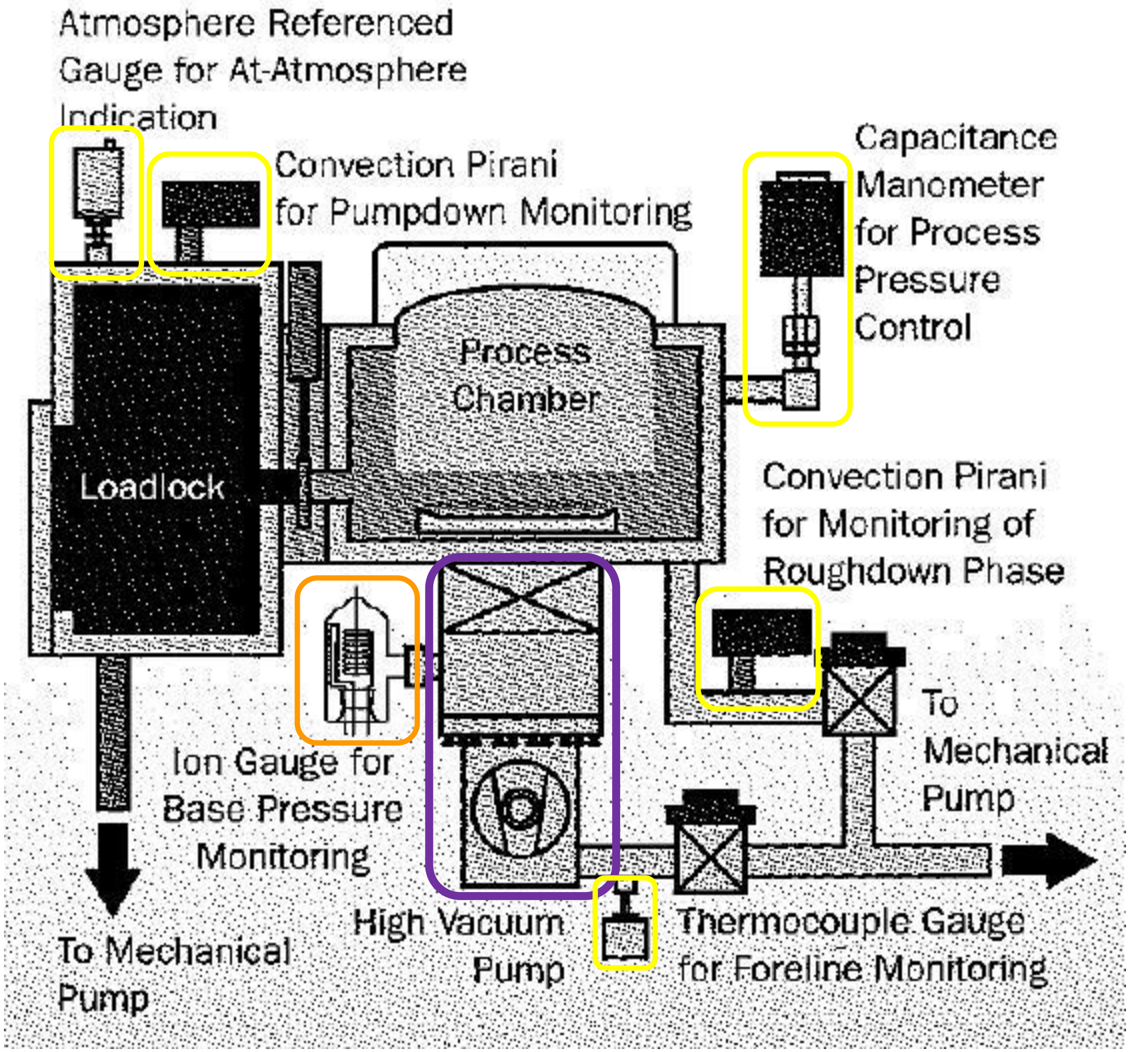
Vacuum Systems and Cryogenics for Integrated Circuit Fabrication Technology 01

Joel Molina

INAOE
Microelectronics Group

jmolina@inaoep.mx

Vacuum system with a variety of gauges for vacuum measurement

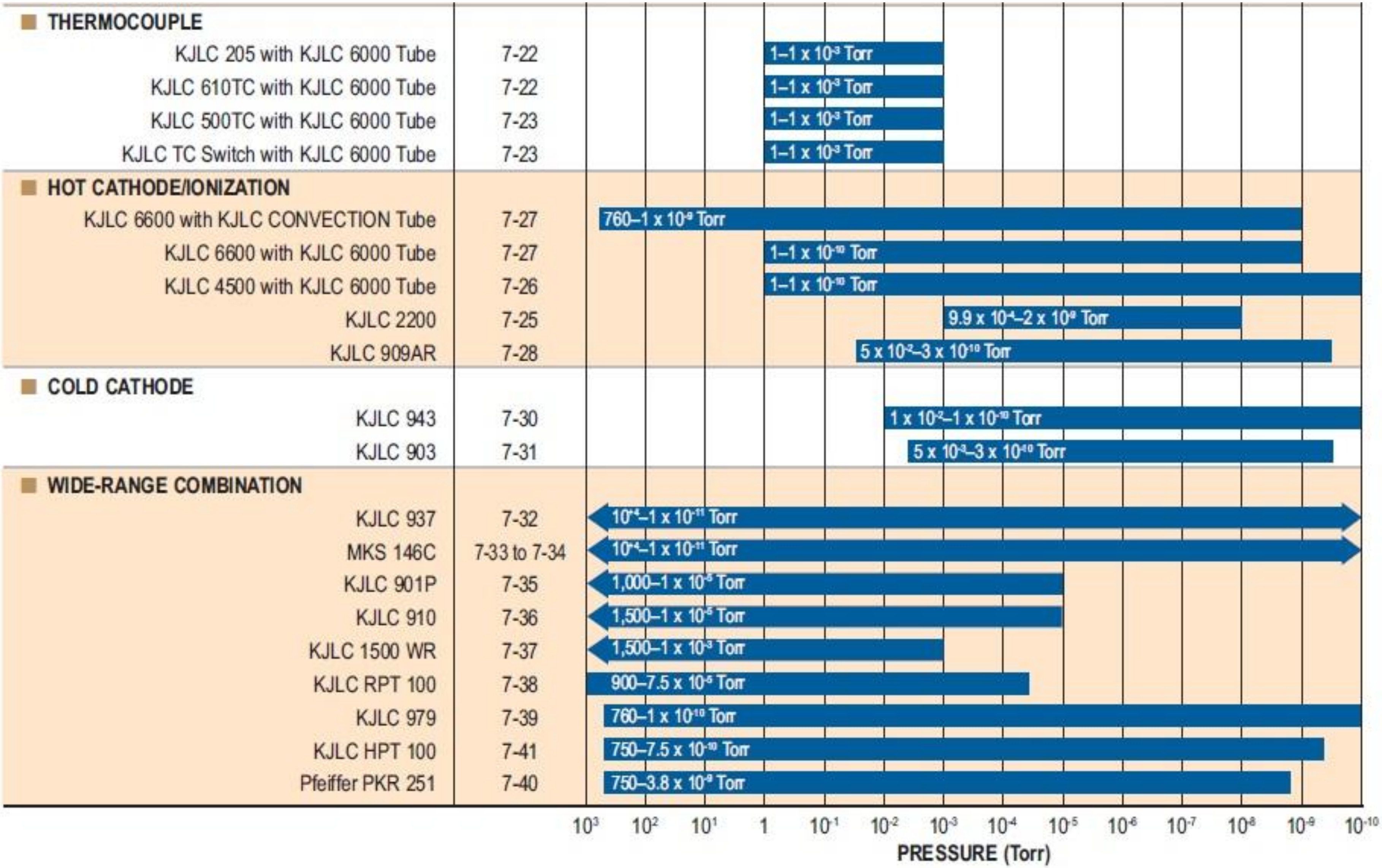


Vacuum pressure ranges and gauges selection guide

PRESSURE (Torr): 10^{3}, 10^{2}, 10^{1}, 1, 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, 10^{-10}

