Vacuum Technology I: Positive Displacement Pumping

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Xu Group Meeting

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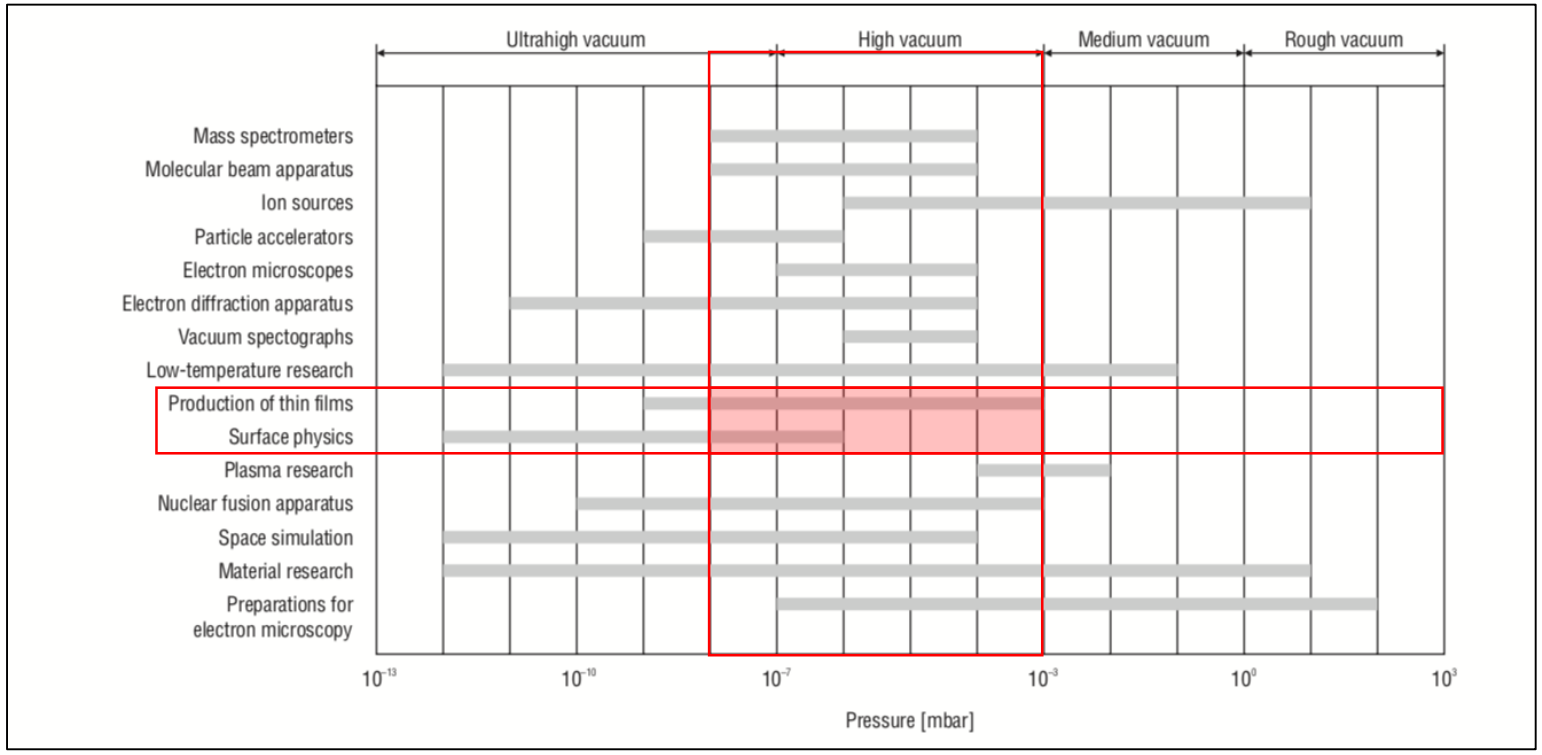
Classifications of Vacuum



Rough vacuum – Viscous flow

$$\lambda < \frac{d}{100} \Leftrightarrow p \cdot d > 6.0 \cdot 10^{-1}\ \text{mbar} \cdot \text{cm}$$

Medium vacuum – Knudsen flow

$$\frac{d}{100} < \lambda < \frac{d}{2} \Leftrightarrow$$

$$\Leftrightarrow 6 \cdot 10^{-1} > p \cdot d > 1.3 \cdot 10^{-2}\ \text{mbar} \cdot \text{cm}$$

