
CRYOGENIC ENGINEERING
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Lecture No - 38

Earlier Lecture

- In the earlier lecture, conductance equations for some commonly used pipes were given.
- Pump Speed : $S_p = \frac{Q}{p_i}$ System Speed : $S_s = \frac{Q}{p}$

$$\frac{1}{S_s} = \frac{1}{S_p} + \frac{1}{C_o}$$

- $\mathbf{S_p}$ depends on vacuum pump and therefore, in order to maximize $\mathbf{S_s}$, $\mathbf{C_o}$ should be maximum.
- For a constant $\mathbf{S_s}$, we have $t_p = \frac{V}{S_s} \ln\left(\frac{p_1 - p_u}{p_2 - p_u}\right)$

Outline of the Lecture

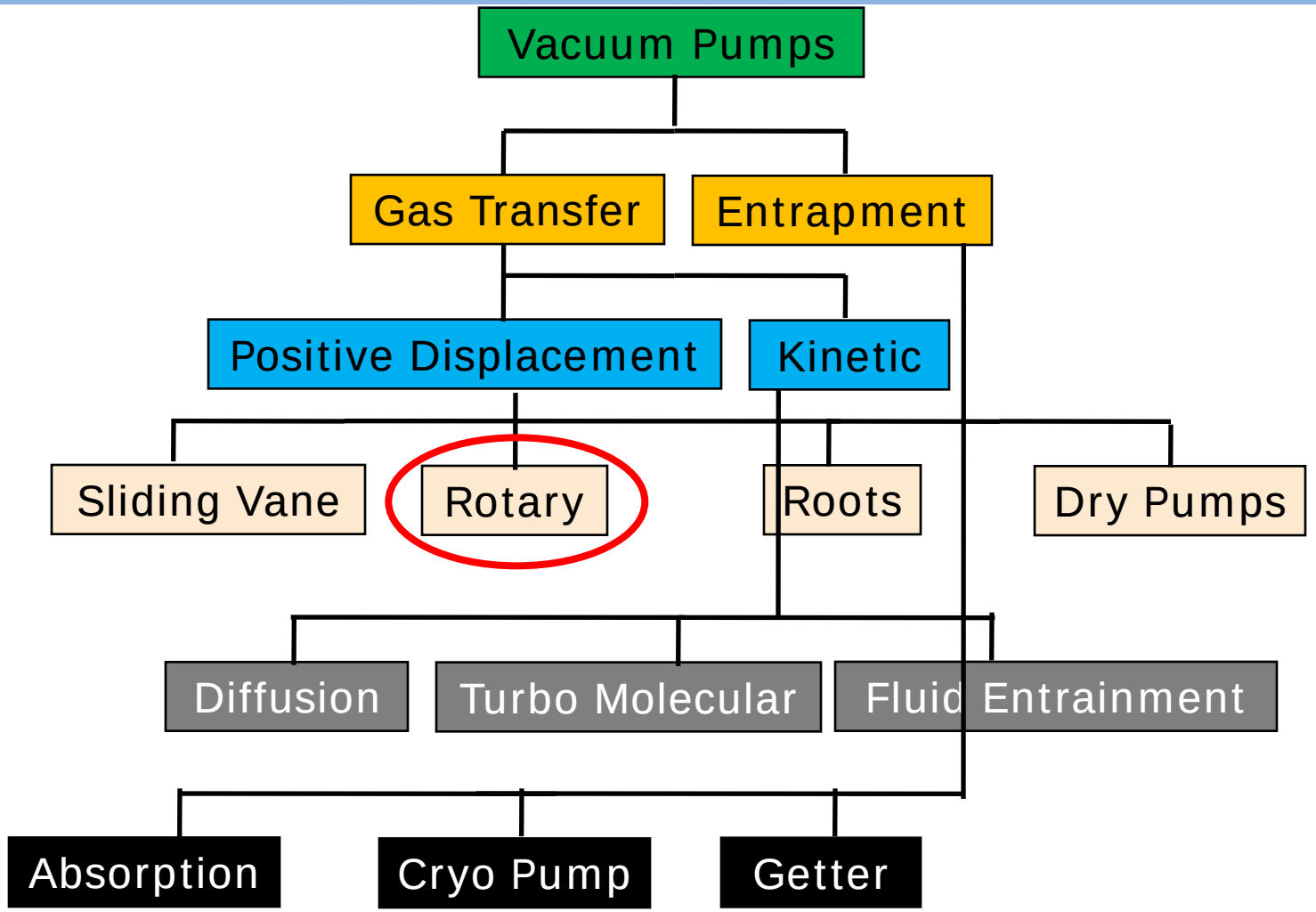
Topic : Vacuum Technology

- Classification of Vacuum Pump
- Types of Vacuum Pump
- Conclusion

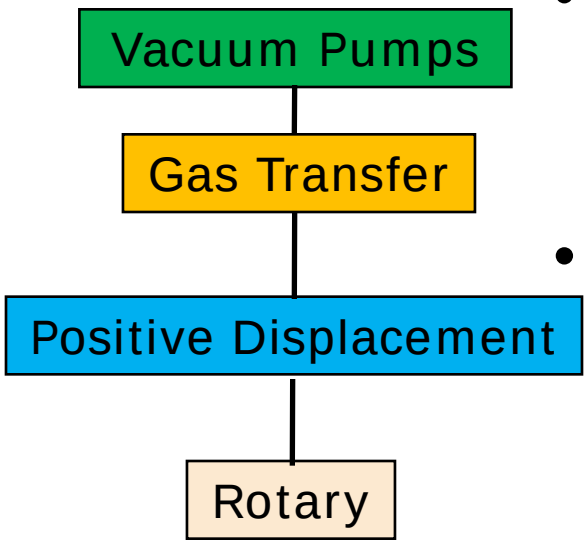
Introduction

- In the earlier lectures, we have seen the importance of vacuum in Cryogenics.
- We have also seen the importance of degree of vacuum and the pump down time from the application point of view.
- For practical applications, a wide variety of pumps are used to achieve the desired vacuum.
- There is a need to study the different types of vacuum pumps and the components of a vacuum system.

Classification

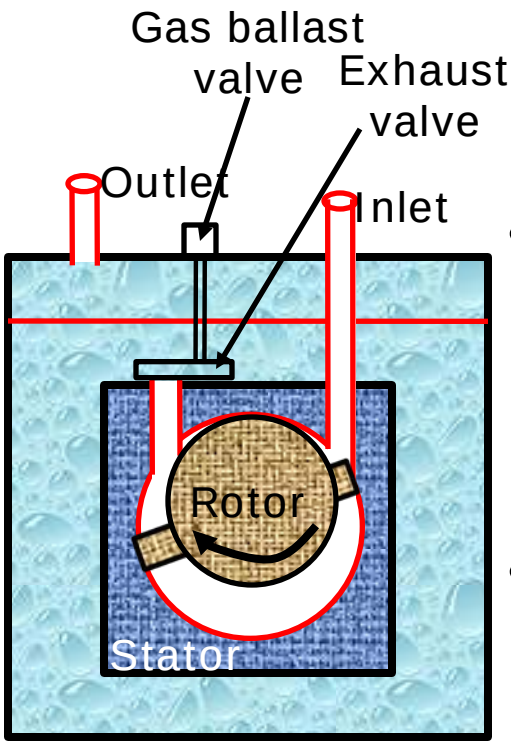


Rotary Vane Pump



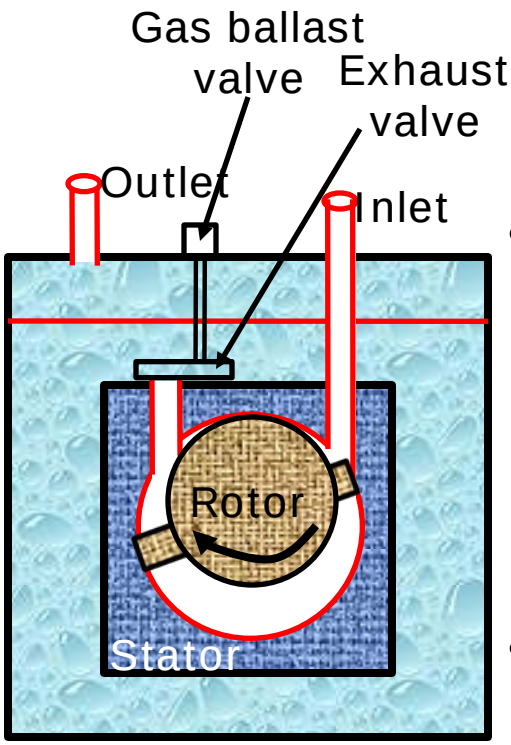
- Rotary vane pump is a widely used pump in vacuum technology.
- It is mostly used as a primary pump for backing or roughing stages.
- It falls under gas transfer category with positive displacement characteristics.