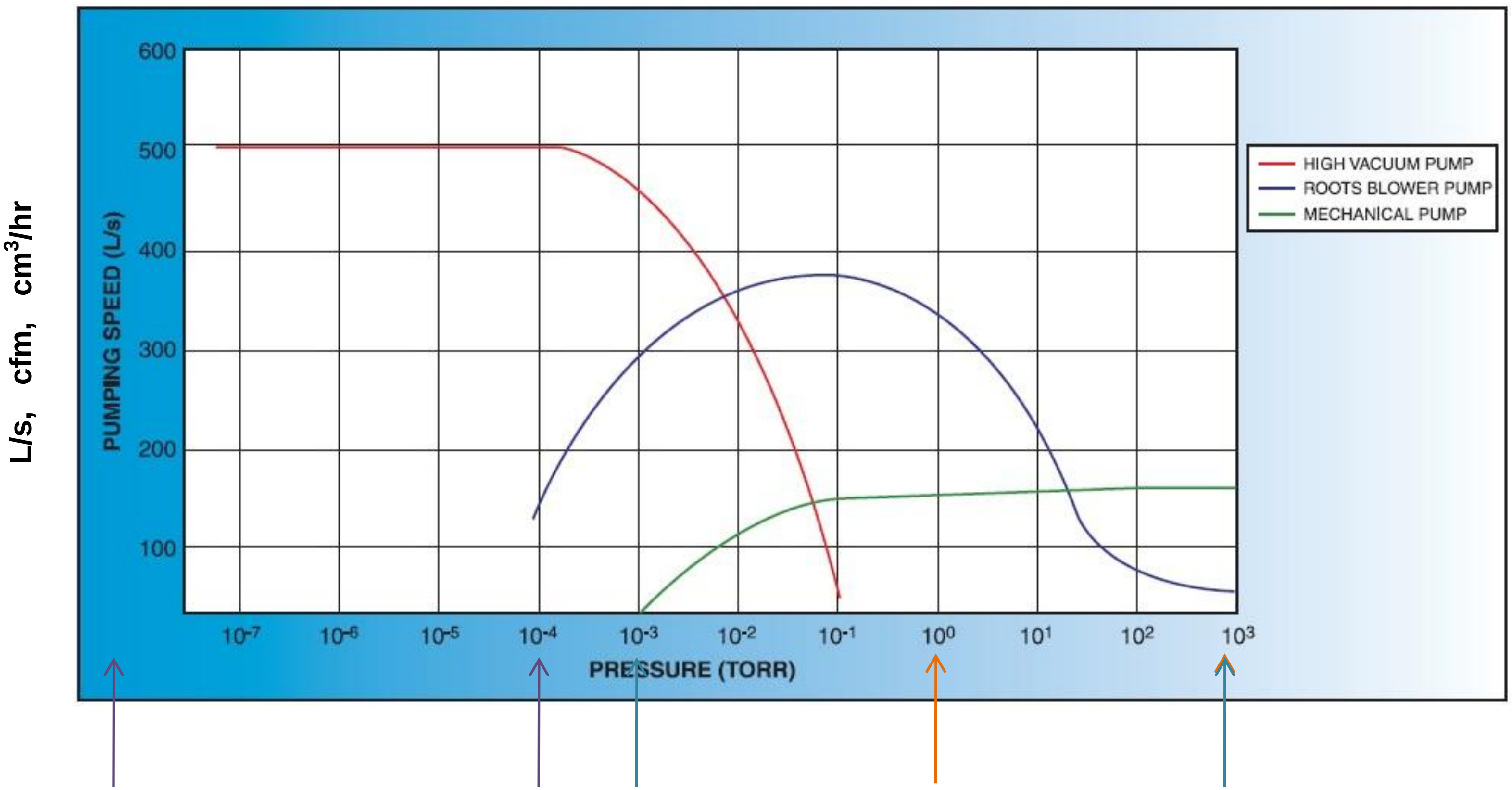
	PAGES	PRESSURE (Torr)
BOURDON (DIAL)		
KJLC BDG 250	7-6	760–1 Torr
PIEZO		
KJLC CPT 100	7-7	1,500–0.75 Torr
KJLC 902	7-8	1,000–0.1 Torr
DIAPHRAGM MANOMETER		
KJLC 1500	7-9	1,500–1 Torr
PIRANI & CONVECTION		
KJLC 947	7-10	1,000–1 x 10^{-3} Torr
KJLC 925C	7-11	760–1 x 10^{-5} Torr
KJLC PPT 100	7-12	750–7.5 x 10^{-5} Torr
KJLC 945	7-13	100–1 x 10^{-4} Torr
KJLC Convectron® Equivalent Series	7-14 to 7-15	1,000–1 x 10^{-4} Torr
CAPACITANCE MANOMETER		
MKS 622 626 627 628 722 (1,000 Torr Full Scale)	7-16 to 7-20	1,000–5 x 10^{-1} Torr
MKS 622 626 722 (500 Torr Full Scale)	7-18, 7-20	500–2.5 x 10^{-2} Torr
MKS 722 (250 Torr Full Scale)	7-20	250–1 x 10^{-1} Torr
MKS 622 626 627 628 722 (100 Torr Full Scale)	7-16 to 7-20	100–5 x 10^{-2} Torr
MKS 622 626 627 628 722 (20 Torr Full Scale)	7-16 to 7-20	20–1 x 10^{-2} Torr
MKS 622 626 627 628 722 (10 Torr Full Scale)	7-16 to 7-20	10–5 x 10^{-3} Torr
MKS 622 626 627 628 722 (2 Torr Full Scale)	7-16 to 7-20	2–1 x 10^{-3} Torr
MKS 622 626 627 628 722 (1 Torr Full Scale)	7-16 to 7-20	1–5 x 10^{-4} Torr
MKS 627 628 (0.25 Torr Full Scale)	7-17, 7-19	2.5 x 10^{-1}–1 x 10^{-4} Torr
MKS 626 627 628 (0.1 Torr Full Scale)	7-16 to 7-19	1 x 10^{-1}–5 x 10^{-5} Torr
MKS 627 628 (0.05 Torr Full Scale)	7-17 to 7-19	5 x 10^{-2}–2.5 x 10^{-5} Torr
MKS 627 (0.02 Torr Full Scale)	7-17, 7-19	2 x 10^{-2}–1 x 10^{-5} Torr
THERMOCOUPLE		

