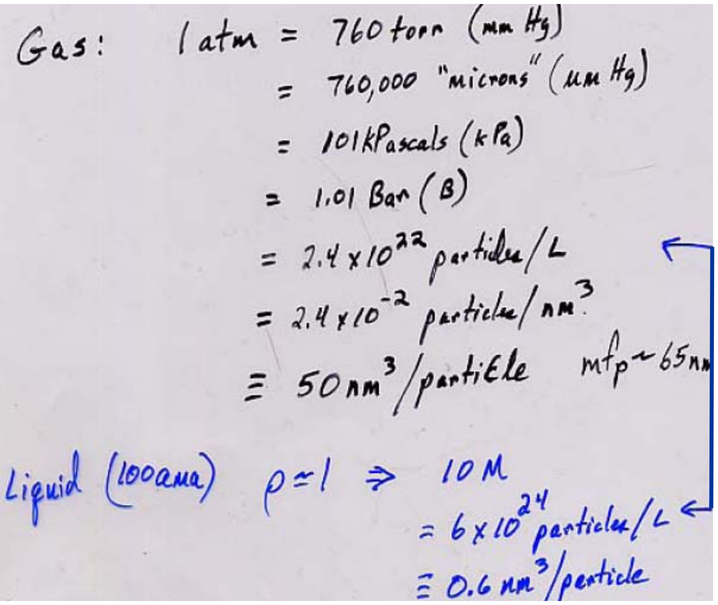
Intro to Vacuum Technology

Gas vs. Liquid



Gas: 1 atm = 760 torr (mm Hg)

= 760,000 "microns" (μm Hg)

= 101 kPascals (kPa)

= 1.01 Bar (B)

= 2.4×10^{22} particles/L

= 2.4×10^{-2} particles/nm^3

≡ 50 nm^3/particle mfp ~ 65n

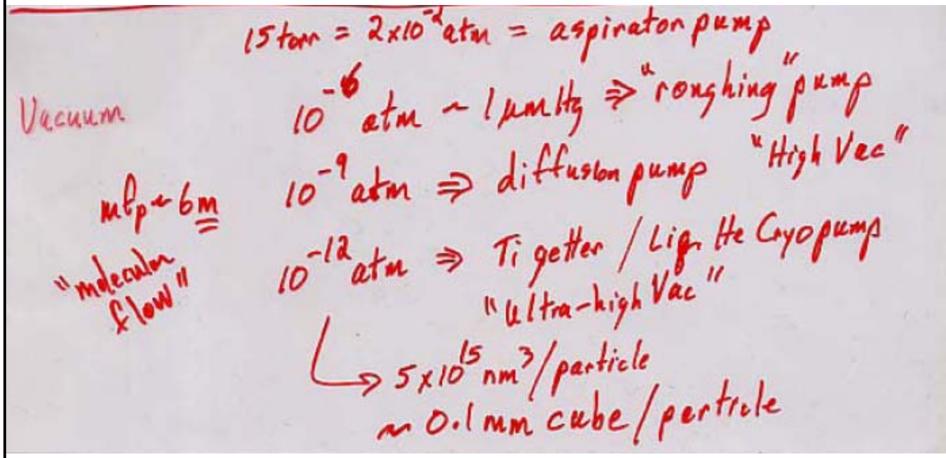
Liquid (100 amu) $\rho \simeq 1$ ⇒ 10 M

= 6×10^{24} particles/L

≡ 0.6 nm^3/particle

300X

Vacuum



Vacuum

$15\ \text{torr} = 2 \times 10^{-2}\ \text{atm}$ = aspirator pump

$10^{-6}\ \text{atm} \sim 1\ \mu\text{m Hg}$ ⇒ "roughing" pump

$10^{-9}\ \text{atm}$ ⇒ diffusion pump "High Vac"

mfp ~ 6 m

"molecular flow"

