Element of Mechanical Engineering (MEL-100)

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Recommended Texts

UNIT-I	•Manufacturing Engineering and Technology by Serope Kalpakjian, Steven R. Schmid, Sixth Edition, Prentice Hall, 2009 •An introduction to Mechanical Engineering by Jonathan Wickert, and Kemper Lewis, Fourth Edition, Cengage Learning, 2017
UNIT-II	•Basic and Applied Thermodynamics by P.K.Nag. •Fundamental of Heat and Mass Transfer by Frank P. Incropera, Seventh Edition, John Wiley & Sons, 2011
UNIT-III	•Fluid Mechanics and Hydraulic Machines by R. K. Bansal, Ninth Edition, Laxmi Publication, 2010 •Fluid Mechanics by Frank M. White, Seventh Edition, Mc Graw Hills, 2011
Other Resources	•Basics of Mechanical Engineering; Integrating Science Technology and Common Sense by Paul D Ronney, USC.

UNIT-I
Materials and Manufacturing Techniques

Recent Advances In Mechanical Engineering

The field of mechanical engineering encompasses the properties of forces, materials, energy, fluids, and motion, as well as the application of those elements to devise products that advance society and improve people's lives. Mechanical engineers are known for their broad scope of expertise and for working on a wide range of machines. Just a few examples include the micro-electromechanical acceleration sensors used in automobile air bags; heating, ventilation, and air-conditioning systems in office buildings; land, ocean, and space robotic exploration vehicles; heavy off-road construction equipment; hybrid gas-electric vehicles; gears, bearings, and other machine components; artificial hip implants; deep-sea research vessels; robotic manufacturing systems; replacement heart valves; noninvasive equipment for detecting explosives; and interplanetary exploration spacecraft.

ASME, founded as the American Society of Mechanical Engineers, which currently "promotes the art, science, and practice of multidisciplinary engineering and allied sciences around the globe." ASME surveyed its members to identify the major accomplishments of mechanical engineers.

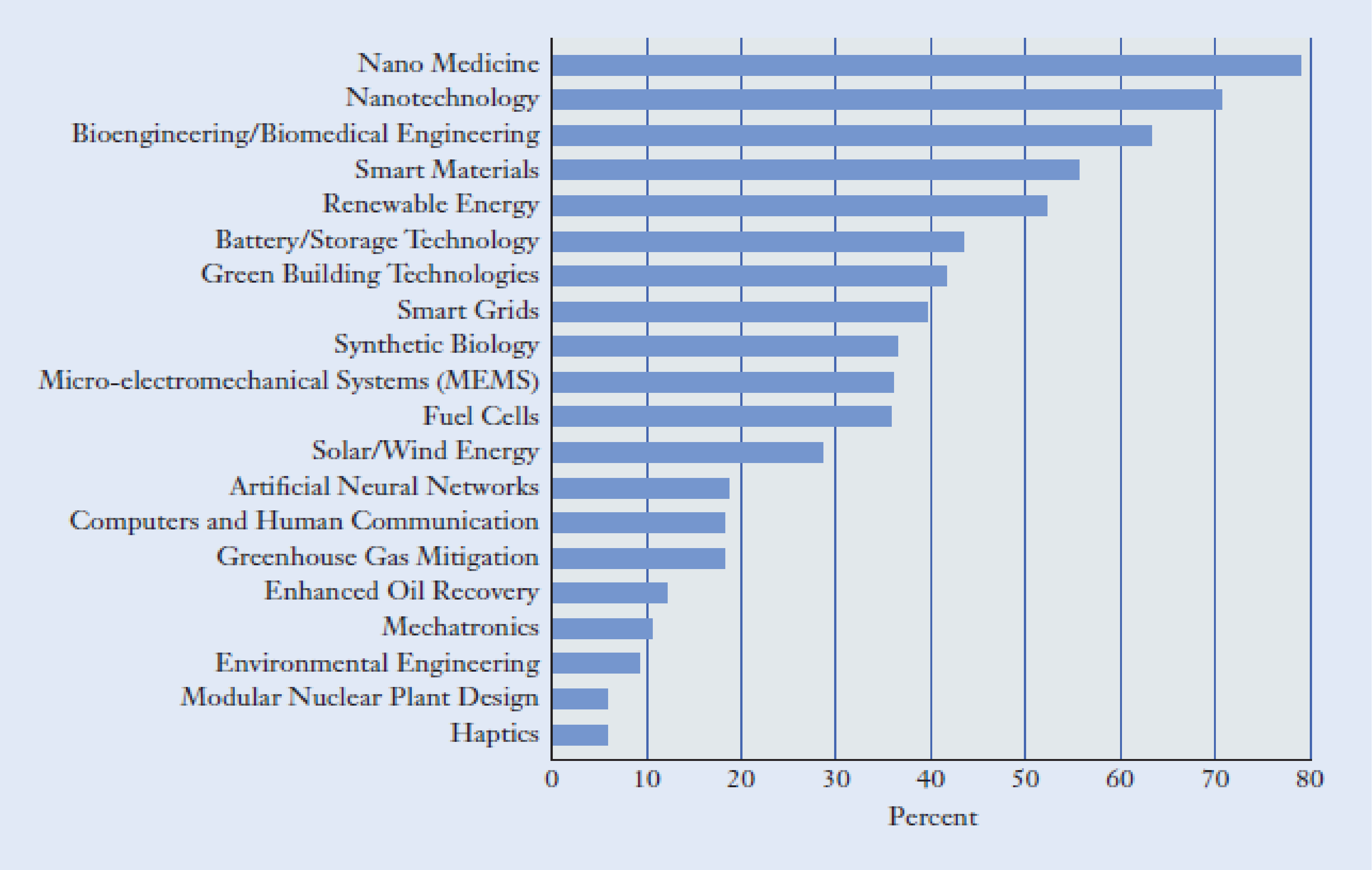
Recent Advances In Mechanical Engineering

This top ten list of achievements is summarized below:

1. The automobile
2. The Apollo program
3. Power generation
4. Agricultural mechanization
5. The airplane
6. Integrated-circuit mass production
7. Air conditioning and refrigeration
8. Computer-aided engineering technology
9. Bioengineering
10. Codes and standards

While the ASME's list of the top ten accomplishments captures the past achievements of the field, ASME also released a study identifying a number of emerging fields within mechanical engineering. In Figure 1.1, the emerging fields are sorted according to how often they were mentioned in the respondent surveys. The top emerging fields are related to solving health care and energy issues. Tremendous advances have been made in all these fields in recent years. Collectively, these fields have become prominent opportunities for mechanical engineers to have significant impact on global health, social, and environmental issues.

Recent Advances In Mechanical Engineering



ure 1.1 : The top emerging fields of mechanical engineering identified by an ASME study

Role of CAD

Computer-aided design (CAD) is the use of computers (or workstations) to aid in the creation, modification, analysis, or optimization of a design.CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term CADD (for *Computer Aided Design and Drafting*) is also used.

As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

CAD drawings offer the flexibility to draft and design in a digital sphere, which were previously done by hand. The digital format makes data handling easier, safer.

Role of CAD

Prior hand drawn blueprints can be scanned and then can be expanded upon digitally. Many CAD programs are now using three-dimensional drawings to maximize productivity and provide quicker, better product results, allowing for the development of the tiniest details.

Commercial CAD softwares

AgiliCity Modelur

Autodesk AutoCAD

Bricsys BricsCAD

Dassault Systemes CATIA

Dassault Systemes SolidWorks

Kubotek KeyCreator

3D Printing

The 3D printing process builds a three-dimensional object from a computer-aided design (CAD) model, usually by successively adding material layer by layer, which is why it is also called additive manufacturing, unlike conventional machining, casting and forging processes, where material is removed from a stock item (subtractive manufacturing) or poured into a mold and shaped by means of dies, presses and hammers.

In an additive process, an object is created by laying down successive layers of material until the object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object. 3D printing is the opposite of subtractive manufacturing which is cutting out / hollowing out a piece of metal or plastic with for instance a milling machine. 3D printing enables to produce complex shapes using less material than traditional manufacturing methods. It encompasses many forms of technologies and materials as 3D printing is being used in almost all industries. It's important to see it as a cluster of diverse industries with a myriad of different applications.

A few examples:

Dental products

Eyewear

3D Printing

Architectural scale models

Prosthetics

Reconstructing fossils in paleontology

Replicating ancient artifacts in archaeology

Reconstructing bones and body parts in forensic pathology

Simulation

Simulation modeling is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. Simulation modeling is used to help designers and engineers understand whether, under what conditions, and in which ways a part could fail and what loads it can withstand. Simulation modeling can also help to predict fluid flow and heat transfer patterns. It analyses the approximate working conditions by applying the simulation software.

Uses of simulation modeling

Simulation modeling allows designers and engineers to avoid the repeated building of multiple physical prototypes to analyze designs for new or existing parts. Before creating the physical prototype, users can investigate many digital prototypes. Using the technique, they can:

Optimize geometry for weight and strength

Select materials that meet weight, strength, and budget requirements

Simulate part failure and identify the loading conditions that cause them

Assess extreme environmental conditions or loads not easily tested on physical prototypes, such as earthquake shock load

Verify hand calculations

Validate the likely safety and survival of a physical prototype before

Material Response

As one of their responsibilities, mechanical engineers design hardware so that it won't break when used and so that it can carry the forces acting on it reliably and safely. It has been found that for a mechanical component to break, stretch, or bend depends not only on the forces applied to it, but also on its dimensions and the properties of the material from which it is made. Those considerations give rise to the concept of *stress* as a measure of the intensity of a force applied over a certain area. Conversely, the *strength* of a material describes its ability to support and withstand the stress applied to it. Engineers compare the stress present in a component to the strength of its material in order to determine whether the design is satisfactory.

Tension, compression, and shear stress are quantities that engineers calculate when they relate the dimensions of a mechanical component to the forces acting on it. Those stresses are then compared to the material's physical properties to determine whether failure is expected to occur. When the strength exceeds the stress, we expect that the structure or machine component will be able to carry the forces without incurring damage. Engineers conduct these types of force, stress, materials, and failure analyses while they design products.

The standard tensile test is used to obtain a variety of material characteristics and strengths that are used in design. Figure 2.1 illustrates a typical tension-test specimen and its characteristic dimensions. The original diameter $d0$ and the gauge length $l0$, used to measure the deflections, are recorded before the test is begun.

Material Response

The specimen is then mounted in the test machine and slowly loaded in tension while the load *P* and deflection are observed. The load is converted to stress by the calculation

$$\sigma = P/A_0$$

where $A = \pi d^2{}_0/4$ is the original area of the specimen.

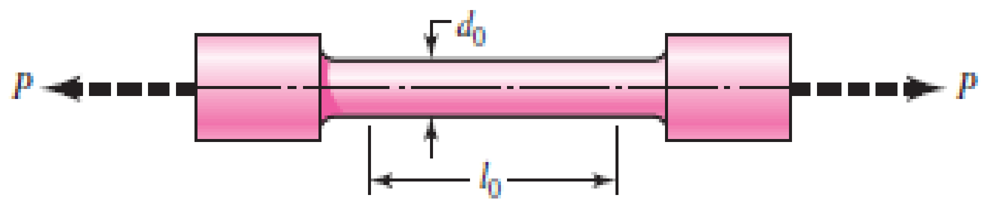


Fig 2.1 Typical tension-test specimen.

The deflection, or extension of the gauge length, is given by $l - l0$ where l is the gauge length corresponding to the load *P*. The normal strain is calculated from

$$\epsilon = \frac{l - l_0}{l_0}$$

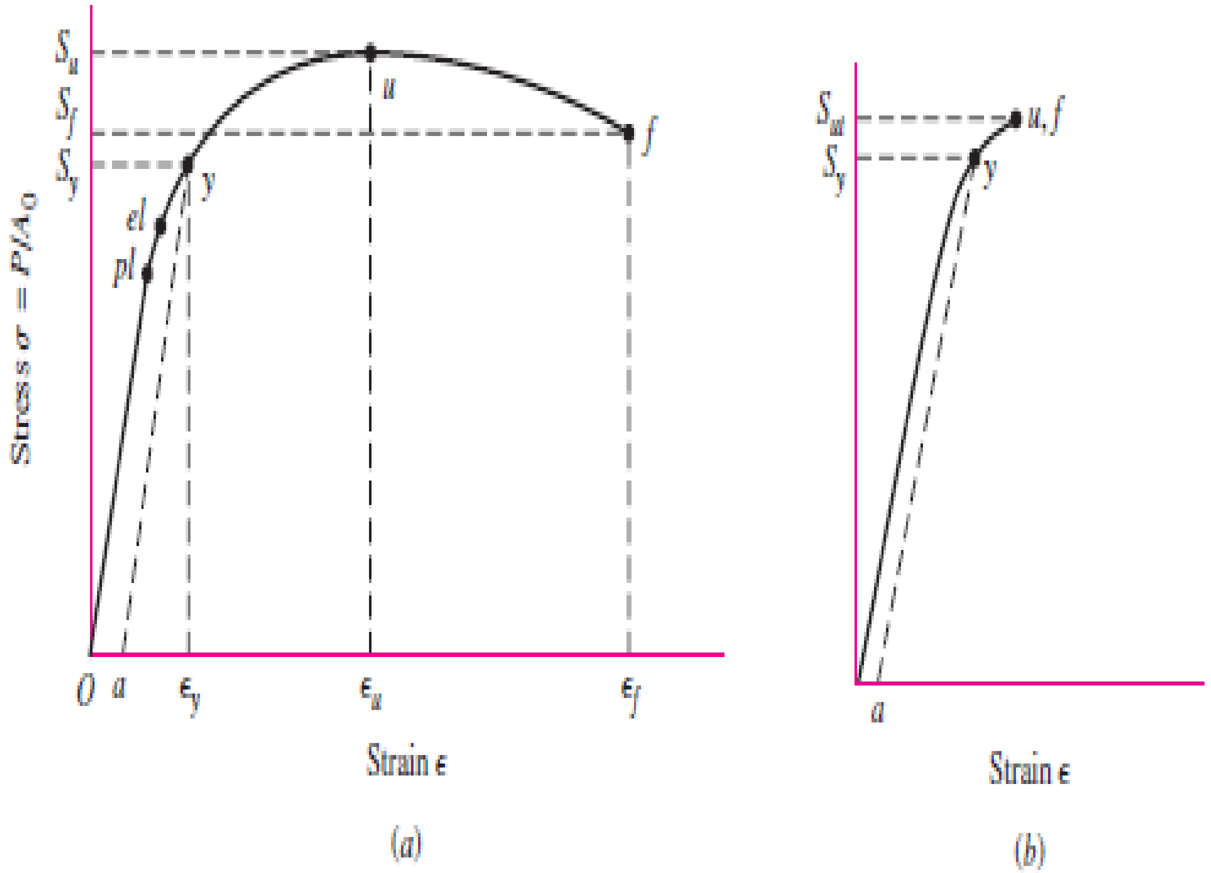
The results are plotted as a *stress-strain diagram*. Figure 2–2 depicts typical stress strain diagrams for ductile and brittle materials. Ductile materials deform much more than brittle materials.