Vacuum pressure ranges and gauges selection guide

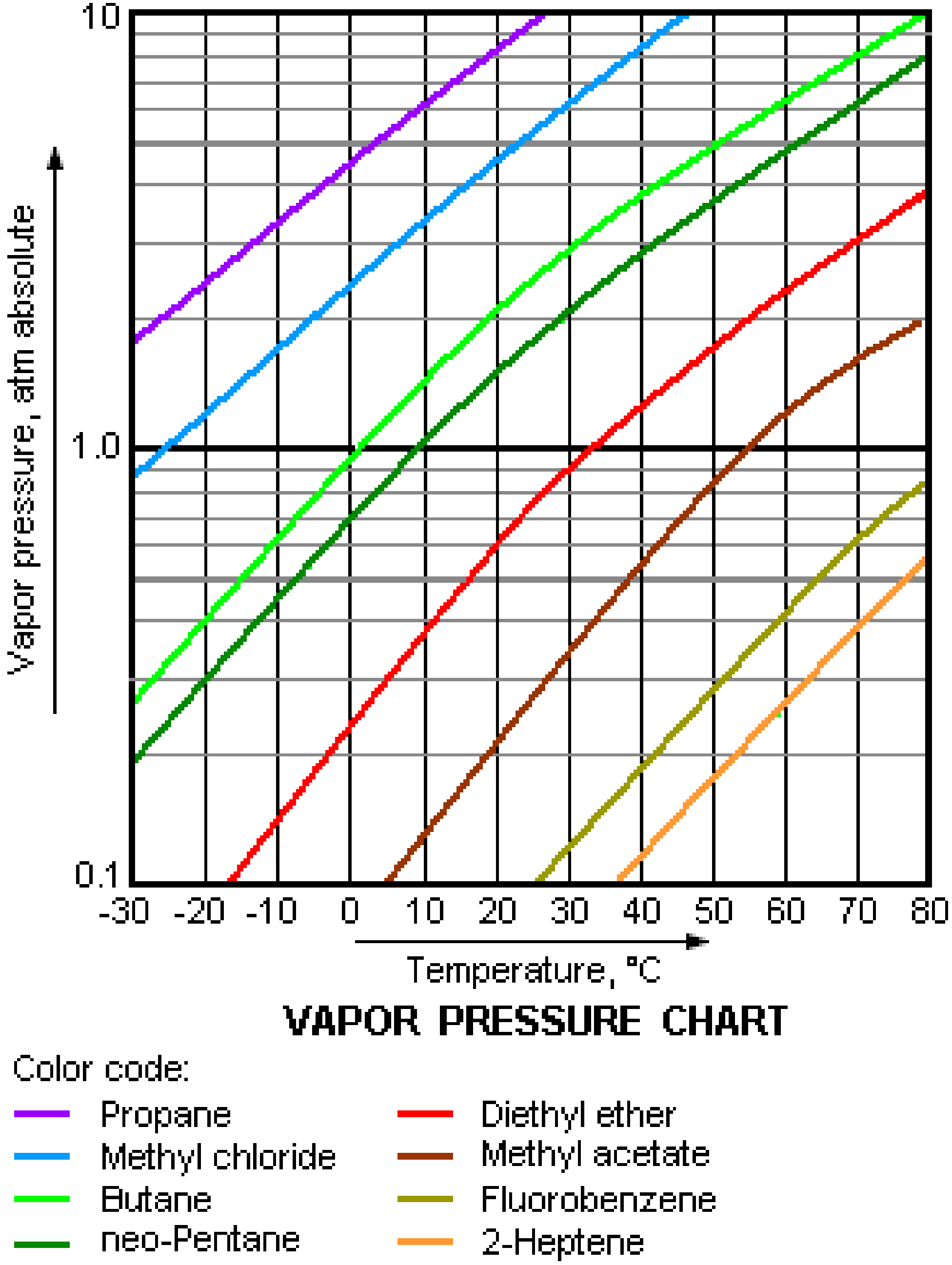


Vacuum ranges

Coarse vacuum:	760 – 1	Torr
Rough vacuum:	760 – 10^{-3}	Torr
High vacuum:	10^{-4} – 10^{-8}	Torr
Ultra-high vacuum:	10^{-9} – 10^{-12}	Torr



Why Vacuum?



Controlled atmosphere

Remove reactive/contaminant gases during fabrication processing.

Long mean-free path

Reduce molecular density and collisions and clear path for source materials

Attain plasma conditions

Constant pressure supporting an ionized gas environment

The **equilibrium vapour pressure** is an indication of a liquid's evaporation rate. It relates to the tendency of particles to escape from the liquid (or a solid). A substance with a high vapour pressure at normal temperatures is often referred to as *volatile*.

Vacuum pumps classification

Gas Transfer versus Gas Capture

Gas transfer pump: these force gas molecules in a preferred direction by positive displacement or momentum exchange. Ultimately, the gas is compressed until slightly above atmospheric pressure when it is ejected into the atmosphere.

Gas capture pump: these immobilize gas molecules on special surfaces within the vacuum system so that the resulting pressure drops at a constant rate generally reaching UHV conditions.

Wet Pump versus Dry Pump

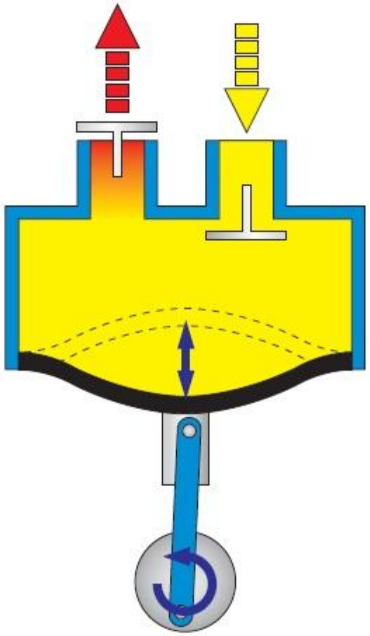
A wet pump uses low vapor pressure oil in the pumping mechanism. A rotary vane pump for example, uses oil to lubricate and seal sliding joints between vanes and casing. So, in any wet pump, oil liquid and vapor coexist in the pumps vacuum volume.

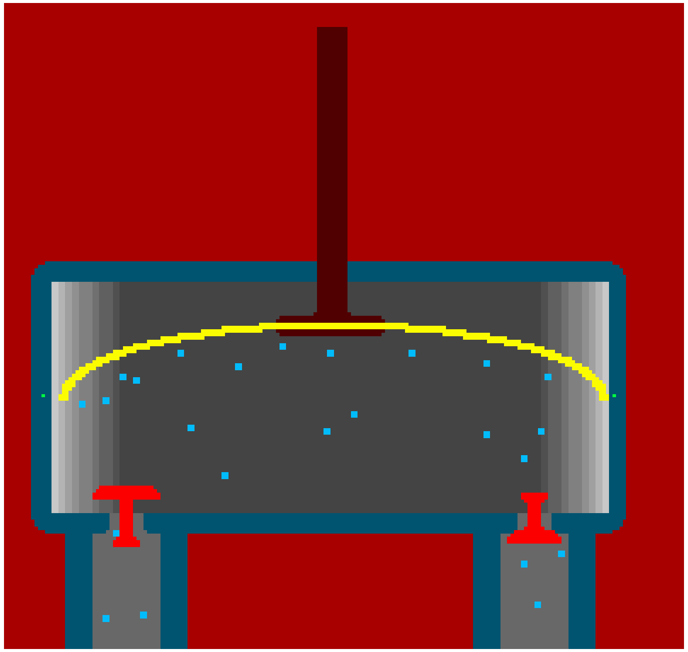
A dry pump has no gas sealing fluid. Some dry pumps may truly have no lubricants while other dry pumps may have lubricated gears/ bearings sealed from the vacuum track by o-rings. For turbo pumps, the pumping mechanism prevents the vapors traveling backwards.

Vacuum pumps classification: **Diaphragm Pump**

Vacuum Level:	760 – 10^{-3} Torr (parallel or series)
Gas Removal Method:	Gas Transfer
Pump Design:	Dry

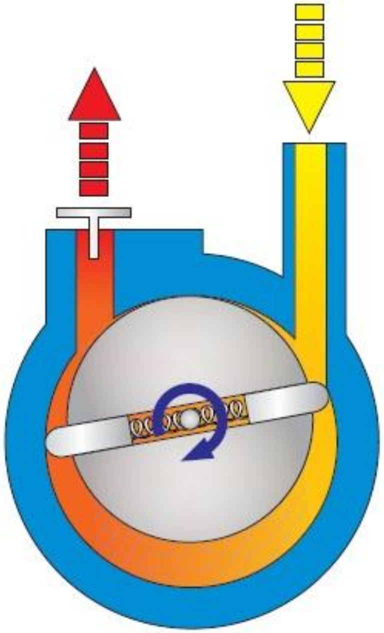
A flexible metal or polymeric diaphragm seals a small volume at one end. At the other end are two spring-loaded valves, one opening when the volume's pressure falls below the "outside" pressure, the other opening when the volume's pressure exceeds the "outside" pressure. A cam on a motor shaft rapidly flexes the diaphragm, causing gas transfer in one valve and out the other. Diaphragm pumps often have two stages in series—to produce a lower vacuum, or in parallel, to produce a higher pumping speed. In general, diaphragm pumps have low pumping speeds (<10 cfm) and produce a poor ultimate vacuum (1 Torr to 10 Torr for single stage pump).