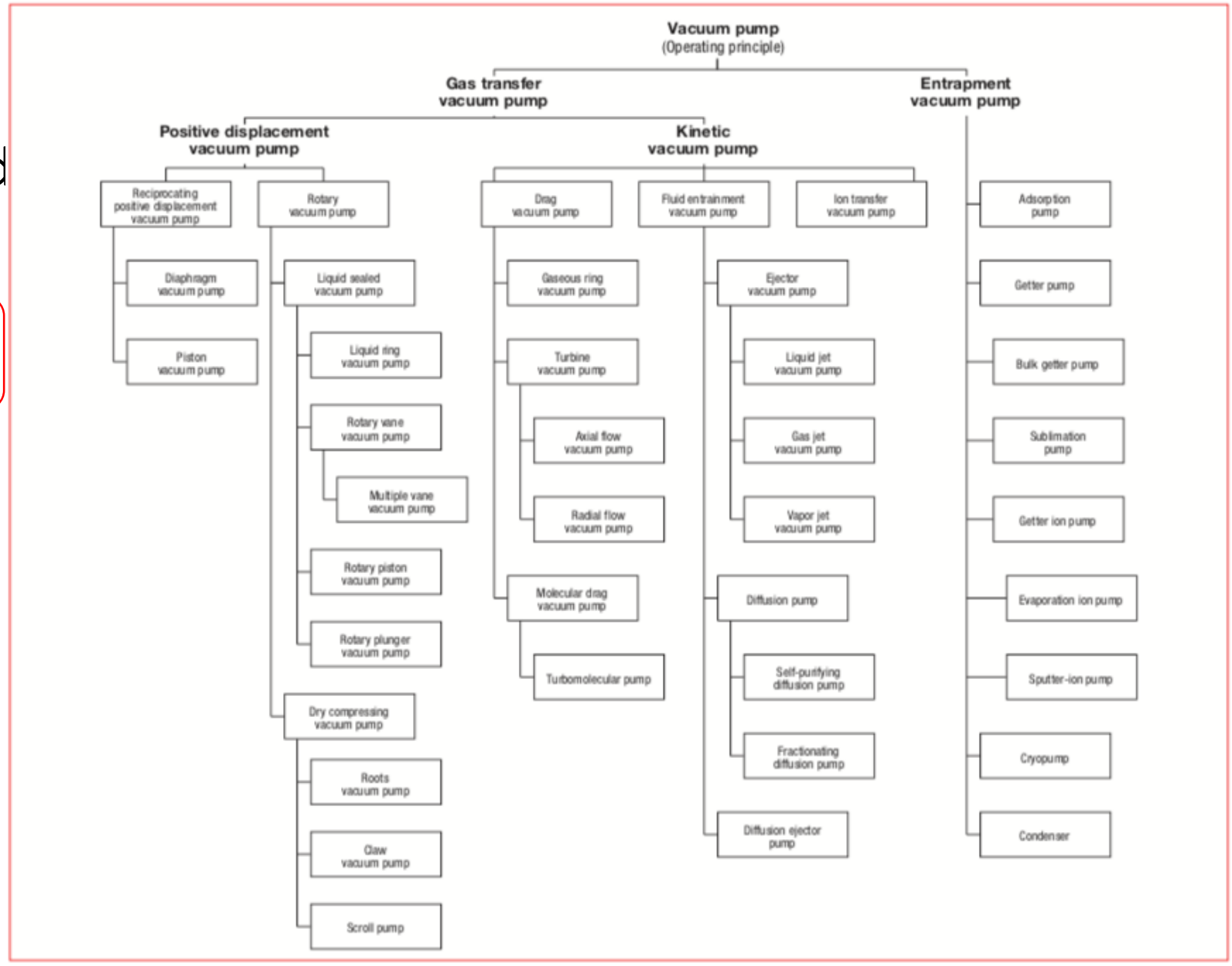
High and ultrahigh vacuum – Molecular flow

$$\lambda > \frac{d}{2} \Leftrightarrow p \cdot d < 1.3 \cdot 10^{-2}\ \text{mbar} \neq \text{cm}$$

Rough vacuum (RV)	1000 – 1	mbar
Medium vacuum (MV)	1 – 10^{-3}	mbar
High vacuum (HV)	10^{-3} – 10^{-7}	mbar
Ultrahigh vacuum (UHV)	10^{-7} – (10^{-14})	mbar

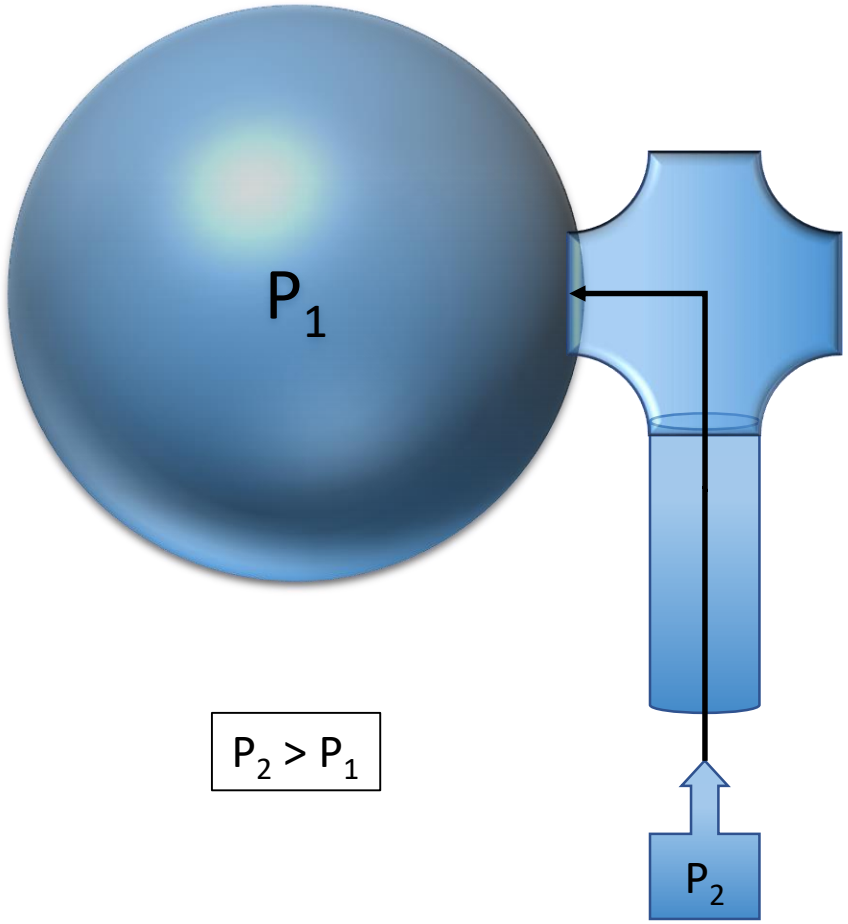
Classification of Pumping Mechanisms

- Lots of mechanisms to consid
- Main mechanisms:
  - Periodic change of chamber volume
  - Direct gas without change of chamber volume
  - Diffusion into a jet vapor
  - Condensation of gasses
  - Absorption to surfaces