$10^{-12}\ \text{atm}$ ⇒ Ti getter / Liq. He Cryopump

"ultra-high Vac"

→ $5 \times 10^{15}\ \text{nm}^3$/particle

~ 0.1 mm cube/particle

Vacuum

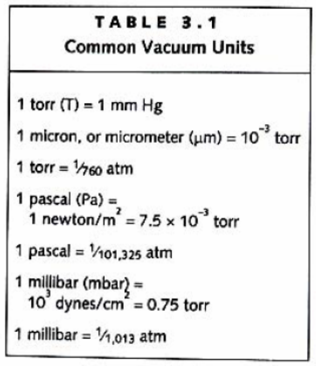


TABLE 3.1

Common Vacuum Units

1 torr (T) = 1 mm Hg

1 micron, or micrometer (μm) = 10^{-3} torr

1 torr = 1/760 atm

1 pascal (Pa) = 1 newton/m^2 = 7.5×10^{-3} torr

1 pascal = 1/101,325 atm

1 millibar (mbar) = 10^3 dynes/cm^2 = 0.75 torr

1 millibar = 1/1,013 atm

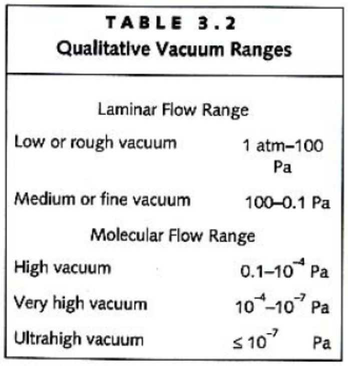


TABLE 3.2

Qualitative Vacuum Ranges

Laminar Flow Range	
Low or rough vacuum	1 atm–100 Pa
Medium or fine vacuum	100–0.1 Pa
Molecular Flow Range	
High vacuum	$0.1–10^{-4}$ Pa
Very high vacuum	$10^{-4}–10^{-7}$ Pa
Ultrahigh vacuum	$\leq 10^{-7}$ Pa

Rotary Pump

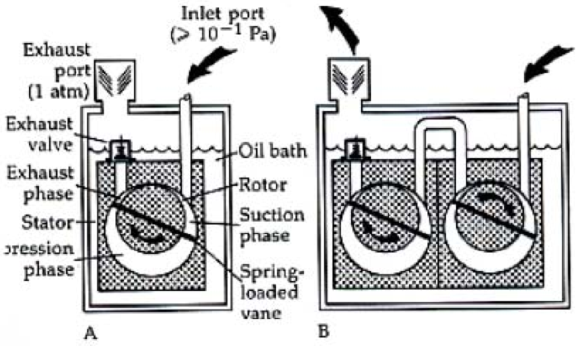
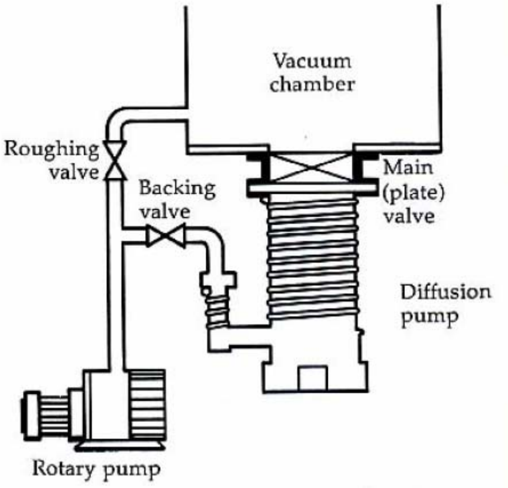


Figure 3.1 Rotary pumps. (A) Schematic of a rotary-vane pump. (B) Schematic illustrating the concept of staging. The two stages are usually mounted coaxially to decrease the number of moving parts. Rotary pumps are used more frequently than any other type of vacuum pump in the EM lab.