Vacuum Level:	760 – 1 to 760 – 10^{-3} Torr (design dependent)
Gas Removal Method:	Gas Transfer
Pump Design:	Oil-Sealed (wet)

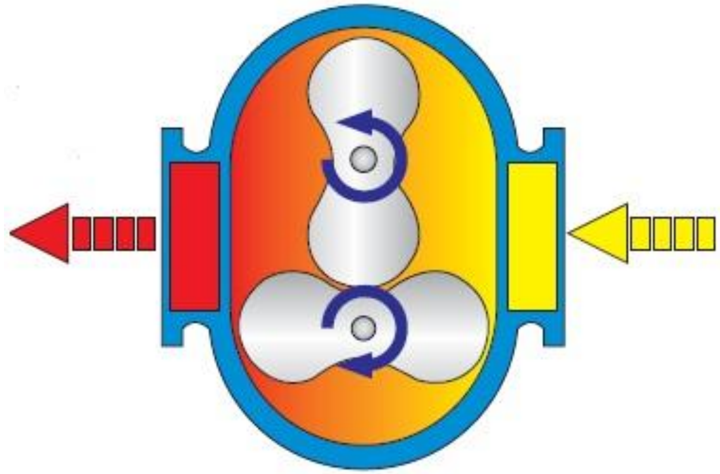
In all rotary vane pumps, **gas from the chamber enters the inlet port and is trapped between the rotor vanes and the pump body**. The eccentrically mounted rotor compresses the gas and sweeps it toward the discharge port. When gas pressure exceeds atmospheric, the exhaust valve opens and gas is expelled. Oil is used as a lubricant, coolant, and gas sealant for the vanes. Single stage rough rotary vane pumps have ultimate pressures around 10-2 Torr range while two stage rough vane pumps reach 10-3 Torr. Pumping speeds vary from 1–650 cfm, depending on whether the pump is a coarse vane or rough vane pump.



Vacuum pumps classification: **Roots (Rotary Lobe) Pump**

Vacuum Level:	$760 – 10^{-3}$ Torr
Gas Removal Method:	Gas Transfer
Pump Design:	Oil-Sealed (wet)

The roots (or rotary lobe) action is excellent for moving huge quantities of gas at pressures between 0.01–10 Torr. In cross-section, **the two lobes are figure-eights that mesh without touching and counter-rotate to continuously transfer gas in one direction through the pump**. The compression ratio (outlet pressure divided by inlet pressure) is between 10 and 100, and single stage lobe pumps must be backed by rotary vane or piston pumps. The compression ratio also varies with the molecular weight of the gas, the higher velocities of the light gases allowing them to return more easily to the chamber. The pump's ultimate pressure is typically 10-4 Torr when backed by a pump pulling 10-3 Torr. Roots pumps handle very high gas loads and will cycle large batch process chambers quickly.



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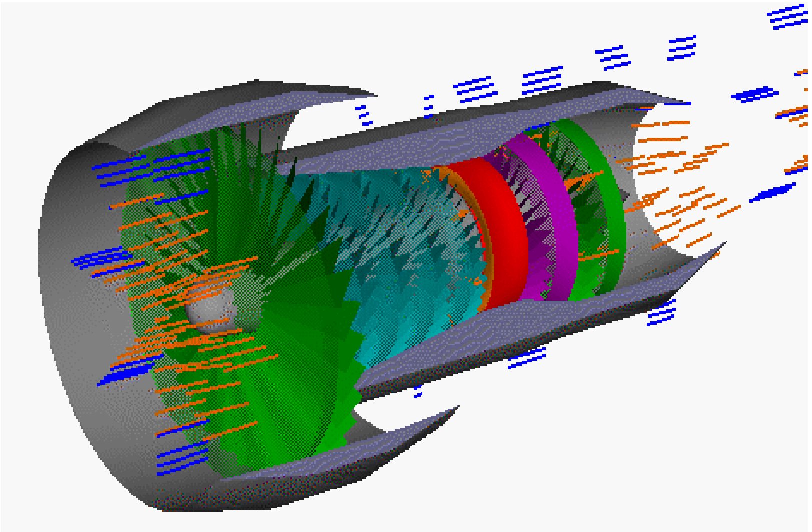
Vacuum pumps classification: **Turbomolecular Pump**

Vacuum Level:	$10^{-4} – 10^{-8}$ to $10^{-9} – 10^{-12}$ Torr (design dependent)
Gas Removal Method:	Gas Transfer
Pump Design:	Dry

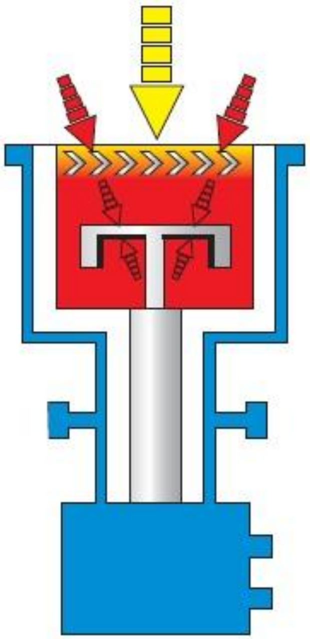
Turbo pumps resemble jet engines. **A stack of rotors, each having multiple, angled blades, rotate at very high speeds between a stack of stators. Gas molecules randomly entering the mechanism and colliding with the underside of the spinning rotor blade are given momentum toward the pump's exhaust.** Turbo pumping speeds range from 50L/s to 3,500L/s for normal commercial pumps. Correctly operated and vented, the turbo mechanism prevents vapor backstreaming from the greased rotor bearings. For truly dry chambers, a turbo with magnetically levitated bearings backed by a dry mechanical pump are used. Turbo pumps are used in all vacuum applications between 10^{-4} and 10^{-10} Torr and are not used on dusty processes or where HF vibration might be a problem.



Vacuum pumps classification: **Cryogenic Pump**

Vacuum Level:	$10^{-4} – 10^{-8}$ to $10^{-9} – 10^{-12}$ Torr (design dependent)
Gas Removal Method:	Gas Capture
Pump Design:	Dry

Cryogenic pumps (commonly called cryopumps) present three surfaces. **An outer surface, which is held at 80K and includes an optically opaque chevron baffle, pumps mostly water vapor. It surrounds (and thermally insulates) an inverted cup-shaped inner surface held at 15K to 20K that traps the common atmospheric gases**. The underside of the cup is coated with activated carbon and provides hydrogen pumping. All surfaces are cooled by a closed cycle helium cryocompressor attached to the pump by insulated tubes. Cryopumps are particularly suited to pumping atmospheric gases and high melting point vapors (H_2O) in the 10^{-6} to 10^{-9} Torr range. The major disadvantages are poor helium pumping and vibration transmitted from the compressor.