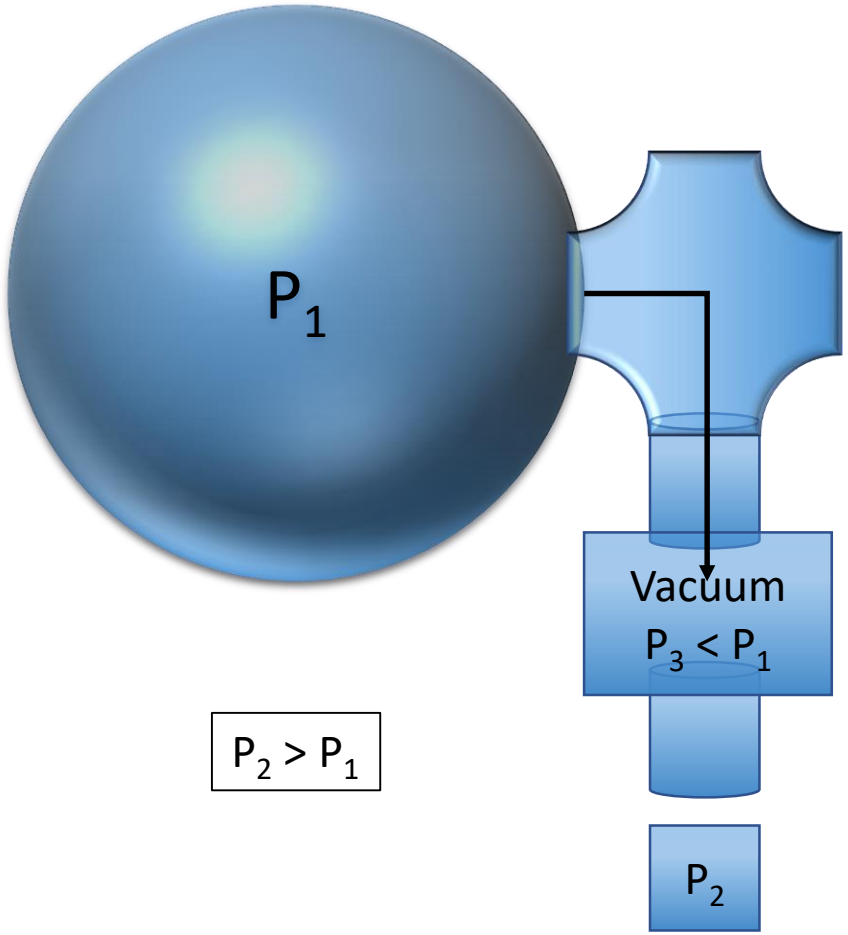
Challenges of Vacuum Pumping

- Fluids flow to higher to lower pressures
- Outside pressure equalizes with chamber



Challenges of Vacuum Pumping

- Fluids flow to higher to lower pressures
- Introduce intermediate stage; pressure lower than chamber



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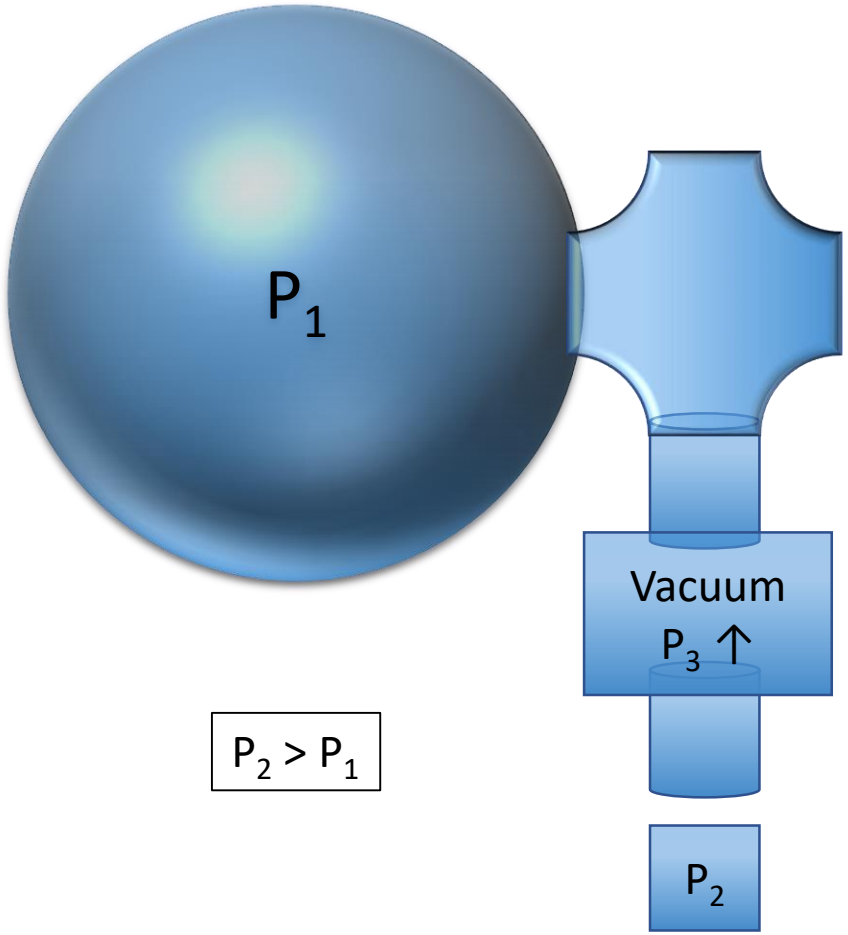
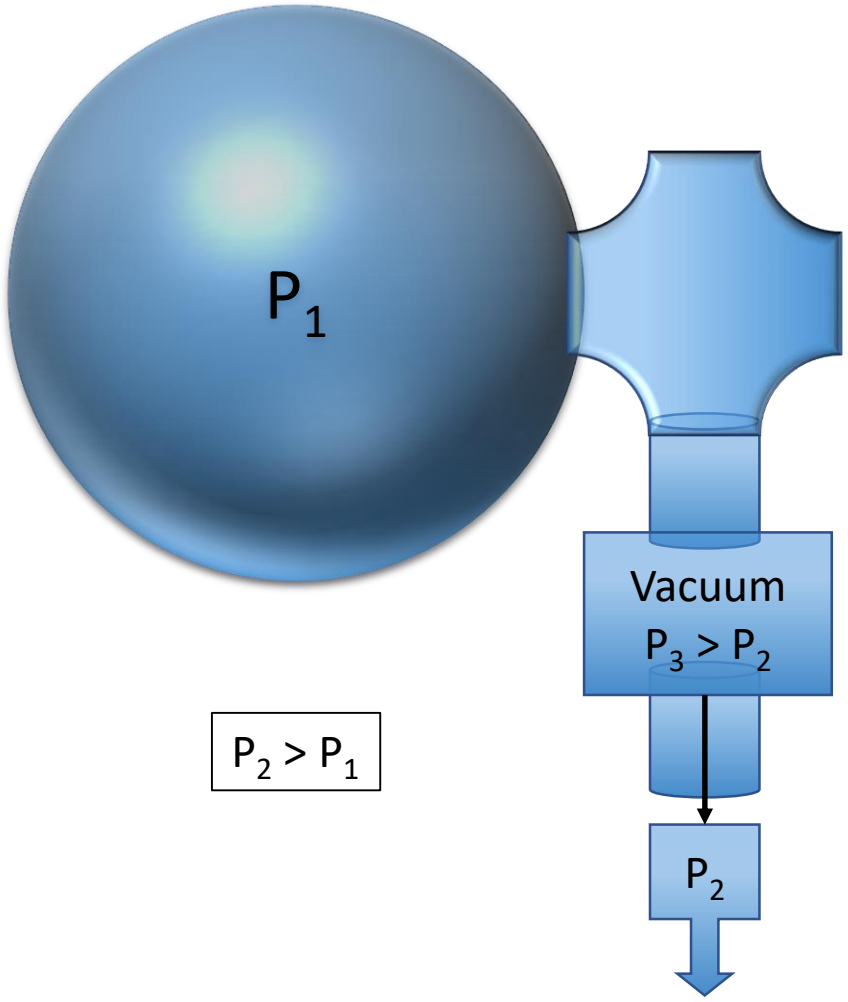