Rotary Vane Pump



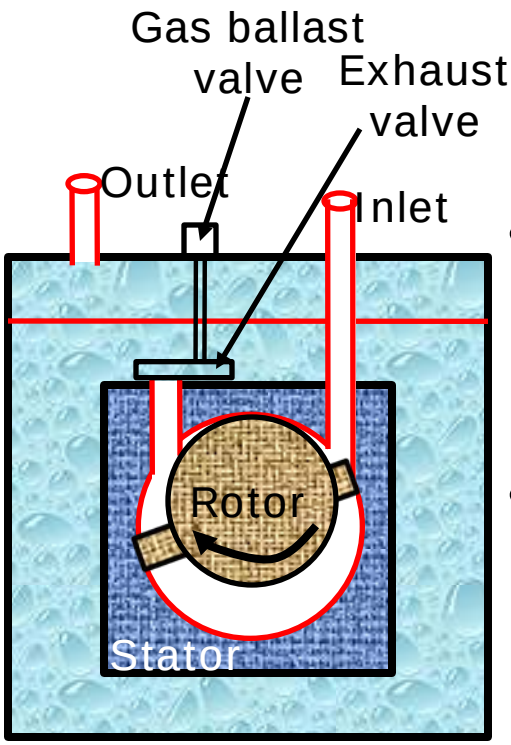
- The schematic of a Rotary vane pump is as shown in the figure.
- It consists of a stationary part, Stator and a moving part, Rotor, assembled inside a casing.
- Moving component is an eccentrically placed slotted rotor, which turns inside cylindrical stator.
- Spring loaded sliding vanes are mounted in the slots of the rotor.

Rotary Vane Pump



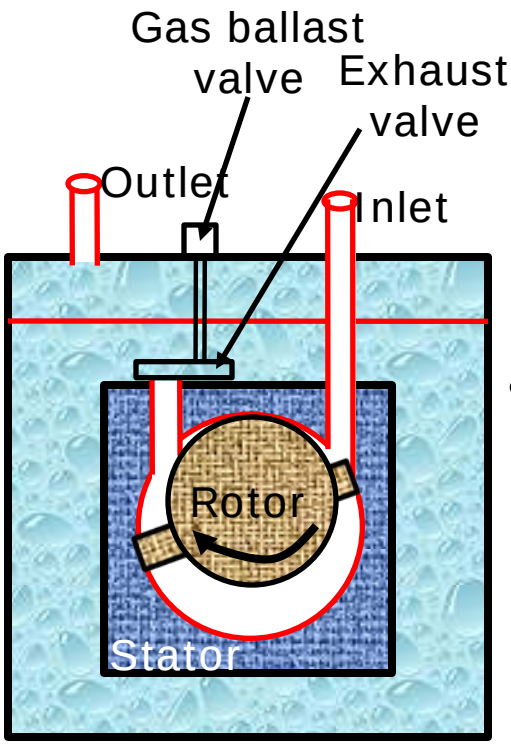
- This rotor is driven by an electric motor at a constant speed.
- Due to the spring action, the rotor sliding vanes are in continuous contact with the stator walls, during the rotation.
- This rubbing action generates huge amounts of heat.
- The heat is dissipated by circulating coolant around the stator.

Rotary Vane Pump



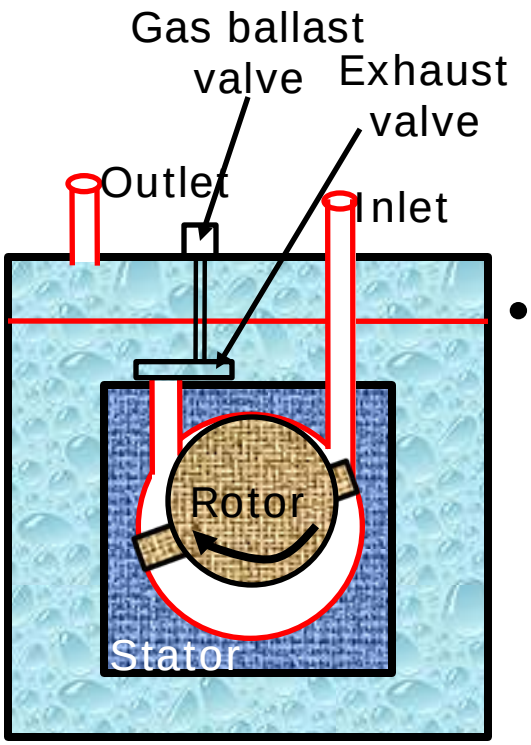
- Air is drawn into the pump through an inlet and it is compressed.
- Spring loaded exhaust valves are used to expel this compressed gas.
- This valve operates only at a preset pressure to avoid the back flow.
- Perfect sealing is maintained by a thin fluid film existing between the moving contacts.

Rotary Vane Pump



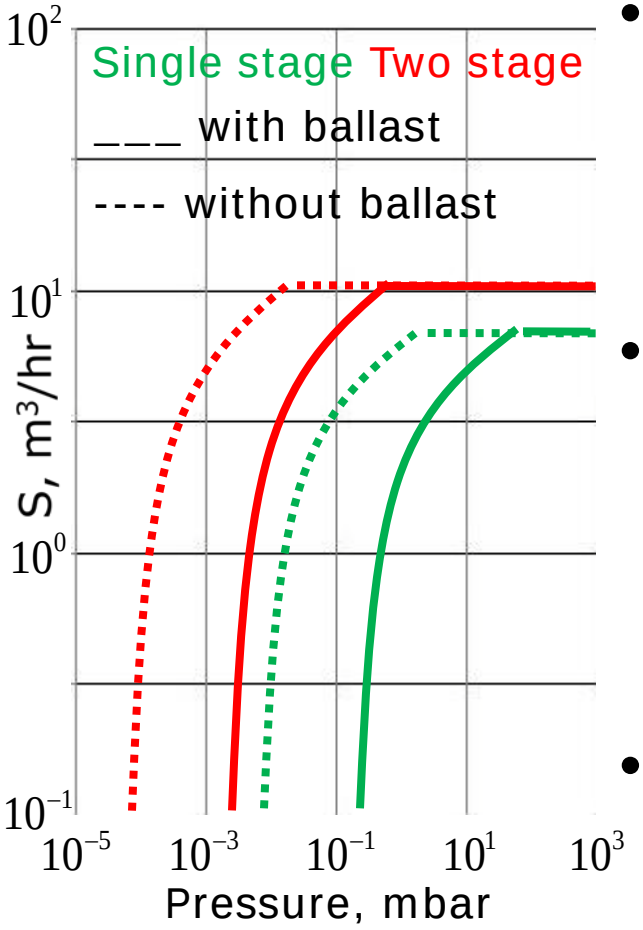
- It is important to note that, there is a possibility of condensation of some gases, say water vapor, during the compression process.
- Gas ballast is an arrangement, in which, a metered amount of non – condensable gas is admitted at the high pressure side.
- This gas packet increases the mole fraction of non – condensable gases in the compressed gas.

Rotary Vane Pump



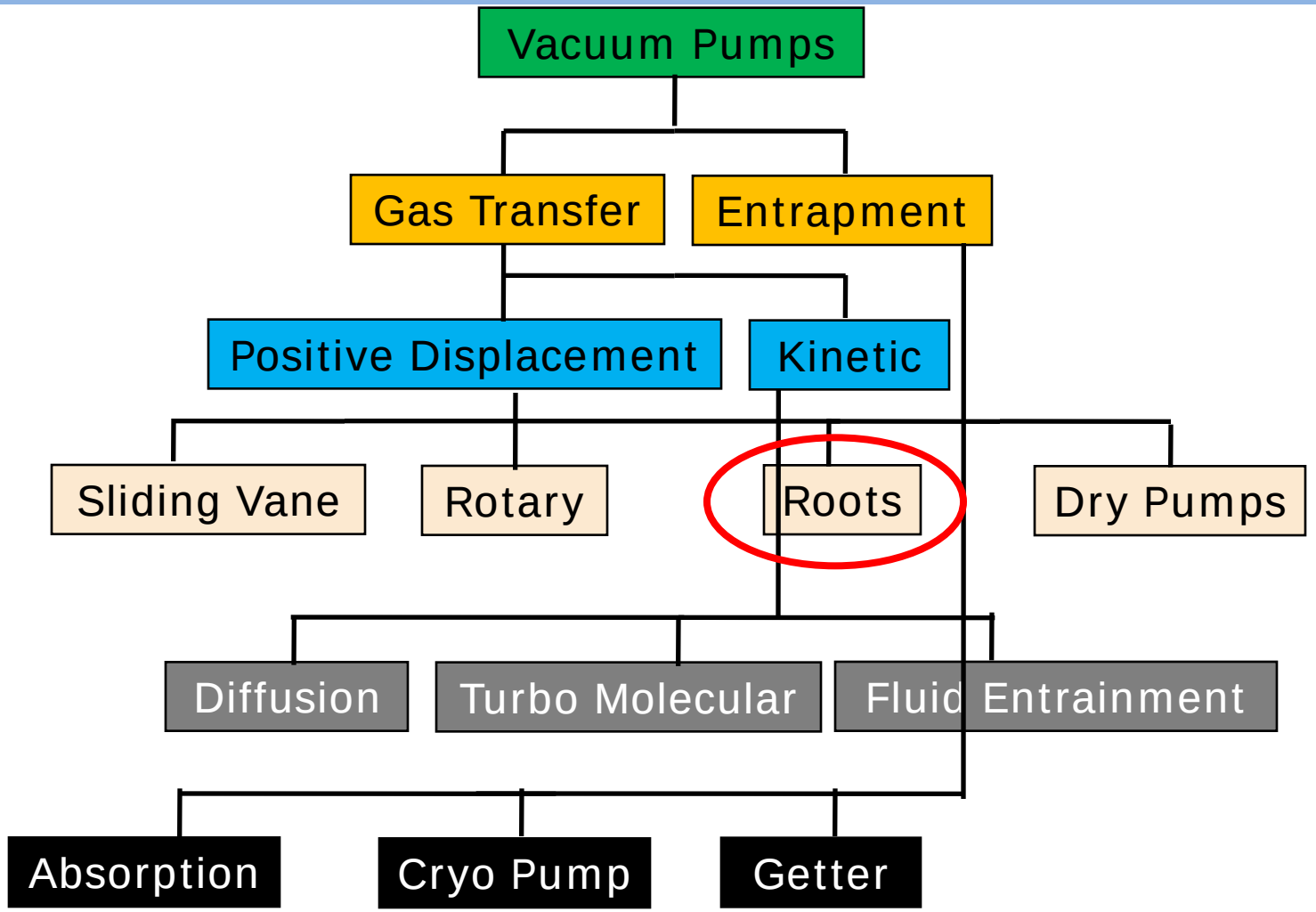
- This decreases the partial pressure of condensable gases (Dalton's Law of Partial Pressure).
- As a result, the water vapor at that temperature does not condense.

