is derived from the organic material itself, the 'intermediate' end products are primarily alcohols, aldehydes, and organic acids, plus carbon dioxide. In the presence of specialised methanogens, the intermediates are converted to the 'final' end products of methane, carbon dioxide, and trace levels of hydrogen sulfide.^[14] In an anaerobic system, the majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane.

Populations of anaerobic microorganisms typically take a significant period of time to establish themselves to be fully effective. Therefore, common practice is to introduce anaerobic

microorganisms from materials with existing populations, a process known as "seeding" the digesters, typically accomplished with the addition of sewage sludge or cattle slurry.

Process stages

The four key stages of anaerobic digestion involve hydrolysis, acidogenesis, acetogenesis and methanogenesis.^[17] The overall process can be described by the chemical reaction, where organic material such as glucose is biochemically digested into carbon dioxide (CO₂) and methane (CH₄) by the anaerobic microorganisms.



- **Hydrolysis**

In most cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids (VFAs) with a chain length greater than that of acetate must first be catabolised into compounds that can be directly used by methanogens.

- **Acidogenesis**

The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulfide, as well as other byproducts. The process of acidogenesis is similar to the way milk sours.

- **Acetogenesis**

The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.

- **Methanogenesis**

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining, indigestible material the microbes cannot use and any dead bacterial remains constitute the digestate.

Configuration

Anaerobic digesters can be designed and engineered to operate using a number of different configurations and can be categorized into batch vs. continuous process mode, mesophilic vs. thermophilic temperature conditions, high vs. low portion of solids, and single stage vs. multistage processes. More initial build money and a larger volume of the batch digester is needed to handle the same amount of waste as a continuous process digester.^[24] Higher heat energy is demanded in a thermophilic system compared to a mesophilic system and has a larger gas output capacity and higher methane gas content.^[25] For solids content, low will handle up to 15% solid content. Above this level is considered high solids content and can also be known as dry digestion. In a single stage process, one reactor houses the four anaerobic digestion steps. A multistage process utilizes two or more reactors for digestion to separate the methanogenesis and hydrolysis phases.

Temperature

The two conventional operational temperature levels for anaerobic digesters determine the species of methanogens in the digesters.

- Mesophilic digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C, where mesophiles are the primary microorganism present.
- Thermophilic digestion takes place optimally around 49 to 57 °C, or at elevated temperatures up to 70 °C, where thermophiles are the primary microorganisms present.

A limit case has been reached in Bolivia, with anaerobic digestion in temperature working conditions of less than 10 °C. The anaerobic process is very slow, taking more than three times the normal mesophilic time process. In experimental work at University of Alaska Fairbanks, a 1,000 litre digester using psychrophiles harvested from "mud from a frozen lake in Alaska" has produced 200–300 litres of methane per day, about 20 to 30% of the output from digesters in warmer climates. Mesophilic species outnumber thermophiles, and they are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are, therefore, considered to be more stable than thermophilic digestion systems. In contrast, while thermophilic digestion systems are considered less stable, their energy input is higher, with more biogas being removed from the organic matter in an equal amount of time. The increased temperatures facilitate faster reaction rates, and thus faster gas yields. Operation at higher temperatures facilitates greater pathogen reduction of the digestate. In countries where legislation, such as the Animal By-Products Regulations in the European Union, requires digestate to meet certain levels of pathogen reduction there may be a benefit to using thermophilic temperatures instead of mesophilic.

Additional pre-treatment can be used to reduce the necessary retention time to produce biogas. For example, certain processes shred the substrates to increase the surface area or use a thermal pretreatment stage (such as pasteurisation) to significantly enhance the biogas output. The pasteurisation process can also be used to reduce the pathogenic concentration in the digestate leaving the anaerobic digester. Pasteurisation may be achieved by heat treatment combined with maceration of the solids.

Complexity

Digestion systems can be configured with different levels of complexity. In a **single-stage digestion system** (one-stage), all of the biological reactions occur within a single, sealed reactor or holding tank. Using a single stage reduces construction costs, but results in less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Therefore, the biological reactions of the different species in a single-stage reactor can be in direct competition with each other. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like, earthen

basins used for the treatment and long-term storage of manures. Here the anaerobic reactions are contained within the natural anaerobic sludge contained in the pool.