Material Response

Figure 2–2

Stress-strain diagram obtained from the standard tensile test (*a*) Ductile material; (*b*) brittle material.

pl marks the proportional limit; *el*, the elastic limit; *y*, the offset-yield strength as defined by offset strain *a*; *u*, the maximum or ultimate strength; and *f*, the fracture strength.



Material Response

pl in Fig. 2–2*a* is called the *proportional limit*. This is the point at which the curve first begins to deviate from a straight line. No permanent set will be observable in the specimen if the load is removed at this point. In the linear range, the uniaxial stress-strain relation is given by *Hooke's law* as

$$\sigma = E\epsilon$$

where the constant of proportionality *E*, the slope of the linear part of the stress-strain curve, is called *Young's modulus* or the *modulus of elasticity*. *E* is a measure of the stiffness of a material, and since strain is dimensionless, the units of *E* are the same as stress. Steel, for example, has a modulus of elasticity of about 30 Mpsi (207 GPa) *regardless of heat treatment, carbon content, or alloying*. Stainless steel is about 27.5 Mpsi (190 GPa).

Point *el* in Fig. 2–2 is called the *elastic limit*. If the specimen is loaded beyond this point, the deformation is said to be plastic and the material will take on a permanent set when the load is removed. Between *pl* and *el* the diagram is not a perfectly straight line, even though the specimen is elastic.

During the tension test, many materials reach a point at which the strain begins to increase very rapidly without a corresponding increase in stress. This point is called the *yield point*. Not all materials have an obvious yield point, especially for brittle materials.

Material Response

For this reason, *yield strength Sy* is often defined by an *offset method* as shown in Fig. 2–2, where line *ay* is drawn at slope *E*. Point *a* corresponds to a definite or stated amount of permanent set, usually 0.2 percent of the original gauge length *(*= 0.002*)*, although 0.01, 0.1, and 0.5 percent are sometimes used.

The *ultimate*, or *tensile*, *strength Su* or *Sut* corresponds to point *u* in Fig. 2–2 and is the maximum stress reached on the stress-strain diagram. That value represents the largest stress that the material is capable of sustaining. As the test continues, the stress in the figure actually decreases, owing to a reduction in the rod's cross-sectional area, until the sample eventually fractures at point *f*.

Engineering Materials

A wide variety of materials is available for engineering products, and choosing the correct ones is an important aspect of the design process. Mechanical engineers select materials in the context of both the product's purpose and the processes that will be used during its manufacture. The main classes of materials encountered in mechanical engineering are:

- Metals and their alloys
- Ceramics
- Polymers
- Composite materials

Electronic materials comprise another class that includes the semiconductors that are used widely in electronic, computer, and telecommunication systems. Devices such as microprocessors and memory chips use metal materials, such as electrical conductors and ceramic materials as insulators.

1. Metals and Their Alloys

Metals are relatively stiff and heavy materials; in other words, from a technical standpoint, they generally have large values for their elastic modulus and density. The strength of metals can be increased by mechanical and heat treatments and by *loying*, which the process of adding small amounts of other carefully is chosen

Engineering Materials

elements to a base metal. From a design standpoint, metals are a good choice to use in structures and machines that must carry large forces. On the negative side, metals are susceptible to corrosion, and, as a result, they can deteriorate and weaken over time. Another attractive feature of metals is that many methods exist to make them, shape them, and attach them. Metals are versatile materials because they can be manufactured by casting, extrusion, forging, rolling, cutting, drilling, and grinding. Some metals, by virtue of their processing and alloys, have high degrees of *ductility*, that is, the ability of a material to withstand a significant amount of stretching before it fractures. Metals include a number of important alloys such as aluminum, copper, steel, and titanium.

2. Ceramics

Engineering ceramics, are used in the automotive, aerospace, electronics, telecommunications, computer, and medical industries for applications encompassing high temperatures, corrosion,

electrical insulation, and wear resistance. Ceramics are produced by heating naturally occurring minerals and chemically treated powders in a furnace to form a rigid mechanical component. Ceramics are hard, brittle, crystalline materials that can comprise metals and nonmetals. Ceramics have large elastic modulus values, but, because they are brittle and tend to break suddenly when overloaded,

Engineering Materials

ceramics are not appropriate for supporting large tensile forces. Mechanical components made from ceramics become significantly weakened by the presence of small defects, cracks, holes, bolted connections, and so forth.

An important characteristic of ceramics is that they can withstand extreme temperatures and insulate other mechanical components from heat. Ceramics are used as thermal barrier coatings to protect turbine blades from the high temperatures developed in jet engines. They are also used in thermal protection systems in rocket exhaust cones and in the windshields of many aircraft, and they were used in the space shuttle to insulate the spacecraft's structural frame during reentry.

Some examples of ceramics are the compositions silicon nitride (Si_3N_4), alumina (Al_2O_3), and titanium carbide (TiC). Alumina is sometimes formed into a honeycomb-like support structure that is used in an automobile's exhaust system and catalytic converter. Because of its mechanical, electrical, and thermal characteristics, the advanced ceramic AlTiC (64% Al_2O_3 and 36% TiC) is used in computer hard disk drives to support the recording heads above the surface of the rotating disks.

Engineering Materials

3. Polymers

Plastics and elastomers are two types of polymers. The root of “polymer” is a Greek word meaning “of many parts,” and it emphasizes the fact that polymers are giant molecules formed as long chains of smaller, building-block molecules. These polymer macromolecules have enormous molecular weights, and they can contain hundreds of thousands of atoms. Each macromolecule is made up of a large number of simpler units that are joined together in a regular repeating pattern. Polymers are organic compounds; that is, their chemical formulation is based on the properties of the element carbon. Carbon atoms are able to attach themselves to one another more than other elements can, and other atoms (such as oxygen, hydrogen, nitrogen, and chlorine) are attached to those carbon chains. From a chemical standpoint, therefore, engineering polymers are formed from large-chained molecules having a regular pattern and based on carbon.

Rubber and silk are two naturally occurring macromolecules, but chemists and chemical engineers have developed hundreds of useful macromolecular materials. Synthetic polymers are classified into two groups: *plastics* (which can be extruded into sheets and pipes or molded to form a wide range of products) and *elastomers* (which are compliant in a manner characteristic of rubber). Unlike the first two classes of materials—metals and their alloys and ceramics—

Engineering Materials

plastics and elastomers are relatively soft materials. They typically have an elastic modulus that is many times smaller than metals. In addition, their properties also change significantly with temperature. At room temperature, polymers may stretch and behave elastically, but, as the temperature is lowered, they become brittle. These materials are not well suited for applications where strength is required or for operation at elevated temperatures. Plastics and elastomers are widely used and remarkable engineering materials. They are relatively inexpensive, lightweight, good insulators against heat and electricity, and easy to shape and mold into complex parts.

Plastics are one of the most utilized engineering materials in any industry, and some of the most common forms are polyethylene, polystyrene, epoxy, polycarbonate, polyester, and nylon. Elastomers, the second category of polymers, are the synthetic rubber-like macromolecules that are elastic and stretchable in a manner that is characteristic of rubber. Elastomers can be greatly deformed and still return to their original shape after being released. In one of their largest applications, elastomers are used to make tires for vehicles ranging from mountain bikes to aircraft. Other elastomers include the polyurethane foam that is used to insulate buildings, silicone sealant and adhesive, and neoprene, which is resistant to chemicals and oils. Elastomers are also used to make supports and mounting blocks that can reduce the vibration produced by a machine.

Engineering Materials

4. Composite Materials

As their name implies, composites are mixtures of several materials, and their formulation can be customized and tailored for specific applications. Composite materials are generally comprised of two components: the matrix and the reinforcement. The matrix is a relatively ductile material that holds and binds together the strong reinforcing particles or fibers embedded in it. Some composite materials comprise a polymer matrix (usually epoxy or polyester) that is reinforced by many small-diameter fibers of glass, carbon, or Kevlar.

Composites are not well suited for high temperatures because, like plastics and elastomers, the polymer matrix softens as the temperature increases. The main idea behind fiber-reinforced composites is that the strong fibers carry most of the applied force. Other examples of composite materials are concrete that has been reinforced with steel rods, automobile tires that include steel reinforcing belts in an elastomers matrix, and power transmission belts that use fiber or wire cords to carry the belt's tension.

Basic Manufacturing Processes

Manufacturing technologies are economically important because they are the means for adding value to raw materials by converting them into useful products. Different manufacturing processes are well suited to a particular need based on environmental impact, dimensional accuracy, material properties, and the mechanical component's shape. Engineers select processes, identify the machines and tools, and monitor production to ensure that the final product meets its specifications. The main classes of manufacturing processes are as follows:

1. CASTING

In *casting*, liquid metal is poured into the cavity of a mold, which can be expendable or reusable. The liquid then cools into a solid object with the same shape as the mold. An attractive feature of casting is that complex shapes can be produced as solid objects without the need to join any pieces. Casting is an efficient process for creating many copies of a three-dimensional object, and, for that reason, cast components are relatively inexpensive. On the other hand, defects can arise if the metal solidifies too soon and prevents the mold from filling completely. The surface finish of cast components generally has a rough texture, and they might require additional machining operations to produce smooth and flat surfaces. Some examples of cast components include automotive engine blocks, cylinder heads, and brake rotors and drums (Figure 1).

Basic Manufacturing Processes

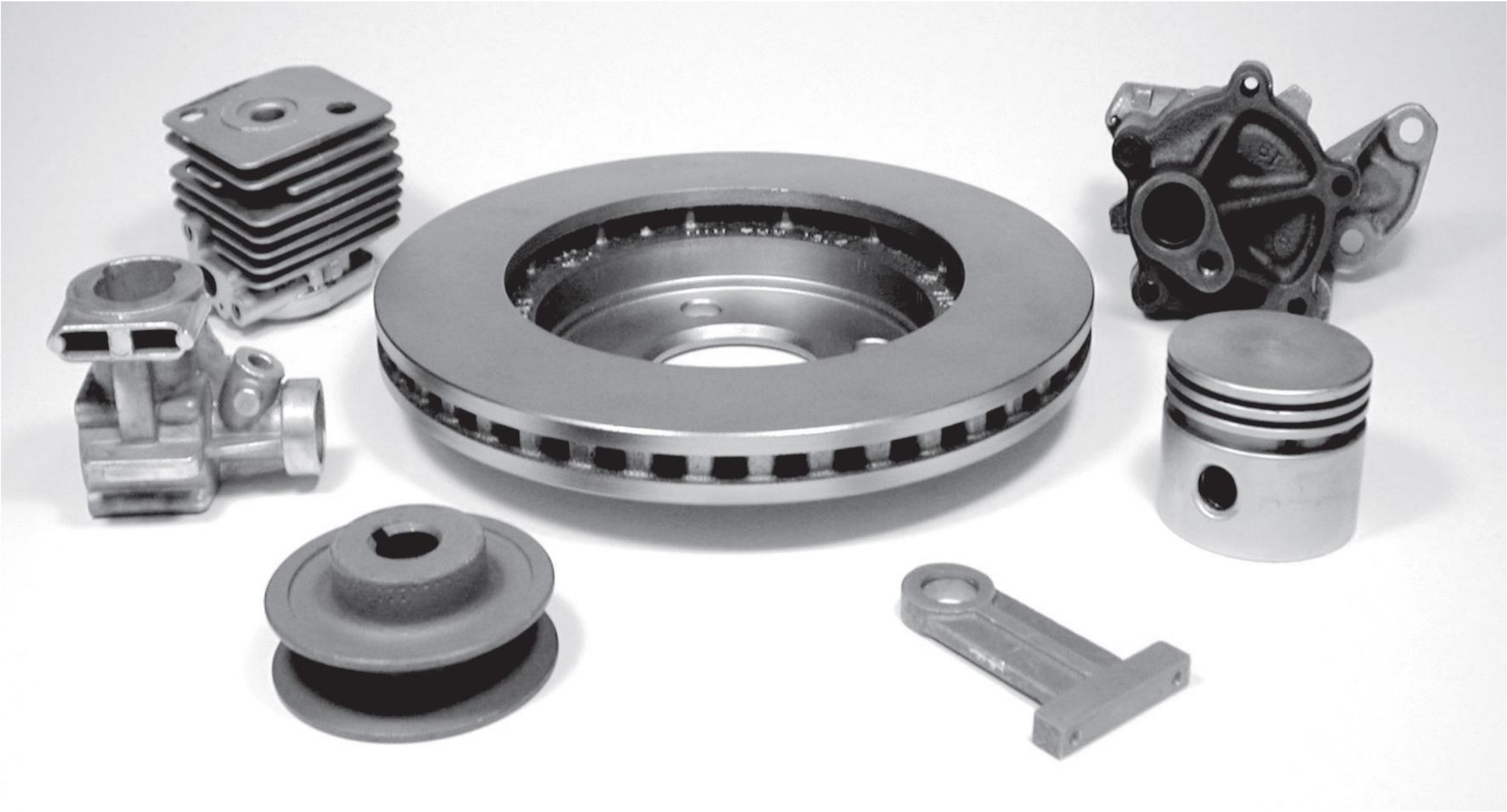


FIGURE 1 Examples of hardware produced by casting include a disk-brake rotor, automotive-oil, pump, piston, bearing mount, V-belt sheave, model-airplane engine block, and a two stroke engine cylinder.

2. FORMING

It encompasses a family of techniques whereby a raw material is shaped by stretching, bending, or compression. Large forces are applied to plastically deform a material into its new permanent shape.

- **Rolling**

One kind of a forming operation is called *rolling*, which is the process of reducing the thickness of a flat sheet of material by compressing it between rollers. Sheet metal that is produced in this manner is used to make aircraft wings and fuselages, beverage containers, and the body panels of automobiles.

- **Forging**

Forging is another forming process, which is based on the principle of heating, impacting, and plastically deforming metal into a final shape. Industrial-scale forging is the modern version of the blacksmith’s art of working metal by hitting it with a hammer against an anvil. Components that are produced by forging include some crankshafts and connecting rods in internal combustion engines. Compared to castings, a forged component is strong and hard, and for that reason, many hand tools are produced this way (Figure 2).

Basic Manufacturing Processes

FIGURE 2: Examples of hardware produced by forging.

Basic Manufacturing Processes

- **Extrusion**

The forming process known as *extrusion* is used to create long straight metal parts whose cross sections may be round, rectangular, L-, T-, or C-shaped, for instance. In extrusion, a mechanical or hydraulic press is used to force heated metal through a tool (called a die) that has a tapered hole ending in the shape of the finished part's cross section. The die used to shape the raw material is made from a metal that is much harder than what is being formed. Conceptually, the process of extrusion is not unlike the familiar experience of squeezing toothpaste out of a tube. Figure 3 shows examples of aluminum extrusions with a variety of cross sections.