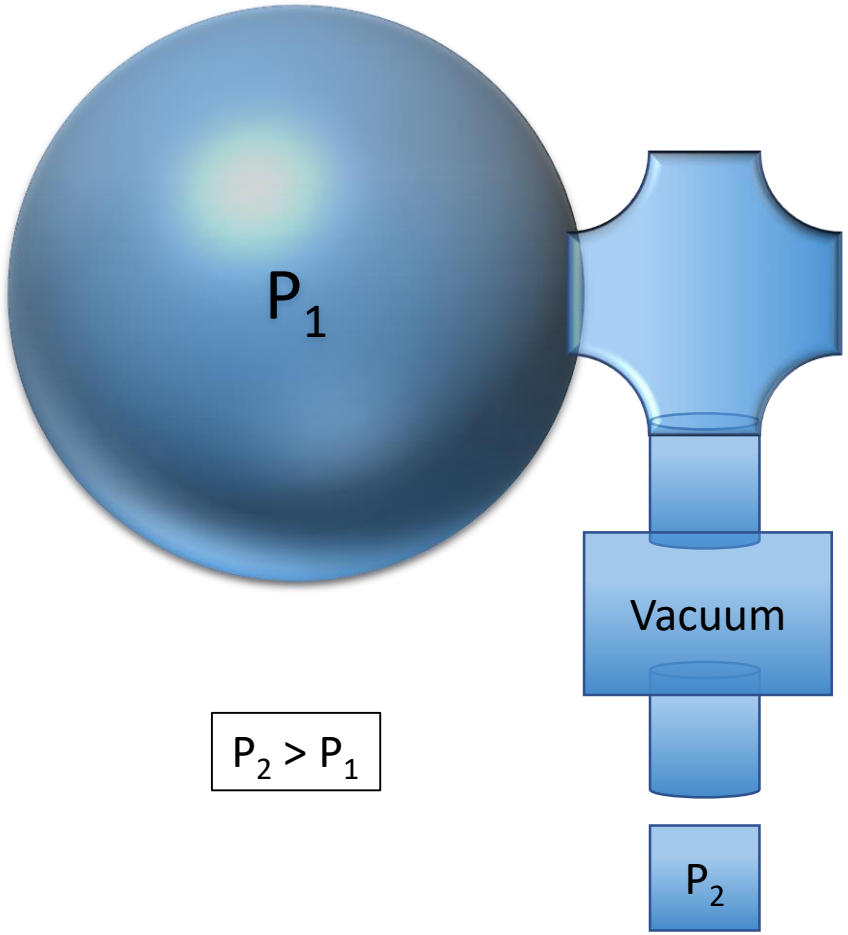
Challenges of Vacuum Pumping

- Fluids flow to higher to lower pressures
- Compress intermediate chamber to pressure larger than exhaust