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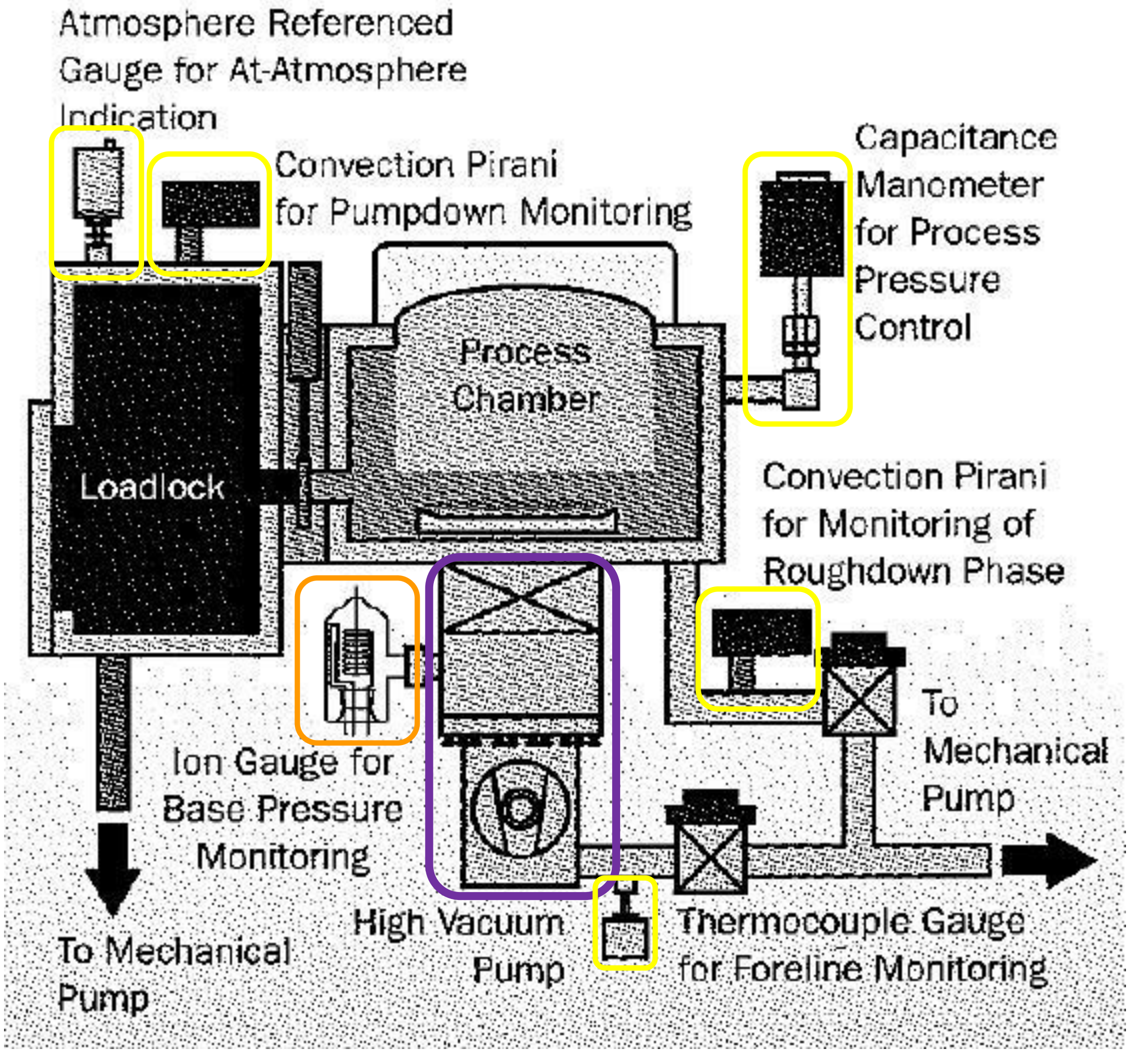
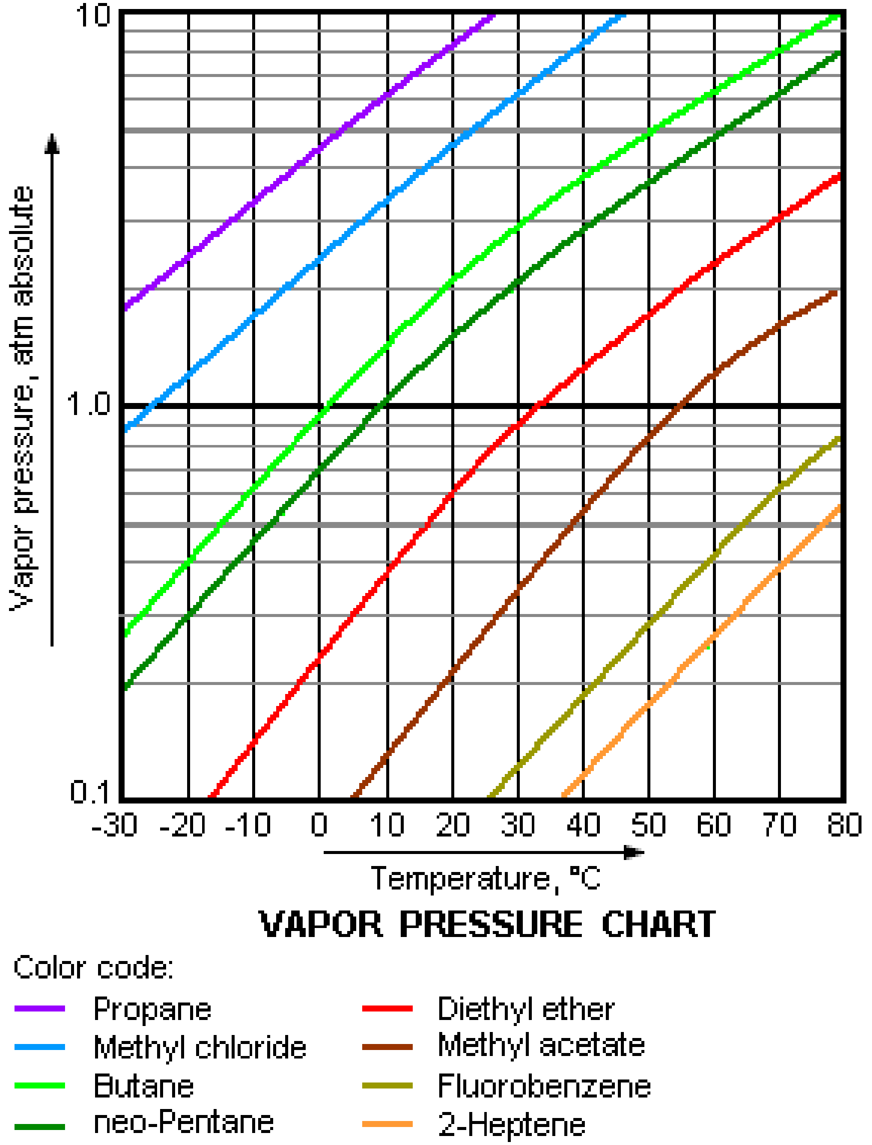
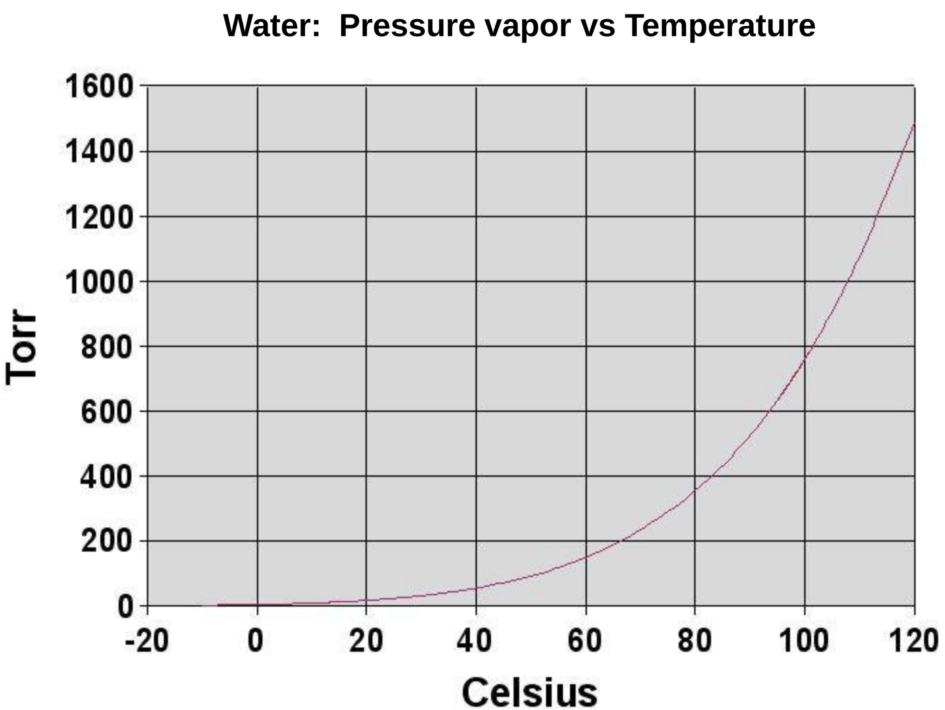
Vacuum system with a variety of gauges for vacuum measurement



Equilibrium Vapor Pressure

The **equilibrium vapor pressure** is the pressure of a vapor in thermodynamic equilibrium with its condensed phases in a closed bottle. **The EVP states where as many molecules are condensing as are vaporizing**.