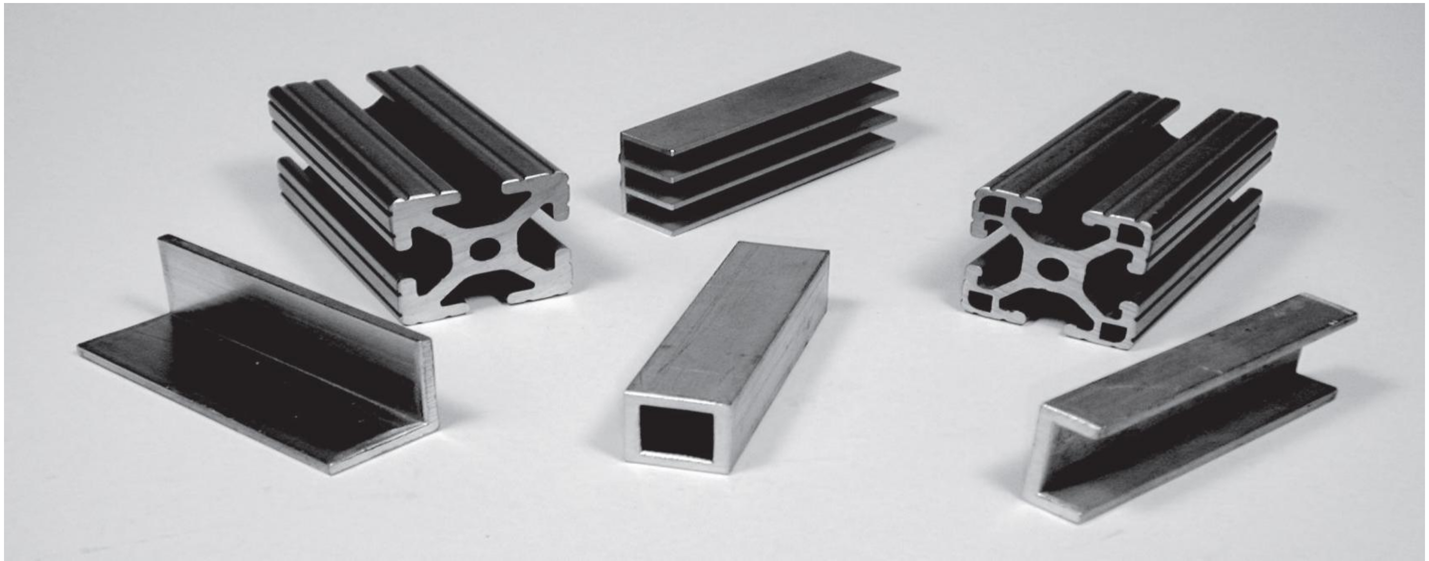


FIGURE 3: Examples of aluminum extrusions

Basic Manufacturing Processes

3. MACHINING

Machining refers to processes whereby material is gradually removed from a work piece in the form of small chips. The most common machining methods are called drilling, sawing, milling, and turning. Machining operations are capable of producing mechanical components with dimensions and shapes that are far more precise than their cast or forged counterparts. One drawback of machining is that (by its very nature) the removed material is wasted. In a production line, machining operations are often combined with casting and forging when cast or forged components require additional operations to flatten surfaces, make holes, and cut threads (Figure 4).

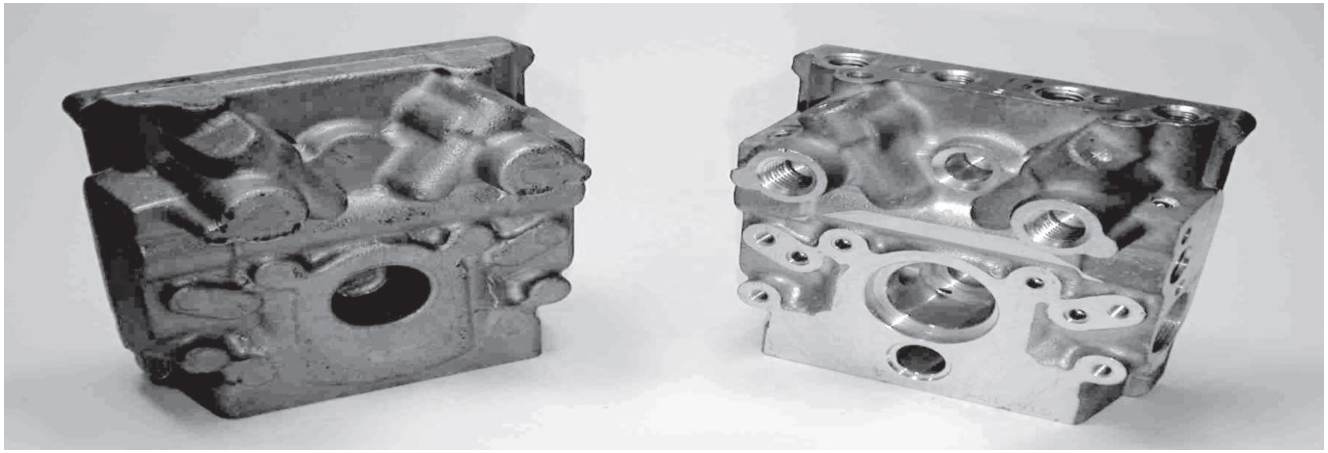


FIGURE 4: This body for a hydraulic valve assembly was first cast from aluminum (left) and then machined in order to produce holes, flatten surfaces, and cut threads (right).

Basic Manufacturing Processes

Machining tools include drill presses, band saws, lathes, and milling machines. Each tool is based on the principle of removing unwanted material from a work piece by means of the cutting action of sharpened blades.

4. JOINING

In this process, operations are used to assemble subcomponents into a final product by welding, soldering, riveting, bolting, or adhesively bonding them. Many bicycle frames, for instance, are welded together from individual pieces of metal tubing.

5. FINISHING

Steps are taken to treat a component's surface to make it harder, improve its appearance, or protect it from the environment. Some processes include polishing, electroplating, anodizing, and painting.

Conventional And Non-conventional Fabrication Processes

There is a broad classification of machines depending on the tasks performed and the speed with which it is done. These classifications are conventional and non-conventional machines.

Conventional machines are those machines that work only with the help of a human operator and produces conventional parts. Some examples of these machines are small scale welding, small scale molding, lathing and those that are used in making small vehicles. Non-conventional machines, on the other hand, are those machines that operate automatically with the help of computers and there is no need for human intervention or operator. These are usually controlled by an automatic robot or computers. Examples of operations that uses non-conventional machines are car painting in car manufacturing plants, welding car units and in manufacturing processes where in there is extreme high and low temperature involved that humans cannot withstand.

The method of conventional machining demands that there must be direct contact between the tool and the work material. For instance, a fast rotating cutter made of iron is necessary to cut an aluminum bar. This method requires physical contact of the cutting tool and material that needs to be cut. The process of non-conventional machining, on the other hand, employs modern and latest technology in processing. This process involves no contact between the machine tools and material.

Conventional And Non-conventional Fabrication Processes

Examples of non-conventional tools used are infrared beam, laser beam, electric arc, plasma cutting and electric beam. The differences between the two are as follow:

Non-conventional method uses tools that are less noisy thus preventing noise pollution.

In conventional machining processes, there is a risk of tool wearing since physical contact is required to perform the job. This is not true when it comes to non-conventional machining processes.

Non-conventional process promote longer tool life because no direct contact is made between the tool and the materials.

Tools used in non-conventional processes are more accurate and with higher precision compared to conventional tools that create conventional parts.

When it comes to costs, non-conventional tools are more expensive compared to conventional ones.

It is easier to find spare parts for conventional machines but harder for non-conventional ones.

Non-conventional tools require skilled operators who are experts in machining because it has a complicated set up while conventional tools are easier to set-up and operate without the assistance of professionals.

UNIT-II
Thermal and Energy Systems

Introduction - Thermodynamics

One branch of knowledge that all engineers and scientists must have a grasp of (to some extent or the other!) is thermodynamics.

In some sense thermodynamics is perhaps the 'most abstract subject' and a student can often find it very confusing if not 'motivated' strongly enough.

Thermodynamics can be considered as a 'system level' science- i.e. it deals with descriptions of the whole system and not with interactions (say) at the level of individual particles.

- I.e. it deals with quantities (like T,P) averaged over a large collection of entities (like molecules, atoms).
- This implies that questions like: "What is the temperature or entropy of an atom?"; do not make sense in the context of thermodynamics (at least in the usual way!).

TD puts before us some fundamental laws which are universal in nature (and hence applicable to fields across disciplines).

Introduction - Thermodynamics

Thermodynamics is the study of the effects of work, heat, and energy on a system

Thermodynamics is only concerned with macroscopic (large-scale) changes and observations

Classical thermodynamics concerns the relationships between bulk properties of matter. Nothing is examined at the atomic or molecular level.

Statistical thermodynamics seeks to explain those bulk properties in terms of constituent atoms. The statistical part treats the aggregation of atoms, not the behavior of any individual atom

System, Surrounding and Universe

To understand the laws of thermodynamics and how they work, first we need to get the terminology right. Some of the terms may look familiar (as they are used in everyday language as well)- but their meanings are more 'technical' and 'precise', when used in TD and hence we should not use them 'casually'.

System is region where we focus our attention.

Surrounding is the rest of the universe.

Universe = System + Surrounding

More practically, we can consider the 'Surrounding' as the immediate neighborhood of the system (the part of the universe at large, with which the system 'effectively' interacts). In this scheme of things we can visualize: a system, the surrounding and the universe at large.

Things that matter for the surrounding: (i) T, (ii) P, (iii) ability to: do work, transfer heat, transfer matter, etc. Parameters for the system: (i) Internal energy, (ii) Enthapy, (iii) T, (iv) P, (v) mass, etc.

Open, Closed and Isolated System

To a thermodynamic system two 'things' may be added/removed:

- ➢ energy (in the form of heat &/or work) ➢ matter.

An open system is one to which you can add/remove matter (e.g. a open beaker to which we can add water). When you add matter- you also end up adding heat (which is contained in that matter).

A system to which you cannot add matter is called closed. Though you cannot add/remove matter to a closed system, you can still add/remove heat (you can cool a closed water bottle in fridge).

A system to which neither matter nor heat can be added/removed is called isolated. A closed vacuum 'thermos' flask can be considered as isolated.

Type of boundary	Interactions
Open	All interactions possible (Mass, Work, Heat)
Closed	Matter cannot enter or leave
Semi-permeable	Only certain species can enter or leave
Insulated	Heat cannot enter or leave
Rigid	Mechanical work cannot be done
Isolated	No interactions are possible

Thermodynamic processes

Here is a brief listing of a few kinds of processes, which we will encounter in TD:

- Isothermal process → the process takes place at constant temperature (e.g. freezing of water to ice at –10°C)
- Isobaric→constant pressure (e.g. heating of water in open air→ under atmospheric pressure)
- Isochoric→constant volume (e.g. heating of gas in a sealed metal container)
- Reversible process → the system is close to equilibrium at all times (and infinitesimal alteration of the conditions can restore the universe (system + surrounding) to the original state. (Hence, there are no truly reversible processes in nature).
- Cyclic process → the final and initial state are the same. However, q and w need not be zero.
- Adiabatic process → dq is zero during the process (no heat is added/removed to/from the system)

A combination of the above are also possible: e.g. 'reversible adiabatic process'.

Temperature

Though we all have a feel for temperature ('like when we are feeling hot'); in the context of TD temperature is technical term with 'deep meaning'.

As we know (from a commons sense perspective) that temperature is a measure of the 'intensity of heat'. 'Heat flows' (energy is transferred as heat) from a body at higher temperature to one at lower temperature. (Like pressure is a measure of the intensity of 'force applied by matter'→ matter (for now a fluid) flows from region of higher pressure to lower pressure).

That implies (to reiterate the obvious!) if I connect two bodies– (A)-one weighing 100kg at 10°C and the other (B) weighing 1 kg at 500°C, then the 'heat will flow' from the hotter body to the colder body (i.e. the weight or volume of the body does not matter).

But, temperature comes in two important 'technical' contexts in TD:

1➢ it is a measure of the average kinetic energy (or velocity) of the constituent entities (say molecules)

2➢ it is the parameter which determines the distribution of species (say molecules) across various energy states available.

Temperature

- Celsius (Farenheit, etc.) are relative scales of temperature and zero of these scales do not have a fundamental significance. Kelvin scale is a absolute scale.
  Zero Kelvin and temperatures below that are not obtainable in the classical sense.
- Classically, at 0K a perfect crystalline system has zero entropy (i.e. system attains its minimum entropy state). However, in some cases there could be some residual entropy due to degeneracy of states (this requires a statistical view point of entropy).
- At 0K the kinetic energy of the system is not zero. There exists some zero point energy.

1^{st} Law of Thermodynamics

The first law of thermodynamics is an extension of the law of conservation of energy

The internal energy of an isolated system is constant.

A closed system may exchange energy as heat or work. Let us consider a close system at rest without external fields.

There exists a state function U such that for any process in a closed system:

$$\Delta U = q + w \quad \text{------------------------} \quad [1]$$

- q → heat flow in to the system
- w → work done on the system (work done by the system is negative of above- this is just 'one' sign convention) q & w are not state functions → i.e. they depend on the path of a process.

U is the internal energy. Being a state function for a process ΔU depends only of the final and initial state of the system. $\Delta U = U_{final} - U_{initial}$.

In contrast to U, q & w are NOT state functions (i.e. depend on the path followed).

1st Law of Thermodynamics

For an infinitesimal process eq. [1] can be written as: $dU = dq + dw$

The change in U of the surrounding will be opposite in sign, such that:

$$\Delta U_{system} + \Delta U_{surrounding} = 0$$

Expression of work done for Open and Closed System for different processes

NOTE: Refer the recommended book.

Steady Flow Energy Equation

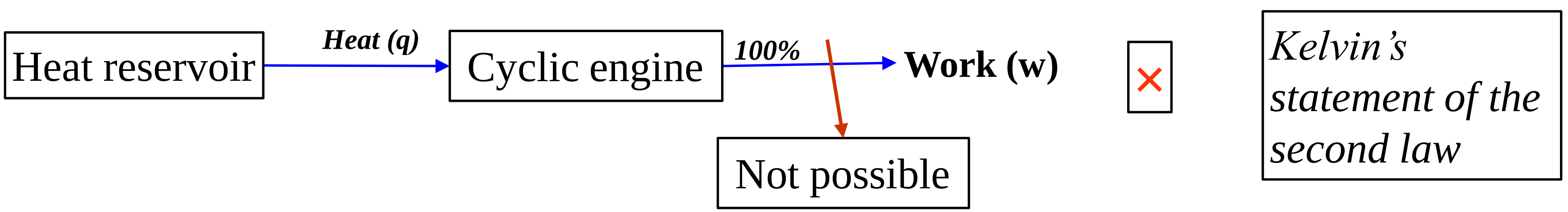
NOTE: Refer the recommended book.

2nd Law of Thermodynamics- Kelvin Plank statement

It is impossible to build a cyclic machine* that converts heat into work with 100% efficiency → Kelvin's statement of the second law.

Another way of viewing the same: it is impossible to construct a cyclic machine that completely (with 100% efficiency) converts heat, which is energy of *random molecular motion*, to mechanical work, which is *ordered motion*.

The unavailable work is due to the role of Entropy in the process.

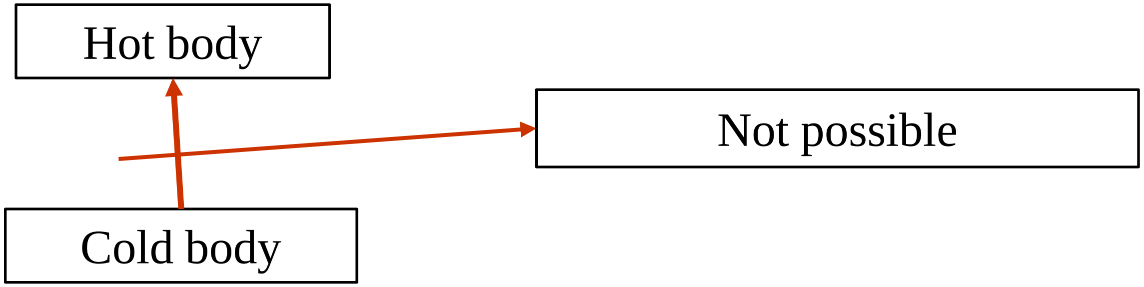


2nd Law of TD- Clausius statement

Heat does not 'flow*' from a colder body to a hotter body, without an concomitant change outside of the two bodies→ Clausius statement of the second law.[(a)]

This automatically implies that the spontaneous direction of the 'flow of heat*' is from a hotter body to a colder body.

The Kelvin's and Clausius statements of the second law are equivalent. I.e. if we violate Kelvin's statement, then we will automatically violate the Clausius statement of the second law (and vice-versa).

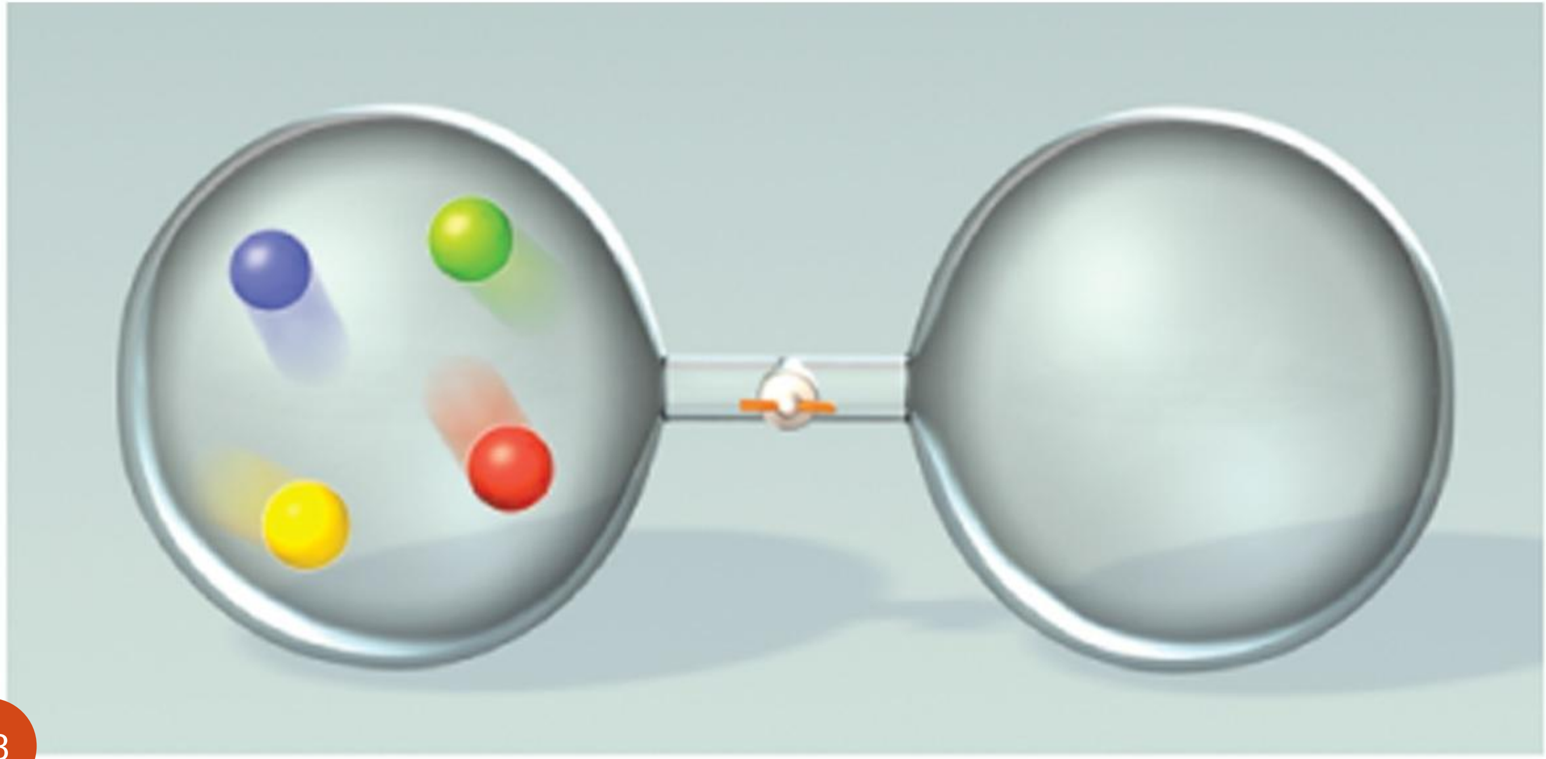


Entropy

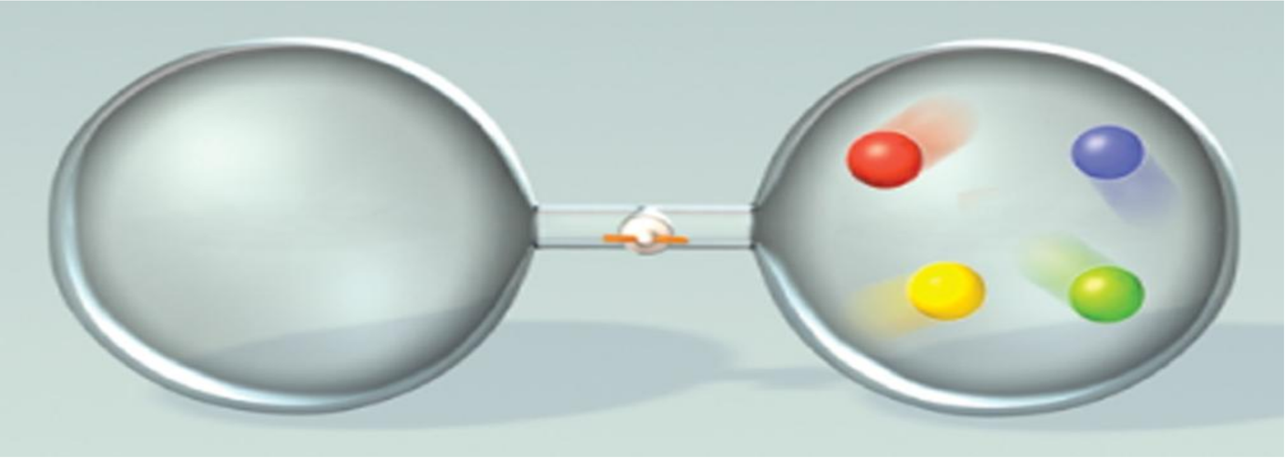
Entropy (*S*): Can be thought of as a measure of the *disorder* of a system

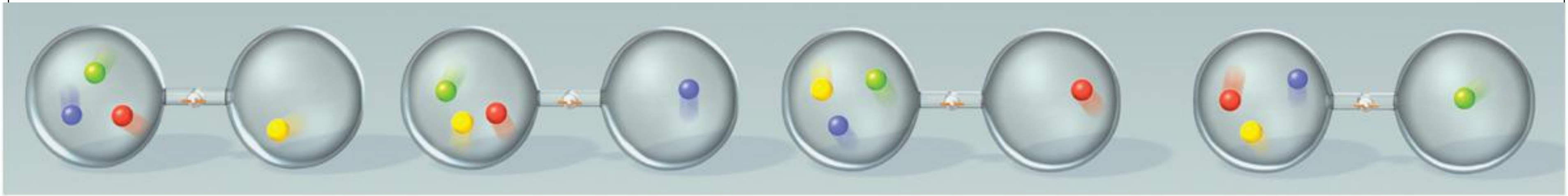
In general, greater disorder means greater entropy

Microstates - How many different arrangements?

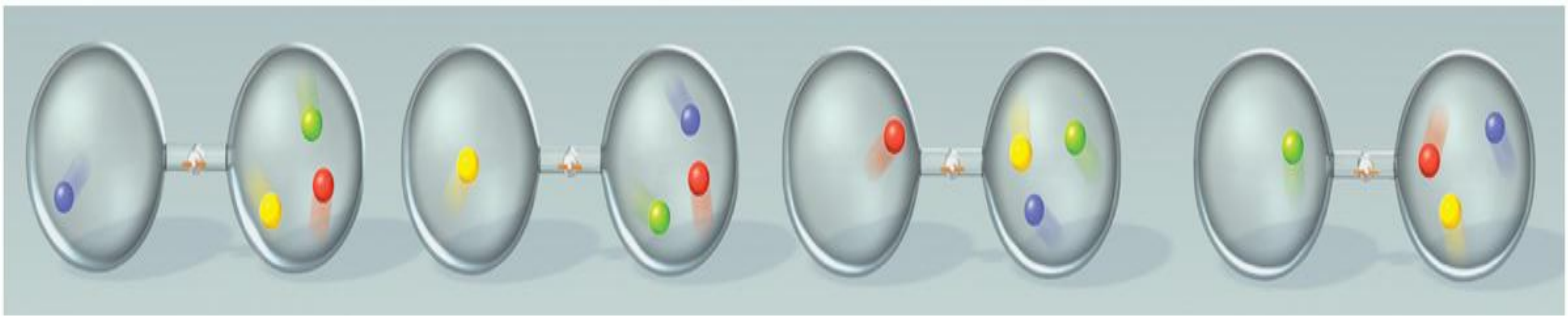


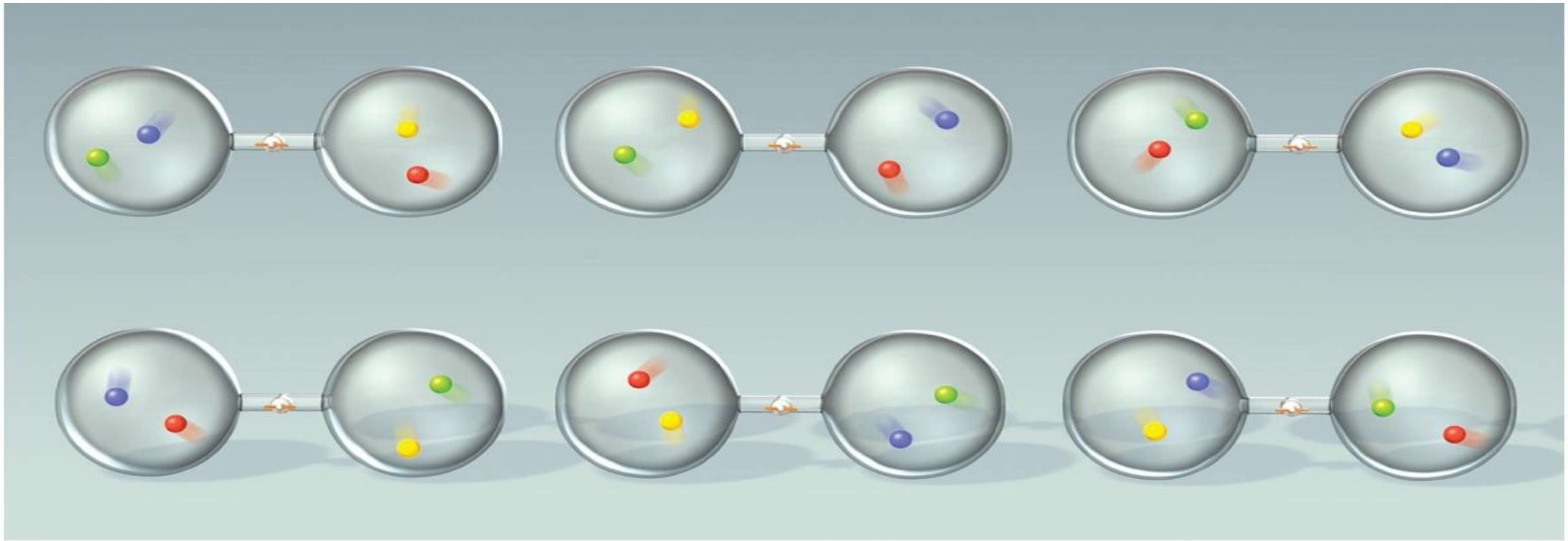
Microstates - Possible distributions





Microstates - More possible distributions





Boltzmann Relation for Entropy

1868 - Boltzmann - entropy of a system is related to the natural log of the number of microstates (W)

$$S = k \ln W$$

W = No. of microscopic energy levels, k = Boltzmann constant (1.38×10^{-23} J/K)

In perfectly ordered solid, at 0K, W = 1

$$S = k \ln 1 = 0$$

This leads to 3rd law of thermodynamics:

"the Entropy of a perfect crystalline substance approaches zero as the absolute temperature approaches zero"

Trends in Entropy

Entropy for gas phase is greater than that of liquid or solid of same substance

I_2 (*g*) has greater entropy than I_2 (*s*)

More complex structures have greater entropy

C_2H_6 (*g*) has greater entropy than CH_4 (*g*)

Allotropes - more ordered forms have lower entropy

Diamond has lower entropy than graphite

Introduction : Engines

Heat engine : It can be defined as any engine that converts thermal energy to mechanical work output. Examples of heat engines include: steam engine, diesel engine, and gasoline (petrol) engine.

On the basis of how thermal energy is being delivered to working fluid of the heat engine, heat engine can be classified as an internal combustion engine and external combustion engine.

In an Internal combustion engine, combustion takes place within working fluid of the engine, thus fluid gets contaminated with combustion products.

- Petrol engine is an example of internal combustion engine, where the working fluid is a mixture of air and fuel .

In an External combustion engine, working fluid gets energy using boilers by burning fossil fuels or any other fuel, thus the working fluid does not come in contact with combustion products.

- Steam engine is an example of external combustion engine, where the working fluid is steam.

Introduction : Engines

Internal combustion engines may be classified as :

- Spark Ignition engines.
- Compression Ignition engines.

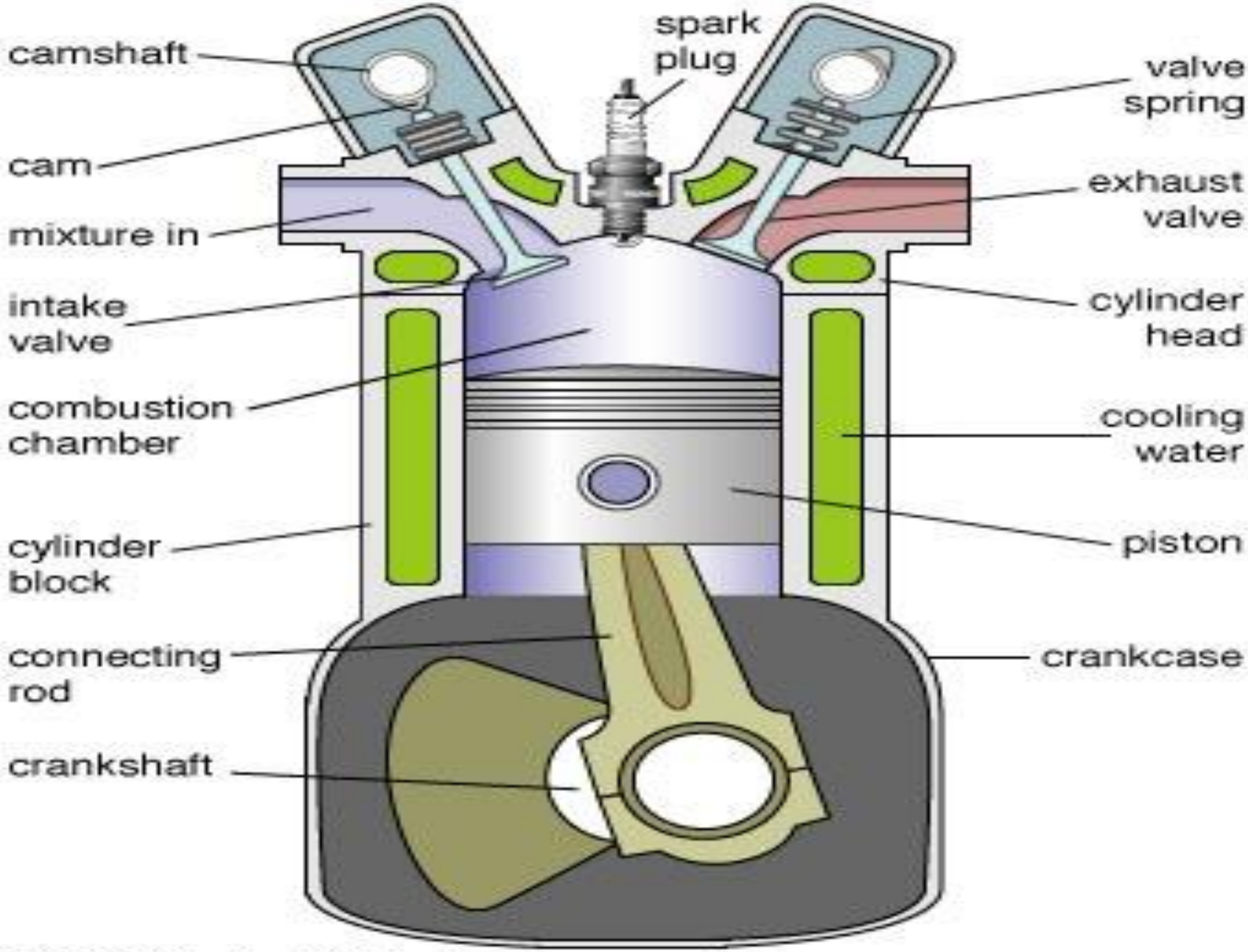
Spark ignition engine (SI engine): An engine in which the combustion process in each cycle is started by use of an external spark.

Compression ignition engine (CI engine): An engine in which the combustion process starts when the air-fuel mixture self ignites due to high temperature in the combustion chamber caused by high compression.

- Spark ignition and Compression Ignition engine operate on either a four stroke cycle or a two stroke cycle.

Four stroke cycle : It has four piston strokes over two revolutions for each cycle.

Two stroke cycle : It has two piston strokes over one revolution for each cycle.


camshaft
cam
mixture in
intake valve
combustion chamber
cylinder block
connecting rod
crankshaft
spark plug
valve spring
exhaust valve
cylinder head
cooling water
piston
crankcase

Internal combustion Engine Components:

I.C. Engine components shown in figure1 and figure2 are defined as follows:

Block : Body of the engine containing cylinders, made of cast iron or aluminum.

Cylinder : The circular cylinders in the engine block in which the pistons reciprocate back and forth.

Head : The piece which closes the end of the cylinders, usually containing part of the clearance volume of the combustion chamber.

Combustion chamber: The end of the cylinder between the head and the piston face where combustion occurs.

- The size of combustion chamber continuously changes from minimum volume when the piston is at TDC to a maximum volume when the piston at BDC.

Internal combustion Engine Components:

Crankshaft : Rotating shaft through which engine work output is supplied to external systems.

- The crankshaft is connected to the engine block with the main bearings.
- It is rotated by the reciprocating pistons through the connecting rods connected to the crankshaft, offset from the axis of rotation. This offset is sometimes called crank throw or crank radius.

Connecting rod : Rod connecting the piston with the rotating crankshaft, usually made of steel or alloy forging in most engines but may be aluminum in some small engines.

Piston rings: Metal rings that fit into circumferential grooves around the piston and form a sliding surface against the cylinder walls.

Internal combustion Engine Components:

Camshaft : Rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage (push rods, rocker arms, tappets) .

Push rods : The mechanical linkage between the camshaft and valves on overhead valve engines with the camshaft in the crankcase.

Crankcase : Part of the engine block surrounding the crankshaft.

- In many engines the oil pan makes up part of the crankcase housing.

Exhaust manifold : Piping system which carries exhaust gases away from the engine cylinders, usually made of cast iron .

Intake manifold :Piping system which delivers incoming air to the cylinders, usually made of cast metal, plastic, or composite material.

- In most SI engines, fuel is added to the air in the intake manifold system either by fuel injectors or with a carburetor.
- The individual pipe to a single cylinder is called runner.

Internal combustion Engine Components:

Carburetor : A device which meters the proper amount of fuel into the air flow by means of pressure differential.

- For many decades it was the basic fuel metering system on all automobile (and other) engines.

Spark plug : Electrical device used to initiate combustion in an SI engine by creating high voltage discharge across an electrode gap.

I.C. Engine components apart from components shown in the figure:

Exhaust System: Flow system for removing exhaust gases from the cylinders, treating them, and exhausting them to the surroundings.

- It consists of an exhaust manifold which carries the exhaust gases away from the engine, a thermal or catalytic converter to reduce emissions, a muffler to reduce engine noise, and a tailpipe to carry the exhaust gases away from the passenger compartment.

Flywheel : Rotating mass with a large moment of inertia connected to the crank shaft of the engine.

- The purpose of the flywheel is to store energy and furnish large angular momentum that keeps the engine rotating between power strokes and smooth out engine operation.

I.C. Engine components apart from components shown in the figure:

Fuel injector : A pressurized nozzle that sprays fuel into the incoming air (SI engines)or into the cylinder (CI engines).

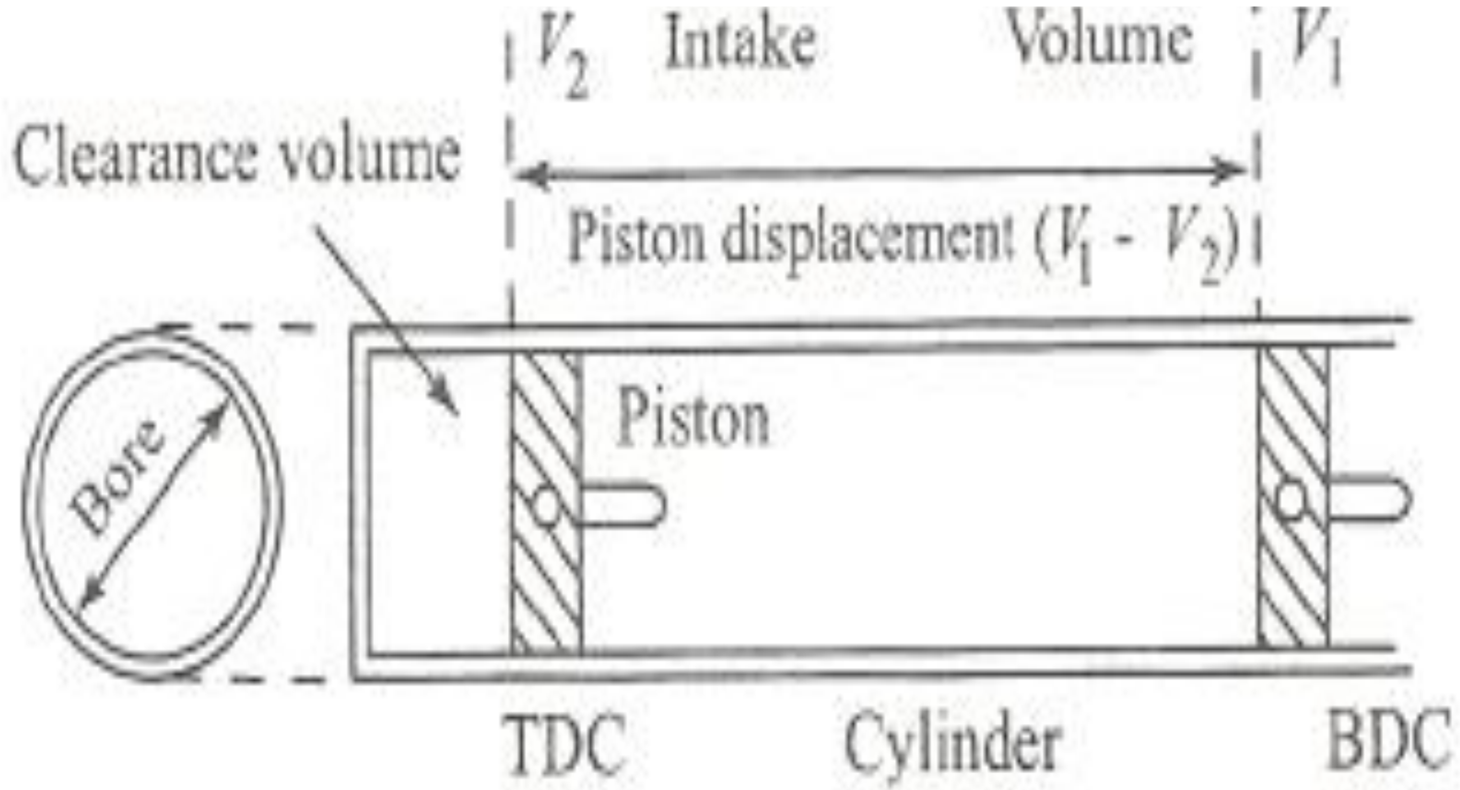
Fuel pump : Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine.

Glow plug : Small electrical resistance heater mounted inside the combustion chamber of many CI engines, used to preheat the chamber enough so that combustion will occur when first starting a cold engine.

– The glow plug is turn off after the engine is started.

Starter : Several methods are used to start IC engines. Most are started by use of an electric motor (starter) geared to the engine flywheel. Energy is supplied from an electric battery.

Engine Terminology:



Engine Terminology :

The pressure volume diagram of ideal engine cycle along with engine terminology as follows:

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

- Top because this position is at the top of the engines (not always), and dead because the piston stops as this point. Because in some engines TDC is not at the top of the

engines(e.g: horizontally opposed engines, radial engines, etc,.)

Some sources call this position Head End Dead Center (HEDC).

- Some source call this point TOP Center (TC).
- When the piston is at TDC, the volume in the cylinder is a minimum called the clearance volume.

Engine Terminology :

Bottom Dead Center (BDC): Position of the piston when it stops at the point closest to the crankshaft.

- Some sources call this **Crank End Dead Center (CEDC)** because it is not always at the bottom of the engine. Some source call this point **Bottom Center (BC).**

Stroke : Distance traveled by the piston from one extreme position to the other : TDC to BDC or BDC to TDC.

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

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

- Swept volume is defined as stroke times bore.
- Displacement can be given for one cylinder or entire engine (one cylinder times number of cylinders).

Engine Terminology :

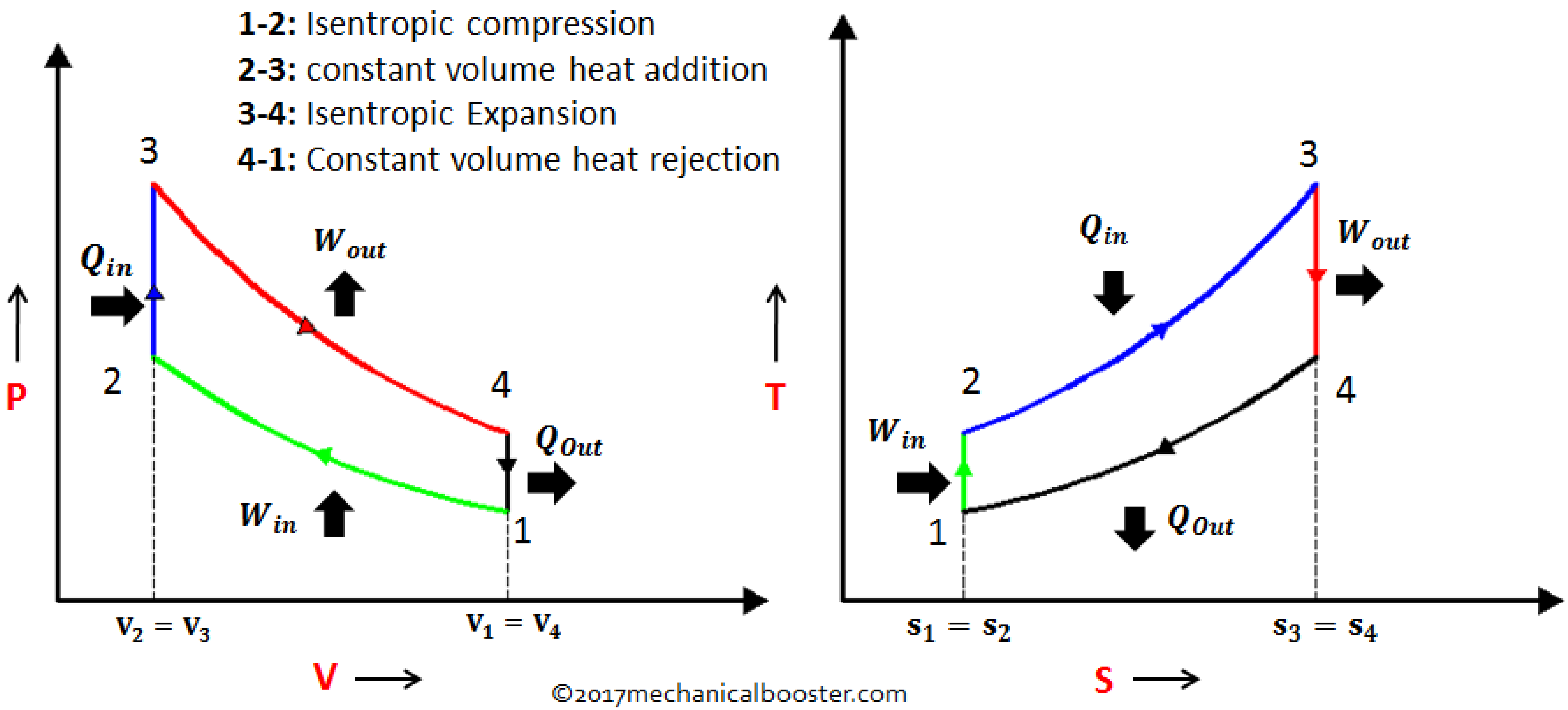
Clearance volume : It is the minimum volume of the cylinder available for the charge (air or air fuel mixture) when the piston reaches at its outermost point (top dead center or outer dead center) during compression stroke of the cycle.

- Minimum volume of combustion chamber with piston at TDC.

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

- Typically compression ratio for SI engines varies form 8 to 12 and for CI engines it varies from 12 to 24

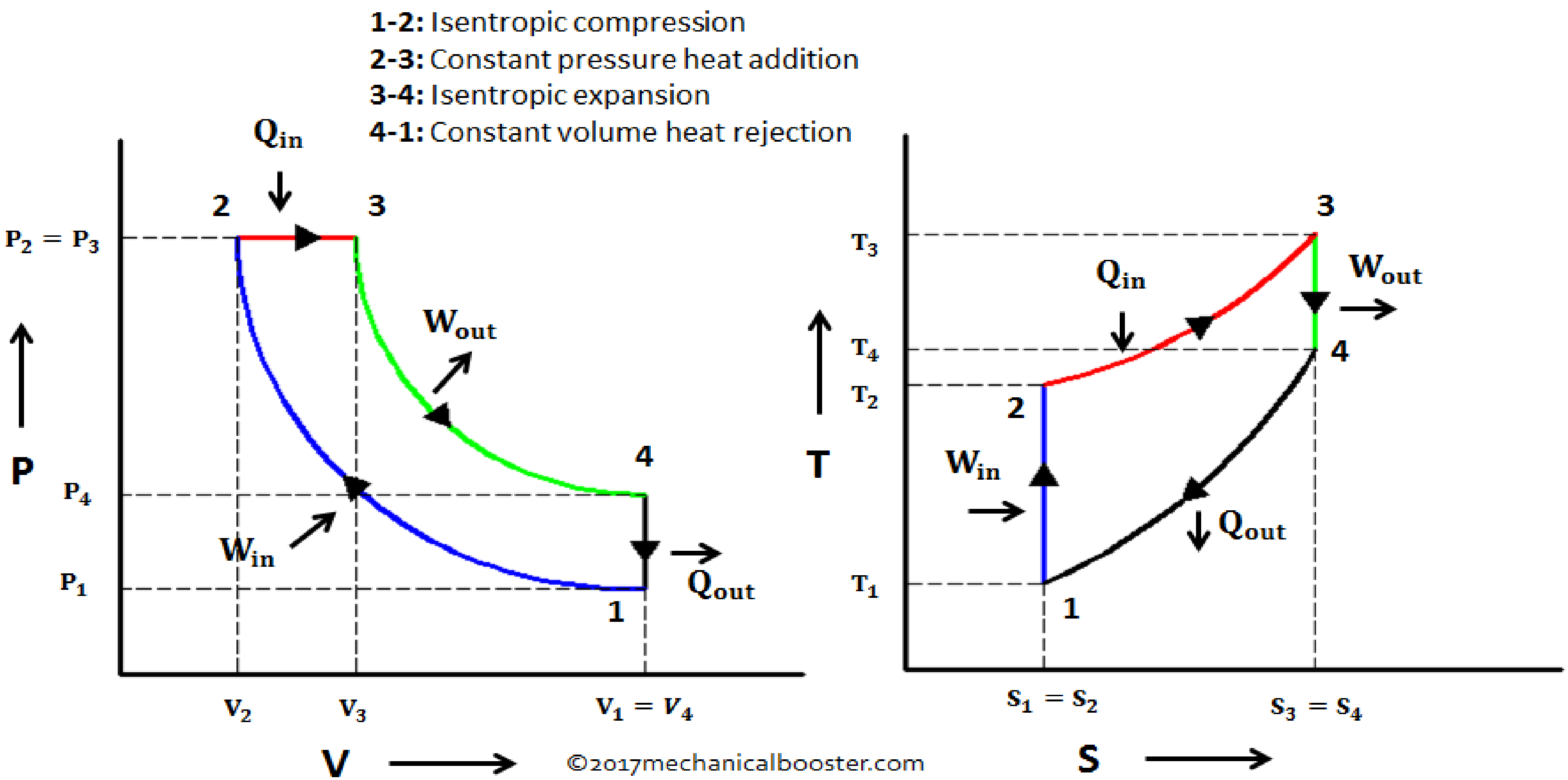
Ideal Otto Cycle:



P-V and T-S Diagram of Otto Cycle

NOTE: Refer the recommended book for the expression of efficiency

Ideal Diesel Cycle:



P-V and T-S Diagram of Diesel Cycle

NOTE: Refer the recommended book for the expression of efficiency

Heat :

Heat is the movement of thermal energy from a substance at a higher temperature to

Heat moves in only one direction:

Under normal conditions and in nature, heat energy will ALWAYS flow the warmer object to the cooler object.

Heat energy will flow from one substance to another until the two substances have the same temperature.

another substance at a lower temperature.

Thermal energy in the form of heat can move in three ways

- Conduction
- Convection
- Radiation

Heat transfer through Conduction:

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.

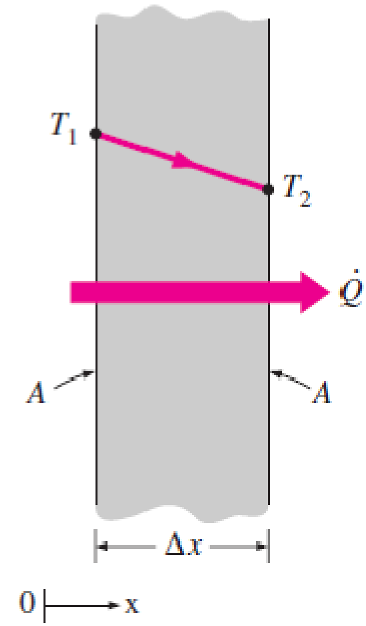
In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. A cold canned drink in a warm room, for example, eventually warms up to the room temperature as a result of heat transfer from the room to the drink through the aluminum can by conduction.

The rate of heat conduction through a medium depends on the geometry of the medium, its thickness, and the material of the medium, as well as the temperature difference across the medium. We know that wrapping a hot water tank with glass wool (an insulating material) reduces the rate of heat loss from the tank.

Heat transfer through Conduction:

The thicker the insulation, the smaller the heat loss. We also know that a hot water tank will lose heat at a higher rate when the temperature of the room housing the tank is lowered. Further, the larger the tank, the larger the surface area and thus the rate of heat loss. Consider steady heat conduction through a large plane wall of thickness Δx= L and area A, as shown in Fig.

The temperature difference across the wall is T= T_2-T_1. Experiments have shown that the rate of heat transfer Q (q dot) through the wall is doubled when the temperature difference T across the wall or the area A normal to the direction of heat transfer is doubled, but is halved when the wall thickness L is doubled.



Heat transfer through Conduction:

Thus we conclude that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer. That is,

$$\text{Rate of heat conduction} \propto \frac{(\text{Area})(\text{Temperature difference})}{\text{Thickness}}$$

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \qquad (\text{W})$$

where the constant of proportionality k is the thermal conductivity of the material, which is a measure of the ability of a material to conduct heat. In the limiting case of x →0, the equation above reduces to the differential form

$$\dot{Q}_{\text{cond}} = -kA\frac{dT}{dx} \qquad (\text{W})$$

This is called Fourier's law of heat conduction.

Heat transfer through Conduction:

Here

dT/dx is the temperature gradient,

The negative sign in Eq. ensures that heat transfer in the positive x direction is a positive quantity.

The heat transfer area A is always normal to the direction of heat transfer.

Heat transfer through Conduction:

Question: The roof of an electrically heated home is 6 m long, 8 m wide, and 0.25 m thick, and is made of a flat layer of concrete whose thermal conductivity is k 0.8 W/m · °C. The temperatures of the inner and the outer surfaces of the roof one night are measured to be 15°C and 4°C, respectively, for a period of 10 hours. Determine the rate of heat loss through the roof that night.

Solution: The area of the roof is A = 6 m x8 m= 48 m^2, the steady rate of heat transfer through the roof is determined to be

$$\dot{Q}_{\text{cond}} = -kA\frac{dT}{dx} \qquad \text{(W)}$$

= 0.8x48x (15-4)/0.25 = 1690 W = 1.69 kW.

Heat transfer through Convection:

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates.

Consider the cooling of a hot block by blowing cool air over its top surface (Fig. 1).

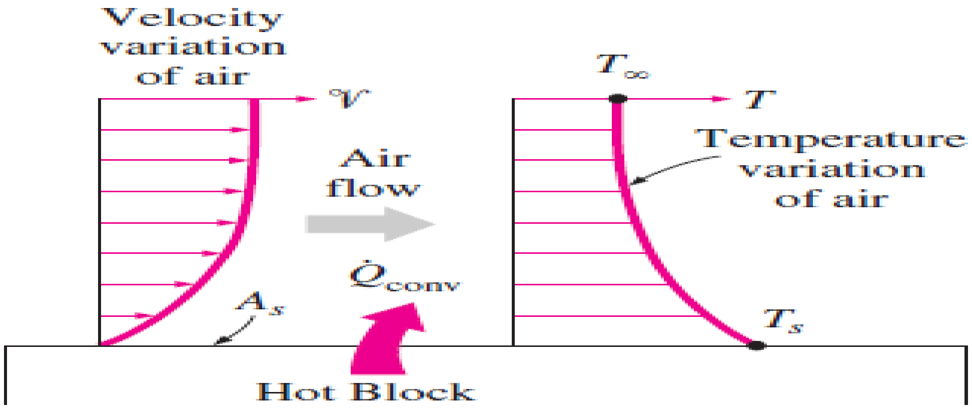


FIGURE 1
Heat transfer from a hot surface to air by convection.

Heat transfer through Convection:

Energy is first transferred to the air layer adjacent to the block by conduction. This energy is then carried away from the surface by convection, that is, by the combined effects of conduction within the air that is due to random motion of air molecules and the bulk or macroscopic motion of the air that removes the heated air near the surface and replaces it by the cooler air. Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind.

In contrast, convection is called natural (or free) convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid.

The rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling as

$$\dot{Q}_{\text{conv}} = hA_s (T_s - T_\infty) \qquad \text{(W)}$$

Heat transfer through Convection:

- where h is the convection heat transfer coefficient in W/m2 · °C or Btu/h · ft2 · °F, As is the surface area through which convection heat transfer takes place, Ts is the surface temperature, and T is the temperature of the fluid sufficiently far from the surface. Note that at the surface, the fluid temperature equals the surface temperature of the solid.
- The convection heat transfer coefficient h is not a property of the fluid. It is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of the fluid, and the bulk fluid velocity. Typical values of h are given in Table 1.

TABLE 1

Typical values of convection heat transfer coefficient

Type of convection	h, W/m^2 · °C*
Free convection of gases	2–25
Free convection of liquids	10–1000
Forced convection of gases	25–250
Forced convection of liquids	50–20,000
Boiling and condensation	2500–100,000

Heat transfer through Convection:

Question: A 2-m-long, 0.3-cm-diameter electrical wire extends across a room at 15°C. Heat is generated in the wire as a result of resistance heating, and the surface temperature of the wire is measured to be 152°C in steady operation. Also, the voltage drop and electric current through the wire are measured to be 60 V and 1.5 A, respectively. Disregarding any heat transfer by radiation, determine the convection heat transfer coefficient for heat transfer between the outer surface of the wire and the air in the room.

Solution: When steady operating conditions are reached, the rate of heat loss from the wire will equal the rate of heat generation in the wire as a result of resistance heating. That is,

$$\dot{Q} = \dot{E}_{\text{generated}} = VI = (60\ \text{V})(1.5\ \text{A}) = 90\ \text{W}$$

Heat transfer through Convection:

The surface area of the wire is $A_s = \pi DL = \pi(0.003 \text{ m})(2 \text{ m}) = 0.01885 \text{ m}^2$

Newton's law of cooling for convection heat transfer is expressed as

$$\dot{Q}_{\text{conv}} = hA_s\,(T_s - T_\infty)$$

Disregarding any heat transfer by radiation and thus assuming all the heat loss from the wire to occur by convection, the convection heat transfer coefficient is determined to be

$$h = \frac{\dot{Q}_{\text{conv}}}{A_s(T_s - T_\infty)} = \frac{90 \text{ W}}{(0.01885 \text{ m}^2)(152 - 15)^\circ\text{C}} = \mathbf{34.9\ W/m^2 \cdot {}^\circ C}$$

Heat transfer through Radiation:

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth.

In heat transfer studies we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature.

All bodies at a temperature above absolute zero emit thermal radiation.

Radiation is a volumetric phenomenon, and all solids, liquids, and gases emit, absorb, or transmit radiation to varying degrees.

Heat transfer through Radiation:

However, radiation is usually considered to be a surface phenomenon for solids that are opaque to thermal radiation such as metals, wood, and rocks since the radiation emitted by the interior regions of such material can never reach the surface, and the radiation incident on such bodies is usually absorbed within a few microns from the surface.

The maximum rate of radiation that can be emitted from a surface at an absolute temperature T_s (in K or R) is given by the Stefan–Boltzmann law as

$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \qquad \text{(W)}$$

where 5.67 108 W/m^2 · K^4 is the Stefan–Boltzmann constant. The idealized surface that emits radiation at this maximum rate is called a blackbody, and the radiation emitted by a blackbody is called blackbody radiation

UNIT-III
Fluid Properties and their Applications

What is a Fluid?

- Substances with no strength
- Deform when forces are applied
- Include water and gases

Solid:

Deforms a fixed amount or breaks completely when a stress is applied on it.

Fluid:

Deforms continuously as long as any shear stress is applied.

What is Mechanics?

The study of motion and the forces which cause (or prevent) the motion.

Three types:

- Kinematics (kinetics): The description of motion: displacement, velocity and acceleration.
- Statics: The study of forces acting on the particles or bodies at rest.
- Dynamics: The study of forces acting on the particles and bodies in motion.

Type of Stresses?

Stress = Force /Area

- Shear stress/Tangential stress:

  The force acting parallel to the surface per unit area of the surface.

- Normal stress:

  A force acting perpendicular to the surface per unit area of the surface.

How Do We Study Fluid Mechanics?

Basic laws of physics:

- Conservation of mass
- Conservation of momentum – Newton’s second law of motion
- Conservation of energy: First law of thermodynamics
- Second law of thermodynamics

+ Equation of state

Fluid properties e.g., density as a function of pressure and temperature.

+ Constitutive laws

Relationship between the stresses and the deformation of the material.

Density and Specific Gravity

The density ρ of an object is its mass per unit volume:

$$\rho = \frac{m}{V},$$

The SI unit for density is kg/m^3. Density is also sometimes given in g/cm^3; to convert g/cm^3 to kg/m^3, multiply by 1000.

Water at 4°C has a density of 1 g/cm^3 = 1000 kg/m^3.

The specific gravity of a substance is the ratio of its density to that of water.

Viscosity

It is defined as the internal resistance offered by one layer of fluid to the adjacent layer.

In case of liquids main reason of the viscosity is molecular bonding or cohesion.

In case of gases main reason of viscosity is molecular collision.

Variation of viscosity with temperature:

In case of liquids, due to increase in temperature the viscosity will decrease due to breaking of cohesive bonds

In case of gases, the viscosity will increase with temperature because of molecular collision increases

Newton's law of viscosity:

This law states that "shear stress is directly proportional to the rate of shear strain".

$$\tau \propto du/dy$$

$$\tau = \mu du/dy$$

where μ= Dynamic Viscosity having

Unit: SI: N-S/m^2 or Pa-s

CGS: Poise= dyne-Sec/cm^2

1Poise= 0.1 Pa-sec

1/100 poise is called Centipoise.

Note: All those fluids are known as Newtonian Fluids for which viscosity is constant with respect to the rate of deformation.

Kinematic Viscosity (ν)

It is defined as the ratio of dynamic viscosity to density.

$$\nu = \mu/\rho$$

Units: SI: m^2/s

CGS: Stoke= cm^2/s

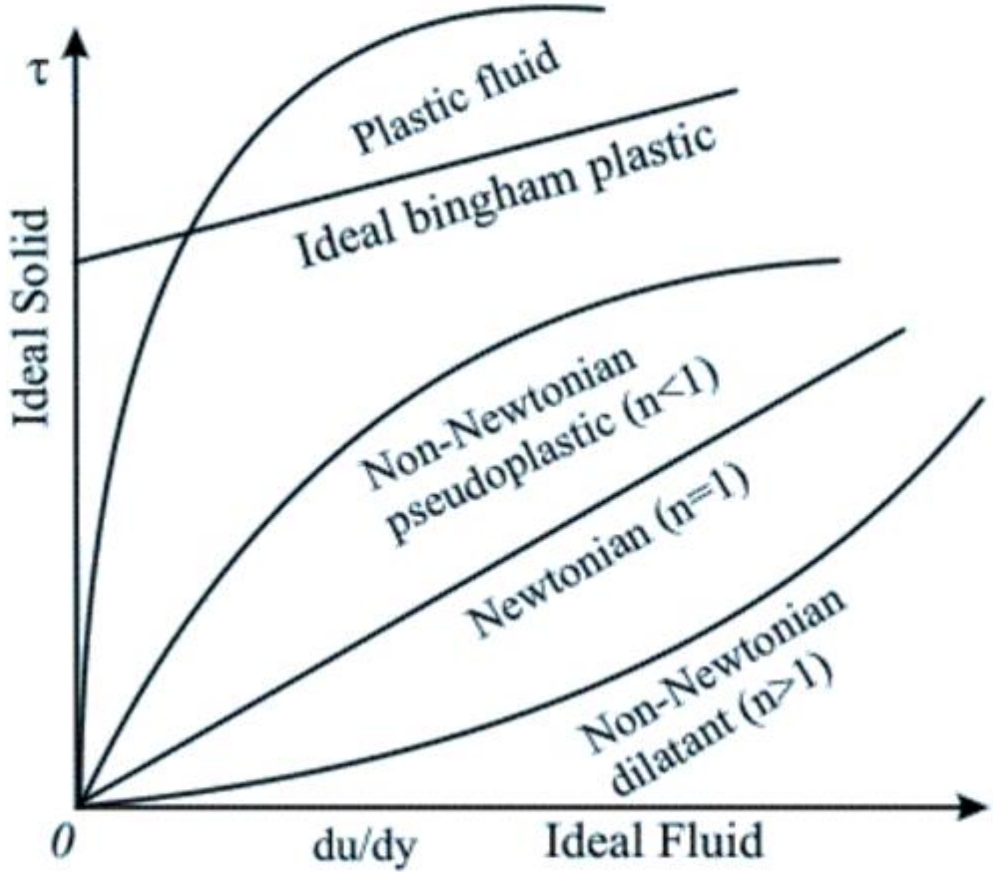
1 Stoke= $10^{-4}\ m^2/s$

Note: Dynamic viscosity shows resistance to motion between two adjacent layers where as kinematic viscosity shows resistance to molecular momentum transfer (molecular collision)

Types of Fluid

- Common fluids, e.g., water, air, mercury obey Newton's law of viscosity and are known as Newtonian fluid.
- Other classes of fluids, e.g., paints, polymer solution, blood do not obey the typical linear relationship of stress and strain. They are known as Non-Newtonian fluids.

Shear Stress and Rate of Deformation Relationship for different fluids



Non-Newtonian Fluids

Non-Newtonian Fluid $(\tau \neq \mu \frac{du}{dy})$		
Purely Viscous Fluids		**Visco-elastic Fluids**
Time - Independent	**Time - Dependent**	**Visco- elastic Fluids**
1. Pseudo plastic Fluids $\tau = \mu\left(\frac{du}{dy}\right)^n ; n < 1$ Example: Blood, milk **2. Dilatant Fluids** $\tau = \mu\left(\frac{du}{dy}\right)^n ; n > 1$ Example: Butter **3. Bingham or Ideal Plastic Fluid** $\tau = \tau_o + \mu\left(\frac{du}{dy}\right)^n$ Example: Water suspensions of clay and flyash	**1.Thixotropic Fluids** $\tau = \mu\left(\frac{du}{dy}\right)^n + f(t)$ *f(t)is decreasing* Example: Printer ink; crude oil **2. Rheopectic Fluids** $\tau = \mu\left(\frac{du}{dy}\right)^n + f(t)$ *f(t)is increasing* Example: Rare liquid solid suspension	$\tau = \mu\frac{du}{dy} + \alpha E$ Example: Liquid-solid combinations in pipe flow.

Atmospheric Pressure and Gauge Pressure

At sea level the atmospheric pressure is about 1.013×10^5 N/m^2; this is called one atmosphere (atm).

Another unit of pressure is the bar:

$1 \text{ bar} = 1.00 \times 10^5 \text{ N/m}^2$

Standard atmospheric pressure is just over 1 bar.

This pressure does not crush us, as our cells maintain an internal pressure that balances it.

Most pressure gauges measure the pressure above the atmospheric pressure—this is called the gauge pressure.

The absolute pressure is the sum of the atmospheric pressure and the gauge pressure.

$P = P_A + P_G$

Pressure Measurement Devices

Manometers

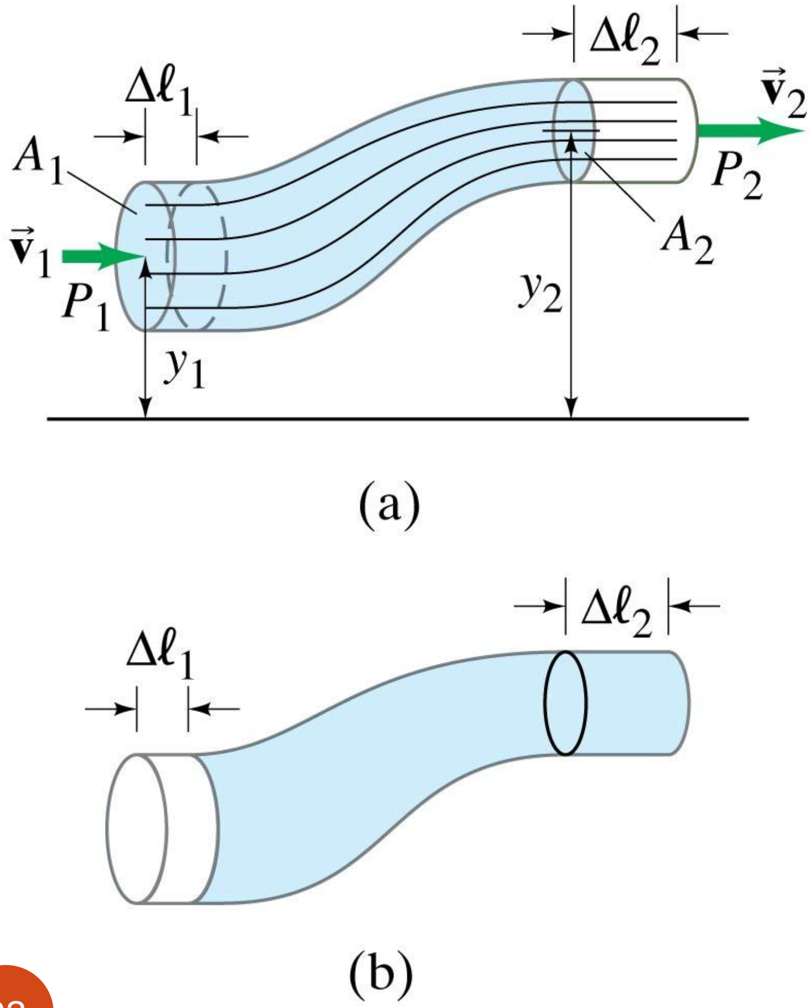
- Simple Manometers
- Differential Manometers

Mechanical Gauges

- Diaphragm Pressure Gauge
- Bourdon tube Pressure Gauge
- Dead Weight Pressure Gauge

NOTE: Refer the recommended book for explanation.

Bernoulli's Equation



A fluid can also change its height. By looking at the work done as it moves, we find:

$$P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 = P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 .$$

This is Bernoulli's equation. One thing it tells us is that as the speed goes up, the pressure goes down.

Applications of Bernoulli's Principle:

1. Venturimeter
2. Orifice meter
3. Pitot tube

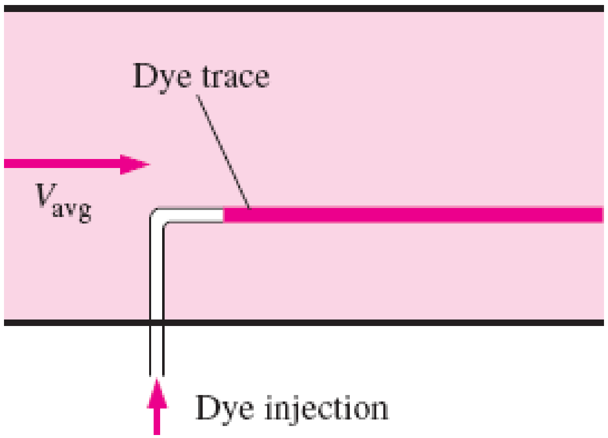
NOTE: Refer the recommended book for explanation.

Laminar And Turbulent Flows

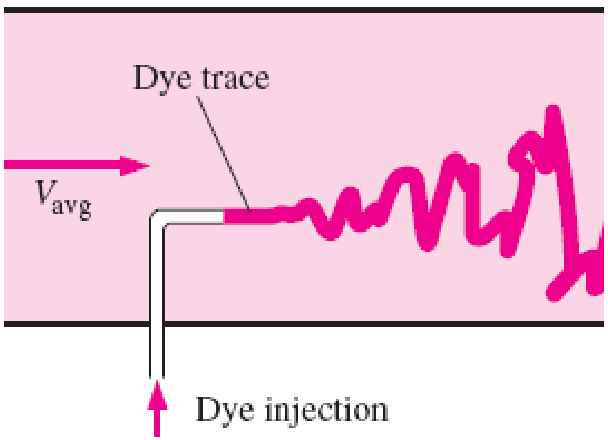
Laminar flow: characterized by *smooth streamlines* and *highly ordered motion.*

Turbulent flow: characterized by *velocity fluctuations* and *highly disordered motion.*

The transition from laminar to turbulent flow does not occur suddenly; rather, it occurs over some region in which the flow fluctuates between laminar and turbulent flows before it becomes fully turbulent.



(*a*) Laminar flow



(*b*) Turbulent flow

Turbines

Introduction and Terminology:

- "*Turbine*" is a general term for any device that extracts mechanical energy from a fluid – generally converting it to rotating energy of a turbine wheel.
- For liquids, we usually call them "*hydraulic turbines*" or "*hydroturbines*".
- For gases, we usually call them "*wind turbines*", "*gas turbines*", or "*steam turbines*", depending on the type of gas being used.

Just as with pumps, there are two basic types of turbine:

- *Positive displacement turbines* – fluid is forced into a closed volume, and then the fluid is pushed out.
- *Dynamic turbines* – no closed volume is involved; instead, rotating blades called

Runner blades or *Buckets* extract energy from the fluid.

- In general, positive-displacement turbines are used for flow measurement, rather than for production of power, whereas dynamic turbines are used for both power generation *and* flow measurement.

Turbines

Positive-Displacement Turbines:

The nutating disc flowmeter, commonly used to measure the volume of water supplied to a house, is an example of a positive-displacement turbine.

Turbines

Dynamic Turbines:

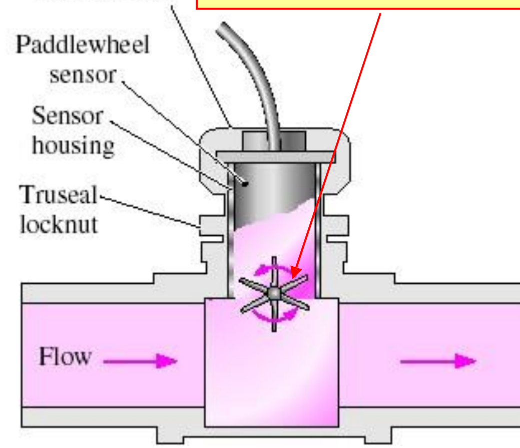
- Dynamic turbines do not have closed volumes. Instead, spinning blades called *runners* or

buckets transfer kinetic energy and extract momentum from the fluid.

- Dynamic turbines are used for both flow measurement and power production. For example, turbine flow meters for air and water.

Turbine used for measurement of air speed

Turbine used for measurement of volume flow rate of water flowing in a pipe



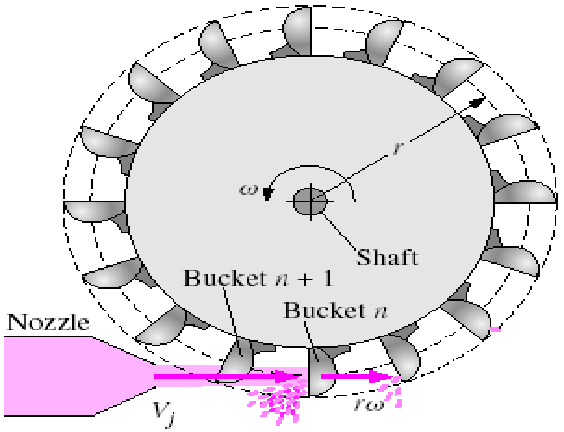
Turbines

There are two main types of dynamic turbines: *impulse turbines* and *reaction turbines.*

- *Impulse turbines*: Fluid is sent through a nozzle that then impinges on the rotating blades, called buckets. Compared to reaction turbines, impulse turbines require higher head, and work with a lower volume flow rate.
- The most common example is the *Pelton wheel turbine.*

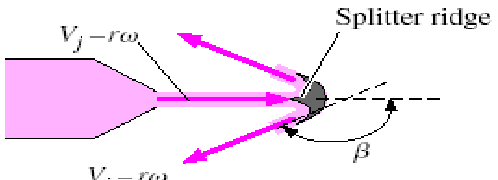
Pelton wheel turbine:

Water flows out of a nozzle at very high speed to rotate the buckets.



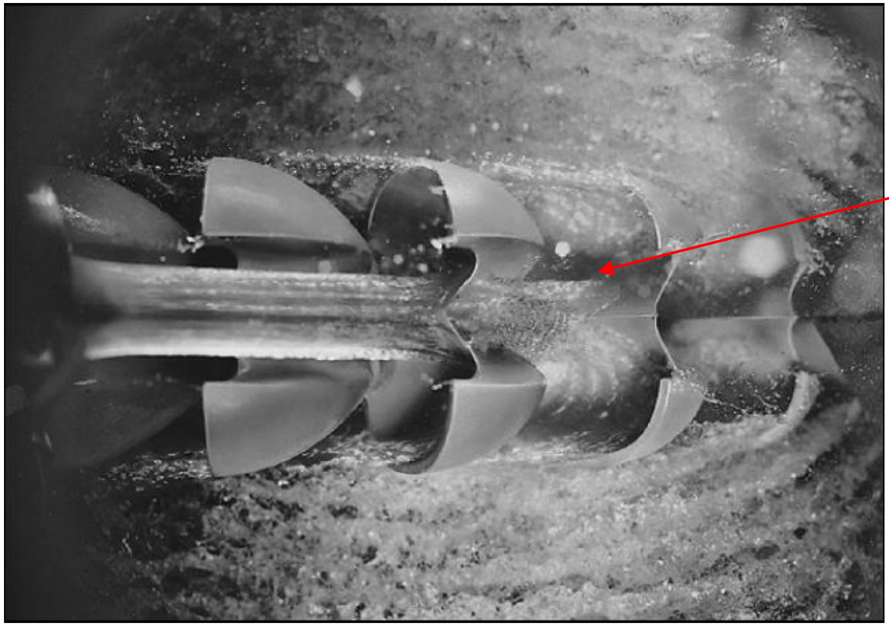
(a)

The source of the water is usually from either a natural or man-made reservoir at much higher elevation, so that it has high momentum to transfer to the buckets.



(b)

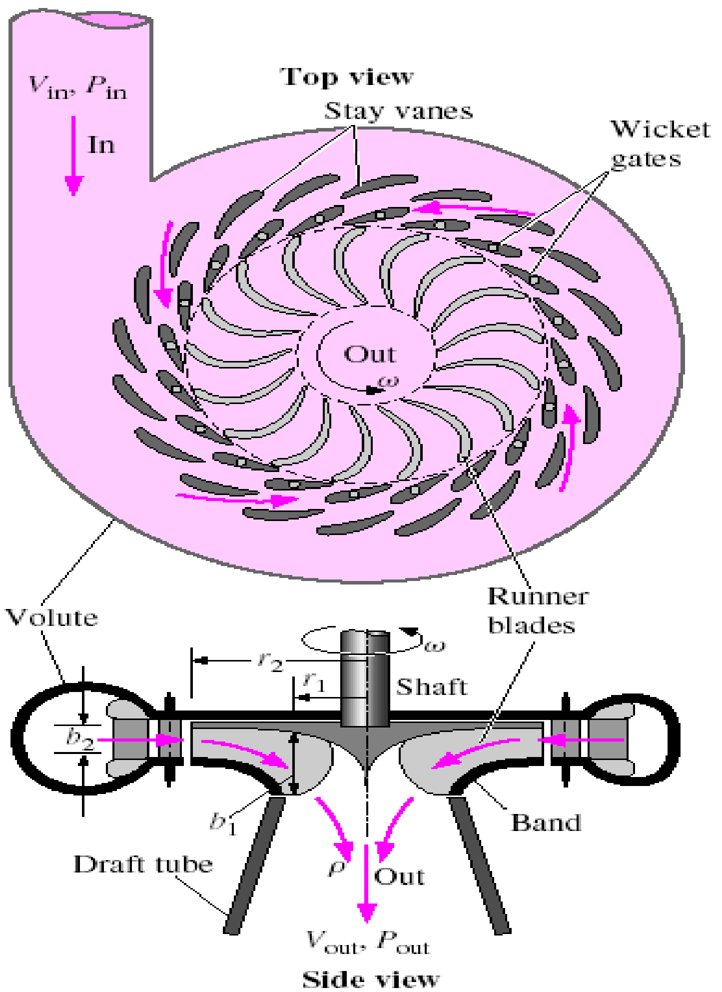
Turbines



The buckets are shaped carefully to take advantage of the high momentum water jet, and are designed to turn around the water nearly 180º for maximum transfer of momentum from the water jet to the rotating turbine wheel.

- ***Reaction turbines***: Instead of using water jets, reaction turbines fill a *volute* with swirling water that rotates the runner blades. Compared to impulse turbines, reaction turbines require a lower head, and work with a higher volume flow rate. They are used primarily for electricity production (hydroelectric dams).

Turbines



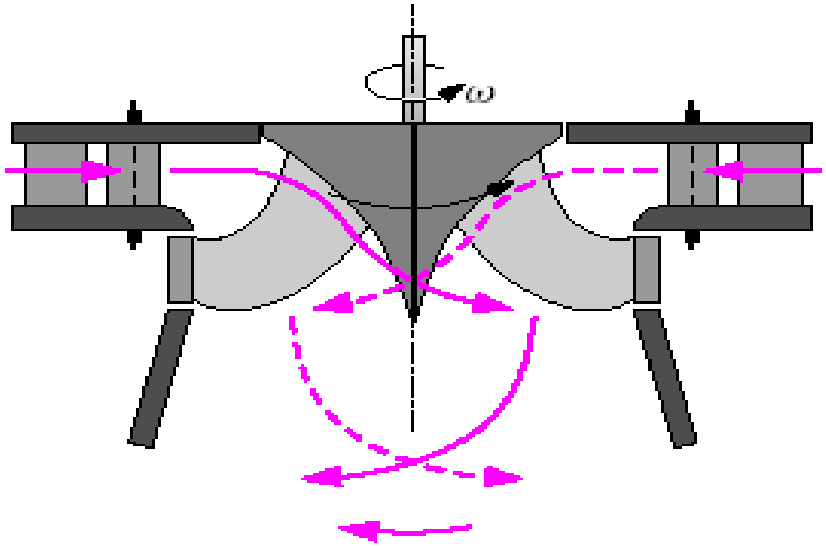
The ***stay vanes*** are fixed guide vanes that induce swirl to the water.

The ***wicket gates*** are adjustable vanes that control the volume flow rate through the turbine. They can usually be completely closed in order to shut off flow to the turbine.

There are various types of hydroturbine designs, as discussed in the text: radial flow, mixed flow, propeller mixed flow, and propeller axial flow.

Turbines

In many modern Francis mixed-flow hydroturbines, the flow exiting the turbine swirls a direction *opposite* to that of the runner itself. This is called ***reverse swirl***, and is designed to extract the maximum possible momentum from water, similar to how a Pelton wheel turbine bucket turns the water nearly 180^o around.



Reverse swirl

Pumps

The purpose of a pump is to add energy to a fluid, resulting in an increase in fluid pressure, not necessarily an increase of fluid speed across the pump.

Some fundamental parameters are used to analyze the performance of a pump. The mass flow rate $\dot{m}$ of fluid through the pump is an obvious primary pump performance parameter. For incompressible flow, it is more common to use volume flow rate rather than mass flow rate.

In the turbomachinery industry, volume flow rate is called capacity and is simply mass flow rate divided by fluid density,

Volume flow rate (capacity): $V = \dot{m}/\rho$

The performance of a pump is characterized additionally by its net head *H*, defined as the change in Bernoulli head between the inlet and outlet of the pump,

Net head: $H = (P/\rho g + V^2/2g + z)_{out} - (P/\rho g + V^2/2g + z)_{in}$

Pumps

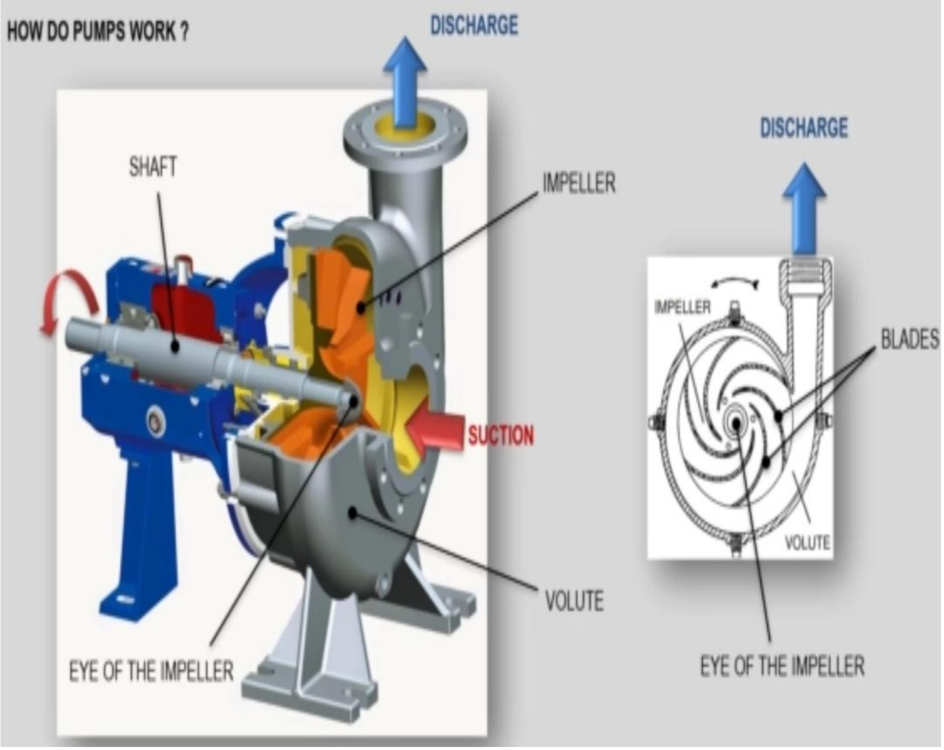
The dimension of net head is length, and it is often listed as an equivalent column height of water, even for a pump that is not pumping water. For the case in which a *liquid is being pumped, the Bernoulli head at the* inlet is equivalent to the energy grade line (EGL) at the inlet, EGL_{in}, obtained by aligning a Pitot probe in the center of the flow.

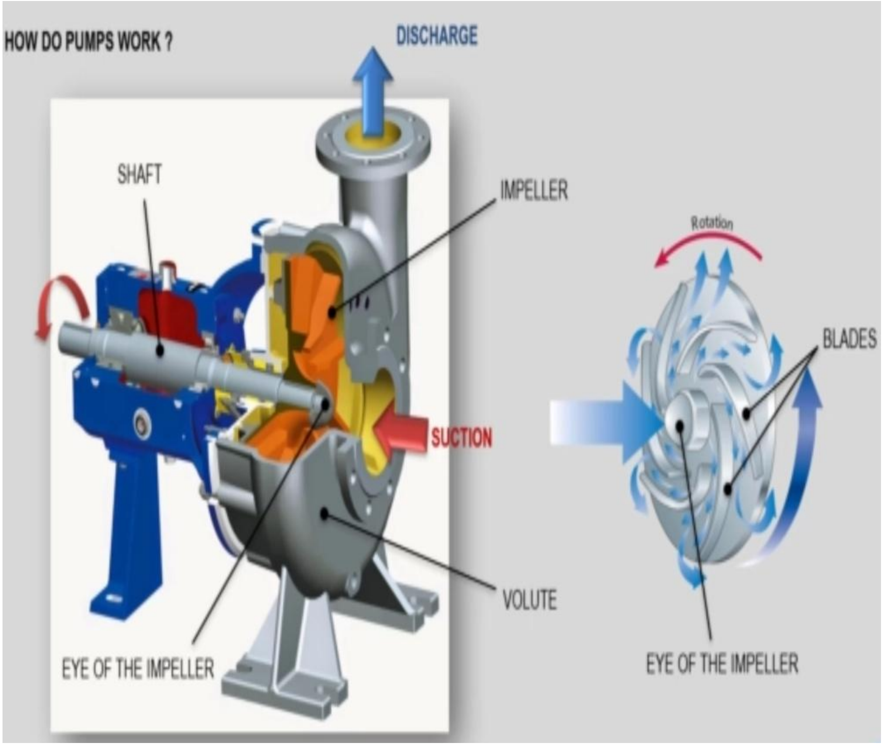
The energy grade line at the outlet EGL_{out} is obtained in the same manner, as also illustrated in the figure. In the general case, the outlet of the pump may be at a different elevation than the inlet, and its diameter and average speed may not be the same as those at the inlet.

Regardless of these differences, net head *H is equal to the difference between* EGL_{out} *and* EGL_{in}

Net Head for a liquid pump: $H = EGL_{out} - EGL_{in}$

Working of Centrifugal Pump





NOTE: Refer to recommended book for explanation

Numerical Problems

For more explanation and numerical problems refer the recommended books.

Thank You