Vacuum Technology

Vacuum:

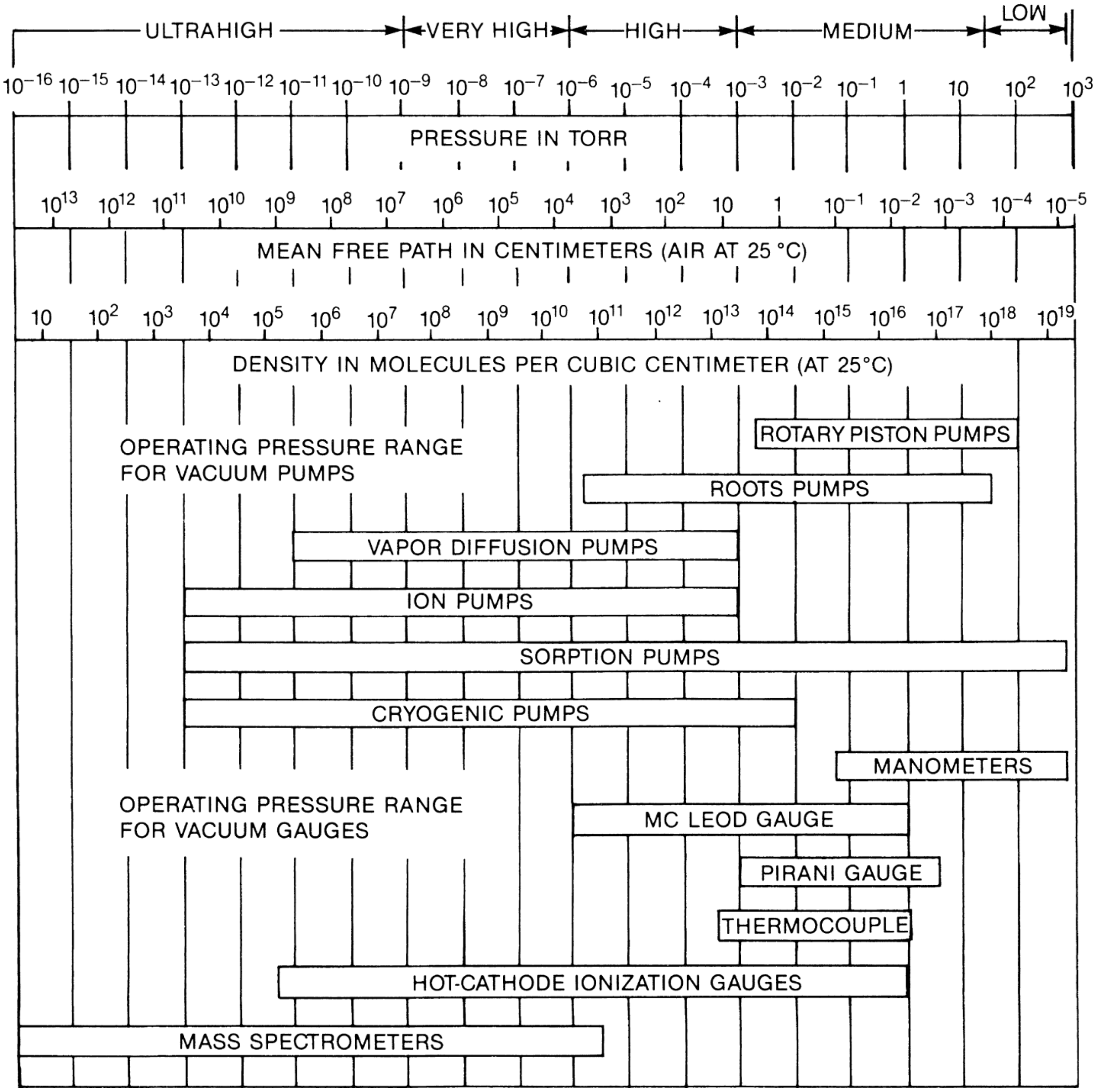
1. Vacuum is derived from the Latin word ***vacuus***, meaning Empty.
2. Absolute vacuum, a space entirely devoid of matter, is a theoretical concept only, never fully achieved by man or nature.
3. In modern usage, the word vacuum applies to any space at less than atmospheric pressure.
4. Vacuum technology is concerned with the equipment for producing, measuring, and maintaining vacuum for various applications in research and industry.
5. Scientists use vacuum to increase the mean free path of an electron, ion, or neutral-particle beam in the residual gas of some research instruments, or to provide an environment free of chemically active gases for surface or deposition studies
6. Modern industrial applications of vacuum include the production of lamps, X-ray tubes, television picture tubes, and solid-state power devices and integrated circuits that involve thin film, plasma, evaporation, sputtering, ion implantation, vacuum baking, and low-pressure chemical decomposition by pyrolysis. Vacuum is also used to increase the evaporation rate of various substances without destructive heating, as in the case of dehydration of frozen fruit juices, penicillin, or blood plasma.

UNITS:

The common unit of pressure in vacuum technology is the Torr (after Torricelli),
1/760 of a standard atmosphere. For all practical purposes, it equals the pressure exerted by a column of mercury 1 mm high. The pascal is also sometimes used as
a unit of pressure and is equal to **7.50 × 10−3 Torr.**

1 torr = 133 Pa (= 133 Nm^2)
1 mbar = 100 Pa = 0.75 torr

Chart showing some gas parameters and the operating pressures ranges for vacuum pumps and gauges:



GAS FLOW AT LOW PRESSURES:

The rate at which a gas flows in a vacuum system at a given temperature depends on the pressure of the gas and on the size and geometry of the system. It is convenient to characterize the type of flow encountered by a dimensionless parameter *Kn*, called the **Knudsen number**. This number is defined as the ratio of the mean free path λ of

the gas molecules to a characteristic dimension *D* of the constraint through which the gas is flowing; for example, the diameter of an orifice or tube. The mean free path is

defined as the average distance traveled by the molecules between successive collisions with one another. It varies inversely with the pressure of the gas. For air at 25◦C

$\lambda = 5 \times 10{-}3/P$ cm

where *P* is the pressure in Torr. Under very high and ultrahigh vacuum conditions the Knudsen number is usually larger than one ($\boldsymbol{\lambda/D = Kn > 1}$ or $PD<0.005$); that is,

the mean free path is larger than the characteristic dimensions of the vacuum system. Consequently, the molecules collide mostly with the walls of the system and seldom

with each other. Under these conditions the ***volumetric gas flow is independent of pressure***. **Molecular flow of gas** through a vacuum system is analogous to current flow through an electric circuit. When gas flows through a constriction such as a length of pipe, orifice, or trap, a pressure drop will be produced across the component. This pressure drop is analogous to the potential drop across a resistance or impedance when an electric current flows through it. Thus the impedance of a component in a vacuum circuit is defined as

$Z = (P_A - P_B) / Q$ sec liter−1

where *P*A is the upstream pressure measured in Torr at the entrance to the component and *P*B is the downstream pressure measured at the exit. *Q* is the quantity of gas flowing through the component measured in Torr · liter sec−1. The gas flow is usually measured at some arbitrary crosssectional plane through the component. The temperature must also be specified since *Q* is dependent upon *T* . From the ideal gas law it follows that

$$\mathbf{Q = P\, dV/dt}$$
$$\mathbf{= dW/dt \times R_0T/M} \qquad \text{Torr liter sec−1}$$

where *dV/dt* is the volumetric flow rate in liters sec−1 at temperature *T* and a reference pressure *P*, usually taken as 1 Torr (although any convenient pressure may be used

since *PV* = constant for a fixed temperature), *dW/dt* the weight of gas flowing through the component in g sec−1 and R_0 the molar gas constant equal to 62.36 Torr liter

deg−1 mol−1. *Q* is called the **throughput** and

$Qm = dW/dt = Q(M / R_0 T)$

is called the **mass throughput**. The throughput will be the same for all of the series components of a vacuum system, provided they are at the same temperature (assuming
no condensation, leaks, or outgassing in the components) since there will be no accumulation of gas in the system. It is sometimes convenient to use a quantity F, called the ***conductance*** of a vacuum element that is the reciprocal of
the impedance.

$F = 1/Z = Q / (P_A - P_B)$ liters sec−1

F is a measure of the ease with which gas flows through the device. For molecular flow, conductance is independent of pressure and depends only on geometry.

Molecular Flow:

Molecular flow is characterized by Knudsen numbers Kn greater than unity, which physically means that the mean free path associated with the prevailing number density of the contained gas molecules is greater than the size of the container, with the consequence that molecule/wall collisions dominate gas behavior. All semblance to fluid behavior is lost because there are no molecule–molecule collisions.

Continuum Flow:

In this regime, gas behaves as a fluid, and molecule–molecule collisions with mean free path much less than the equipment size determine gas behavior

Pumping Speed:

The speed S of any vacuum pump may be defined as the rate at which the pump removes gas from the system. This rate may be expressed in grams or liters per second. If P is the pressure at the inlet to the pump, then the volumetric flow rate through the pump at pressure P is Q /P *and hence*

$S = Q /P$ liters sec−1

This definition of pumping speed may be applied to a mechanical, diffusion, ion, or cryogenic pump or even to an orifice connecting a vacuum system at pressure P to a region of lower pressure. However, pumping speed should not be confused with conductance, which is measured in the same units. ***Conductance implies a pressure gradient across geometric arrangement through which there is a gas flow , while pumping speed may be determined at any plane in the system and is simply the volume of gas flowing across the plane per second***, measured at a pressure equal to that in the plane.

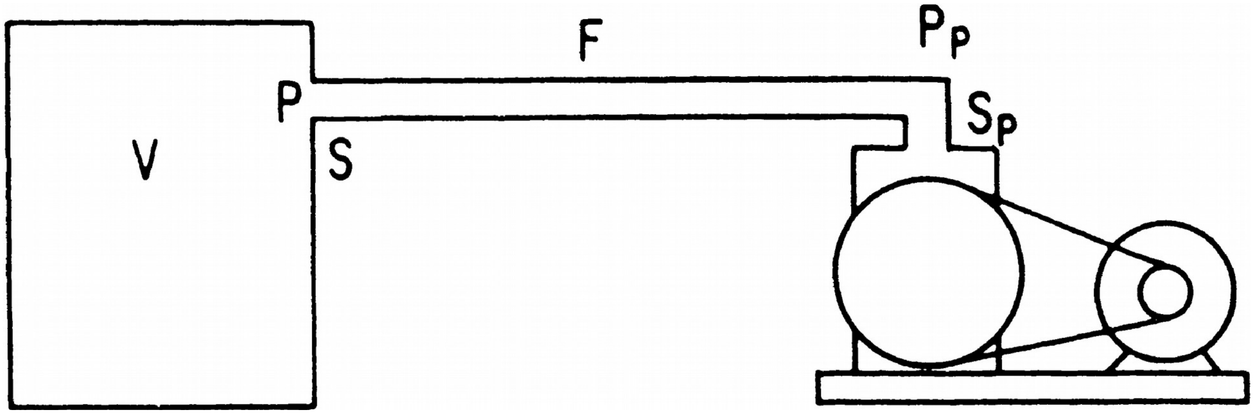
The speed of most pumps is nearly constant over a wide pressure range. However, there is a lower limit to the pressure obtainable with a given pump and, as this ultimate
pressure P_a is approached, the speed drops off.

A small quantity of gas flowing back into the system determines this low-pressure limit. Assume that the pump has a fixed intrinsic pumping speed $S_0 = Q / P_p$ independent of the pump inlet pressure P_p, and a constant small leakage of gas q back into the system also independent of pressure. The effective pumping speed S_p at the inlet of the pump is

$$S_p = (Q - q) / P_p$$

$$= s_0 (1 - q/Q)$$

When the limiting pressure is reached, Q will be just equal to the leakage q; thus $S_0 = Q / P_p = q / P_a$.



Creating a Vacuum — Pumps:

The function of a vacuum pump is to withdraw gas from a designated volume so that the pressure is lowered to a value suitable for the purpose in hand. The variety of applications of vacuum technology is such that a very wide range of vacua has to be provided. An ultrahigh vacuum ~10−10 mbar is necessary to secure adequately clean conditions for investigations in surface science.

The types of pumps that are available to meet these needs may be usefully classified under just three headings that summarize what they do to the gas presented to them.

In **positive displacement pumps,** gas is manipulated using repetitive mechanical movements of driven parts and synchronized valve actions that displace it from the inlet to the outlet in relatively small discrete amounts at a high repetition rate and with some compression. The rotary vane pump is an example of prime importance. Others are the Roots pump,

In **momentum transfer pumps,** incoming gas molecules interact with either a high-velocity stream of fluid or very fast-moving solid surfaces that add a directed component to their motion and transfer them continuously to an outlet, usually at a pressure much below atmospheric. Examples are vapor jet (diffusion) pumps, drag pumps, and turbo molecular pumps.

In **capture pumps,** molecules are removed from the gas phase by being trapped on surfaces by the physical or chemical processes of condensation and adsorption. Cryogenic pumps, sublimation pumps, and ion pumps in which the capture process is assisted by the presence of electric or magnetic fields, are examples. In these cases there is no pump outlet and the pumped gas is stored in a condensed state.

In both displacement and transfer pumps, gas is compressed to arrive at the outlet still in a gaseous condition, and they are therefore called throughput pumps, in contrast to those whose action depends on capture and storage

Positive Displacement Pumps:

The Rotary Vane Pump:

Construction:

- A metallic stator block immersed in oil contains a cylindrical pumping chamber
  in which a rotor is mounted off-center.

- The rotor has diametral slots containing sliding vanes that are pushed outwards by springs to make contact with the stator wall.
- The whole assembly is precisely machined and assembled, and the distance between the rotor and stator surfaces along the line where they are closest there is a few hundredths of a millimeter.
- The motor has a slightly unbalanced load, but with vanes made of a lightweight plastic material, the levels of vibration induced are small.
- Centrifugal forces contribute to keeping the vanes in contact with the stator wall.

Principle:

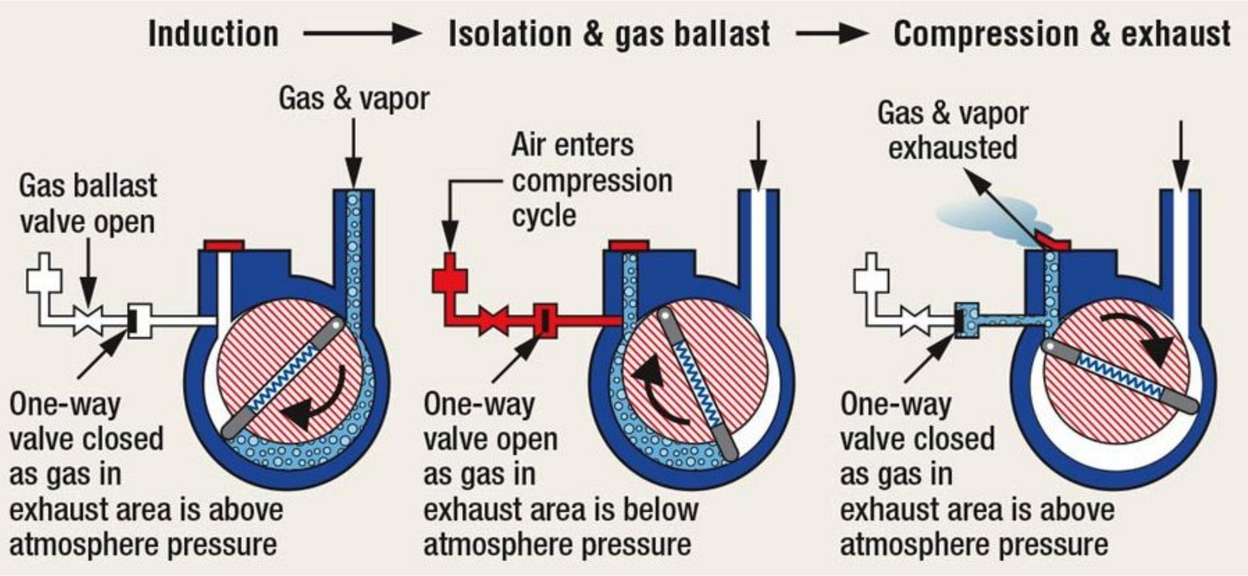
The pumping action is illustrated in Figure below and may be briefly described as “induction, isolation, compression, and exhaust.”

In **Induction** the half turn of the rotor that concludes with vane V being in the position shown induces air into the pumping chamber. The total volume available to the gas increased and so it expanded to occupy the available volume.

In Isolation , the movement of vane V past the inlet isolates the induced air in a crescent-shaped volume. Further rotation, results in the reduction of this volume and **compression** of the air with a rise of pressure and temperature to a point shown in figure where the pressure is sufficient to open the exhaust valve so that the air is **expelled**. This sequence is completed twice per revolution.

Energy is expended not only to do work against inertial and frictional forces but also to compress and move the pumped gas, and so pumps run hot, typically at about 75°C. As well as lubricating and forming the seals, the oil also has the important role, as it slowly moves through the pump, of taking away some of the heat generated in the interior.

Figure:



Advantages:

- Low internal leakage
- Compact design
- Simplicity in construction
- Low cost
- High efficiency
- Low noise

Disadvantages:

Lower operating pressure (120-150 bars)