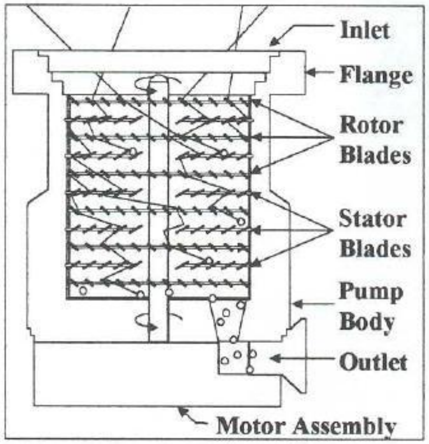


	10^{-10}	10^{-7}	10^{-4}	10^{-3}
Water	130K	153K	185K	198K
Argon	23.7K	28.6K	35.9K	39.2K

At lower density and pressure, molecules no longer condense and vaporize: **adsorption and desorption processes occurring at the chamber surface develop**.

Turbopump vs Cryopump. Pumping Speed Performance

Vacuum Pumps - Turbopump



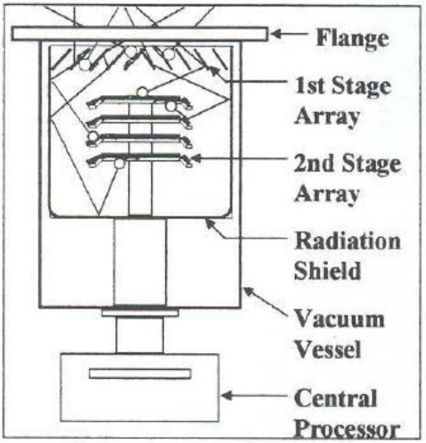
Characteristics:

- Relatively clean and simple operation
- Fast start-up
- Pumping speed about equal for all gases
- Low water speed
- Low compression ratio for light gases
- Multiple orientations
- Bearing maintenance
- Susceptible to contamination
- High cost for liters/sec

Pumping speeds [liters/sec]

	4”	6”	8”	10”	16”
Water	200	400	900	1300	4000
Air (N_2)	68	280	650	1000	3400
Hydrogen	45	210	510	1150	3200
Argon	67	235	462	840	2856

Vacuum Pumps - Cryopump



Characteristics:

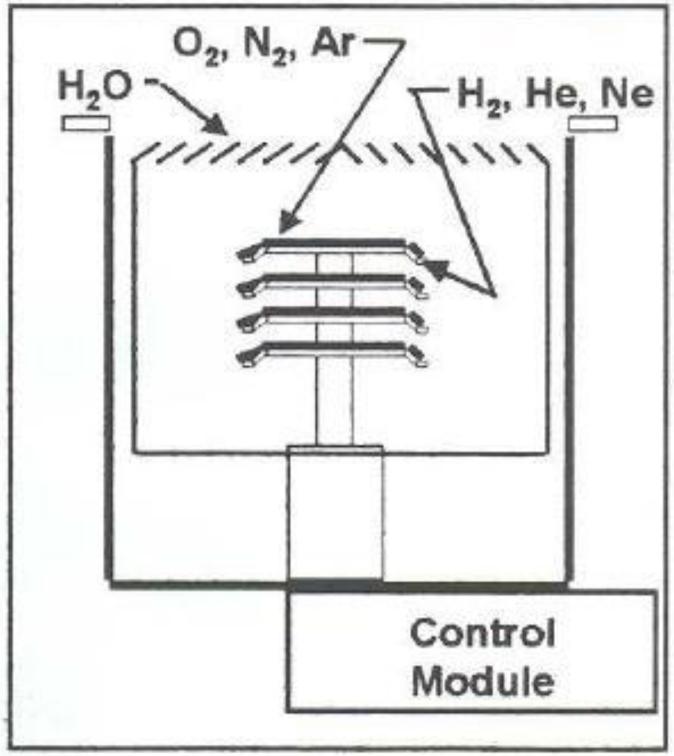
- Cleanest high vacuum pump
- No fluids, lubricants, or moving parts
- High crossover capability minimizes backstreaming
- Highest pumping speeds
- Tailorable pumping speeds
- Fast system pumpdown
- Limited He capacity
- Regeneration cycles
- Thermal shielding

Pumping speeds [liters/sec]

	4”	8”	8”(F)	10”	16”
Water	1100	4000	4000	9000	16000
Air (N_2)	370	1500	1500	3000	6000
Hydrogen	370	2500	2500	5000	12000
Argon	310	1200	1200	2500	5000

Cryopump Concept

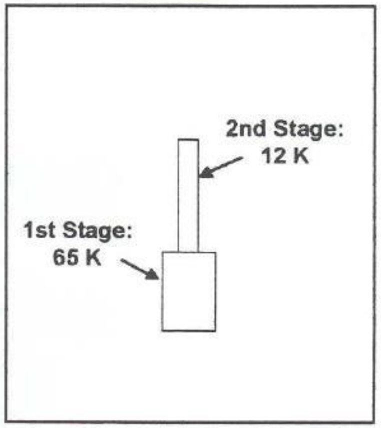
- Cryopumps pump different gases at different places at different temperatures.
- Array spacing provides molecular "Optical Path"
- Necessary temperatures are maintained with an integrated control module.



Cryopump Fundamentals

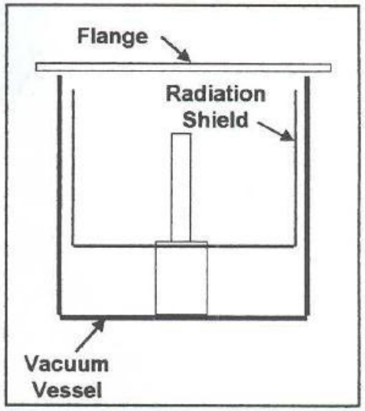
System Design - Cryopump Components

- A cryopump is built around the cold-head.
  - Creates temperatures needed to condense and adsorb gases
  - Two stages for different temperatures
- Achieves these temperatures by the expansion of helium.



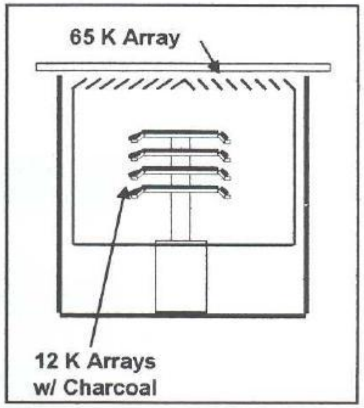
System Design - Cryopump Components

- A radiation shield is attached to the 1st stage of the cold-head.
  - Copper for conductivity
  - Nickel plating for protection
- The vacuum vessel isolates the cryopump.
- The inlet flange attaches to the chamber.