100 – 1000 L/min

Diffiusion Pump

Figure 3.11 Diffusion-pumped vacuum system. This vacuum system is the one found on most electron microscopes. The rotary pump first rough-pumps the chamber or column; then the final vacuum is attained by opening the main valve to the diffusion pump. The rotary pump then backs the diffusion pump by removing gas compressed in the space of its bottom stage.



Diffiusion Pump

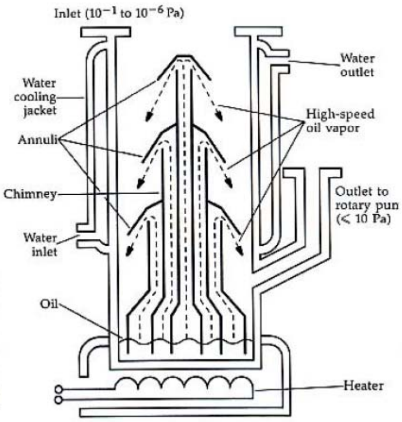


Figure 3.2 Longitudinal schematic of a three-stage vapor-diffusion pump. Although it has no moving parts, the vapor-diffusion pump is considered a mechanical pump. Gas molecules are knocked down stage by stage by supersonic oil vapor, which condenses on the cooled outer surface and flows back to the boiler for recycling. The vapor-diffusion pump is the most common high-vacuum pump in EM equipment.

$\sim 10^3$ L/s

Turbomolecular Pump

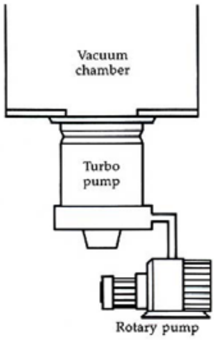


Figure 3.12 Turbomolecular-pumped vacuum system. The turbomolecular-pumped system can be valveless, since the rotary backing pump can rough-pump the system through the accelerating turbomolecular pump. The turbo pump needs to be backed by the rotary pump to lower drag on the rotors to the point at which the turbomolecular effect can take place.

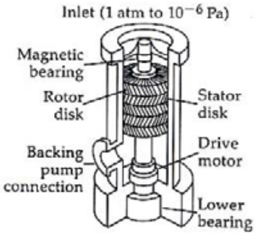


Figure 3.3 Cutaway schematic of a turbomolecular pump. The turbo pump rotor/stator sets act as compressor stages, each concentrating the gases more. These pumps require a (usually rotary) backing pump to remove gas from the last stage. Turbo pumps provide a clean vacuum rapidly.

10^5 rpm!

10^{-13} atm

He, H_2 primary residual gas

Turbomolecular Pump

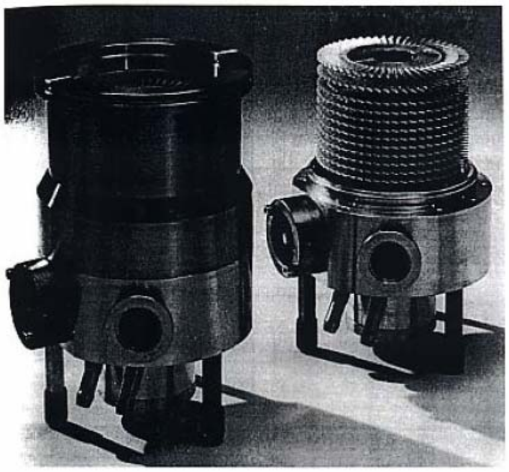


Figure 8.3. A turbopump (with and without its casing) which is nothing more than a small turbine that rotates at high speed. Like a jet turbine it pulls air in at the front end and forces it out of the back. The blades are designed like airfoils to enhance the flow of gas through the system.

Ti Getter/Sublimation Pump

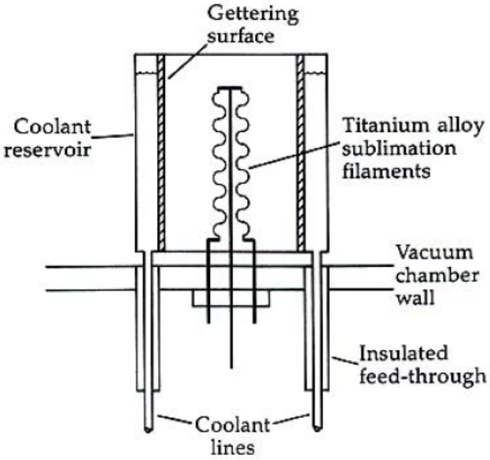


Figure 3.4 Longitudinal schematic of a titanium-sublimation pump. Titanium-sublimation pumps are found on ultrahigh-vacuum systems. Gas molecules stick to the walls of the pump body freshly coated with titanium. These surfaces are much more efficient at lower temperatures.

$\sim 10^4$ L/s

Ti Getter/Sublimation Pump

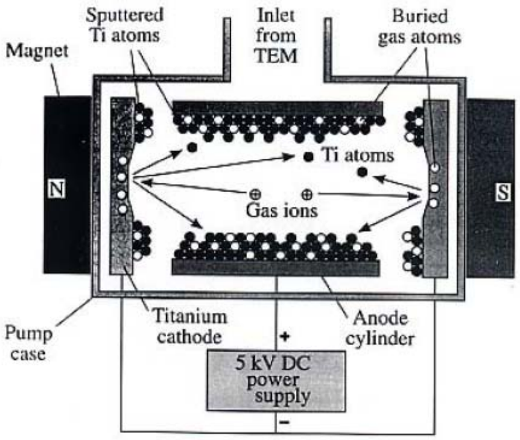


Figure 8.4. Schematic diagram showing how ion pumps trap ionized gas atoms by layers of Ti atoms at electrodes. Once trapped, the ions cannot escape until the pump is turned off.

Cryo - Pump

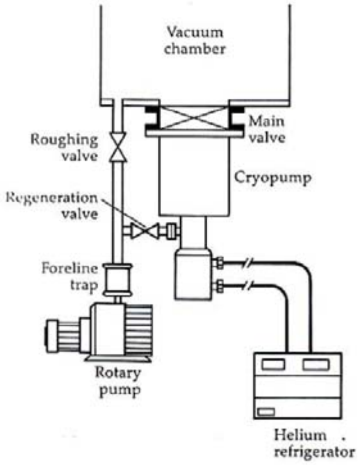


Figure 3.13 Cryo-pumped vacuum system. The cryopumped system requires a roughing pump, much like the diffusion-pumped system. Once the bulk of the gas has been rough-pumped out of the system and the plate valve to the cryoadsorption pump opened, the backing pump is no longer needed, since the gas is entrained in the cryopump head. As the adsorptive surfaces become saturated, the pump needs to be regenerated by heating the pump head and pumping out the liberated gas with the rotary pump.

Cryo - Pump

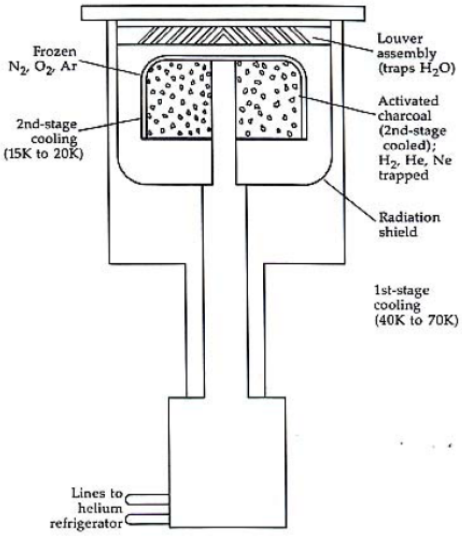


Figure 3.6 Longitudinal schematic of a cryoadsorption pump head. The two-stage cryoadsorption pump uses two cooling ranges either to freeze or to adsorb gas. The first stage traps water vapor and shields the inner stages. The second stage traps all gases either by freezing them or by adsorbing them.

Vacuum Gauges

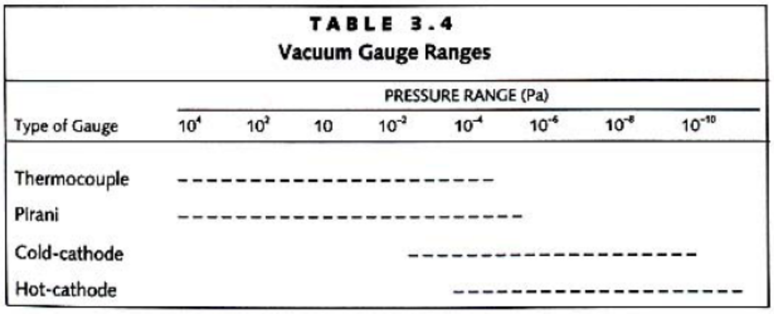


TABLE 3.4
Vacuum Gauge Ranges

Type of Gauge	PRESSURE RANGE (Pa) 10^4	10^2	10	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}
Thermocouple	– – –	– – –	– – –	– – –	– – –			
Pirani	– – –	– – –	– – –	– – –	– – –			
Cold-cathode					– – –	– – –	– – –	– – –
Hot-cathode					– – –	– – –	– – –	– – –

Thermocouple Gauge

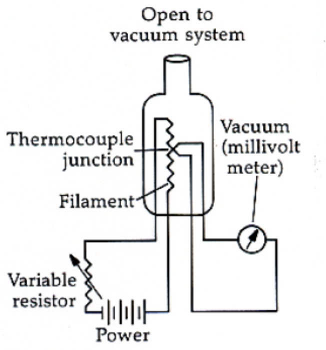


Figure 3.8 Thermocouple gauge system. Schematic of the gauge tube and the measuring circuit. The thermocouple gauge simply measures the temperature on a heated wire with a thermocouple, which is attached to it. As the vacuum increases, the wire gets hotter because fewer gas molecules are colliding with it and removing heat.

Cold Cathode Gauge

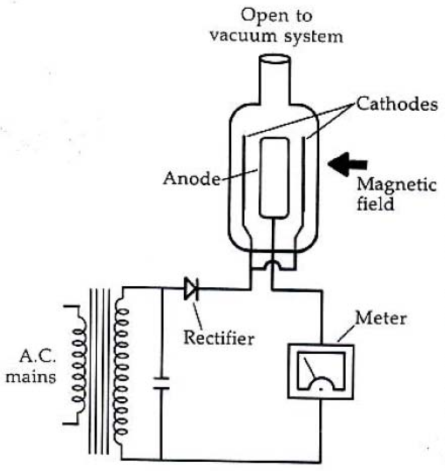


Figure 3.9 Cold-cathode gauge system. Schematic of the gauge tube and the measuring circuit. The cold-cathode gauge works by a magnetic field that lengthens the time of flight of electrons emitted from a cold source, improving the chance that they will hit a gas molecule and ionize it. Gas molecules ionized by these collisions create a current proportional to the vacuum.

Hot Cathode Gauge

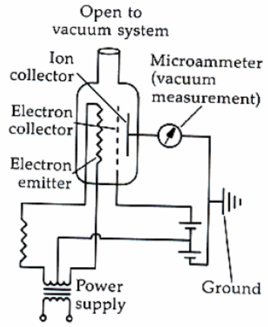


Figure 3.10 Hot-cathode gauge system. Schematic of the gauge tube and the measuring circuit. At higher vacuums, the cold discharge of electrons is insufficient. By heating the electron emitter, the electron flux improves, providing a higher probability that gas molecules will be ionized and eliminating the need for a magnetic field. Hot-cathode gauges can measure higher vacuums but are more sensitive to leaks than cold-cathode gauges are.