Rotary Vane Pump

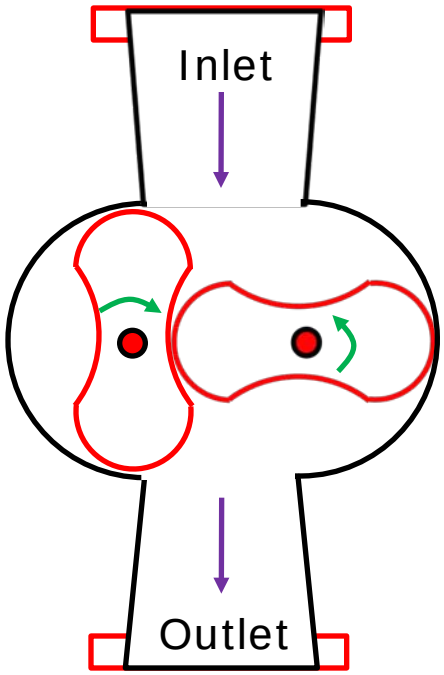


- The adjacent figure shows the pump characteristics for Single and Two stage Rotary pumps.
- The solid and dotted lines correspond to pumps with and without gas ballast arrangements respectively.
- Two stage or multi stage pumps are used to improve the performance and the ultimate pressure ($\mathbf{p_u}$) of the system.

Classification

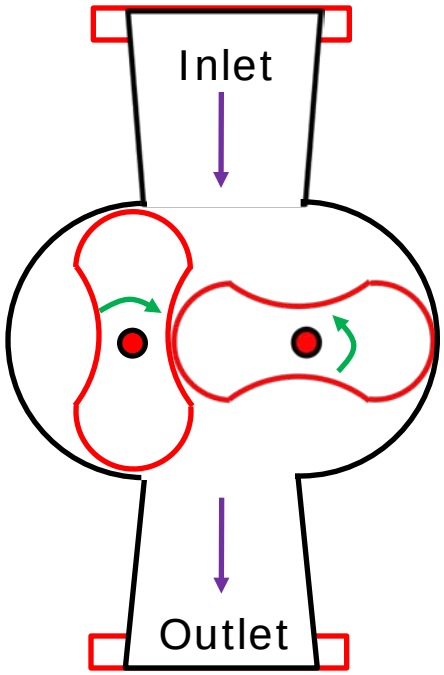


Roots Pump



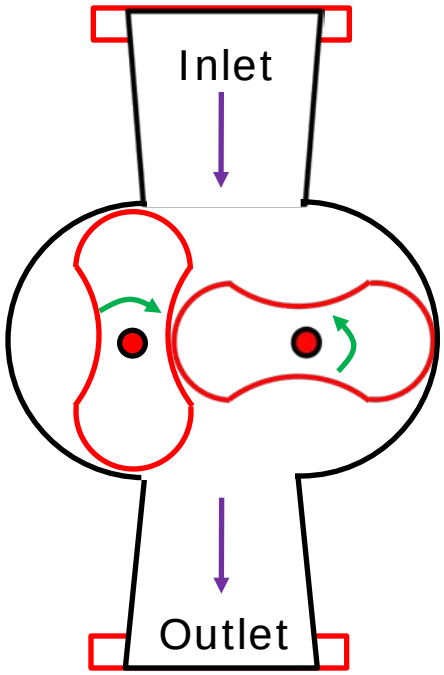
- The schematic of a Roots pump is as shown in figure.
- It is often used for low and medium degrees of vacuum.
- The pump is best suited in applications, where there are high mass flow rates.
- It consists of two identical lobed rotors mounted inside a casing.

Roots Pump



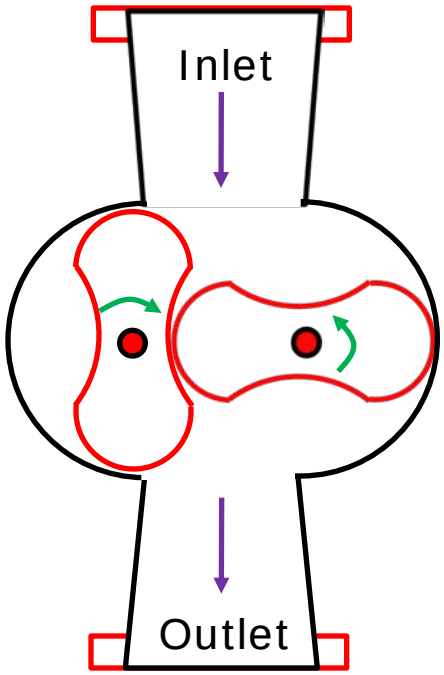
- These lobed rotors are synchronized by an external gear mechanism and are connected to an electric drive.
- A fine clearance of 0.3 mm is maintained between the moving lobes and the stator.
- As a result, these pumps can be operated at a very high speeds.
- The lobes are rotated in opposite direction, with respect to each other.

Roots Pump



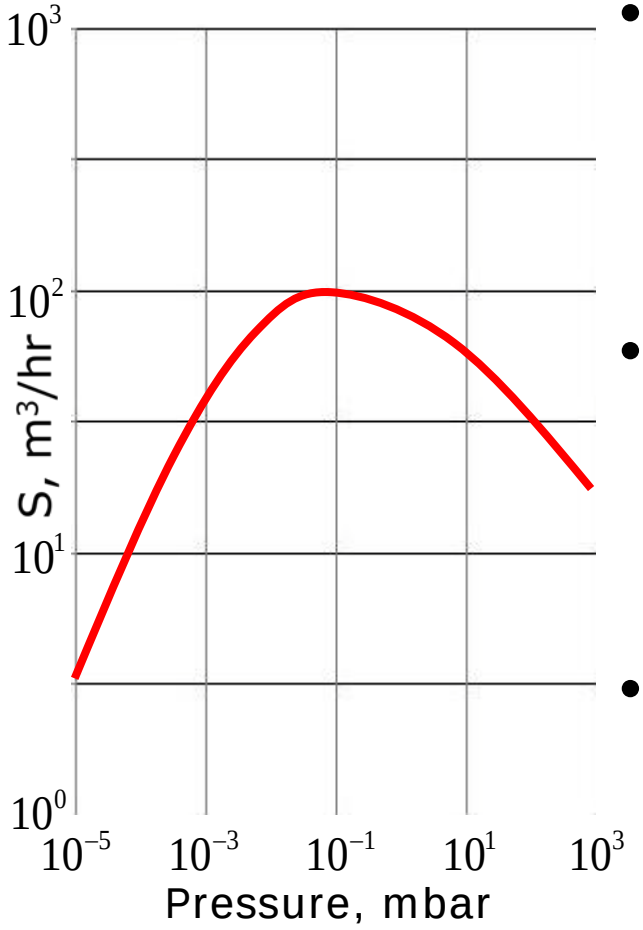
- Gas is displaced from inlet to outlet, maintaining a pressure drop.
- A backing pressure is necessary on the outlet side before the operation of the pump.
- This is needed to prevent the over heating of the casing.

Roots Pump



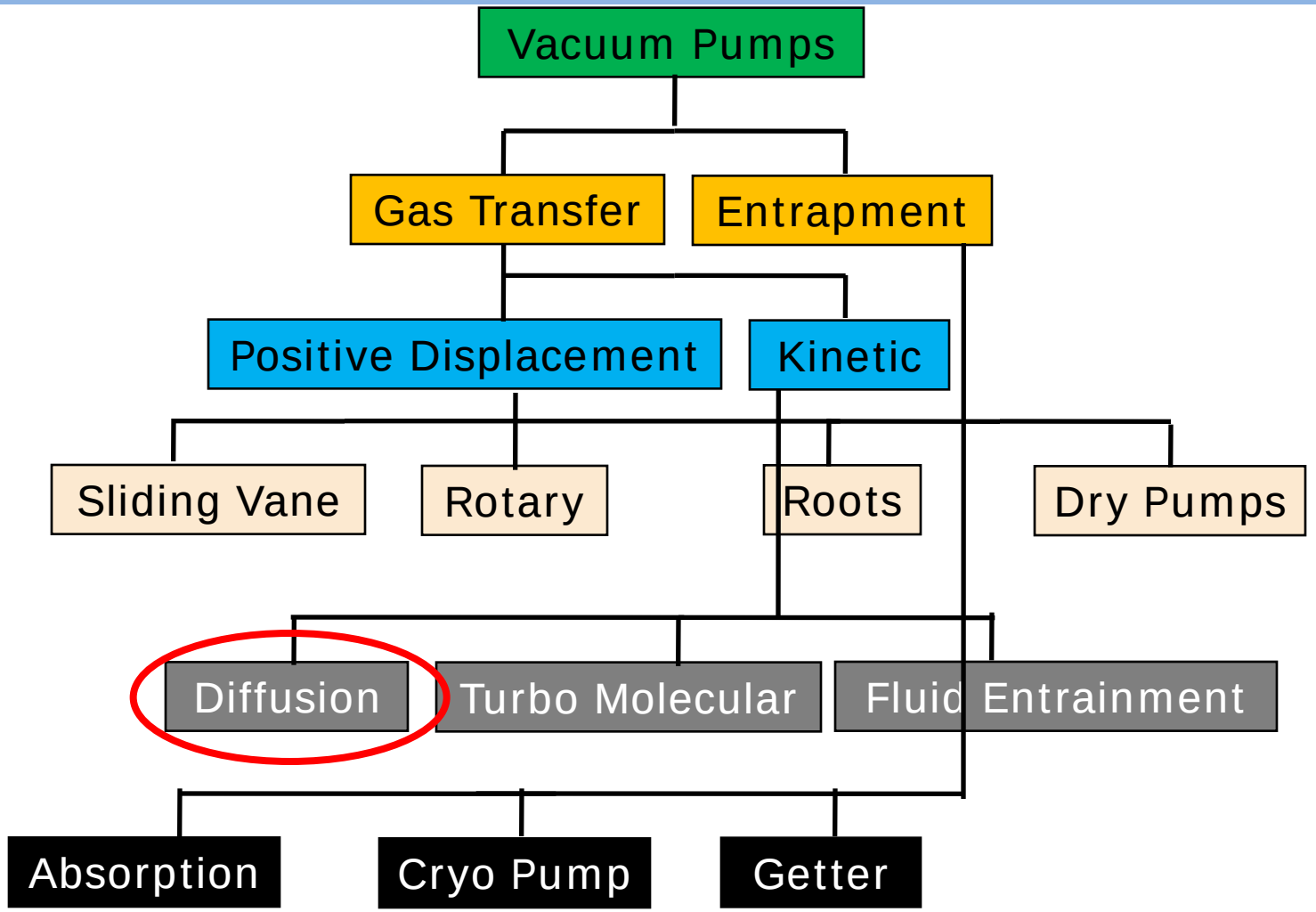
- The over heating of casing results in thermal expansion of lobed rotors and thereby, the possible contact between the moving parts.
- It is important to note that, against these high mass flow rates, one has to compromise on the vacuum level.

Roots Pump



- The adjacent figure shows the pump characteristics for a single stage Roots pump.
- Initially, the pumping speed (**S**) increases steadily with the drop in pressure.
- With the further decrease in the pressure, the pumping speed (**S**) goes through a maxima and then decreases.

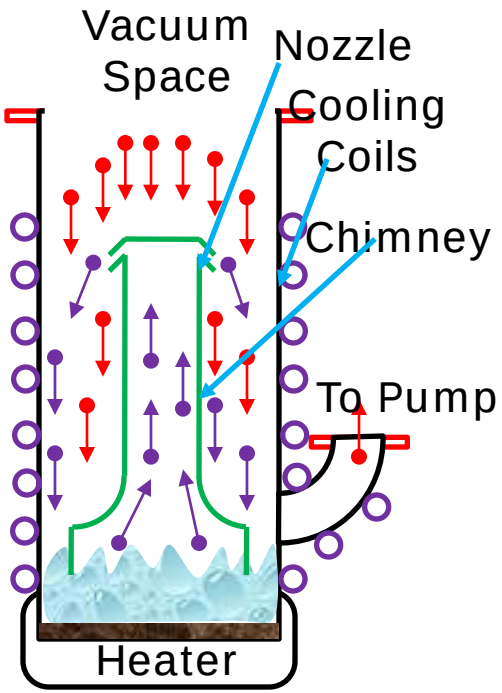
Classification



Kinetic Pumps

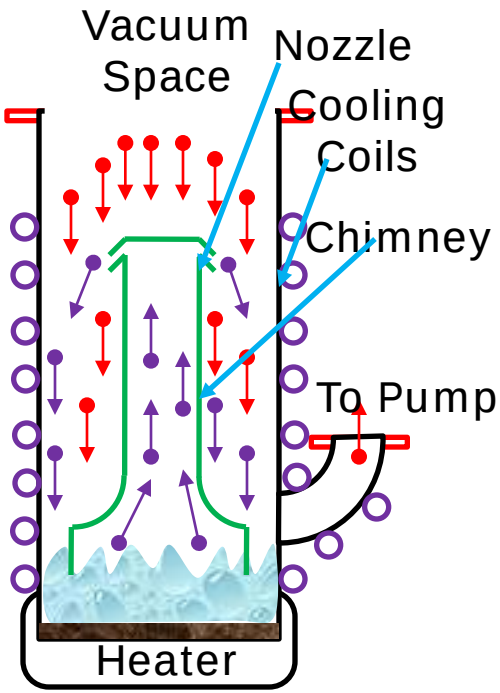
- Kinetic pumps are used when a higher degree of vacuum, in comparison to Rotary or Roots pump, is needed.
- In these pumps, kinetic energy or momentum is imparted to a gas molecule.
- This momentum is used in expelling gas molecules from the system and thereby, vacuum is created.
- As mentioned earlier, diffusion pump, turbo molecular pump, fluid entrainment pump are the common examples of kinetic pumps.

Diffusion Pump



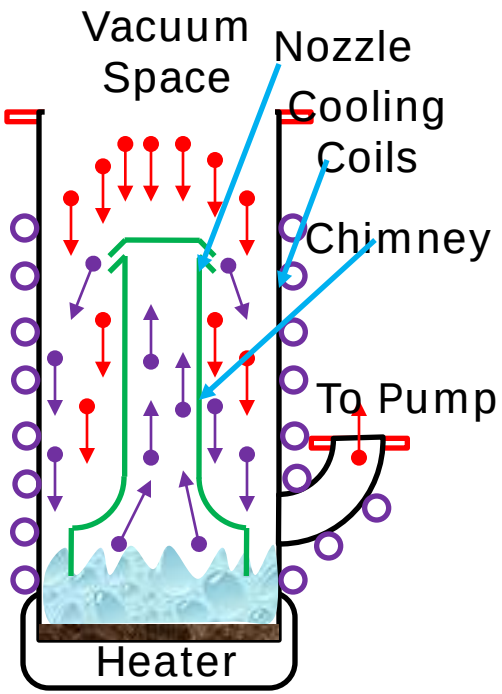
- The schematic of a diffusion pump is as shown in the figure.
- It consists of a chamber housing a oil vessel with a heater, a chimney and a nozzle. On chamber's outer surface, cooling coils carrying water are wound.
- These pumps are most effective when operated in free molecular regime. In practical applications, it is coupled with a backing pump.

Diffusion Pump



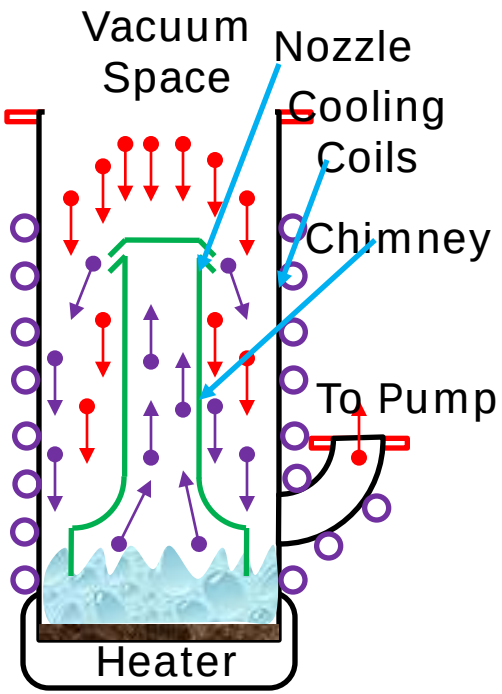
- The heater vaporizes the oil and these hot vapors rise into the vapor chimney.
- The hot vapors are deflected downwards by an annular nozzle or a jet assembly mounted at the top of the chimney.
- This jet, moving downwards at supersonic speeds, imparts momentum to randomly moving gas molecules in the chamber.

Diffusion Pump



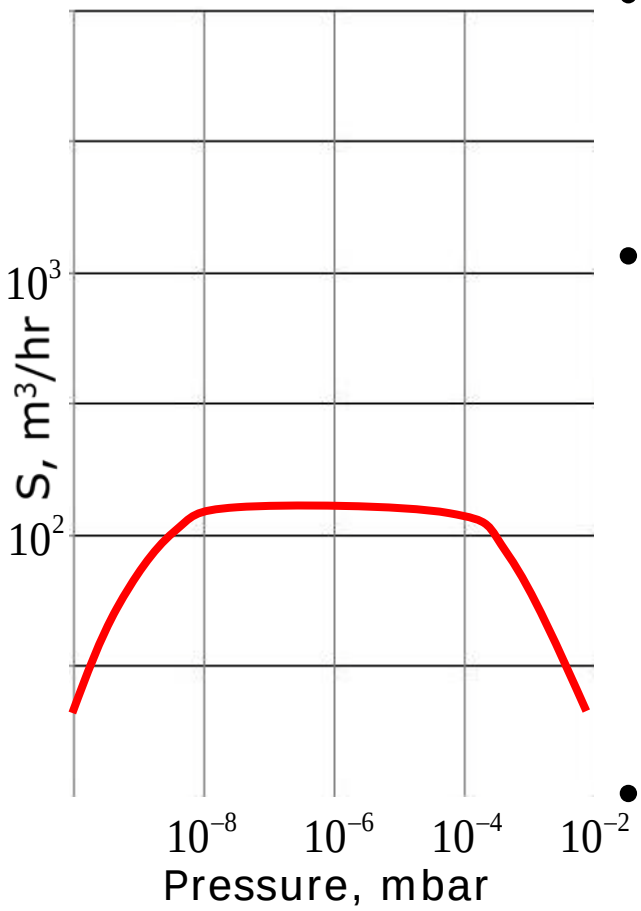
- This momentum deflects the molecules towards the pump outlet.
- In other words, this momentum gives direction to randomly moving molecules, towards the pump exit.
- A backing pump is constantly used to remove the gas molecules.
- The hot oil condenses on cold walls and returns to the vessel at bottom.

Diffusion Pump



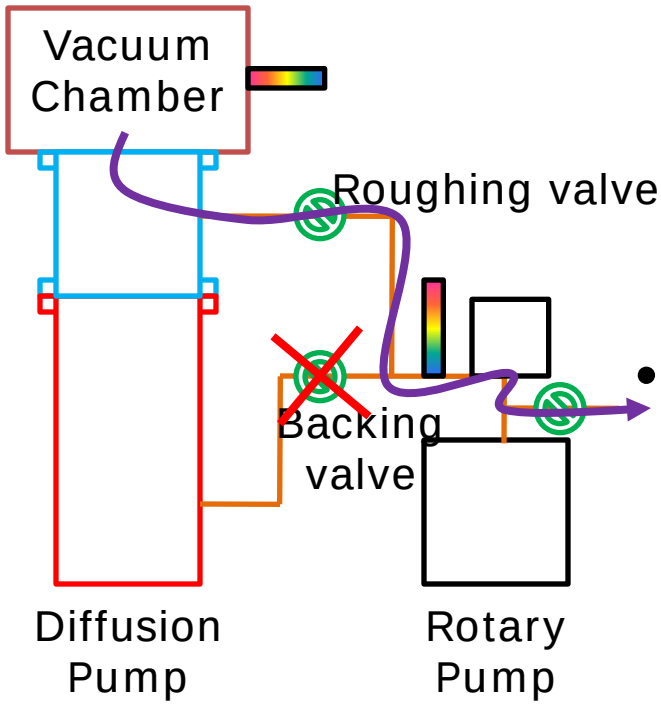
- One of the common problems in diffusion pumps is the back streaming of oil.
- This occurs when the pump oil molecules move above the upper portion of the jet. This causes contamination of vacuum chamber.
- Chilled baffles or cold trap is used to prevent the flow of oil molecules into the vacuum chamber.

Diffusion Pump



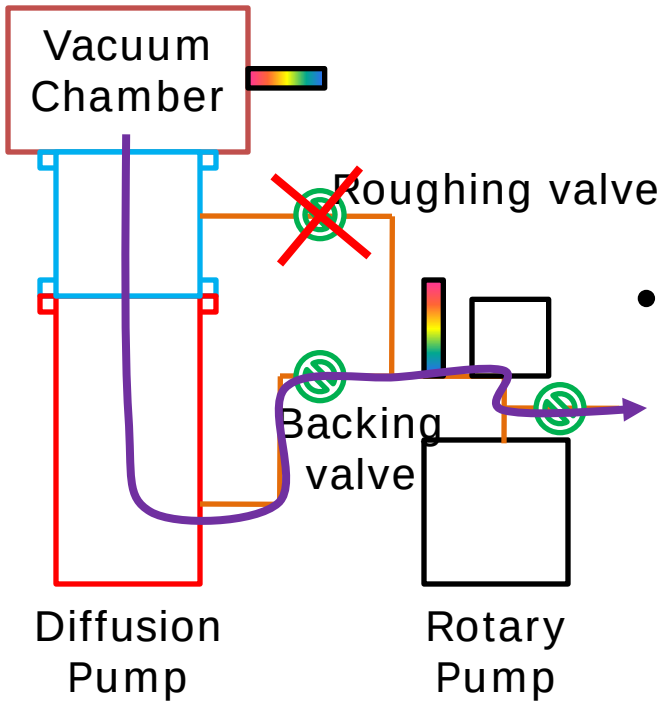
- The figure shows the variation of pump speed (**S**) with pressure.
- The ultimate pressure ($\mathbf{p_u}$) depends on
  - Vapor pressure of oil
  - Pump design
  - Gas load from vacuum space.
- The schematic of a Diffusion pump together with a Rotary pump is as shown in the next slide.

Diffusion Pump



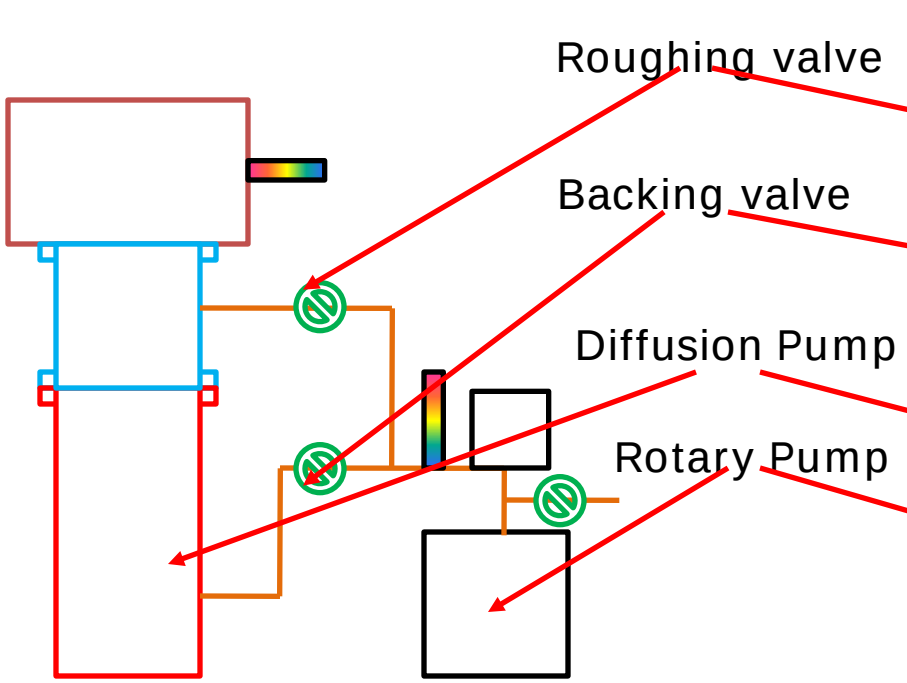
- As mentioned before, diffusion pump is effective in free molecular regime, the initial pump down of the system is done using a Rotary pump.
- With backing valve closed and roughing valve opened positions respectively, the gas is pumped out of system as shown in the figure.

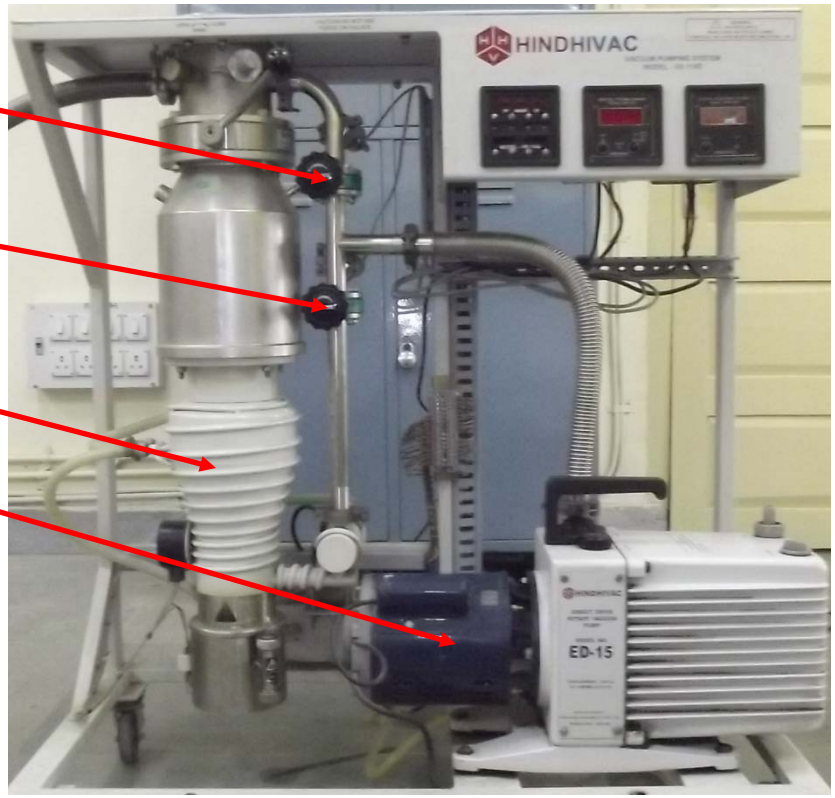
Diffusion Pump



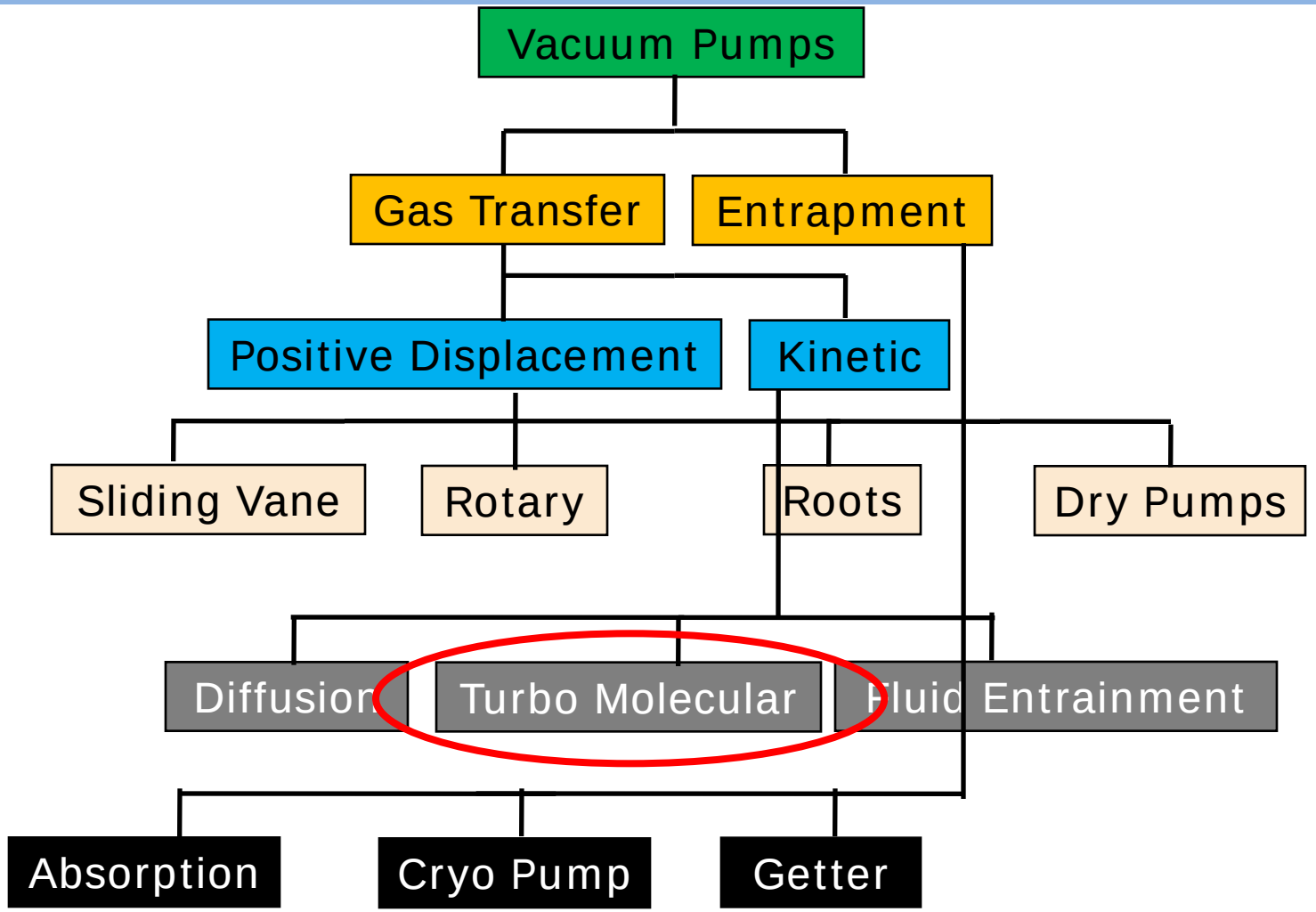
- When the pressure in system falls well below, to ensure a free molecular regime, the diffusion pump is put to use.
- With backing valve opened and roughing valve closed positions respectively, the gas is pumped out of system as shown in the figure.

Diffusion Pump

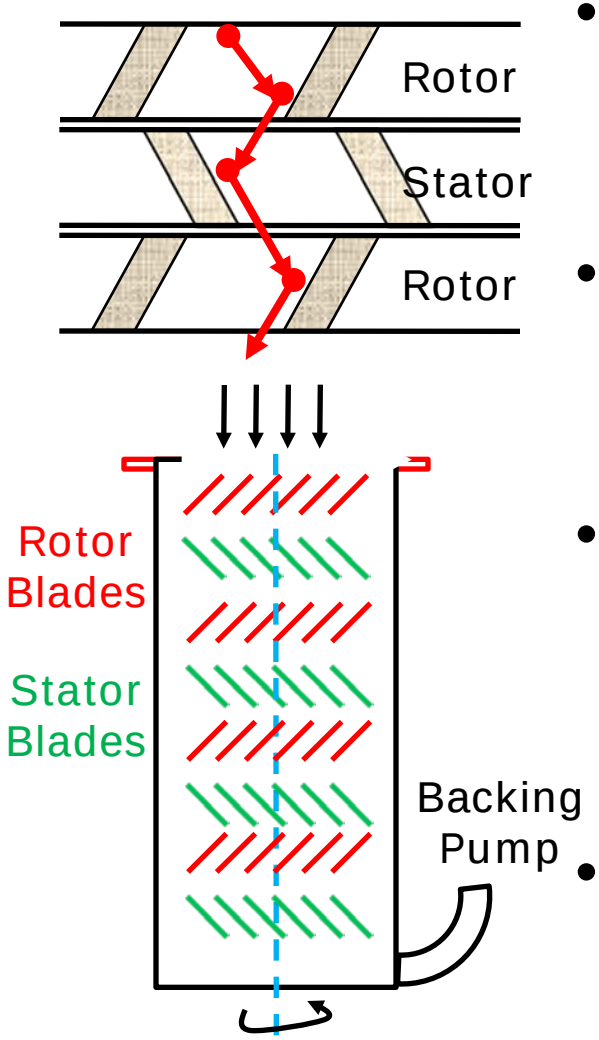




Classification

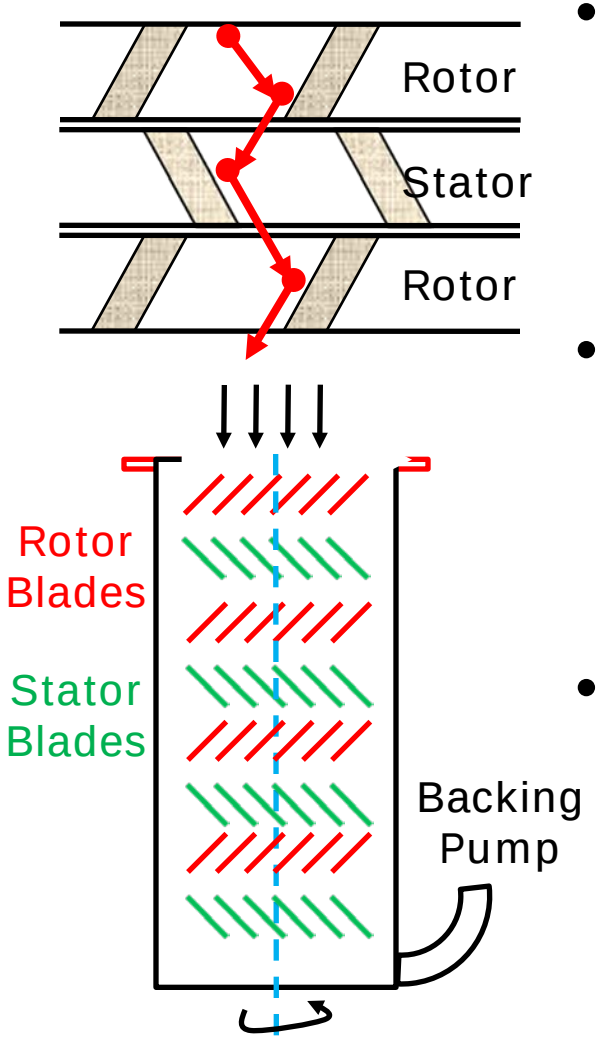


Turbo Molecular Pump



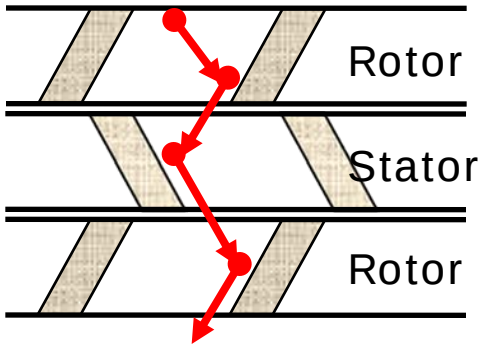
- The schematic of a Turbo Molecular Pump (TMP) is as shown.
- It consists of alternate layers of stator and rotor discs.
- The rotor rotates at a very high RPM, typically, of the orders of 27000 and above.
- The blades are mounted at an optimum angle, on both stator and rotor.

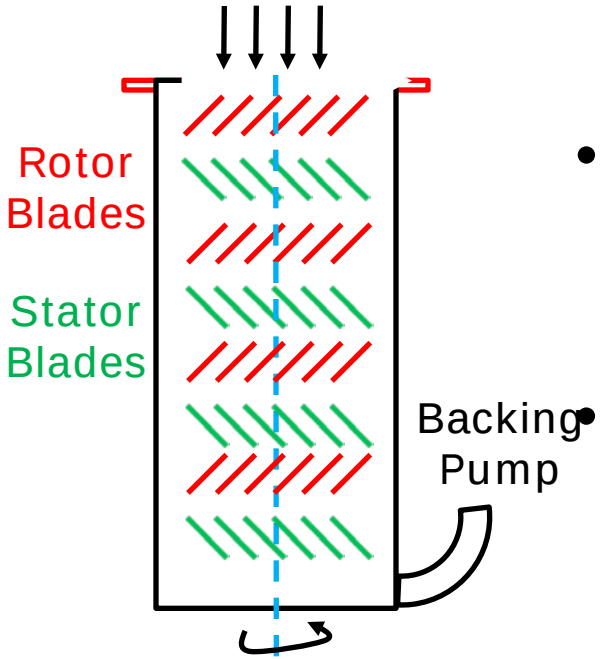
Turbo Molecular Pump



- This high speed rotation imparts momentum to the gas particles upon collision with the rotor discs.
- The high speed molecules are directed towards the exit using the stator discs.
- These two adjacent discs are often called as a stage in the TMP.

Turbo Molecular Pump



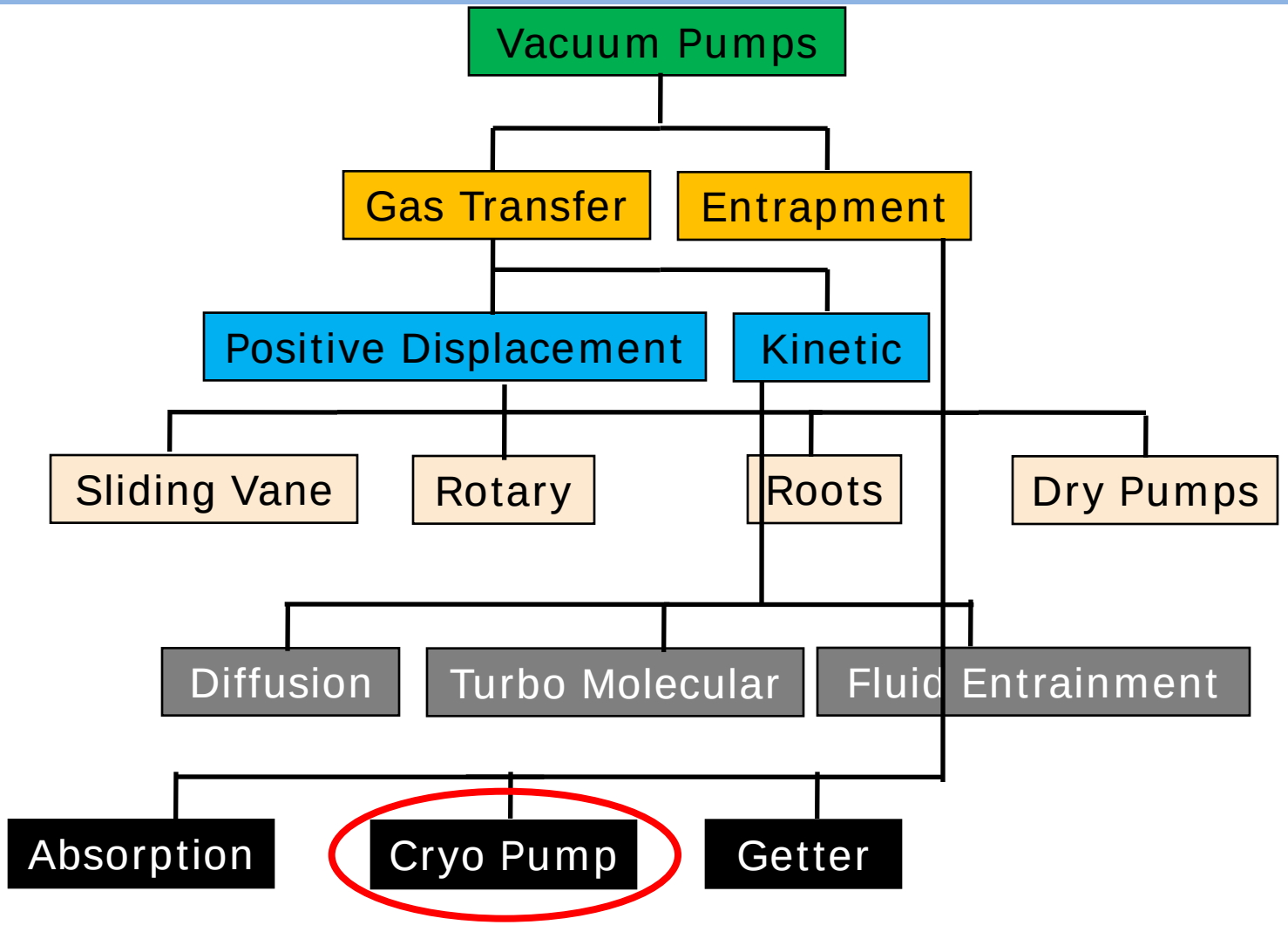


- A TMP has 6 to 7 stages depending upon the level of vacuum required.
- These pumps are more efficient in free molecular flow regime.
- They are often backed up by mechanical pumps.
- Latest developments in TMP include replacement of oil bearings with dry, non lubricant bearings.

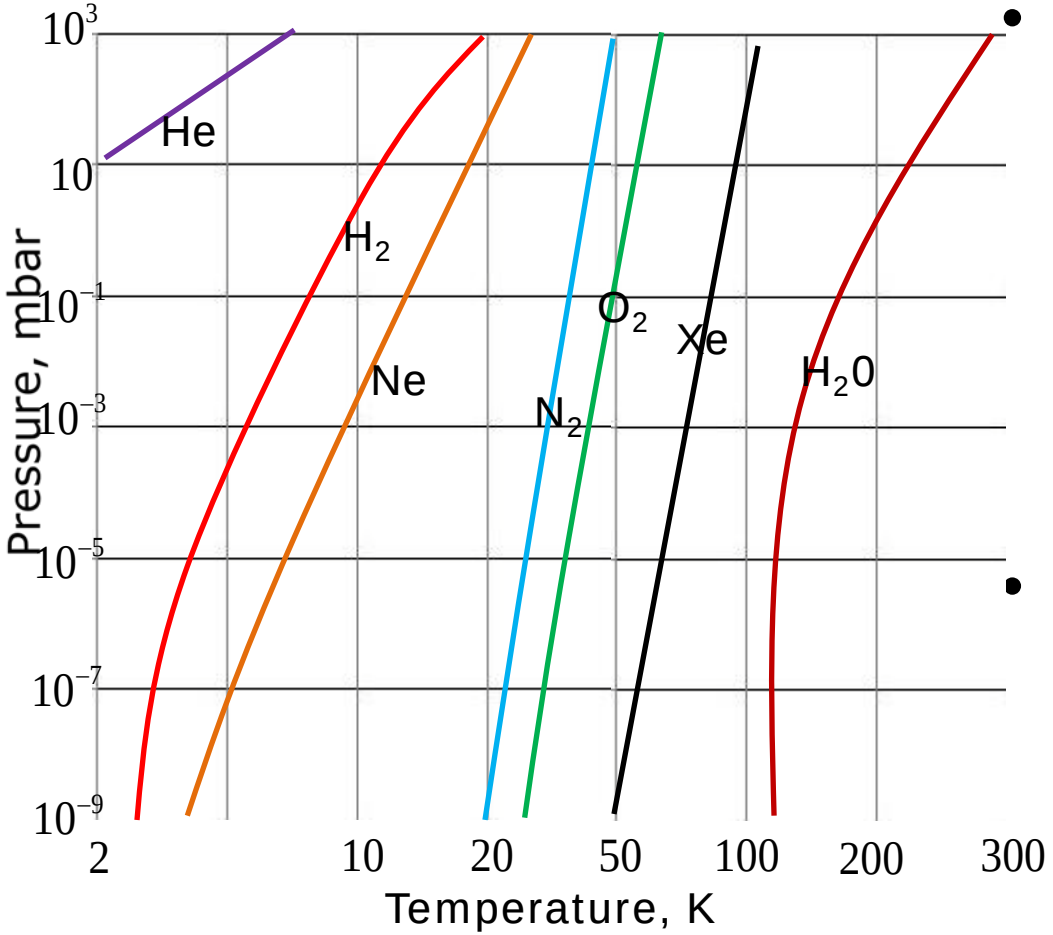
Turbo Molecular Pump

- The following photograph shows the various components of Turbo Molecular Pump.

Classification

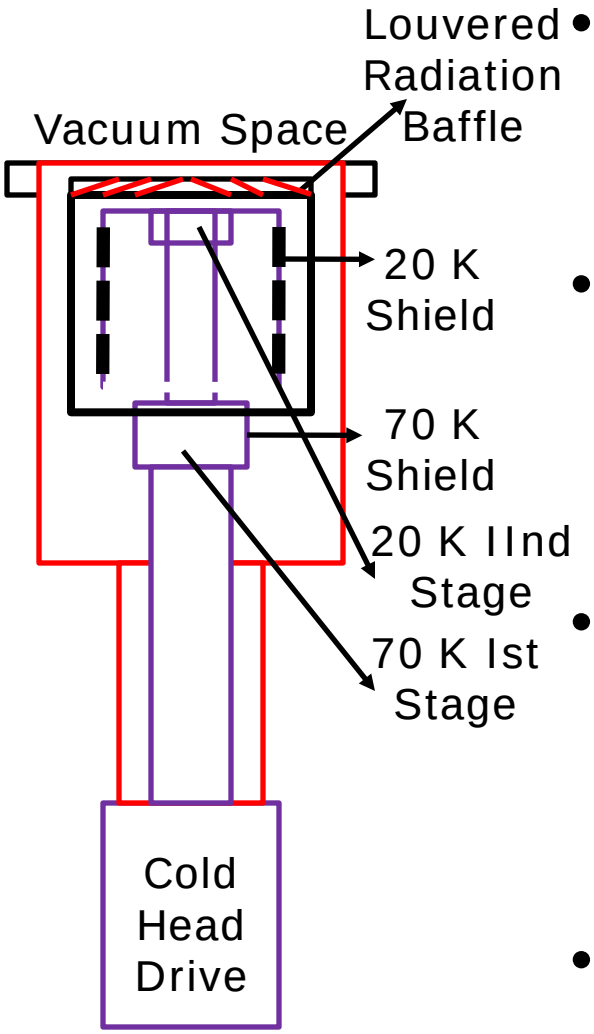


Cryo Pump



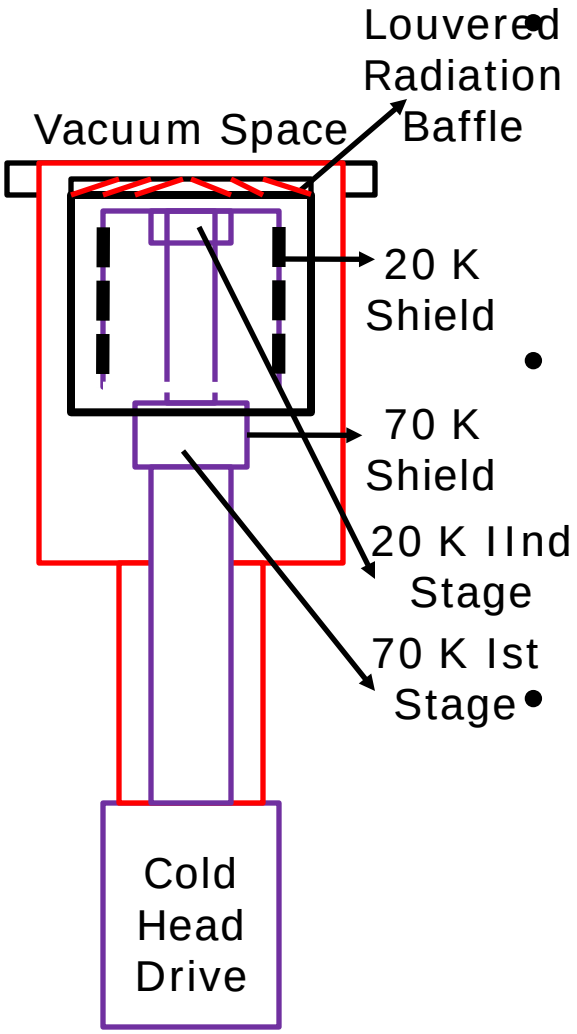
- The adjacent figure shows the variation of equilibrium vapor pressure with temperature for different gases.
- When the temperature is less than 20 K, the vapor pressure of gases other than **He**, **H_2** and **Ne** are close to 10^{-9} mbar.

Cryo Pump



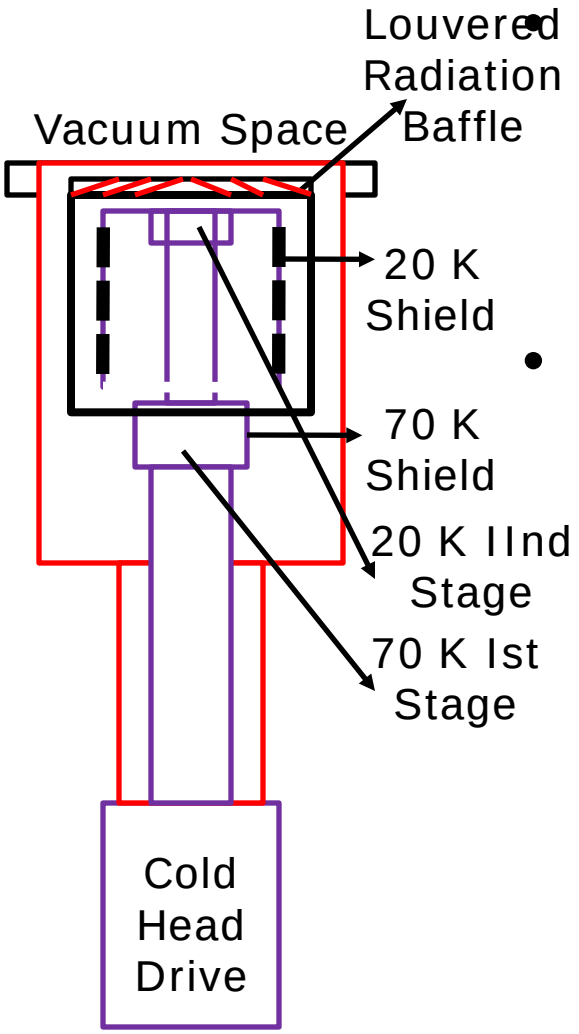
- The schematic of a Cryo pump is as shown in the figure.
- A two stage cold head unit produces temperatures of 70 K (1st stage) and 20 K (2nd stage).
- Adequate shielding and insulation is provided to avoid various heat in leaks.
- This pump can reach pressures as 10^{-10} Torr.

Cryo Pump



- The vacuuming process involves condensation of the gases onto the cold head.
- As mentioned earlier all the gases, except **He**, **H_2** and **Ne** are frozen at 70 K baffle and 20 K cold head.
- Gases **He**, **H_2** and **Ne** are adsorbed onto the charcoal provided on the underneath of the 20 K shield.

Cryo Pump



- Hence, it is clear that S_p of this pump is directly proportional to the surface area of cold head.
- These pumps are self contained, hydrocarbon free and are cooled by a two stage cryocooler.

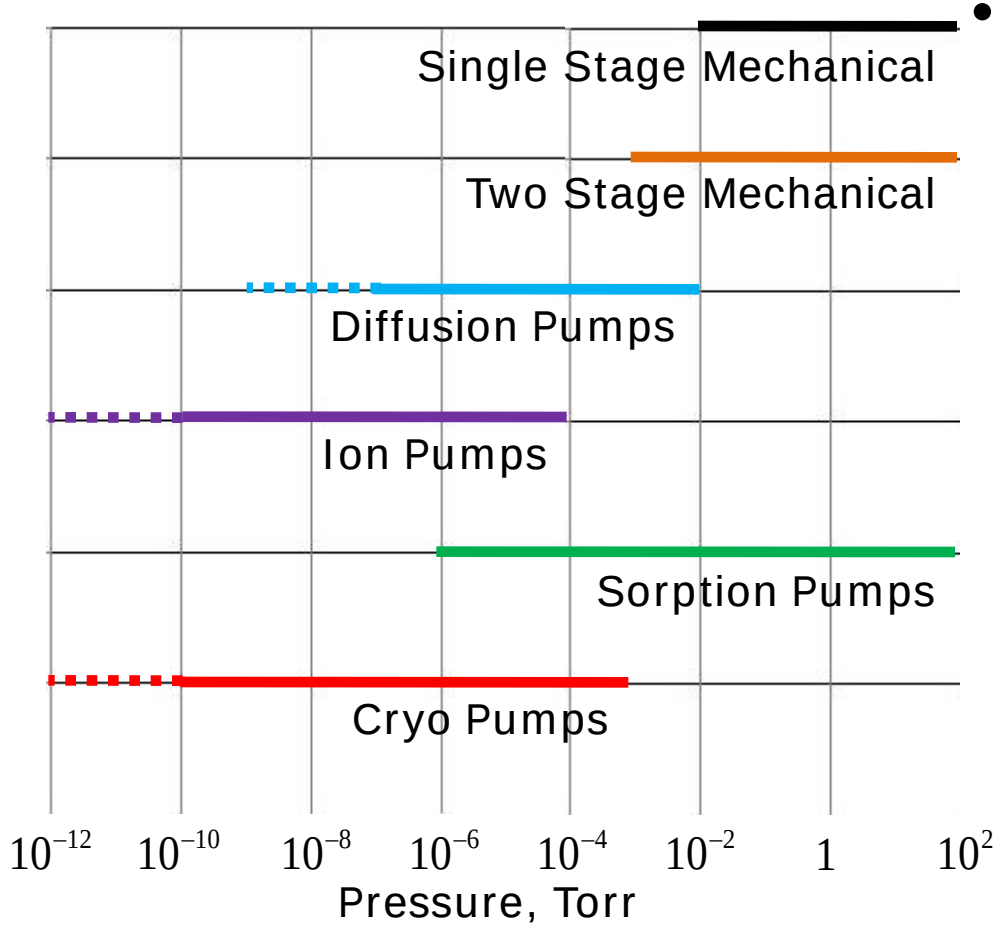
Other Pumps

- The other commonly used pumps are
  - Getter Pump
  - Sputter Ion Pump
  - Sublimation Pump
  - Adsorption Pump

Pump Selection

- The correct selection of a vacuum pump depends on the following factors.
  - Working process
  - Ultimate pressure (p_u) required
  - Total volume, surface area of the chamber
  - Out gassing rate and operating pressure
  - Pump down time required from atmosphere and special venting or gas recovery requirement
  - Dimensions, weight, vibration limits and costs
  - Special requirements : Hydrocarbons, reactive gases, bake out etc

Operating Range



- The adjacent figure shows the operating range for different vacuum pumps.

- A self assessment exercise is given after this slide.
- Kindly asses yourself for this lecture.

Self Assessment

1. Rotary vane pump is a ___ pump.
2. In a rotary pump, spring loaded exhaust valves expel ____.
3. In ___ a metered amount of non – condensable gas is admitted at the high pressure side.
4. ____ is best suited for high mass flow rates.
5. In a kinetic pump, ___ is used in expelling gas molecules.
6. TMPs operate in _____ regime.
7. Diffusion pump, TMP are coupled with ____ pump.
8. _____ of oil is a common problem in diffusion pumps.

Answers

1. Positive displacement
2. Compressed gas
3. Gas ballast
4. Roots pump
5. Kinetic energy
6. Free molecular flow
7. Backing pump
8. Back streaming

Thank You!