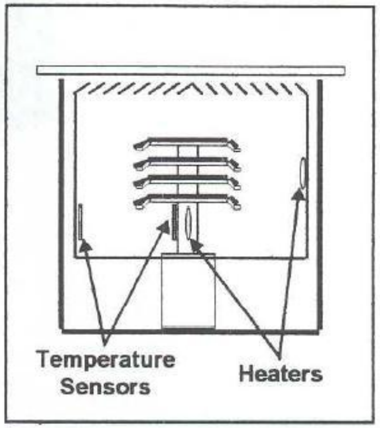
System Design - Cryopump Components

- The 1st stage (65 K) array is attached to the radiation shield.
  - Condenses water vapor
- A series of arrays with charcoal are attached to the 2nd stage (12 K) of the cold-head.
  - Condenses O_2, N_2, Ar
  - Adsorbs H_2, He, Ne



System Design - Cryopump Components

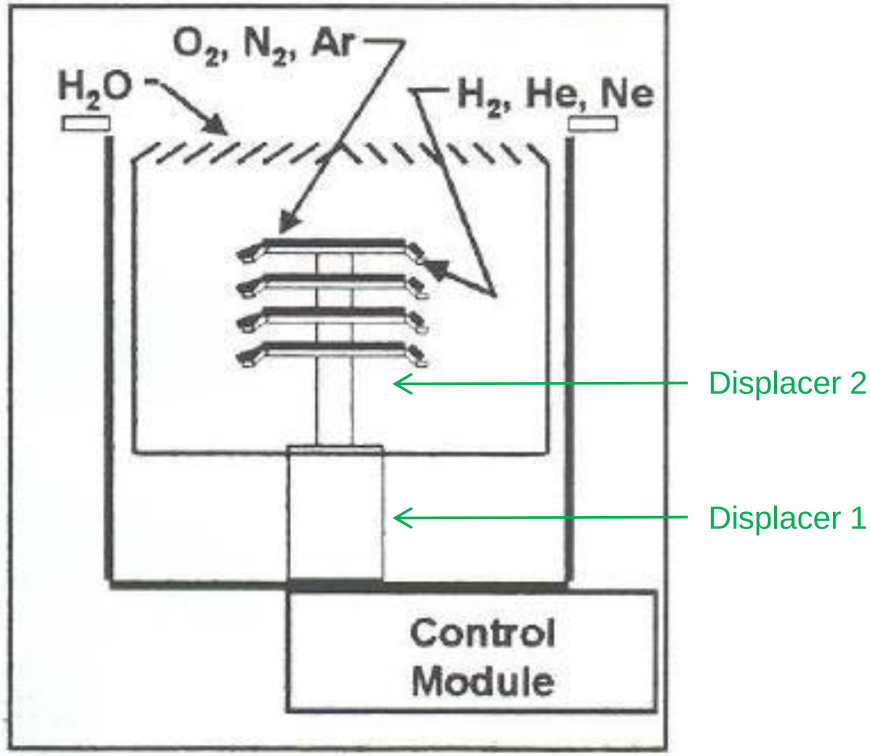
- Both the 1st and 2nd stages have an attached heater and temperature sensor to maintain optimum control and operation of the pumping process.



Cryopump functions are **monitored and controlled** by the control module interfaced to the sensors and heaters.

Cryopump Concept

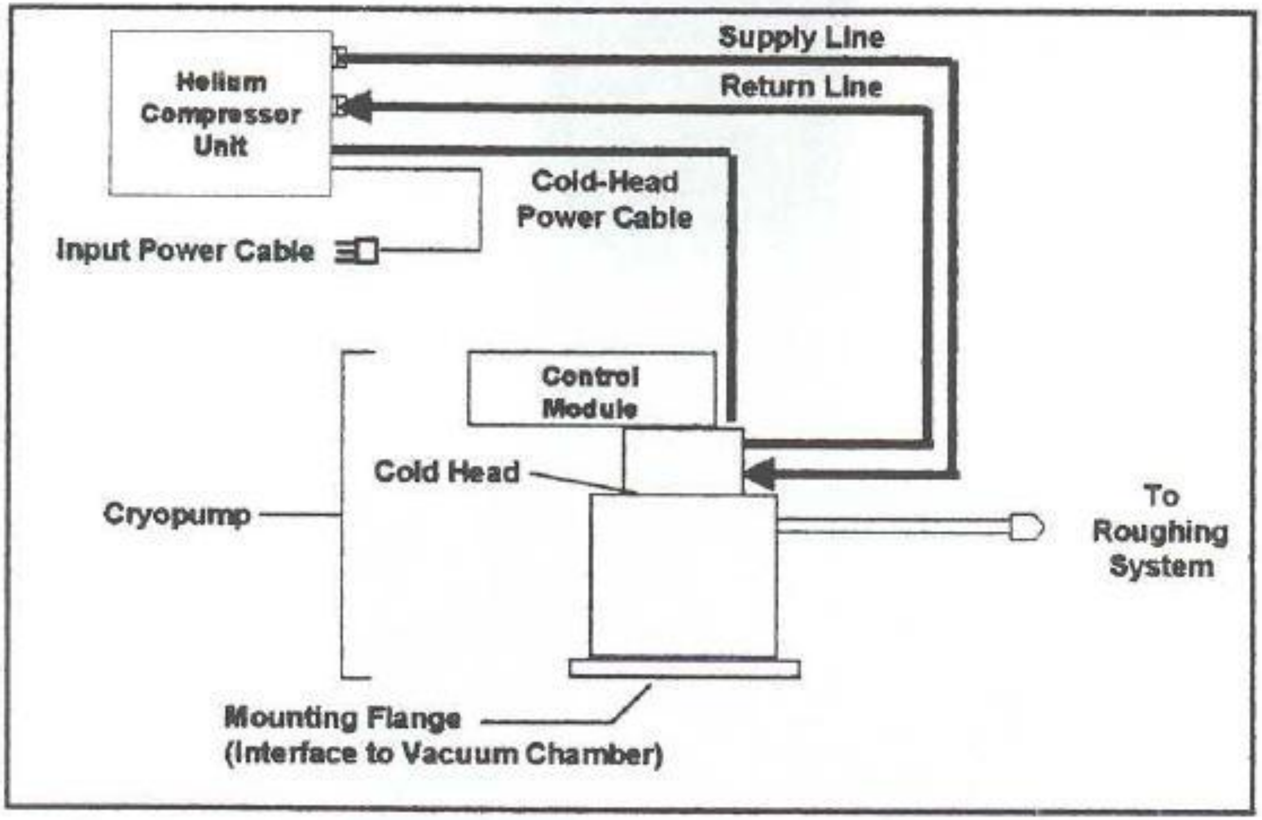
- **Cryopumps pump different gases at different places at different temperatures.**
- **Array spacing provides molecular "Optical Path"**
- **Necessary temperatures are maintained with an integrated control module.**