In a **two-stage digestion system** (multistage), different digestion vessels are optimised to bring maximum control over the bacterial communities living within the digesters. Acidogenic bacteria produce organic acids and more quickly grow and reproduce than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature to optimise their performance.

Under typical circumstances, hydrolysis, acetogenesis, and acidogenesis occur within the first reaction vessel. The organic material is then heated to the required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic reactor. The initial hydrolysis or acidogenesis tanks prior to the methanogenic reactor can provide a buffer to the rate at which feedstock is added. Some European countries require a degree of elevated heat treatment to kill harmful bacteria in the input waste. In this instance, there may be a pasteurisation or sterilisation stage prior to digestion or between the two digestion tanks. Notably, it is not possible to completely isolate the different reaction phases, and often some biogas is produced in the hydrolysis or acidogenesis tanks.

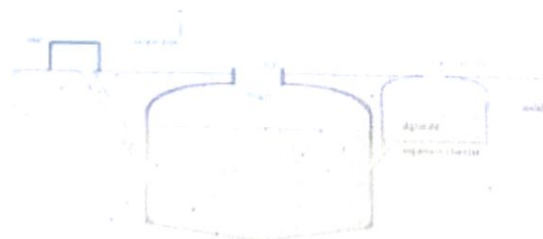
Moisture content

A second consideration related to the feedstock is moisture content. Drier, stackable substrates, such as food and yard waste, are suitable for digestion in tunnel-like chambers. Tunnel-style systems typically have near-zero wastewater discharge, as well, so this style of system has advantages where the discharge of digester liquids are a liability. The wetter the material, the more suitable it will be to handling with standard pumps instead of energy-intensive concrete pumps and physical means of movement. Also, the wetter the material, the more volume and area it takes up relative to the levels of gas produced. The moisture content of the target feedstock will also affect what type of system is applied to its treatment. To use a high-solids anaerobic digester for dilute feedstocks, bulking agents, such as compost, should be applied to increase the solids content of the input material. Another key consideration is the carbon:nitrogen ratio of the input material. This ratio is the balance of food a microbe requires to grow; the optimal C:N ratio is 20–30:1. Excess N can lead to ammonia inhibition of digestion.

Contamination

The level of contamination of the feedstock material is a key consideration. If the feedstock to the digesters has significant levels of physical contaminants, such as plastic, glass, or metals, then processing to remove the contaminants will be required for the material to be used. If it is not removed, then the digesters can be blocked and will not function efficiently. It is with this understanding that mechanical biological treatment plants are designed. The higher the level of pretreatment a feedstock requires, the more processing machinery will be required, and, hence, the project will have higher capital costs.

Applications



Using anaerobic digestion technologies can help to reduce the emission of greenhouse gases in a number of key ways:

- Replacement of fossil fuels
- Reducing or eliminating the energy footprint of waste treatment plants
- Reducing methane emission from landfills
- Displacing industrially produced chemical fertilizers
- Reducing vehicle movements
- Reducing electrical grid transportation losses
- Reducing usage of LP Gas for cooking
- An important component of the Zero Waste initiatives.

Power generation

In developing countries, simple home and farm-based anaerobic digestion systems offer the potential for low-cost energy for cooking and lighting.^{[33][72][73][74]} From 1975, China and India have both had large, government-backed schemes for adaptation of small biogas plants for use in the household for cooking and lighting. At present, projects for anaerobic digestion in the developing world can gain financial support through the United Nations Clean Development Mechanism if they are able to show they provide reduced carbon emissions.

Vehicle fuel

After upgrading with the above-mentioned technologies, the biogas (transformed into biomethane) can be used as vehicle fuel in adapted vehicles. This use is very extensive in Sweden, where over 38,600 gas vehicles exist, and 60% of the vehicle gas is biomethane generated in anaerobic digestion plants.

Cooking gas

By using a bio-digester, which produces the bacteria required for decomposing, cooking gas is generated. The organic garbage like fallen leaves, kitchen waste, food waste etc. are fed into a crusher unit, where the mixture is conflated with a small amount of water. The mixture is then fed into the bio-digester, where the bacteria decomposes it to produce cooking gas. This gas is piped to kitchen stove. A 2 cubic meter bio-digester can produce 2 cubic meter of cooking gas. This is equivalent to 1 kg of LPG. The notable advantage of using a bio-digester is the sludge which is a rich organic manure.

Biogas

TYPICAL COMPOSITION OF BIO GAS

<u>Compound</u>	<u>Formula</u>	<u>%</u>
<u>Methane</u>	CH ₄	50–75
<u>Carbon dioxide</u>	CO ₂	25–50
<u>Nitrogen</u>	N ₂	0–10
<u>Hydrogen</u>	H ₂	0–1

	2	
<u>Hydrogen sulfide</u>	H 2S	0-3
<u>Oxygen</u>	O 2	0-0

Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock^[96] (the methanogenesis stage of anaerobic digestion is performed by archaea, a micro-organism on a distinctly different branch of the phylogenetic tree of life to bacteria), and is mostly methane and carbon dioxide,^{[97][98]} with a small amount hydrogen and trace hydrogen sulfide. (As-produced, biogas also contains water vapor, with the fractional water vapor volume a function of biogas temperature).^[38] Most of the biogas is produced during the middle of the digestion, after the bacterial population has grown, and tapers off as the putrescible material is exhausted.^[99] The gas is normally stored on top of the digester in an inflatable gas bubble or extracted and stored next to the facility in a gas holder.

The methane in biogas can be burned to produce both heat and electricity, usually with a reciprocating engine or microturbine^[100] often in a cogeneration arrangement where the electricity and waste heat generated are used to warm the digesters or to heat buildings. Excess electricity can be sold to suppliers or put into the local grid. Electricity produced by anaerobic digesters is considered to be renewable energy and may attract subsidies.^[101] Biogas does not contribute to increasing atmospheric carbon dioxide concentrations because the gas is not released directly into the atmosphere and the carbon dioxide comes from an organic source with a short carbon cycle.

Biogas may require treatment or 'scrubbing' to refine it for use as a fuel.^[102] Hydrogen sulfide, a toxic product formed from sulfates in the feedstock, is released as a trace component of the biogas. National environmental enforcement agencies, such as the U.S. Environmental Protection Agency or the English and Welsh Environment Agency, put strict limits on the levels of gases containing hydrogen sulfide, and, if the levels of hydrogen sulfide in the gas are high, gas scrubbing and cleaning equipment (such as amine gas treating) will be needed to process the biogas to within regionally accepted levels.^[103] Alternatively, the addition of ferrous chloride FeCl₂ to the digestion tanks inhibits hydrogen sulfide production.^[104]

Aerobic digestion

Aerobic digestion is a process in sewage treatment designed to reduce the volume of sewage sludge and make it suitable^[1] for subsequent use.^[2] More recently, technology has been developed that allows the treatment and reduction of other^[3] organic waste, such as food, cardboard and horticultural waste. It is a bacterial process occurring in the presence of oxygen. Bacteria rapidly consume organic matter and convert it into carbon dioxide, water and a range of lower molecular weight organic compounds. As there is no new supply of organic material from sewage, the activated sludge biota begin to die and are used as food by saprotrophic bacteria. This stage of the process is known as *endogenous respiration* and it is a process that reduces the solid concentration in the sludge.

Process

Aerobic digestion is typically used in an activated sludge treatment plant. Waste activated sludge and primary sludge are combined, where appropriate, and passed to a thickener where the solids content is increased. This substantially reduces the volume that is required to be treated in the digester. The process is usually run as a batch process with more than one digester tank in operation at any one time.^[4] Air is pumped through the tank and the contents are stirred to keep the contents fully mixed. Carbon dioxide, waste air and small quantities of other gases including hydrogen sulfide are given off.

Advantages

Because the aerobic digestion occurs much faster than anaerobic digestion, the capital costs of aerobic digestion are lower.

The process is usually run at ambient temperature and the process is much less complex than anaerobic digestion and is easier to manage.

Disadvantages

The operating costs are typically much greater for aerobic digestion than for anaerobic digestion because of energy used by the blowers, pumps and motors needed to add oxygen to the process. However, recent technological advances include non-electrically aerated filter systems that use natural air currents for the aeration instead of electrically operated machinery. The digested sludge is relatively low in residual energy and although it can be dried and incinerated to produce heat, the energy yield is very much lower than that produced by anaerobic digestion.

ATADs

Autothermal Thermophilic Aerobic Digestion (ATAD) is a faecal sludge treatment design concept that uses the nutrients in the sludge and the metabolic heat of the bacteria to create high temperatures in the aerobic digester. This gradually shifts the microbial community towards termophilic at temperatures typically at 55 degree Celsius or above. While the higher aeration requirements of ATADs further increase energy use and potential smell nuisance, the increased temperature makes the resulting biosolids much safer for re-use.^[5]

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STUDY PROJECT WORK
ACADEMIC YEAR 2019-2020

SUBMITTED TO

DEPARTMENT OF PHYSICS

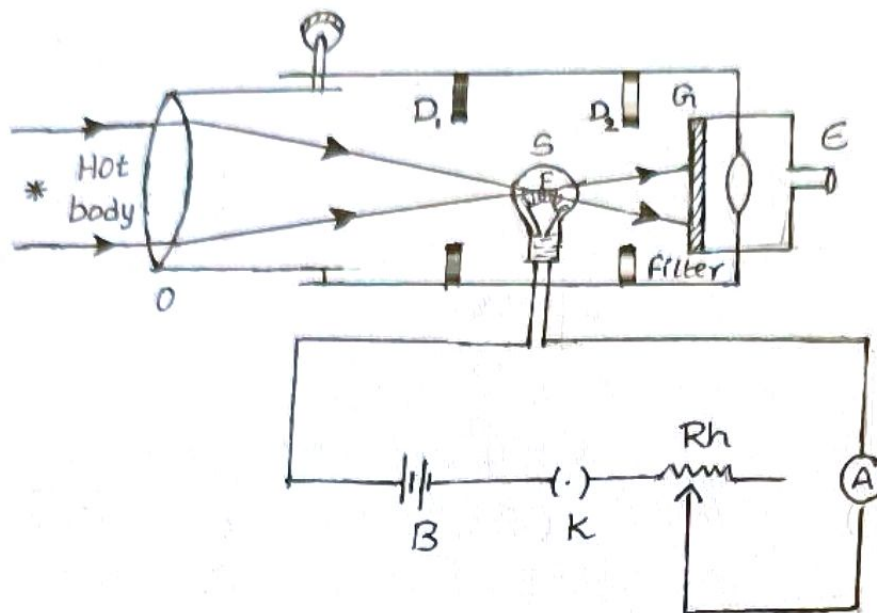
TOPIC: DISAPERAING FILAMENT OPTICAL PYROMETER

M Uday Vamsi babu-MPC TM
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Under Guidance of

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DISAPPEARING FILAMENT OPTICAL PYROMETER :



The disappearing filament optical pyrometer consists of telescope in the tube of which is mounted a filter f of red glass and a small electric lamp bulb. The objective can be moved to and fro by means of rack and pinion screw. In the position of cross wires electric lamp filament was substituted. The filament is heated through electric circuit contained battery, rheostat and an ammeter. The temperature of filament can be varied by varying the current by means rheostat. The ammeter reading gives the value of current disappearing filament optical pyrometer consists of telescope in the tube of which is mounted a filter f of red glass and a small electric lamp bulb flowing through the filament D_1 and D_2 limit the radiation entering into the eyepiece.

The object of the pyrometer is directed towards the hot body whose temperature is to be measured. The object is moved until the heat image of the hot body is focused on the filament

of the lamp. This image is viewed through the eyepiece E via the red glass filter f. 2

Initially the dark lamp filament is viewed against the bright background of the image of the hot body. Now the electric current is switched on and the filament is heated the current is adjusted until the brightness of the filament just matches the brightness of the background. The filament disappears ammeter reading I is measured. Since both the filament and image of the hot body are equal brightness. They must be emitting equal amount of energy per unit area per second and hence they must be at same temperature.

CALCULATION :

The temperature T_0 of the hot body can be calculated from the following equation $I = a + bT + cT^2$ where a, b, c are constants. using several sources of knowing temperature we can draw a graph between I and T and calculated the pyrometer knowing the value of I for the hot body we can find the temperature T .