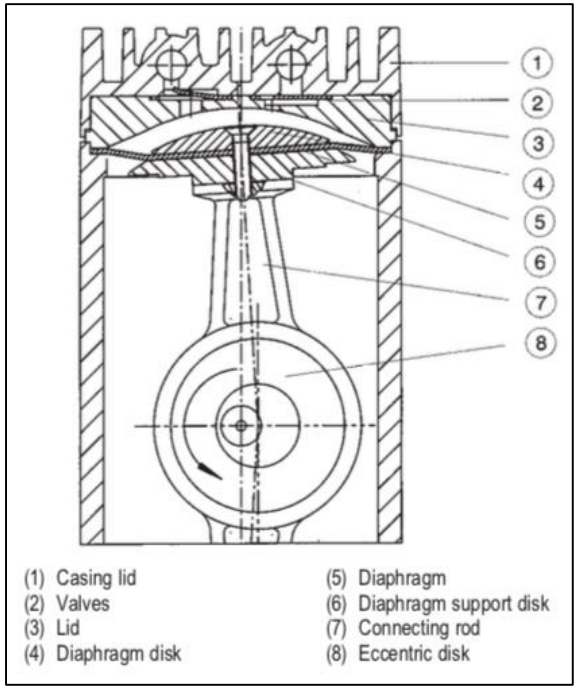
Challenges of Vacuum Pumping

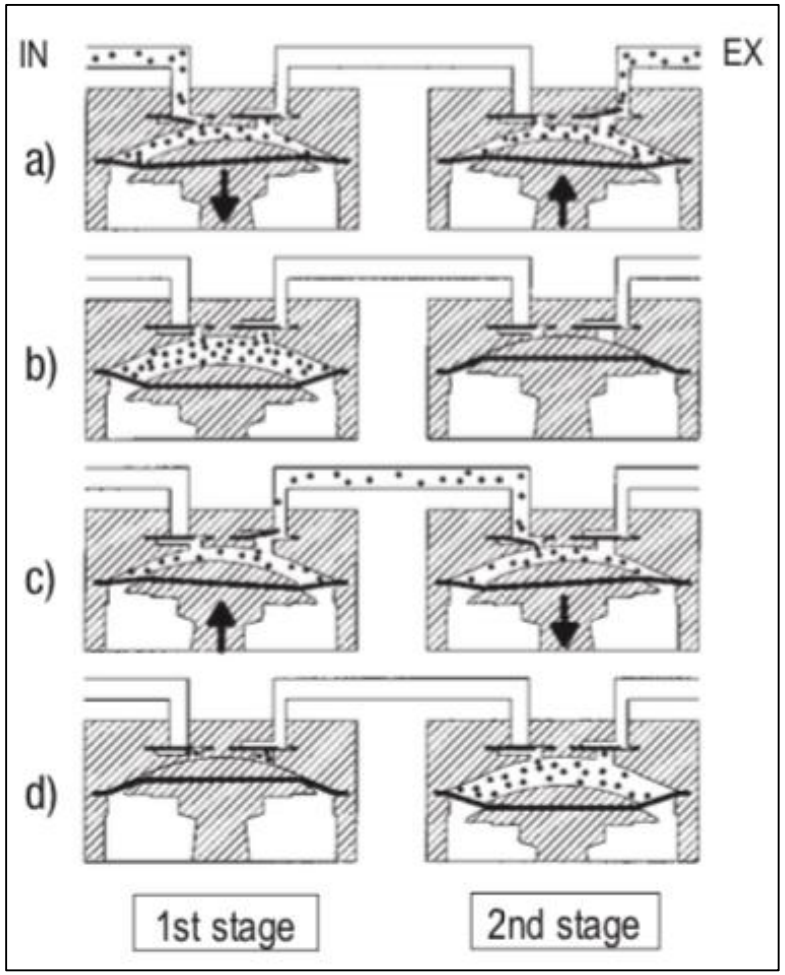
- Fluids flow to higher to lower pressures
- Changing pressure of fixed amount of gas is principle of *displacement pumping*



Diaphragm Pumping

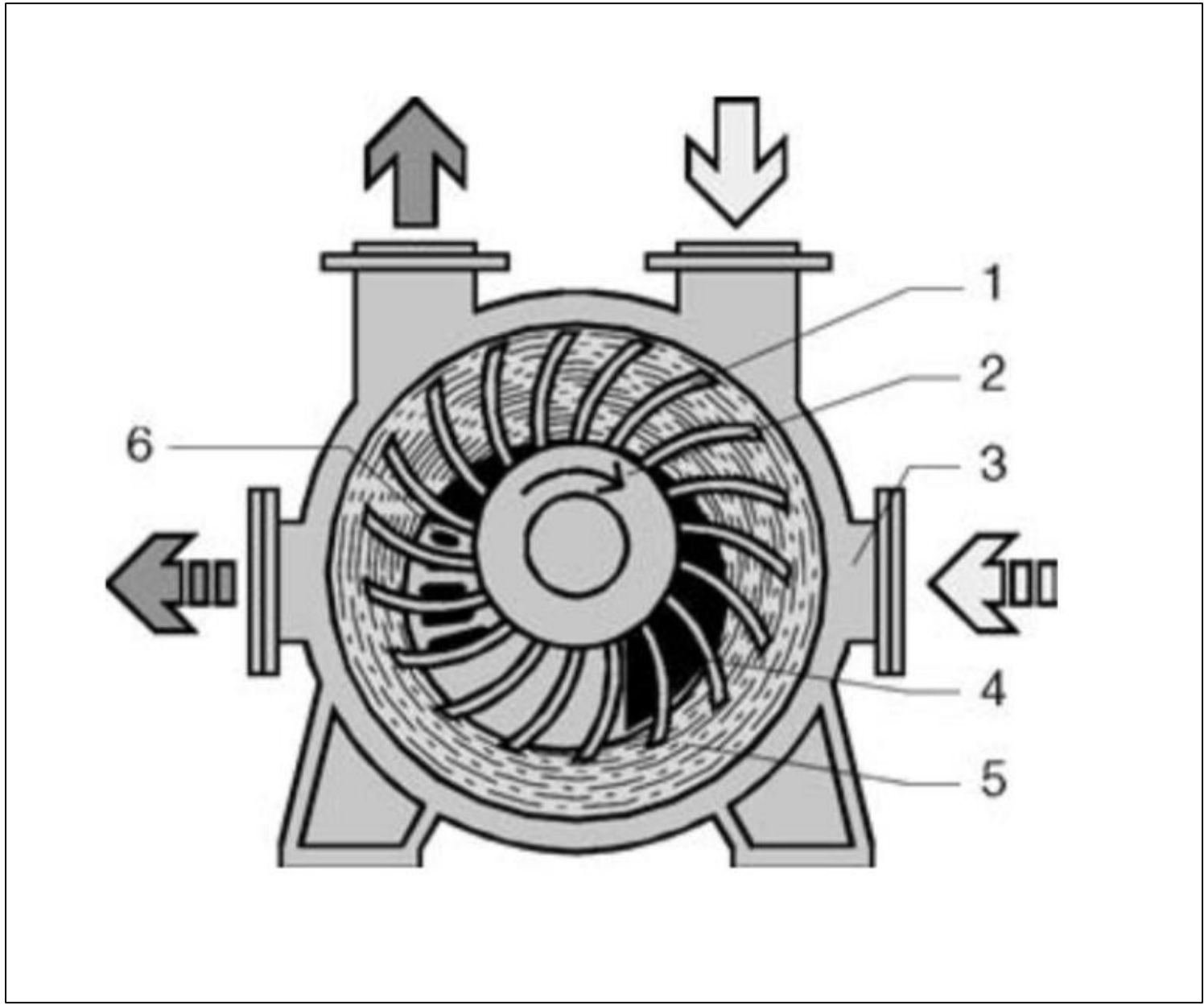
- Two-stage process
- Diaphragm: flexible membrane
- Low pumping speed, based on diaphragm flexibility
- Limited by “dead space” pressure
  - Pump rate drops quickly





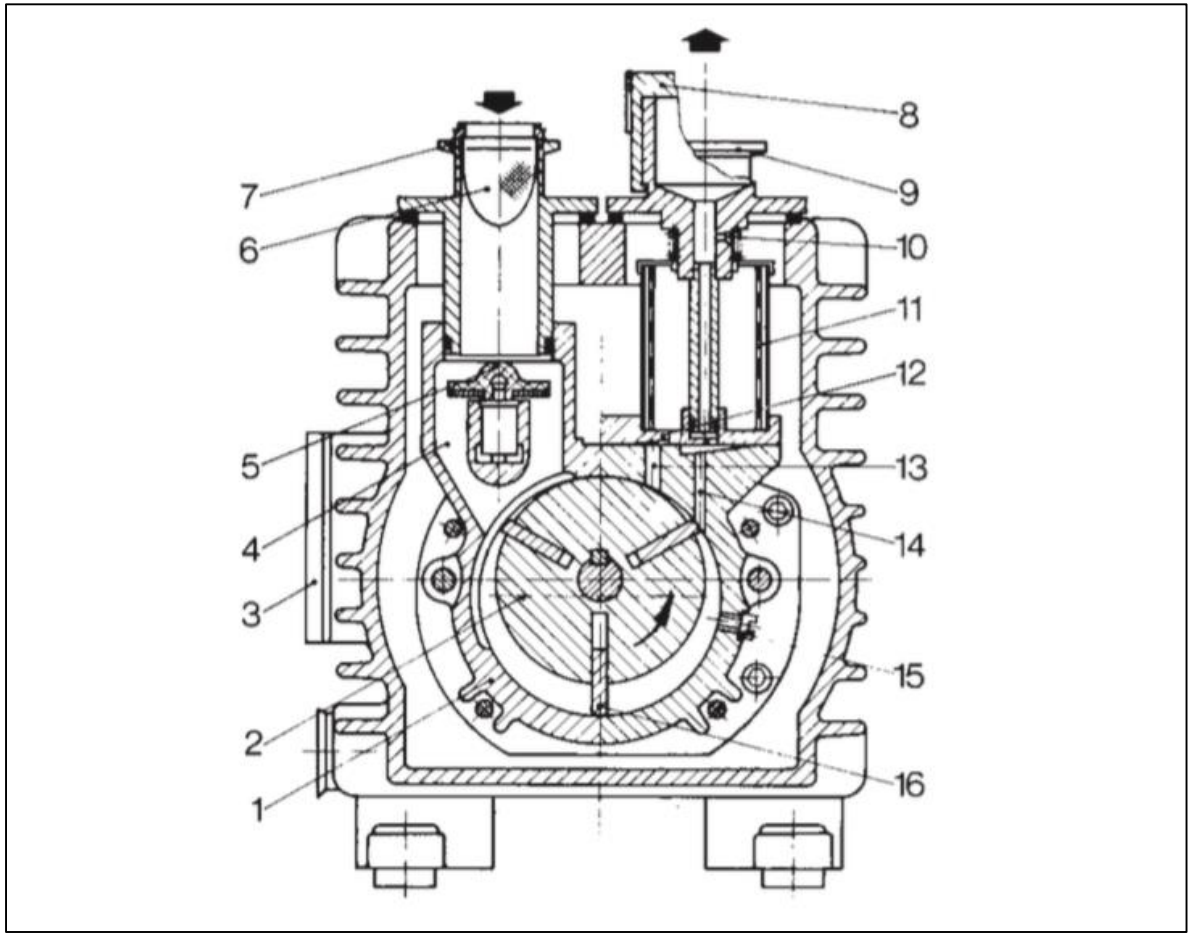
Liquid Ring Pumps

- Suction created between rotors, outer liquid cylinder
- Good for especially “wet” pumped chambers
  - Facilitates condensation and removal of vapor
- Maximum efficiency depends on vapor pressure of liquid