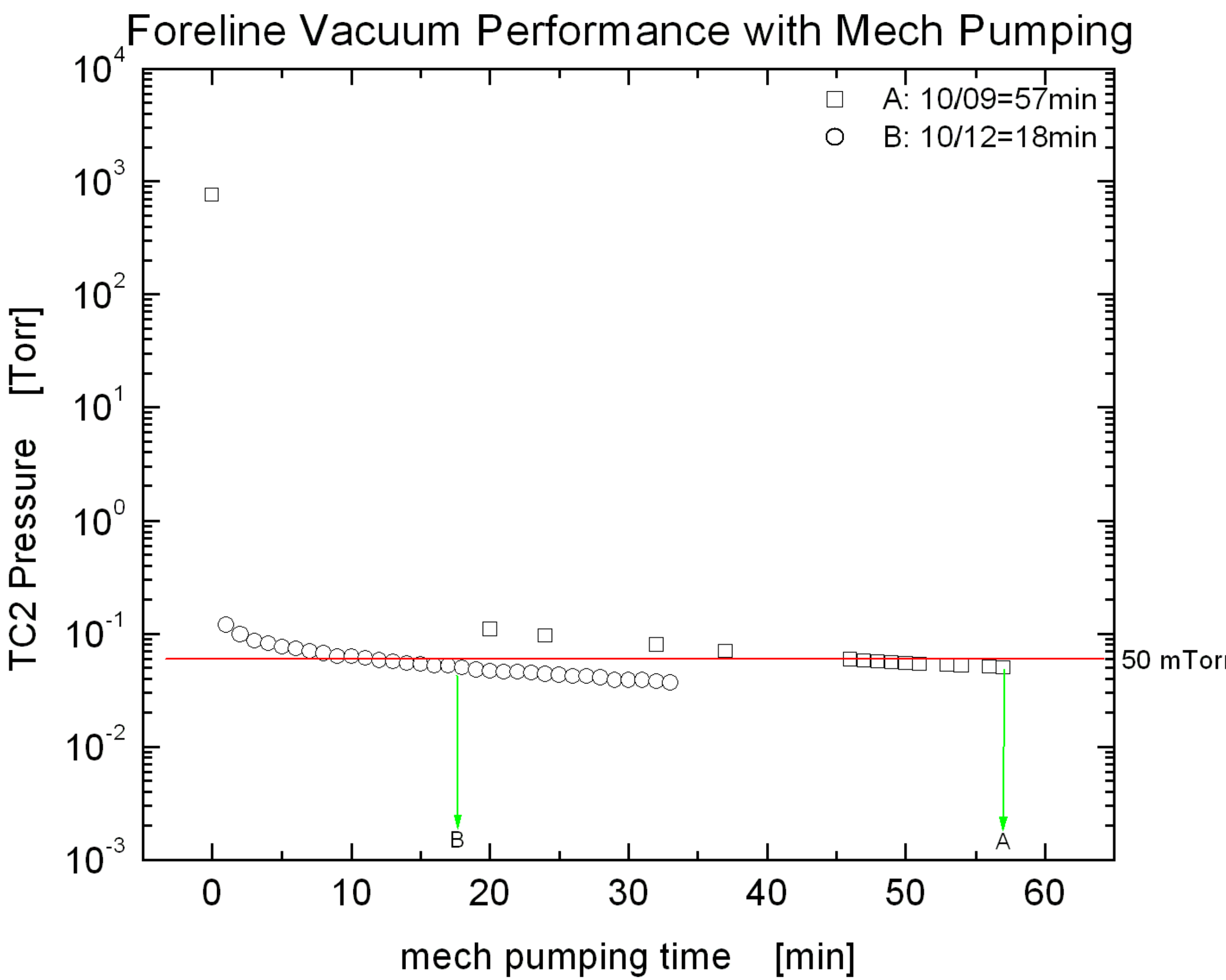


Video: Cryopump Testing

Flash: Cryopump Fundamentals

System Design - System Overview




Foreline Vacuum Performance with Mech Pumping
A: 10/09=57min
B: 10/12=18min
50 mTorr
B
A
TC2 Pressure [Torr]
mech pumping time [min]
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
10
20
30
40
50
60

The objective of regenerating a cryopump is to remove the captured gases from the pump and **restore its pumping capacity**.

Flash: Cryopump Fundamentals

Water Pumping

Water vapor capture is dependent on surface temperature and pressure.

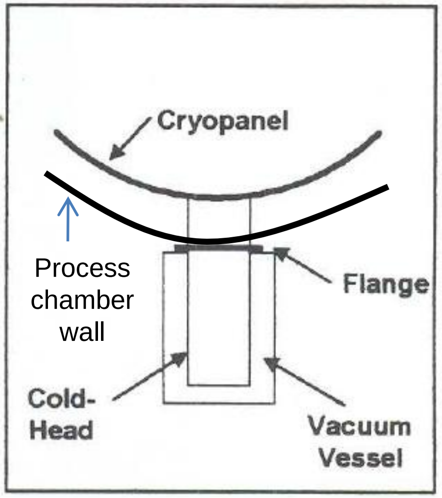
Temperature		Water Vapor Partial Pressure
113 K	(-160° C)	10^{-13} Torr
124 K	(-149° C)	10^{-11} Torr
137 K	(-136° C)	10^{-9} Torr
153 K	(-120° C)	10^{-7} Torr
173 K	(-100° C)	10^{-5} Torr
199 K	(-74° C)	10^{-3} Torr
233 K	(-40° C)	10^{-1} Torr
284 K	(10° C)	10^{1} Torr

Water Pumping Speed Comparison

Port Size	Typical Turbopump (l/s)	On-Board Waterpump (l/s)
4”	200	1,100
6”	400	2,500
8”	900	4,000
10”	1,300	7,000
16”	4,000	16,000

System Design - Waterpump Components

- A cryopanel is attached to the cold-head.
- The vacuum vessel isolates the refrigerator from the surroundings.
- The flange attaches the waterpump to the process chamber.

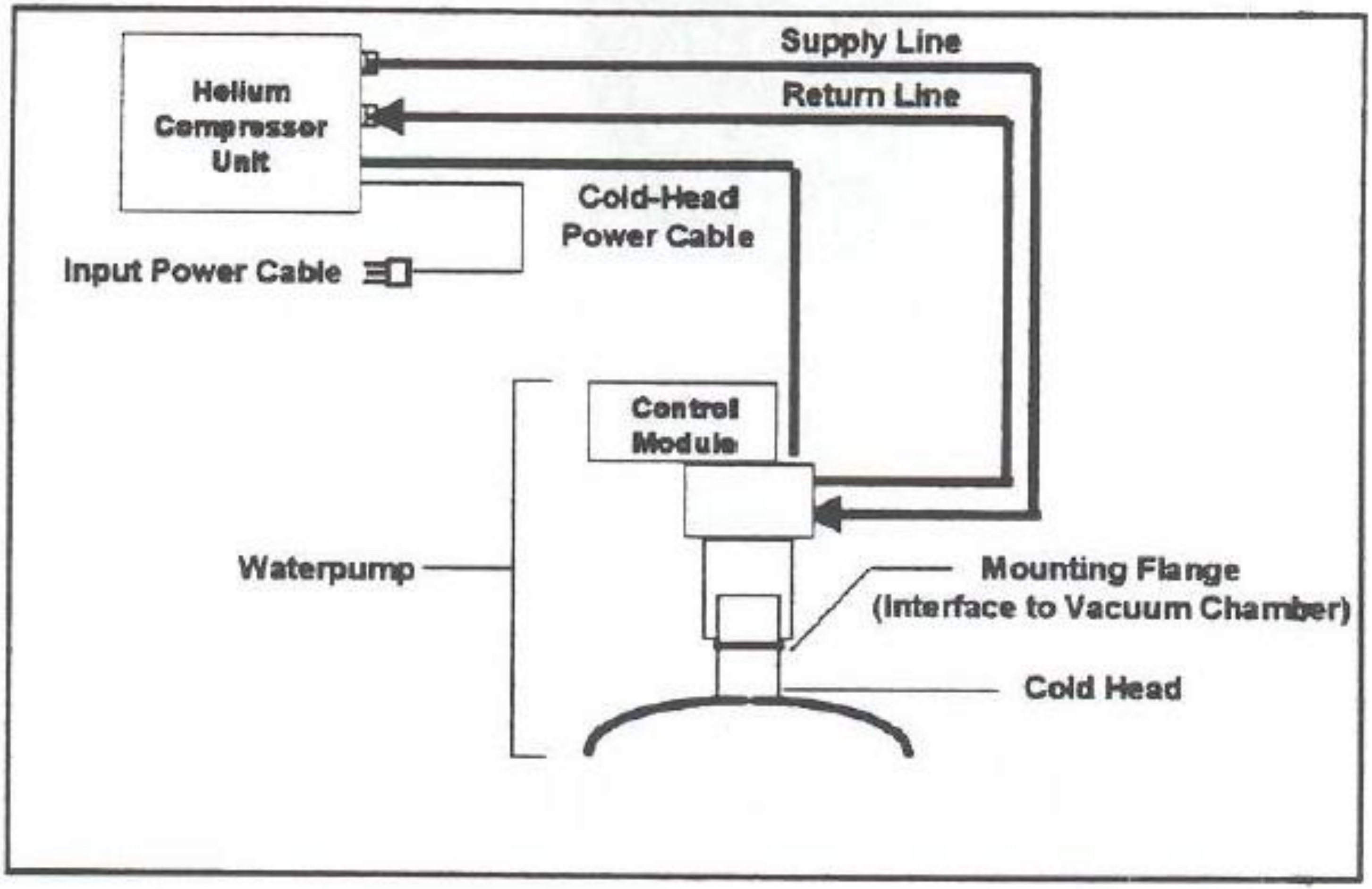


In Situ Configuration

•An In Situ waterpump has its cryopanel inside the process chamber.
Cryopanel shape conforms the chamber.

•Waterpump functions and temperature are monitored/controlled with a control module interfaced to the sensor and heater.

System Design - System Overview



Cryopump Fundamentals

System Design - Helium Curcuit: