Vacuum technology
Generating and gauging fore vacuum

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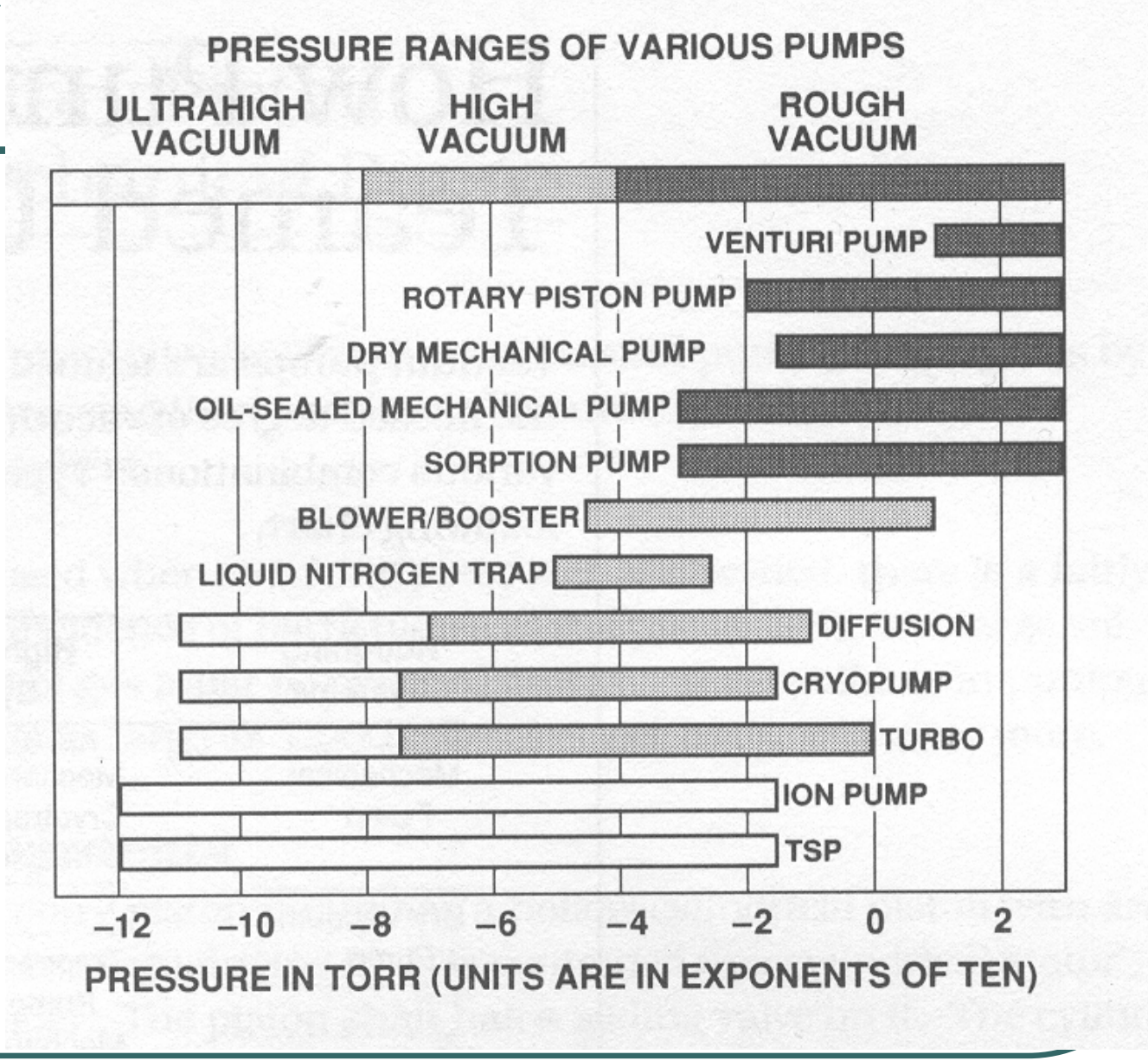
Fore vacuum

- 1000 mbar - 0.001 mbar
- 1000 mbar - 1 mbar: viscous (in general laminar) flow. Heat conduction and viscosity are independent of pressure (heat transport by convection has pressure dependence). Rough vacuum.
Mean free path $7*10^{-8}$ m - $7*10^{-5}$ m.
- 1 mbar - 0.001 mbar: transition range to high vacuum. Heat conduction and viscosity are dependent of pressure (and gas!). Backstream against main flow of gas can be important. Fine vacuum.
Mean free path $7*10^{-5}$ m - $7*10^{-2}$ m.

Main fore vacuum pump types

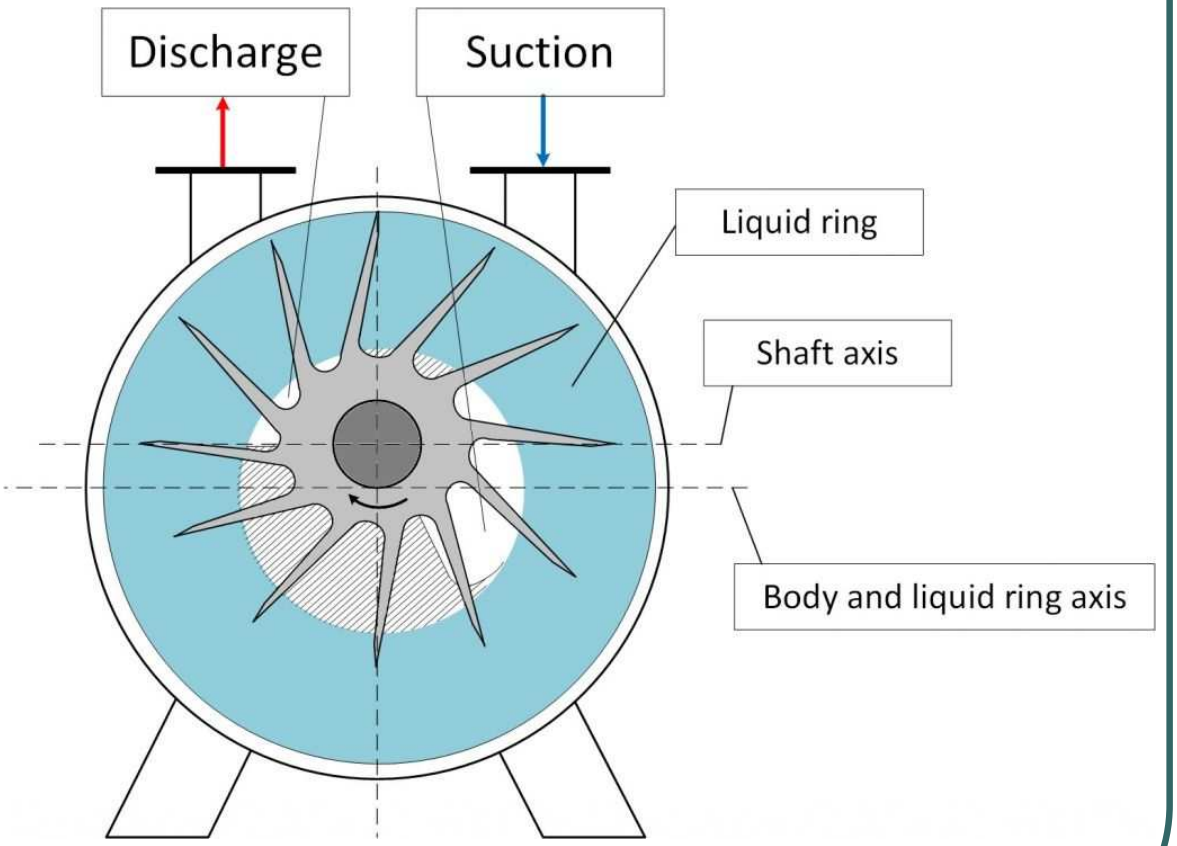
- Positive displacement pumps
  - Liquid ring pumps
  - Oil pumps (rotary vane, rotary piston)
  - Oil-free pumps (piston, membrane, Roots, scroll)
- Other pumps
  - Sorption pump
  - Bernoulli-principle and impulse-transmittance pumps (ejector, water jet aspiration, Venturi)

Working range of pumps

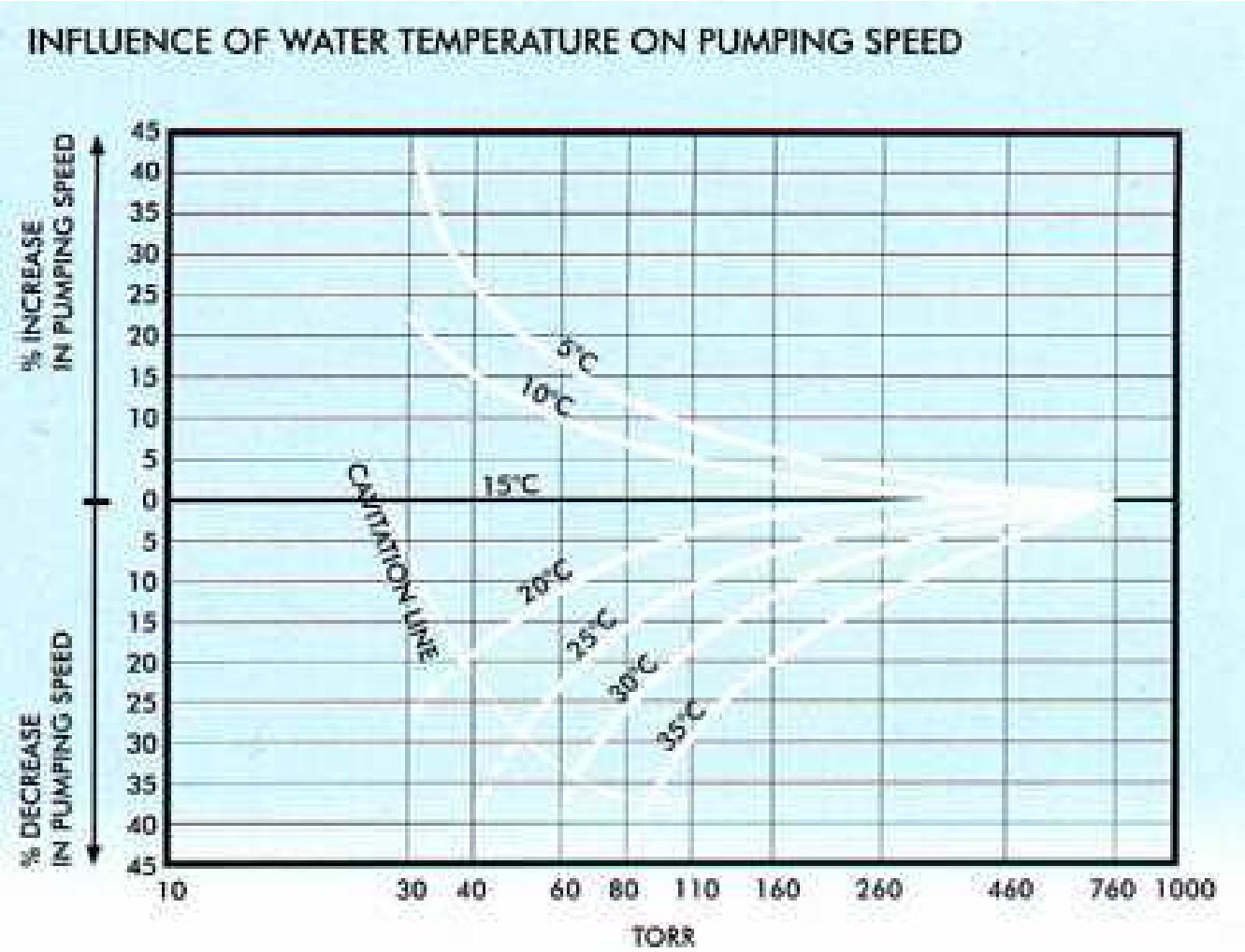


Liquid ring pump

- Simple, sturdy, high capacity
- Good at high amount of condensables (water vapor)
- Water 20 tor (15 °C), spec. oil to 0.1 tor), exhaust pressure to 3 bar
- Liquid should be cooled
- Cavitation!
- Precondenser increase capacity
- Fore vacuum for Roots pump



Liquid ring pump



Rotary vane pump

- The „work horse”
- Pumping speed 1-300 m^3/s
- End pressure 0.1 mbar (one stage) - 0.001 mbar (two stage)
- Older ones with power belt drive (tension!), new ones with direct drive coupling
- 10000* compression

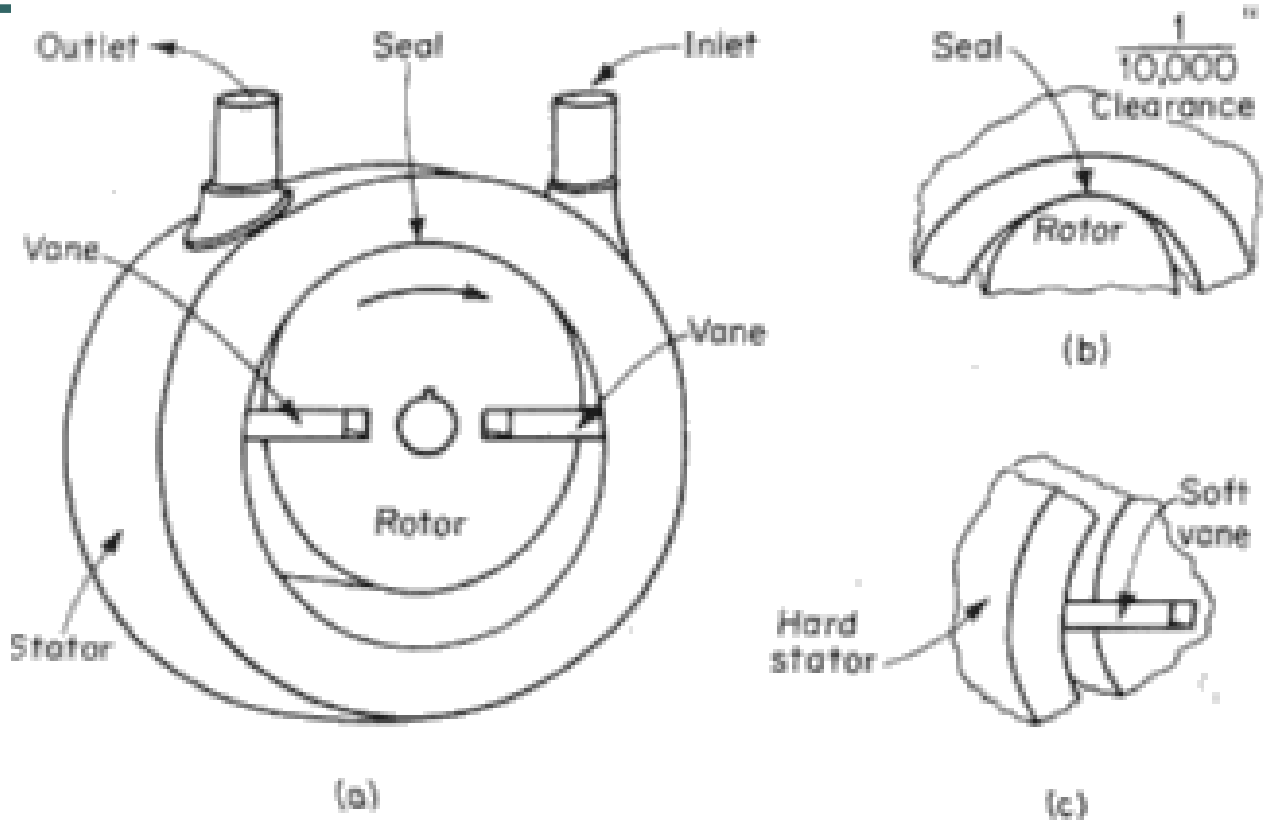
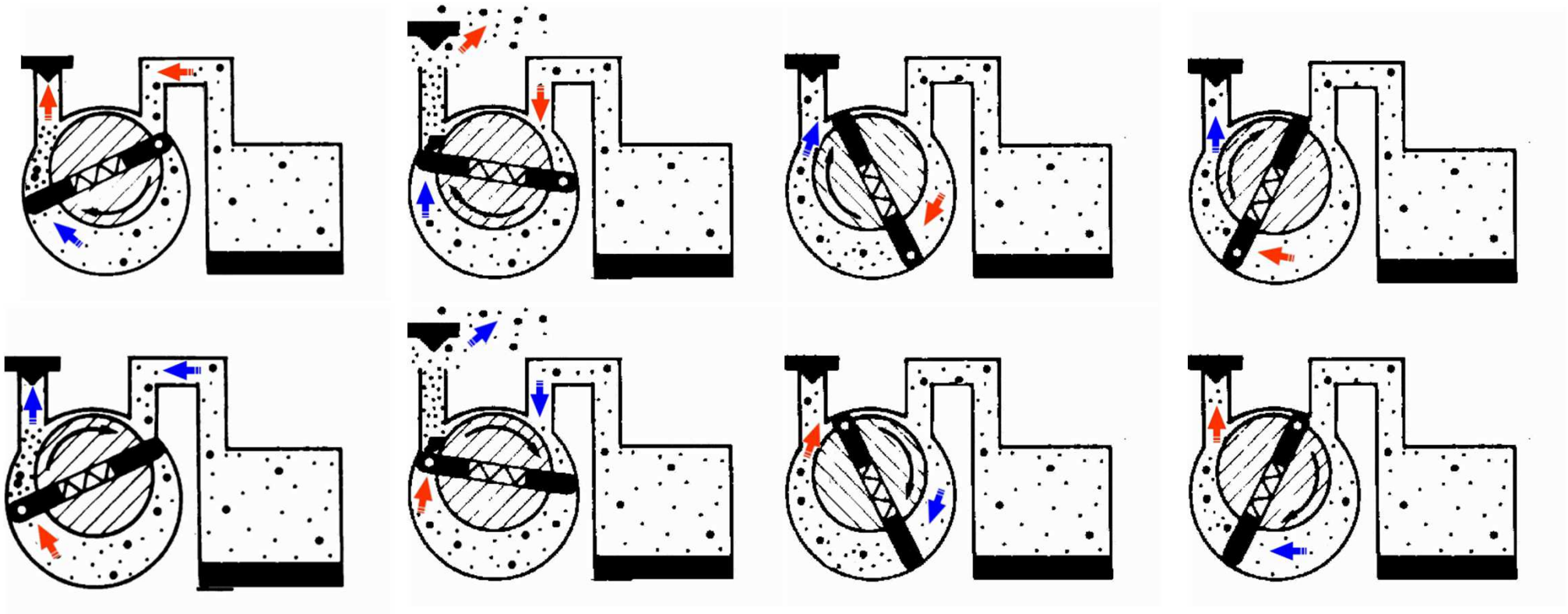
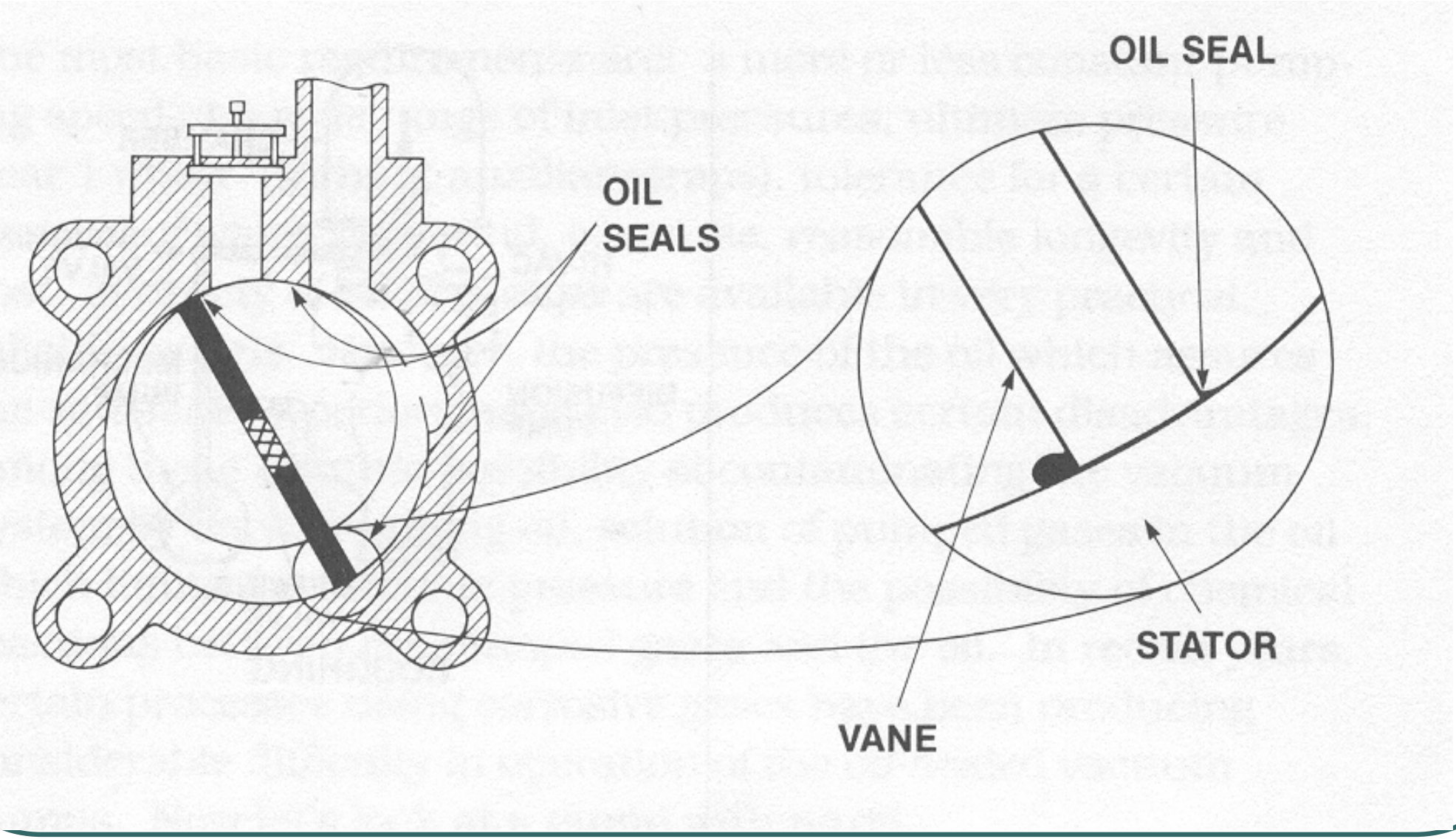


Fig. 4.1 Vane-type mechanical pump: (*a*) diagram of the movement; (*b*) view showing seal; (*c*) view showing vane construction. (*Sargent-Welch Scientific Co., Skokie, Ill.*)

Rotary vane pump



Rotary vane pump



Rotary vane pump

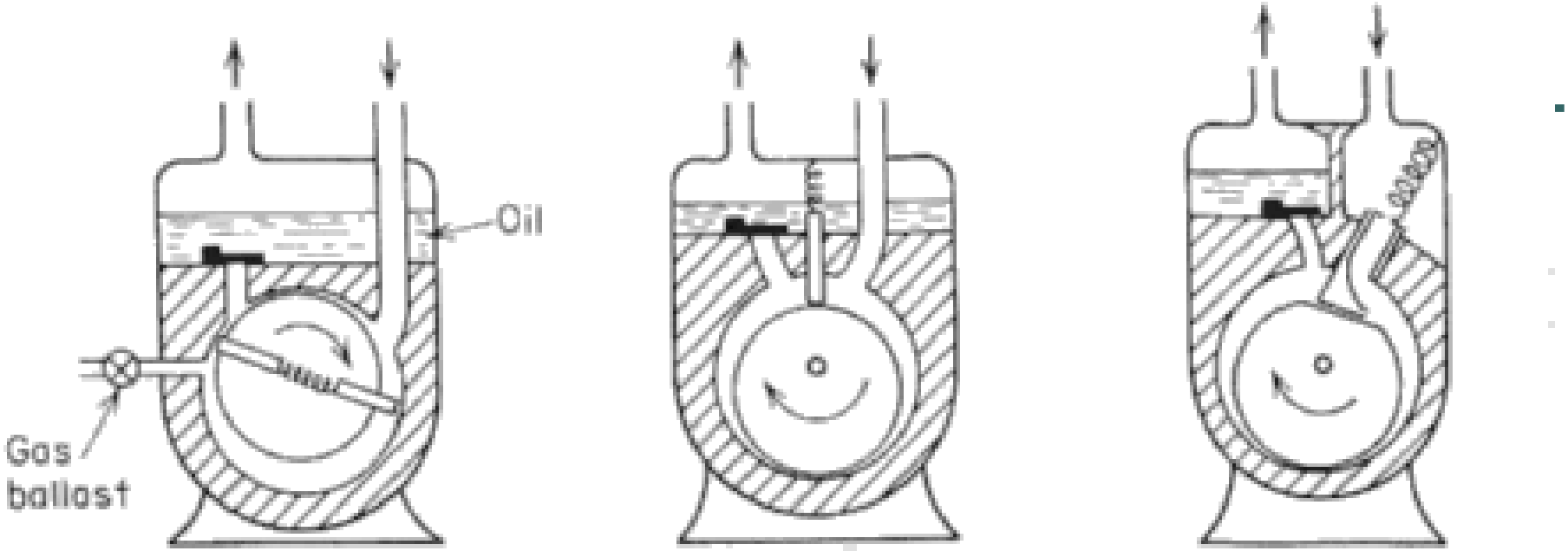
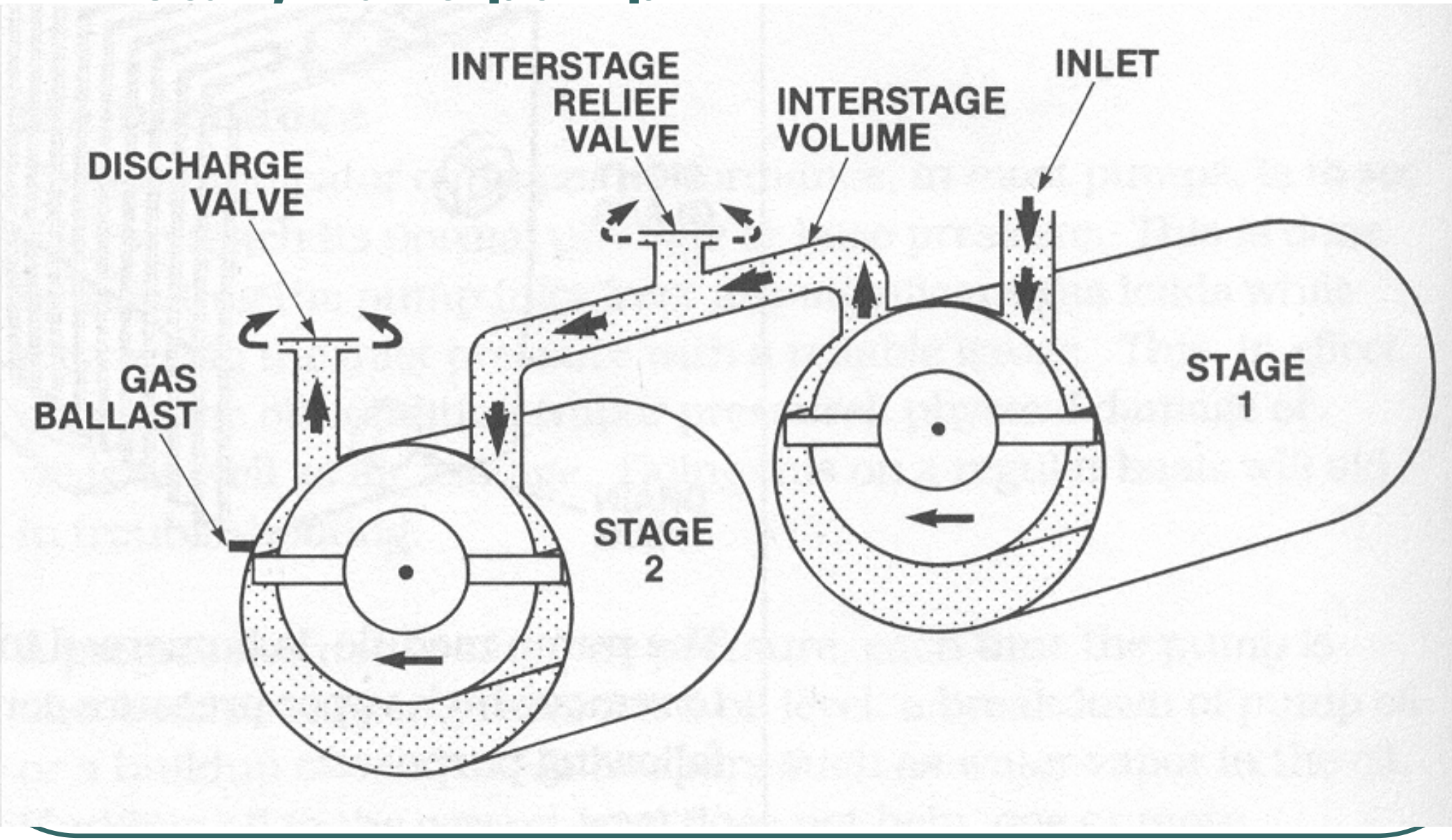


Fig. 6.2. Internal-vane, external-vane, and plunger-type rotary vacuum pumps. It will be noted that the internal-vane pump involves a rotor concentric with the drive shaft, but which is off-center with respect to the stator. By contrast, the external-vane and rotary-plunger pumps have a rotor which is asymmetric with respect to the shaft; however, the shaft is centered in the stator. All three involve close tolerances, so the high-vacuum performance is impaired by particles of dirt or corrosive gases. Some pumps are partially constructed from soft die-cast metal, which is eroded by mercury. Special corrosion-resistant pumps and inert flourinated pumps are used in the semiconductor industry.

Rotary vane pump



Rotary vane pump

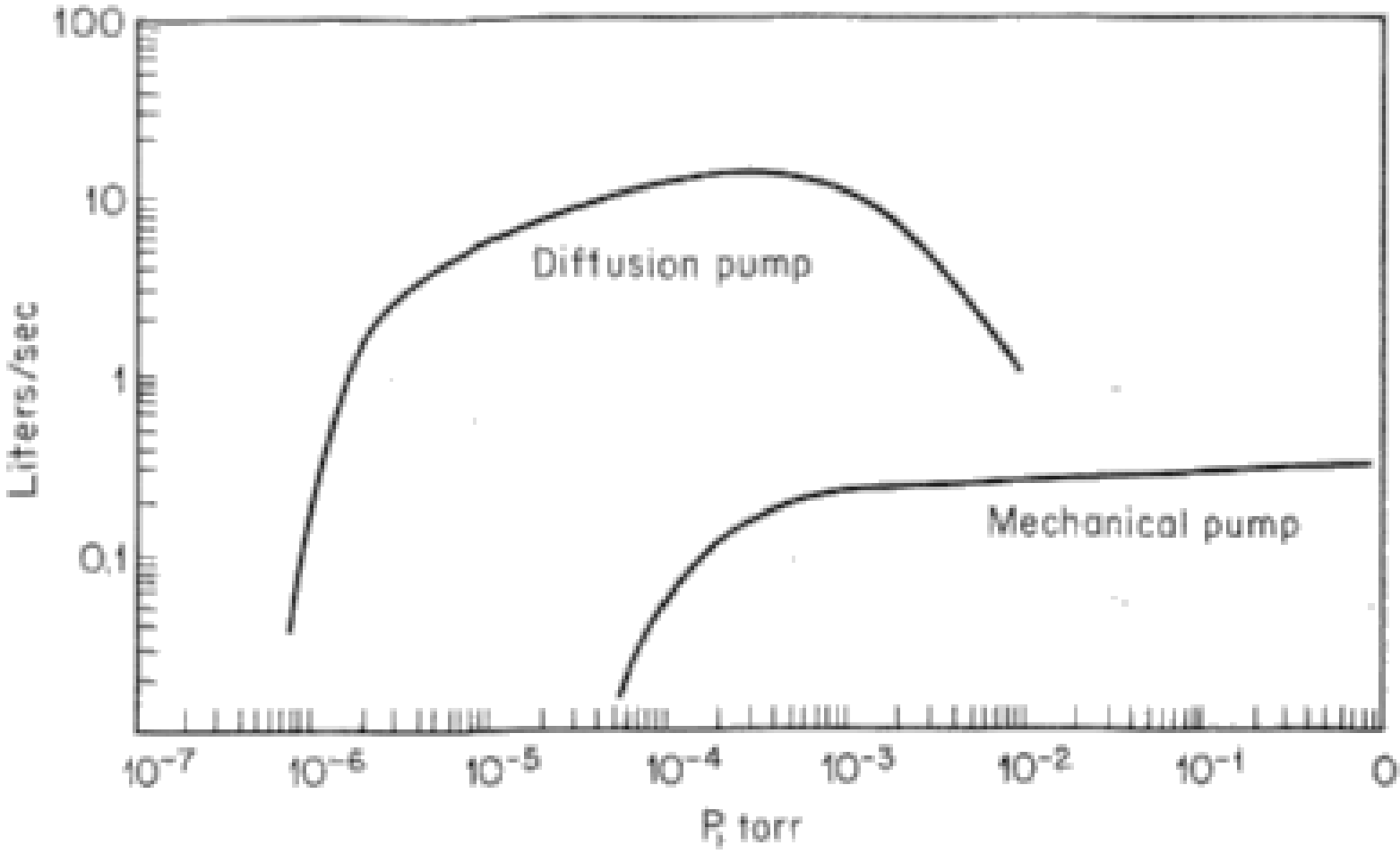
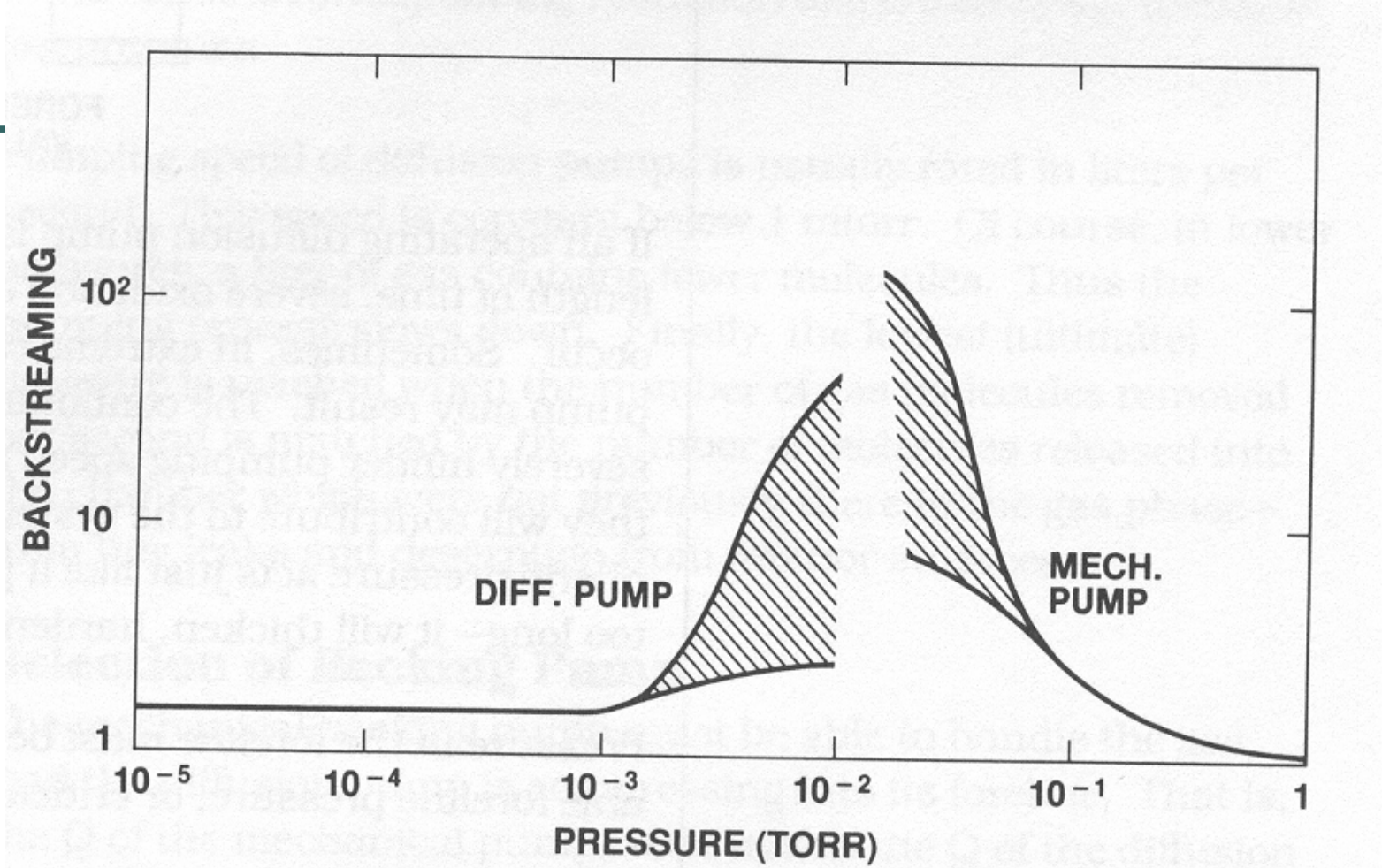


Fig. 6.3. Comparison of the pumping speed of a typical two-stage mechanical pump with a single-stage diffusion pump.

Rotary vane pump



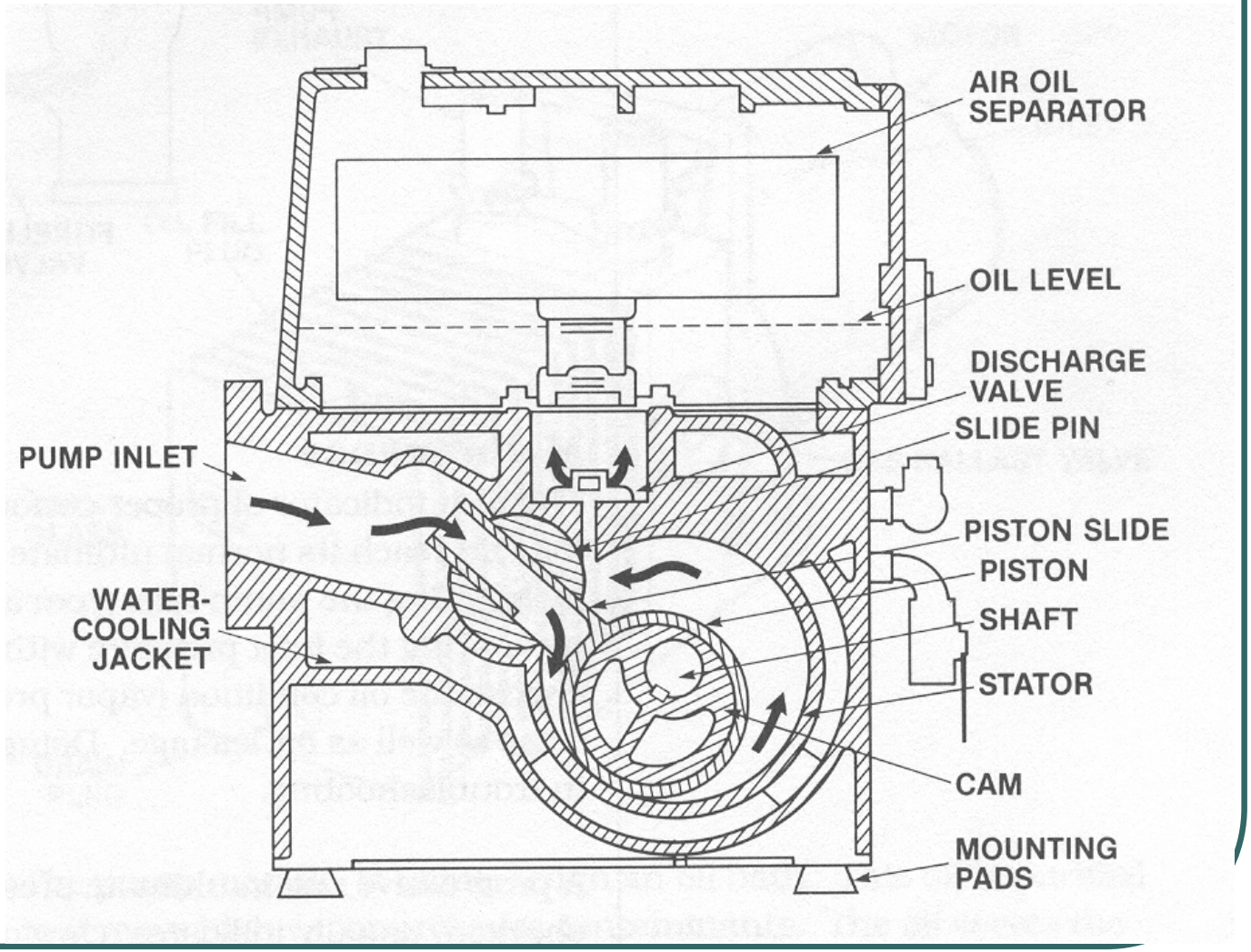
PUMPING AND LUBRICATION FLUID BACKSTREAMING
IN THE TRANSITION ZONE
BETWEEN DIFFUSION AND MECHANICAL PUMPS

Rotary vane pump
Need-to-knows in nutshell

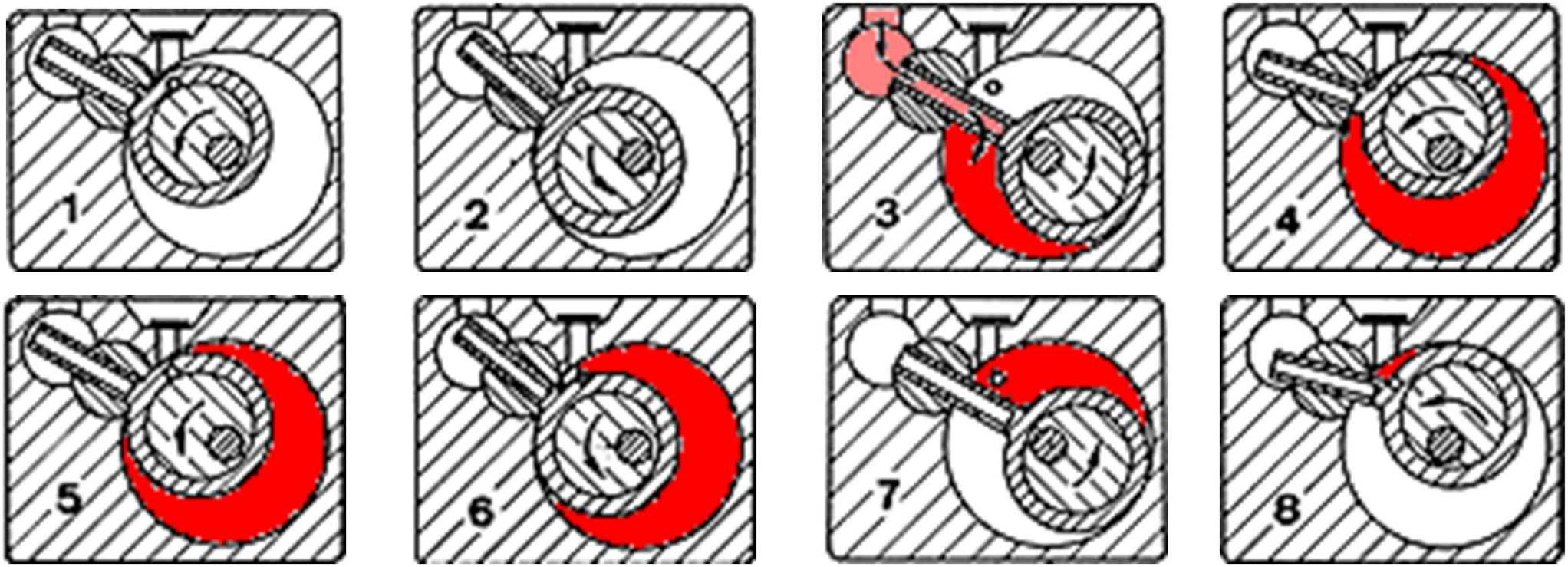
- Molecular sieve trap against oil vapor (X-13, regular baking)
- lN_2 trap against vapors
- Brake vacuum on switching off to prevent oil flood of system
- Check oil (color, smell, consistency), change in case of doubt
- Safeguard from solids
- A small amount of water or solvent can be removed by ballasting do not forget to close ballast gas)
- Rotary direction of three phase electric motor
- Do not obstruct exhaust, vent to ventilation

Rotary piston pump

- High capacity, high longevity (decades of work)
- 0.1 mm fitting, low rpm (400-600 1/min), viscous pump oil – „dust proof”
- Pumping speed 1 - 1500 m^3/h
- End pressure 0.01 mbar
- Liquid cooling
- Industrial



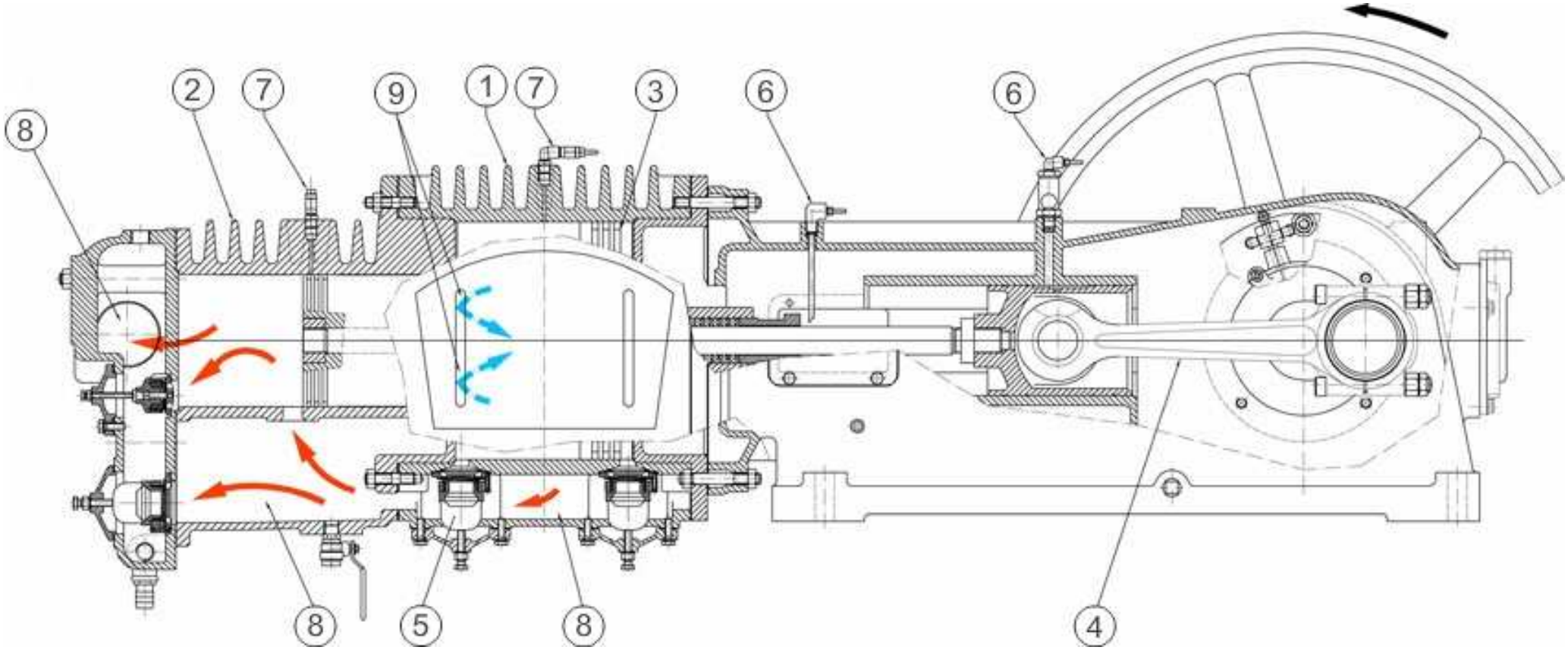
Rotary piston pump



Piston pump

- Drabec (Ganz)
- Italvacuum - Saurus
- Sacrificial oiling (min. 10 g/h, FDA-approved oil, food and pharmaceutical), dust and corrosion proof (p.e. drying HCl-salts)
- one (few mbar) or two stages (<mbar)
- Roots for pump (1/100 mbar)
- Industrial (few hundred m^3/h)
- Related to steam engine in construction and sturdiness

Piston pump

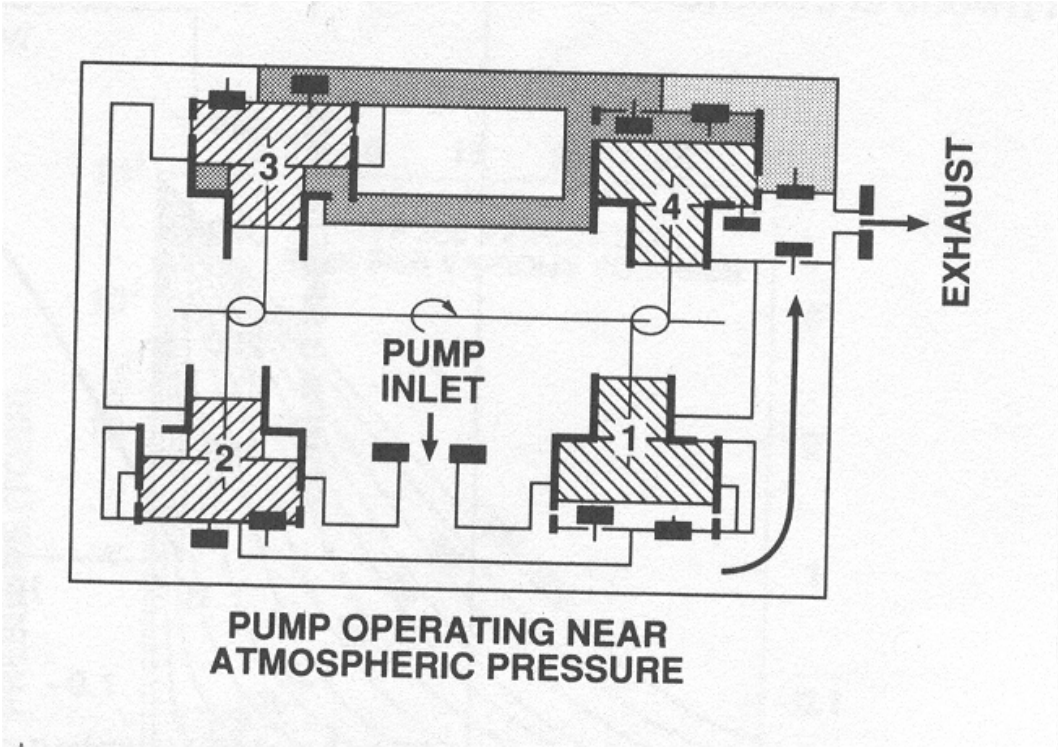


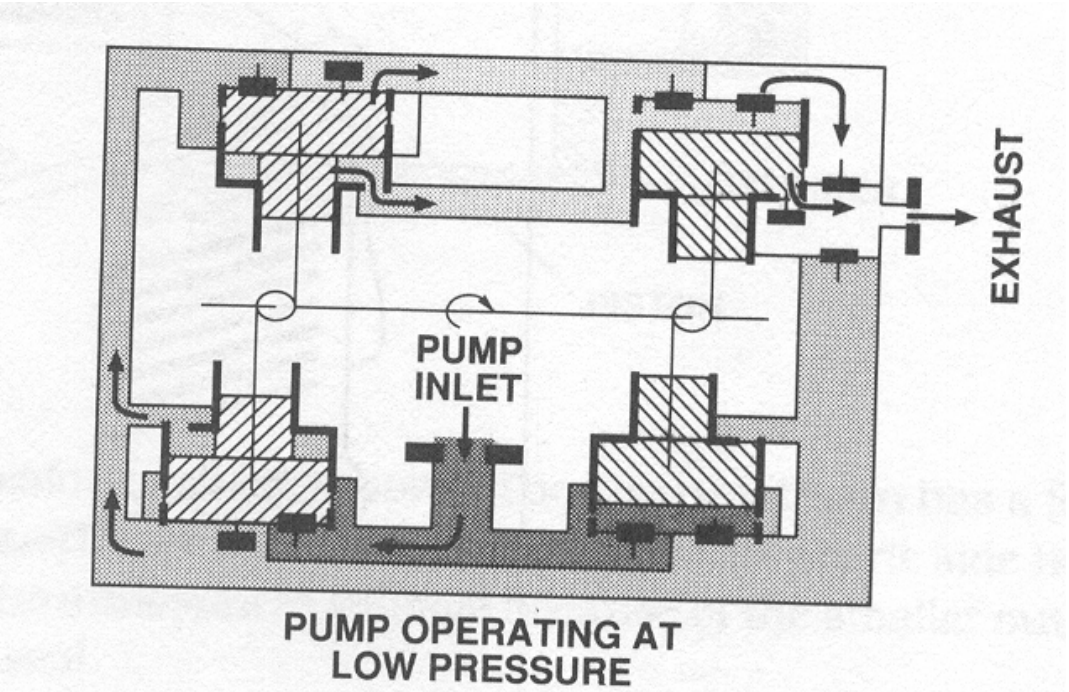
1 Barrel - 1st stage
2 Barrel - 2nd stage
3 Piston
4 Rod
5 Discharge valves
6 Oil-feeder for recirculated oil
7 Oil-feeder for the injection of non-reusable oil
8 Discharge
9 Intake

Oil-free pumps

- For high purity demands, as fore vacuum of oil-free high vacuum pumps
- Substitution for water jet aspirator pump
- In lack of cooling effect of oil, usually more stages with lower compression (20-100)

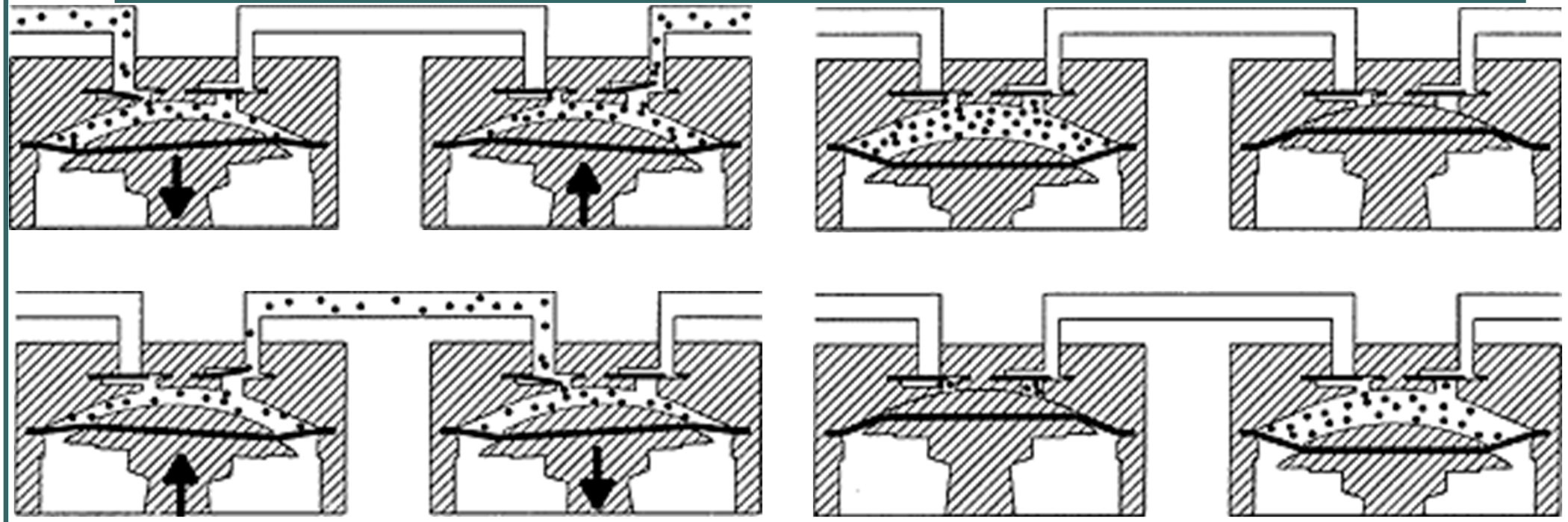
Oil-free pumps
Piston (Varian)





- Teflon or fluorinated surfaces (self lubricating)
- Variable compression (as in case of two stage oil rotary vane pump)

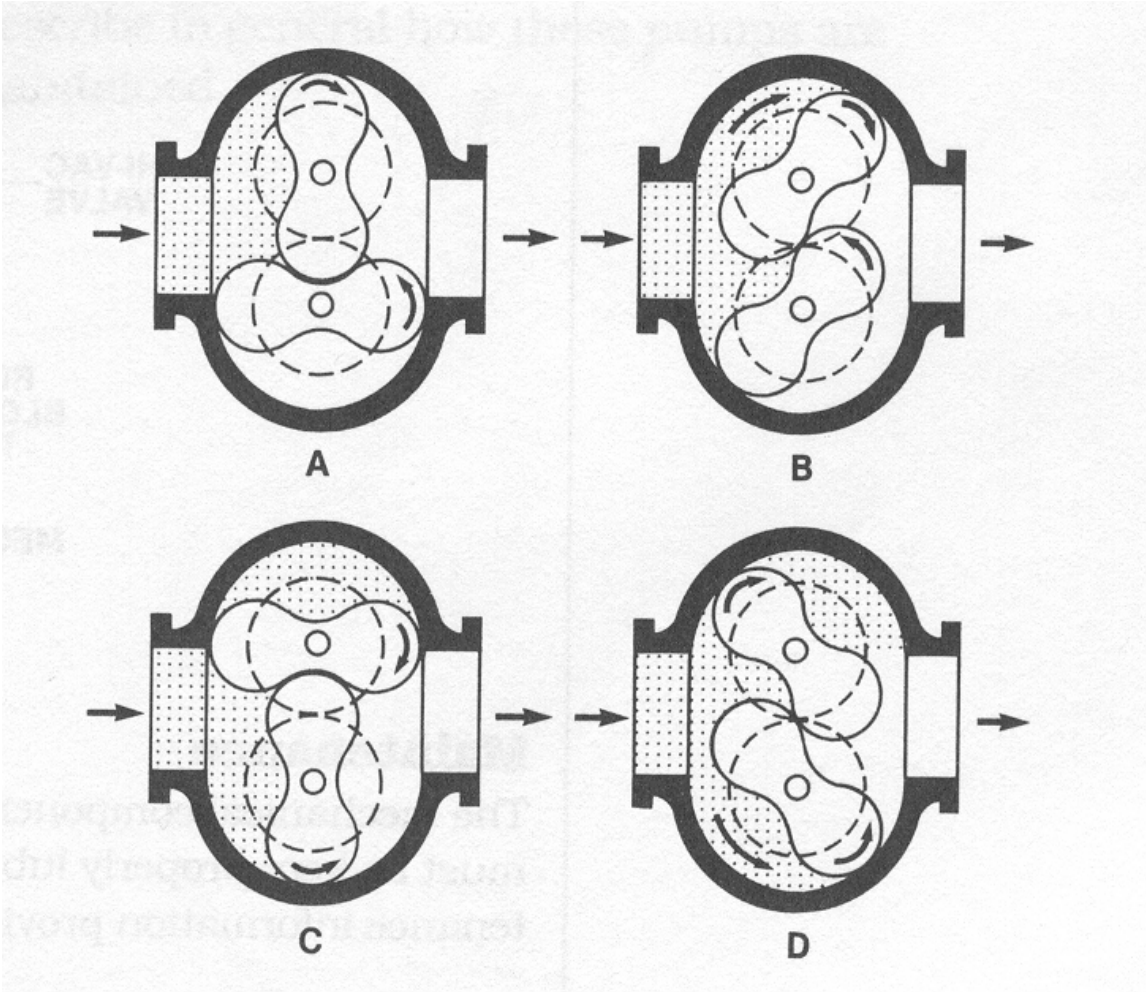
Oil-free pumps
Membrane



- Multistage (1-2-3-4)
- „Chemical” with fluorinated plastics

Oil-free pumps
Blower (Roots)

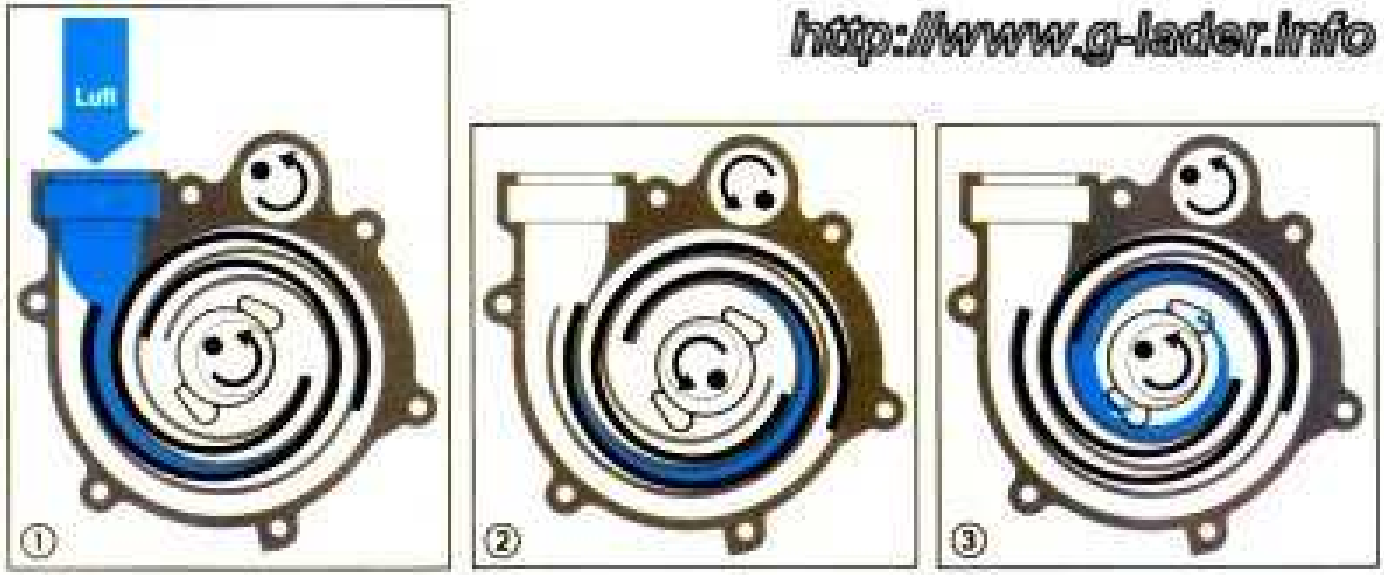
- 3-4 magnitude pressure difference, the usual ones require a fore pump (membrane, liquid ring, rotary vane)
- Beware of warming: tight fittir



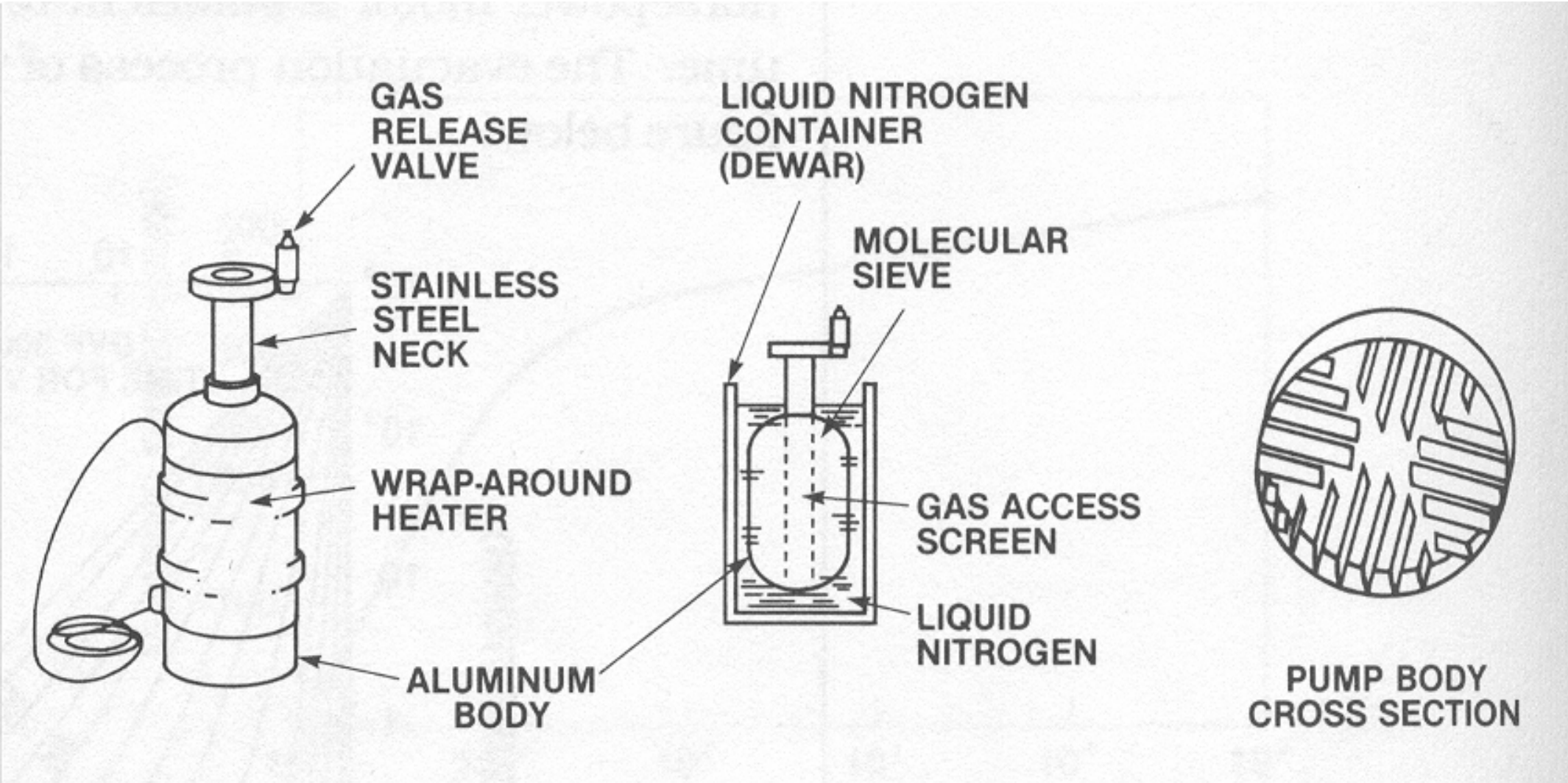
Oil-free pumps
Scroll pump

- Spiral labyrinths
- Face sealings wears, needs regular replacement, can produce some dust
- Small power consumption.

I.e. 9m^3/h, 10^{-2} mbar: 270 watt



Sorption pump

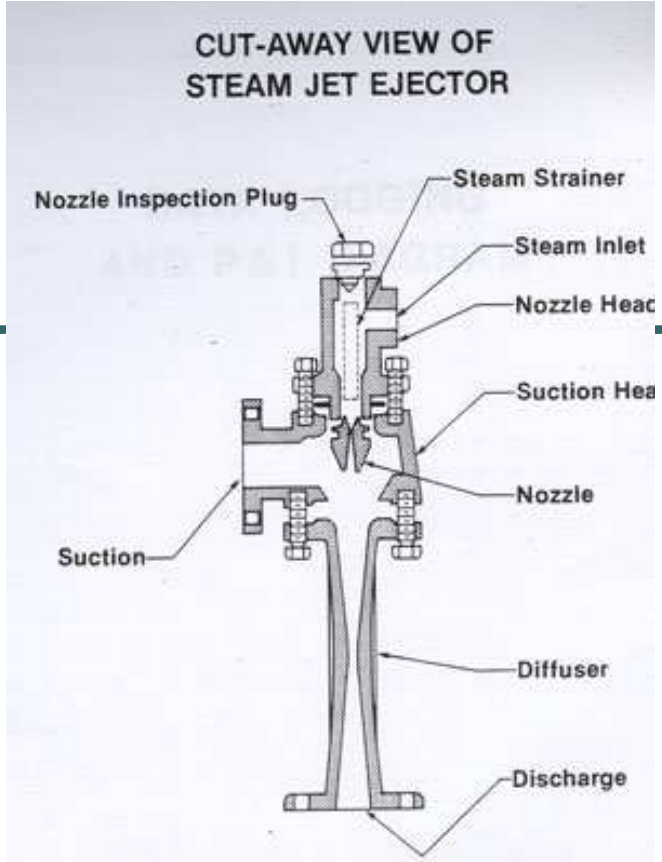


Sorption pump

- Easy fore pump of oil-free UHV
- Limited capacity (few 10000 mbar*liter): more set, while regenerating one, the other works. Venture fore pump
- He, Ne, H_2 are not pumped, anything else do (freezing or adsorption)
- Possible fire/explosion on warming up (organics + O_2)
- Keep lN_2 level
- Overpressure at warming up
- Vent poisons to fume hood
- Can be home made. Do not use active carbone, reacts with oxygen. N_2 doe not fit into pore 4 molecular sieve, therefore pore 5 and 13
- Heat conduction! 10+ minutes starting up
- If does not pump (10 s-min), close and regenerate to avoid backstreaming
- In 5-6 cycles baking at 250 °C to remove water

Steam ejector pump

- Filtration, evaporation, drying, distillation
- End pressure: few mbar
- Sensitive to overload
- (Steam engine: Hardy vacuum break, forced draught through chimney ☺)



Steam ejector pump

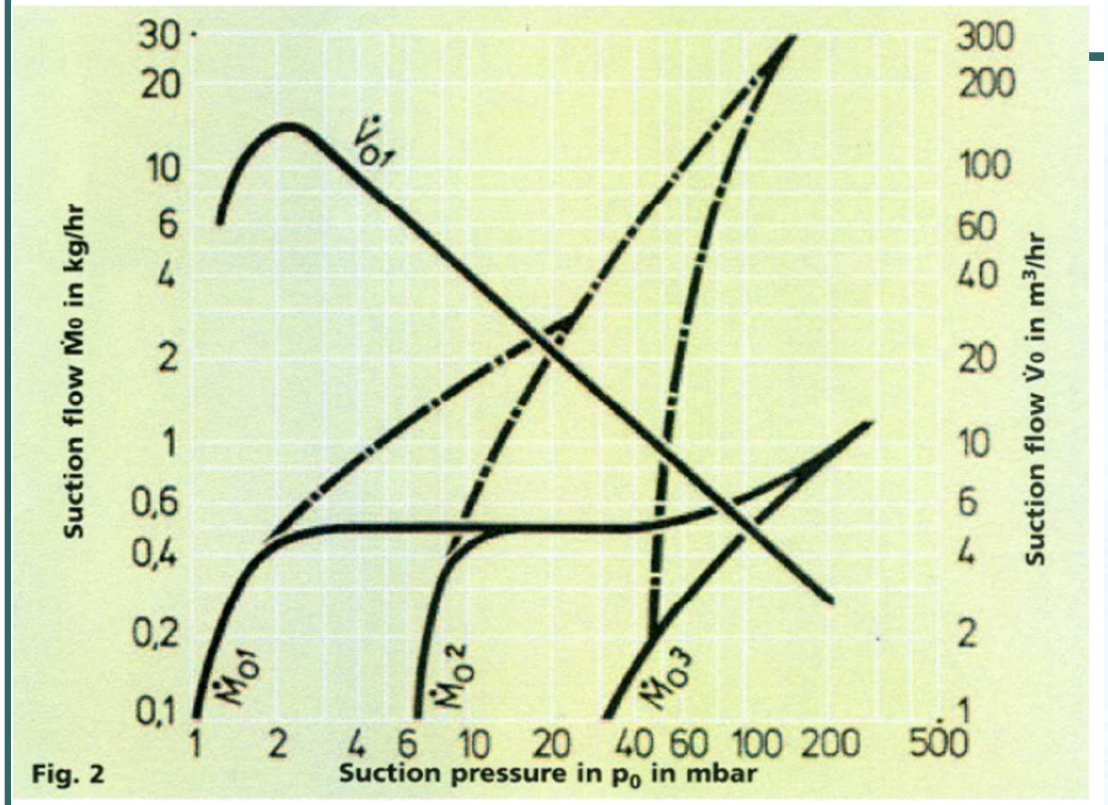
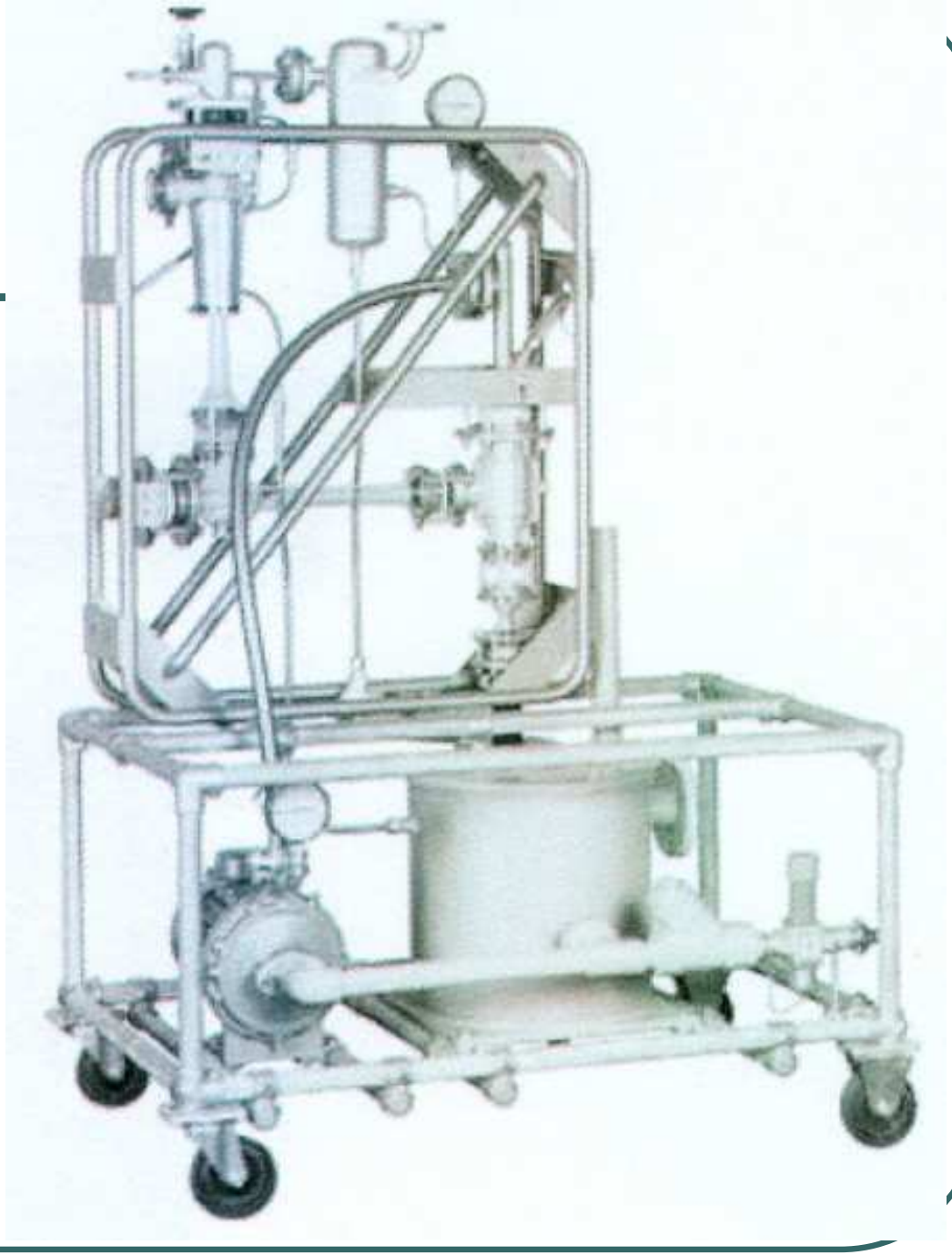


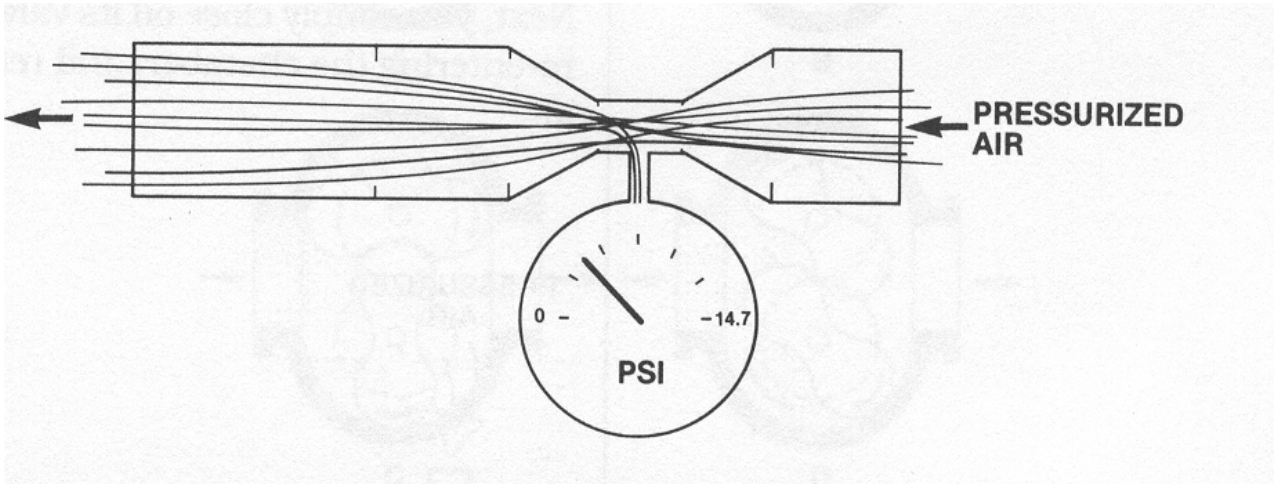
Fig. 2



- 2 steam jet and 1 water jet stage
- 1 mbar
- 25 kg/h steam, 3.4 m^3/h water

Venturi pump

- Few tens of mbar end pressure
- I.e. fore vacuum for sorption pump
- Inert gas, not air, if possible



Water jet aspiratory

- Filtration, evaporation, drying, distillation
- End pressure: vapor pressure of water (few tens of mbar)
- Drying with silicagel
- On verge of extinction: high water consumption, polluting water (organic vapors), sensitive to water pressure
- Exists with water recirculation

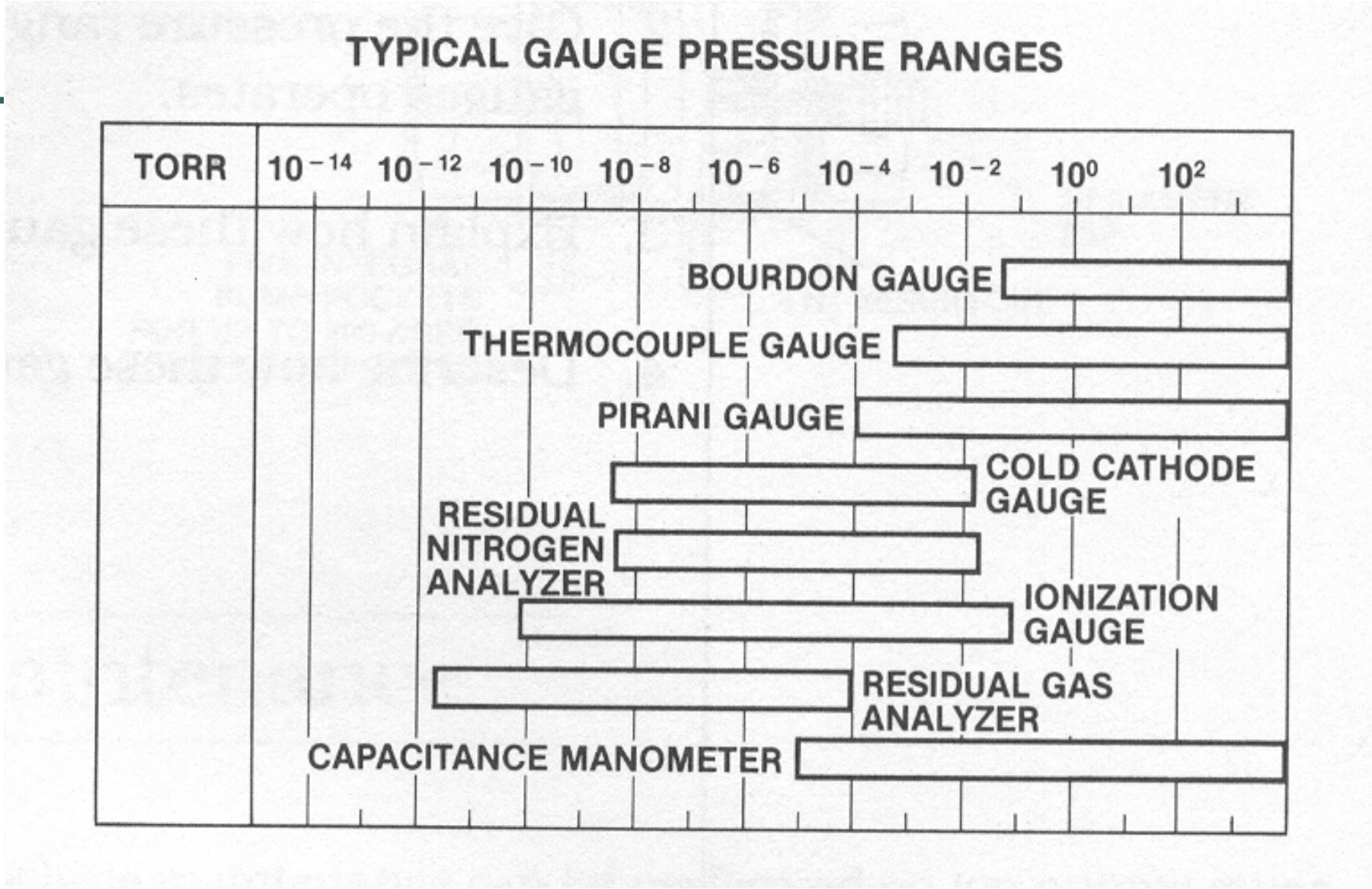
Main types of fore vacuum gauges

- F=A*p principle: does not depend on quality of gas
  - Direct (Toricelli, McLeod)
  - With calibration (Bourdon, diaphragm)
- Heat conductivity principle (Pirani, thermocouple)
- „Viscosity” gauge

- Depend on quality of gas (usually reads air, M=29)
- Non-linear signal-pressure function

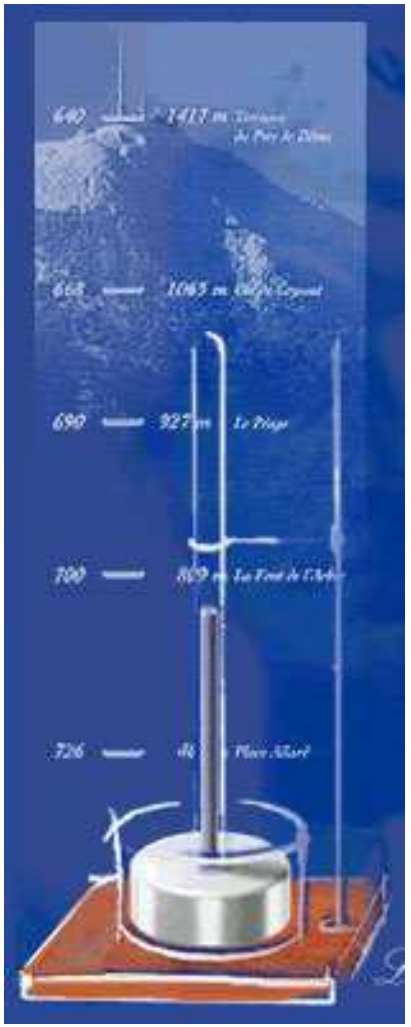
- Consider: reading vs. real pressure (conductance, condensation, impurities, temperature differences etc.)

Pressure range of gauges



F=A*p
Toricelli

- Theoretical limit: vapor pressure of mercury (0.001 mbar)
- Practical limit: accuracy of reading (capillary effect, Hg impurities, vibration etc.) - 0.1 torr, in fact 1 mbar
- Can be used continuously, can be used for controlling (i.e. electric contacts in Hg column)
- Hg-pollution



F=A*p
McLeod

- Gas laws: compressing a given starting volume, reading end volume (precalibrated scale)
- Even down to 10^{-6} mbar! Calibration purposes
- Not continuous, not automated
- Beware on condensing vapors!
- Breaks easily

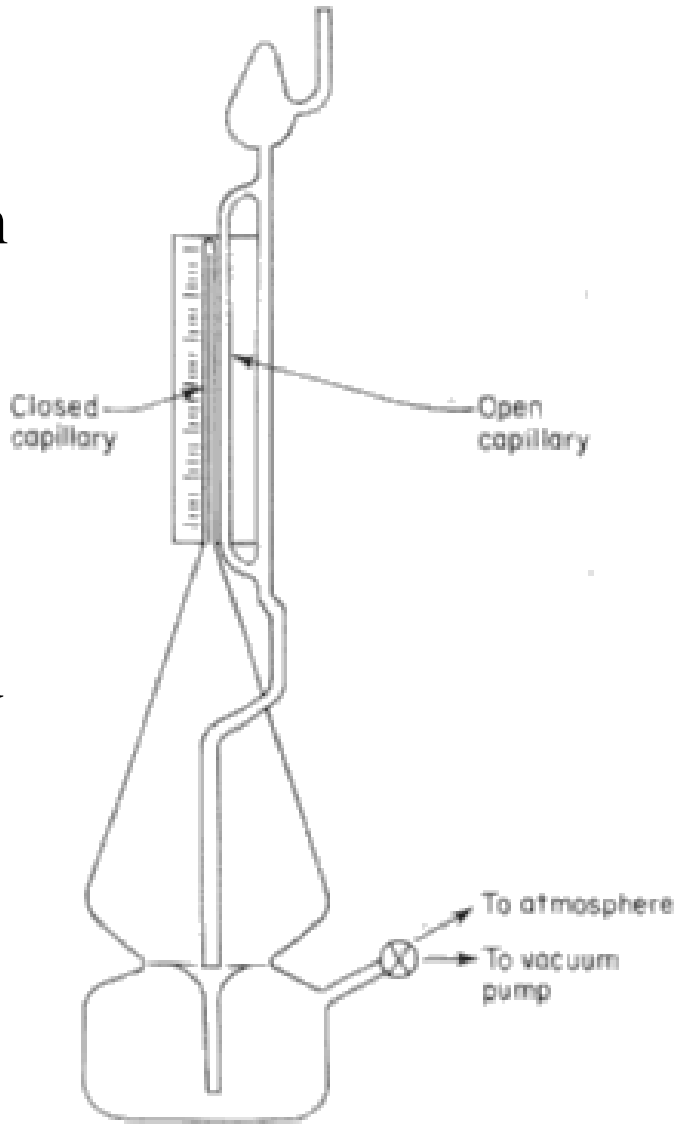
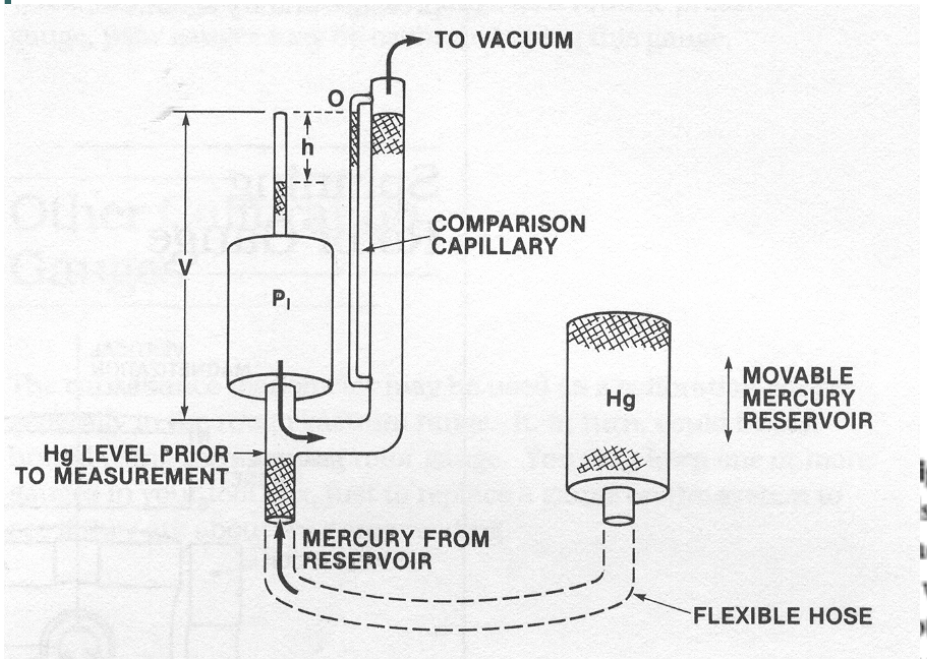
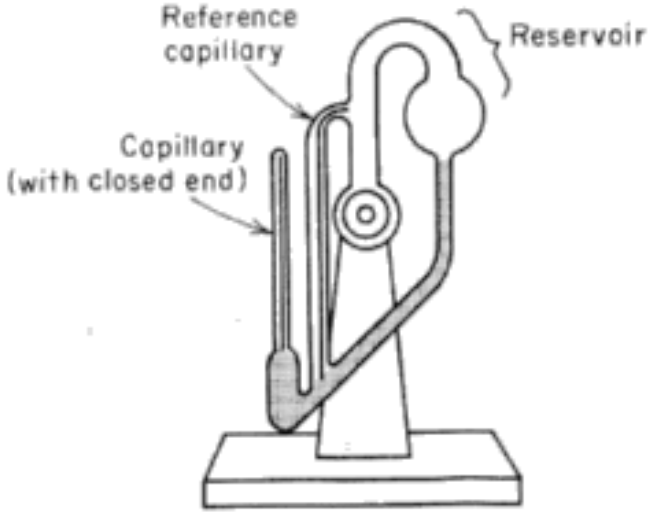


Fig. 11.1 McLeod gauge.

F=A*p
McLeod

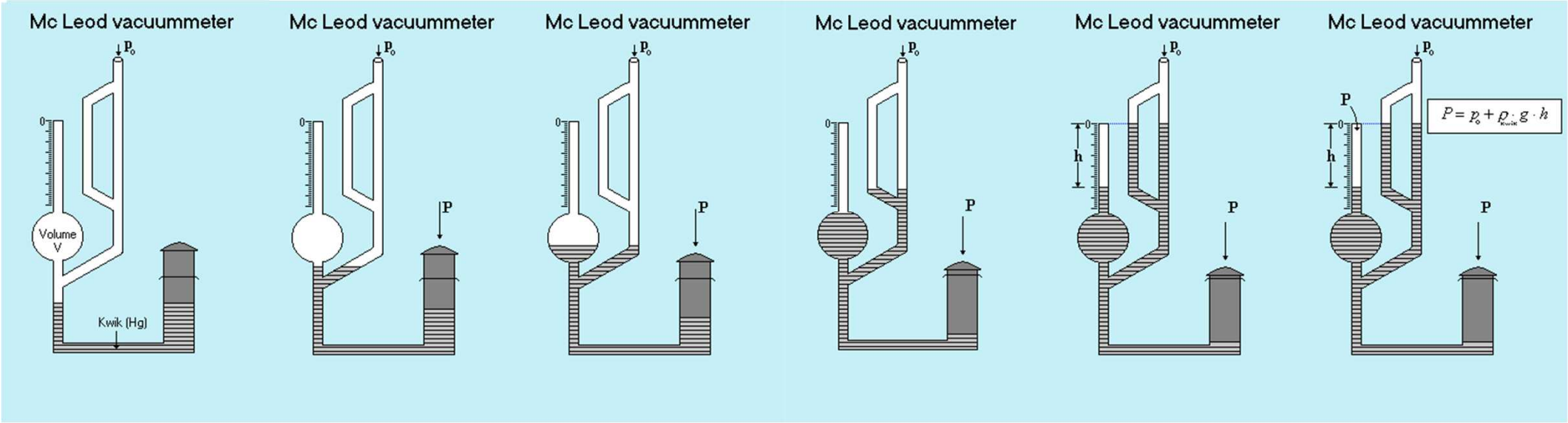




ig. 7.8. Tilting McLeod gauge. The gauge rotates around the center section. This center section so contains a nipple (extending out from the back of the drawing) which may be attached to the acuum system through a hose. For a more permanent arrangement, the center section is attached to vacuum line by means of a standard taper joint and the base is discarded. Initially, the gauge is otated so that the mercury runs into the reservoir. When pressure equilibrium is established with ne system being measured, the gauge is rotated back so that gas is compressed into the dead-end capillary and the top of the mercury in the reference capillary coincides with the top end of the dead-end capillary. Generally, the gauge is provided with a scale which may be read directly in terms of pressure. These gauges cover the medium-vacuum range, but generally do not extend into the high-vacuum region.

- Small „rotating” is excellent for quick checks down to 0.001 mbar

F=A*p
McLeod


Mc Leod vacuummeter
Volume V
Kwik (Hg)
Mc Leod vacuummeter
P
Mc Leod vacuummeter
P
Mc Leod vacuummeter
P
Mc Leod vacuummeter
h
P
Mc Leod vacuummeter
P
h
P
$P = p_0 + \rho_{Hg} \cdot g \cdot h$

F=A*p
Bourdon

- To 1 mbar
- Used for pressure as well, as on gas reductors
- Easy to buy from dairy industry supplies (milking machines work with vacuum)

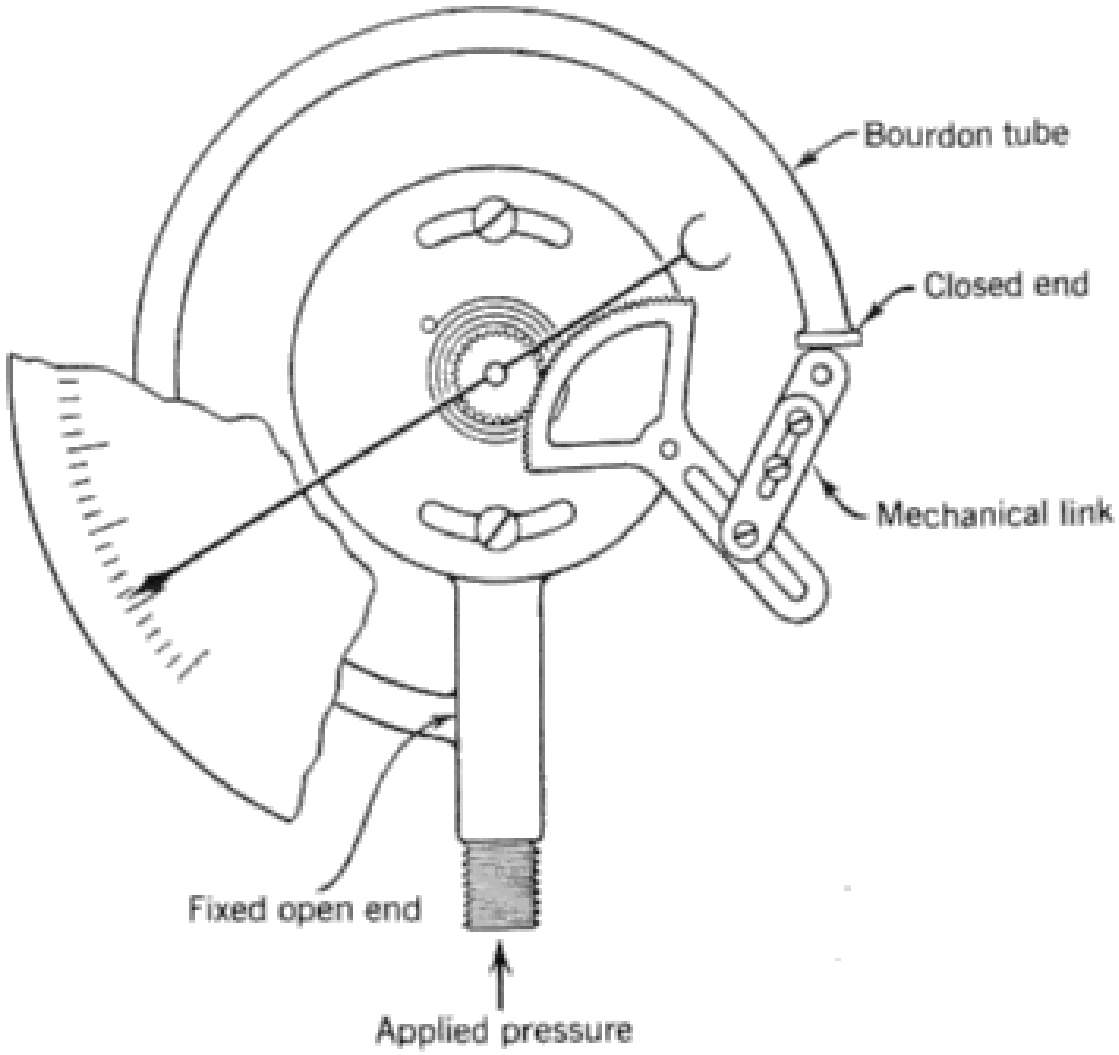
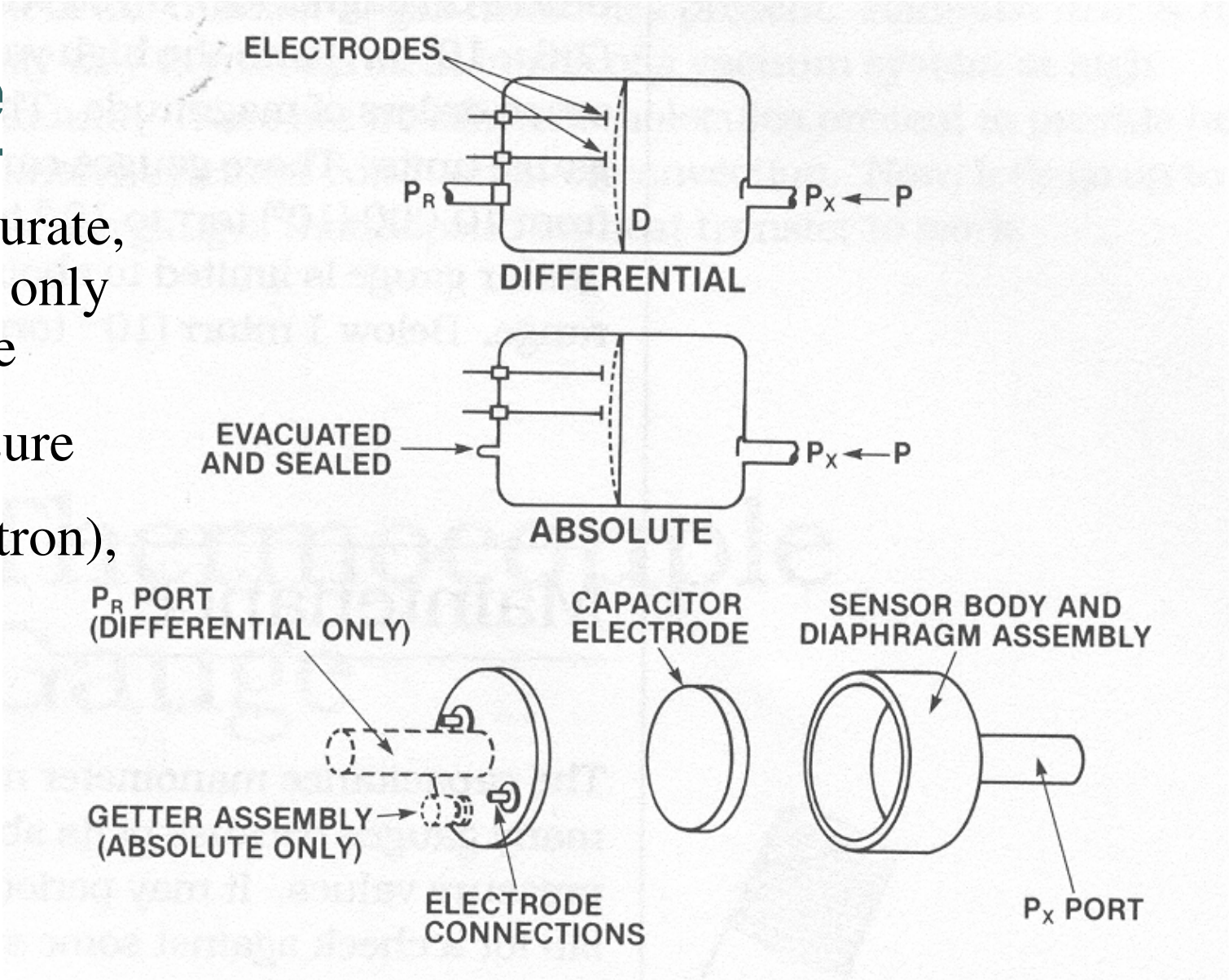


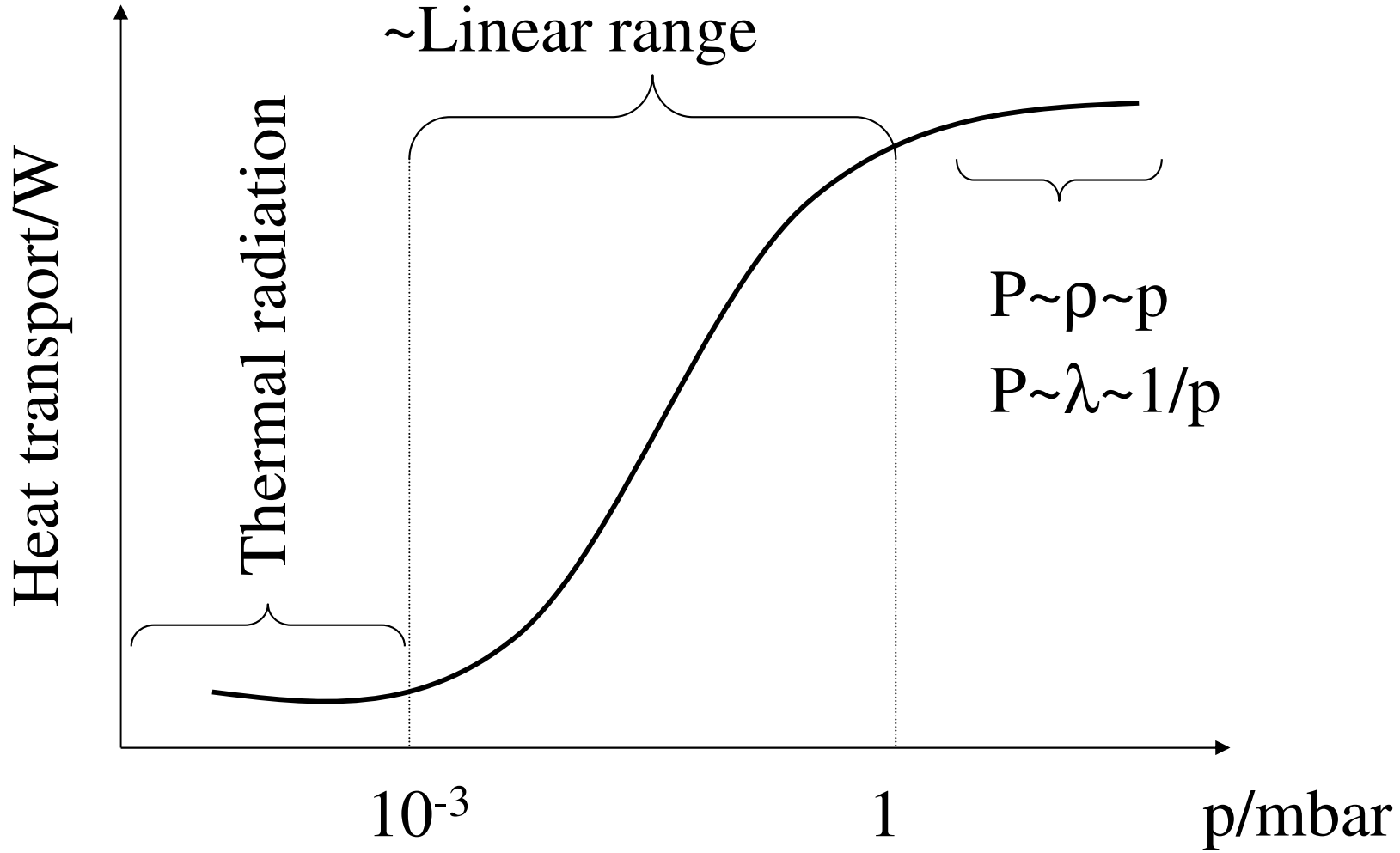
Fig. 7.5. A metal Bourdon gauge. The thin Bourdon tube is sensitive to the pressure differential between the surrounding atmosphere and the gas contained within the tube. The tube deflects an indicating needle which allows a direct pressure determination from the calibrated scale.

F=A*p Membrane

- To 0.001 mbar accurate, usable to 10^{-5} mbar, only 3-4 magnitude range
- Can measure pressure
- Capacitance (Baratron), piezoelectric

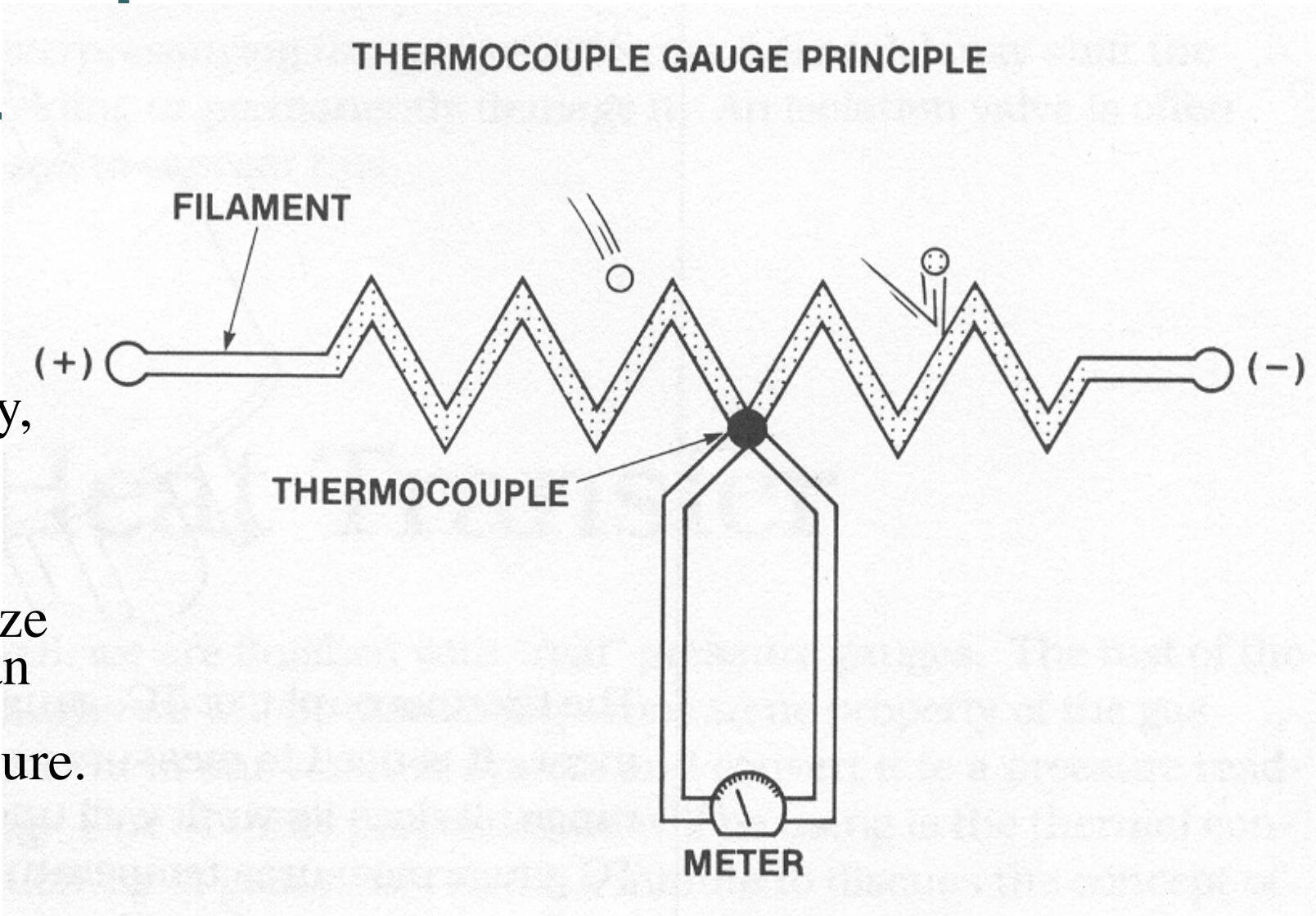


Heat conductance of gases



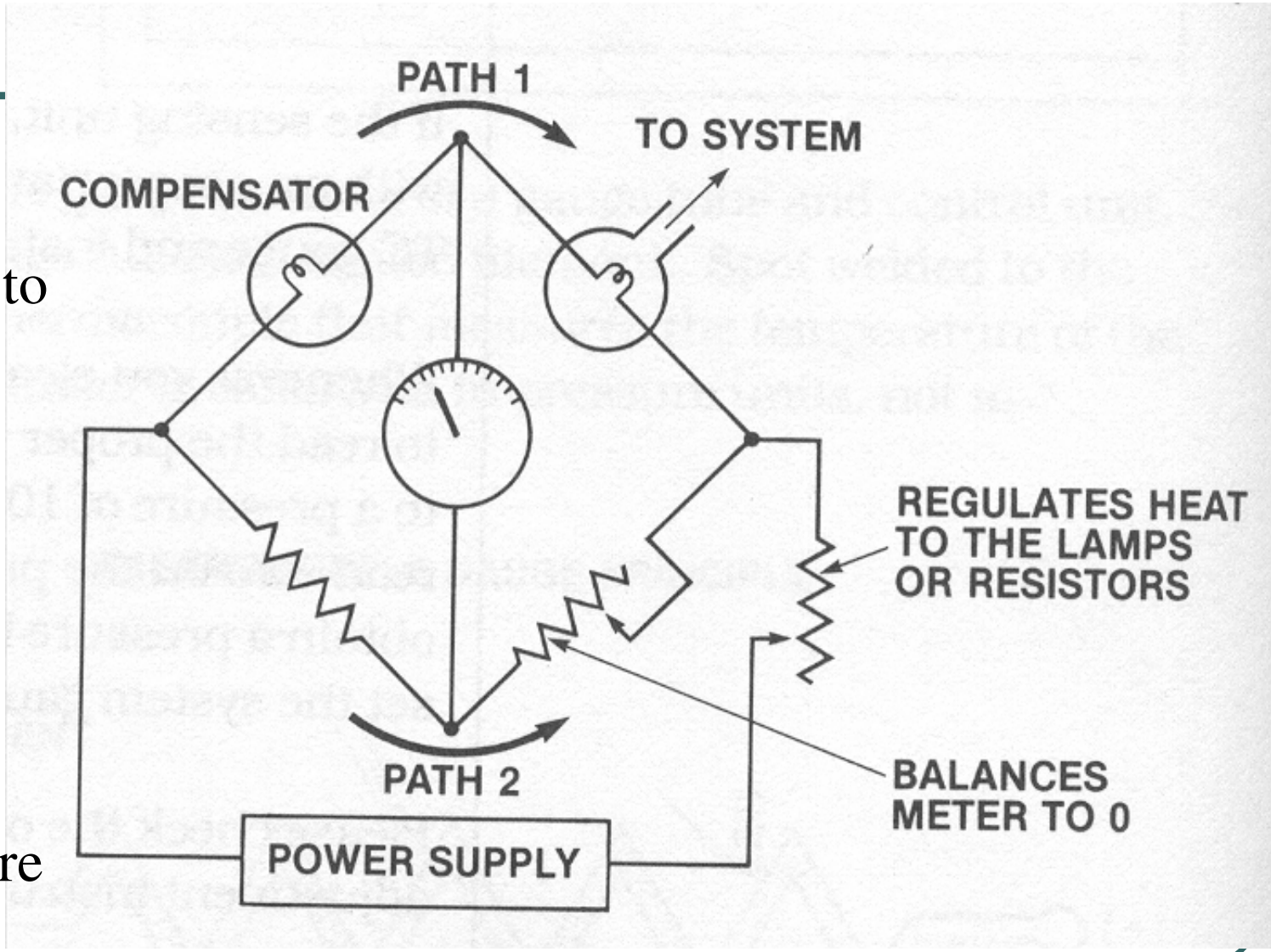
Thermocouple

- Temperature of heated wire with calibrated scale
- To 0.001 mbar
- Can became dirty, wire can burn out
- Slow
- Newer ones utilize convection and can gauge to over atmospheric pressure.



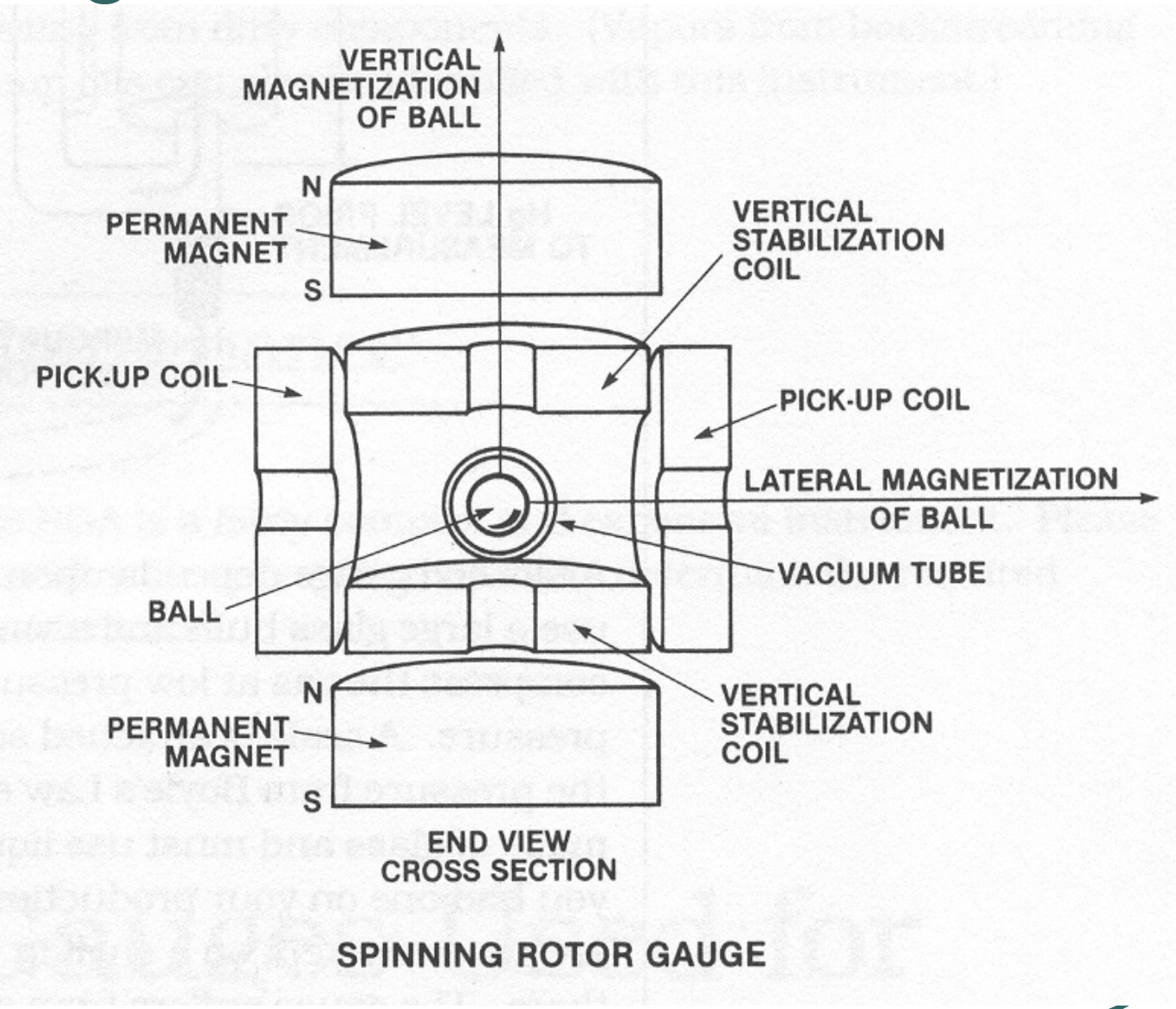
Pirani

- Most abundant
- Fast, range 0.0001-2 mbar (+convection up to 2 bar)
- Electric resistance of heated wire or power demand of keeping steady temperature-resistance (compensated) Wheatstone-bridge
- Can became dirty, wire can burn out



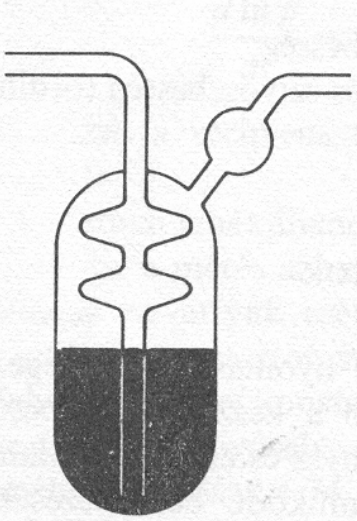
„Viscosity” gauge

- Gauges impulse transfer between surface and gas phase
- 10^{-2} - $5*10^{-7}$ mbar: 1%
- Ancient type: attenuation of vibration of quartz fiber (tuning fork)
- For calibration purposes, not for everyday use

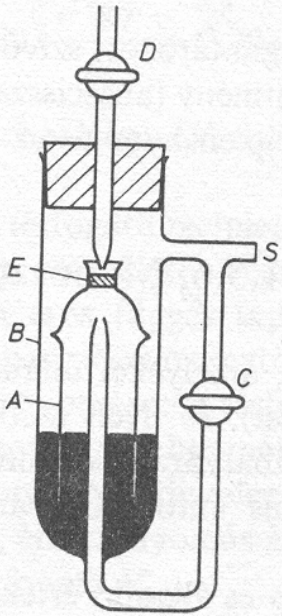


Vacuum-control

- Most electronic vacuum gauge can control. At least a switch relay
- Vacuum control: valve open-close, rpm of electric motor, Vacutron, mass regulators
- Ancient systems: Hg-bubbler, Cartesian-diver (pressure affects buoyancy through gas volume)



1.75. ábra. Egyszerű manosztát



1.76. ábra. Cartesius–manosztát *A*–úszó, *B*–higanyos edény, *C* és *D*–csapok, *E*–gumidugó, *S*–csatlakozás az állandó nyomáson levő térhez