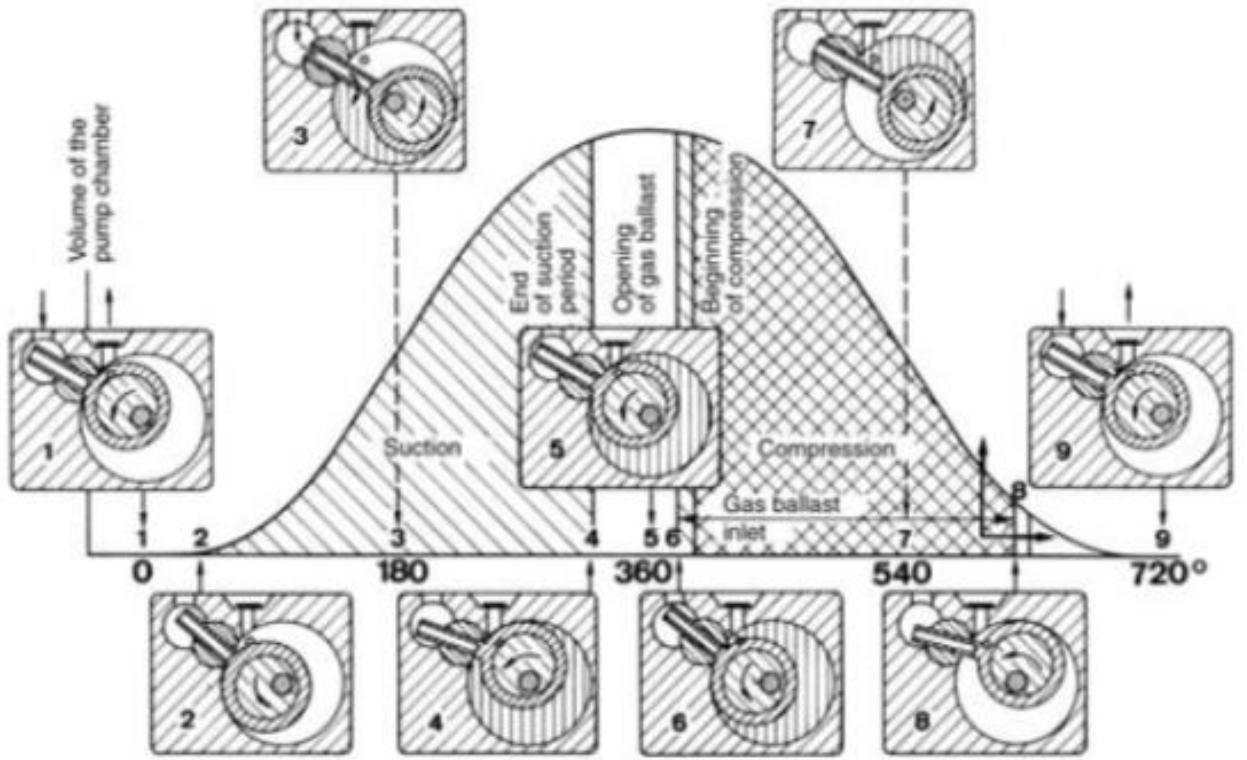
Rotary Vane Pump

- Wheel rotates off-center; vanes press outward due to spring forces
- Oil reservoir provides for heat sink, lubrication, and sealing at top of rotor



Piston Pumping

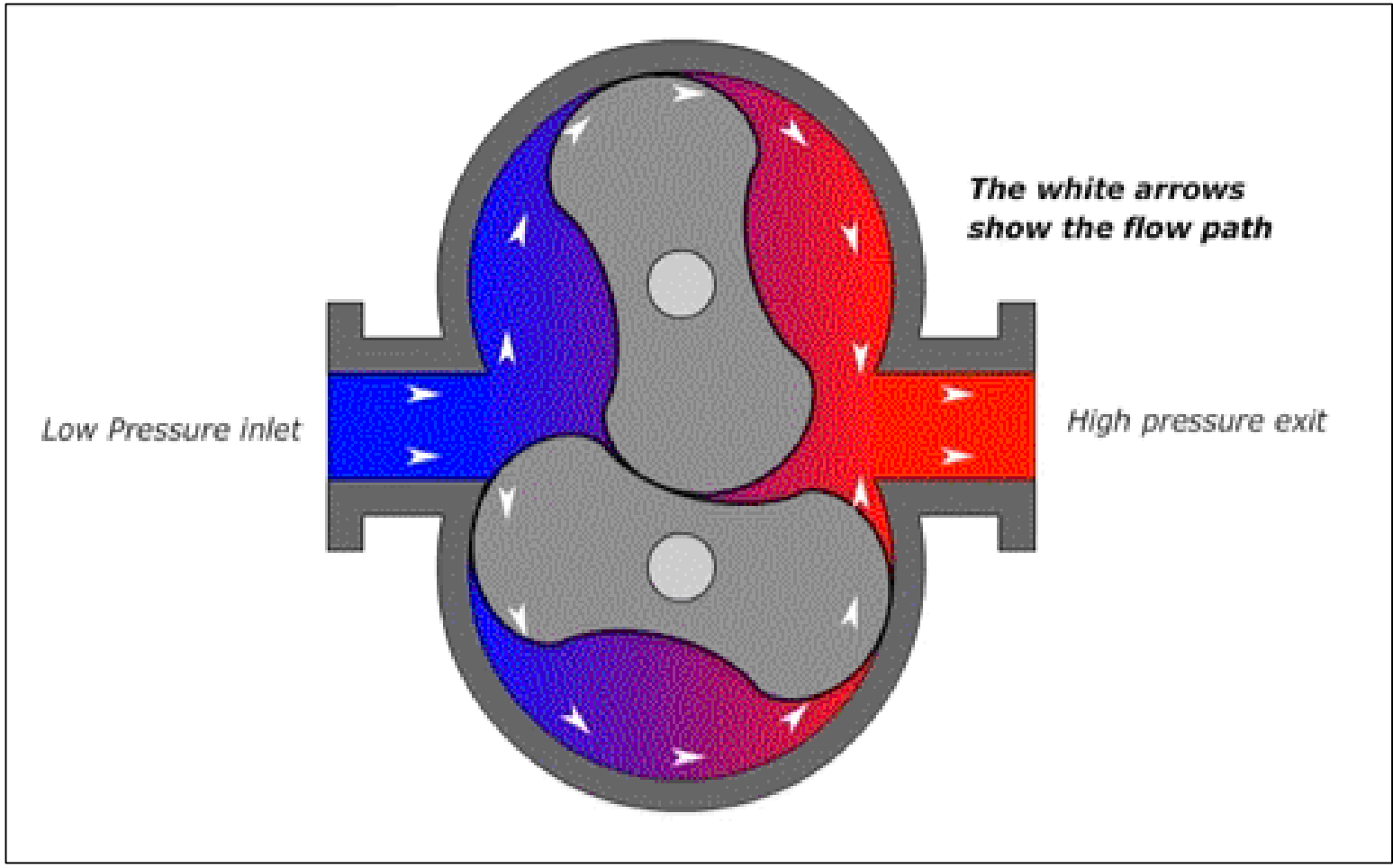
- Piston drives off-center wheel
  - One chamber has expanding, compressing areas
- Possible issue: condensing vapor does not increase exhaust pressure
  - Condensate can lower oil effectiveness
  - Gas ballast provides extra air before compression to prevent condensation



1 Upper dead point
2 Slot in suction channel of slide valve is freed – beginning of suction period
3 Lower dead point – slot in suction channel is quite free, and pumped-in gas (arrow) enters freely into the pumping chamber (shown shaded)
4 Slot in suction channel is closed again by swivelling hinge bar – end of suction period
5 Upper dead point – maximum space between rotating piston and stator
6 Shortly before beginning of compression period, the front surface of the rotating plunger frees gas ballast opening – commencement of gas ballast inlet
7 Gas ballast opening is quite free
8 End of gas ballast inlet
9 End of pumping period.

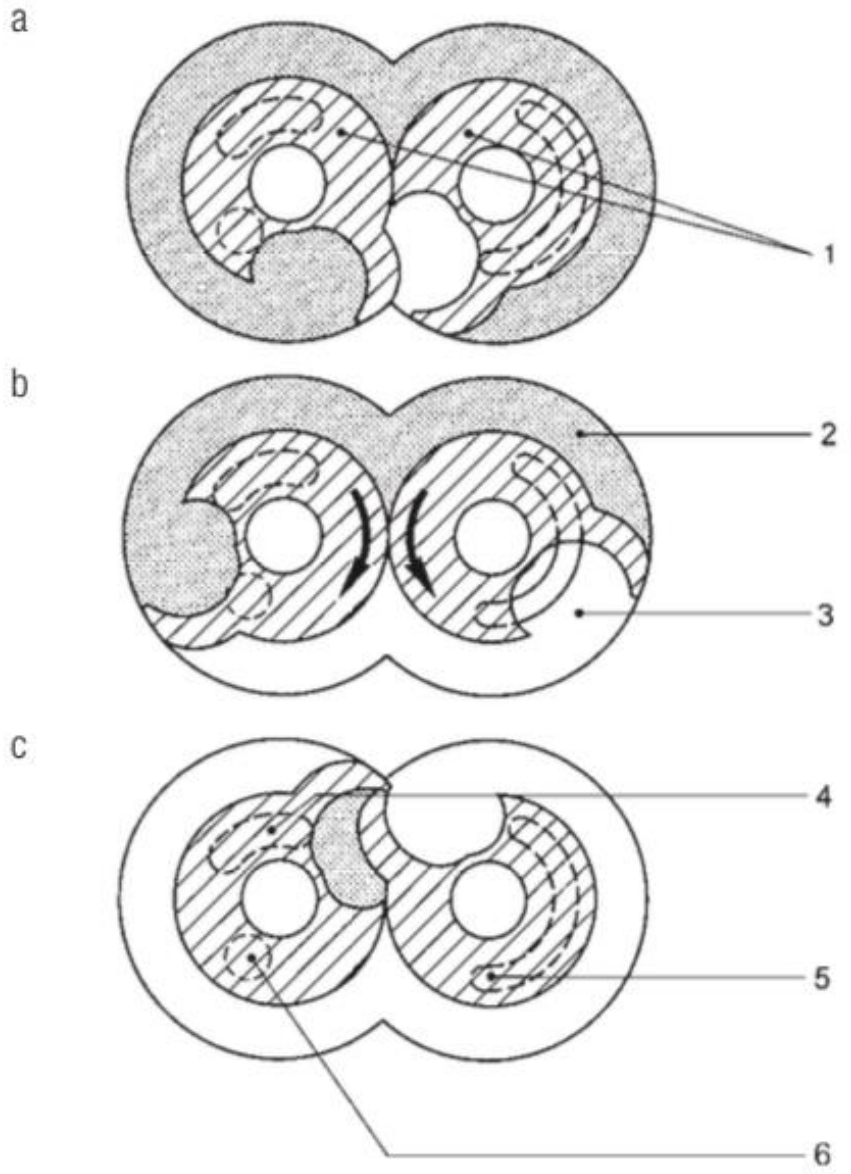
Roots Vacuum Pump

- Two counter-rotating “figure-8” impellers lower pressure at intake, increase at exhaust
- Rotor clearance ~100µm
  - No oil lubrication needed
  - Maximum compression limited
- Heat expansion from compression can cause motor seizure
  - Overflow valve often used



Claw Pumps

- Partially overlapping cylindrical rotors selectively input, compress, then release gas
  - 2 rotations in full cycle
- Gas purge to keep gas speed high enough to prevent particulate settling



1 Rotors
2 Compression chamber
3 Intake space
4 Exhaust slot
5 Intake slot
6 Intermediate stage purge gas

Scroll Pumping

- One fixed, one movable scroll creates pockets of intake air
- Relatively few parts
  - Efficient, quiet performance

Effectiveness of Displacement Pumps

- Rely on a *continuum theory* of gasses
  - Subject to ideal gas law, Boyle's law, etc.
- Choice of dry pump depends on type of gas pumped, desired pumping speed, ultimate pressure needed, etc.
- Multi-stage systems suitable down to medium vacuum
  - Act as backing pumps for HV and UHV systems
- Other considerations include choice of valves, geometry and material of piping, etc.

Next time: HV and UHV pump systems

Thank you