Vacuum pumps
真空幫浦

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Definition & 分類

真空幫浦是一種用來減少某特定體積內的氣壓和氣體密度的機器，亦即把氣體從某體積中移除。

- 誘捕式幫浦(entrapment vacuum pump)：利用冷凝或結合至系統的內(化學/物理方法)，而不將氣體排放至大氣中，稱之。
  Ex: 冷凝陷阱、吸附幫浦、冷凍幫浦、離子幫浦、鈦昇華幫浦

- 氣體轉換幫浦(gas transfer vacuum pump)：藉由一至數個壓縮機，把某體積內的氣體移除並注入大氣中。

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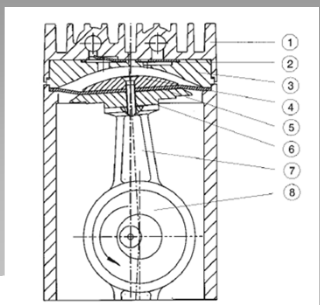
Gas transfer vacuum pump 氣體轉換幫浦

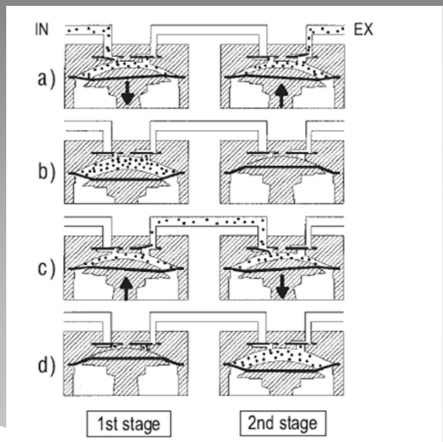
- 正排量幫浦(positive displacement vacuum pump)
  Ex: 旋片幫浦(rotary vane pump)、迴轉幫浦(scroll pump)、魯式幫浦(root pump)、隔膜幫浦(Diaphragm vacuum pump)
- 動力學幫浦(kinetic vacuum pump)：利用高速運動之蒸氣分子，經碰撞把動量給待抽氣體，並將待抽氣體排往較高壓力之區域。
  Ex: 渦輪分子幫浦(turbo molecular pump)、蒸汽幫浦(vapor ejector pump)、擴散幫浦(diffusion pump)

正排量幫浦

Diaphragm vacuum pump

極限壓力約為80mbar
二級泵可達到10mbar
三級的可達2mbar
四級能達到5×10^{-1} mbar





Opening and closing of the valves, path and pumping mechanism during four subsequent phases of a turn of the connecting rod (a-d)

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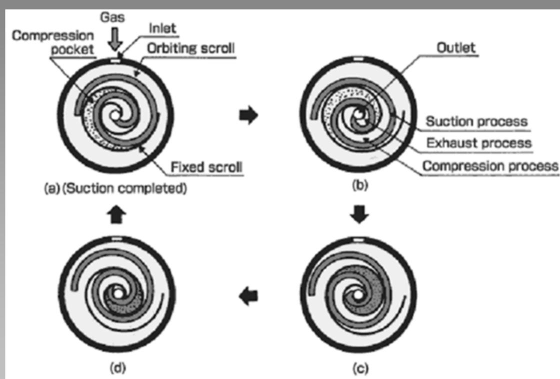
Scroll pump 迴轉幫浦



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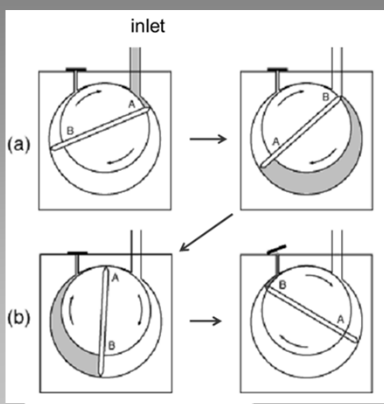
Dry
Shorter maintenance interval (5000 hrs)
Poorer corrosive resistance
Ultimate pressure: 5×10^{-3} Torr

Scroll Pump.flv

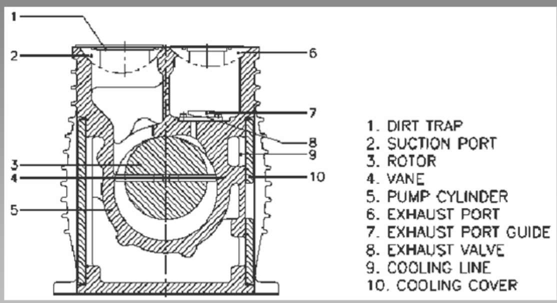
Rotary vane pump

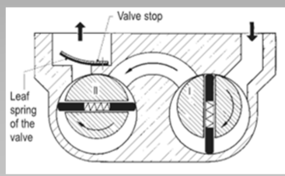


幫浦內有一旋轉的葉片，週期性的旋轉，隨著葉片旋轉將增加或減少腔壁內的體積。
其造成之氣體運動分為：
1. 進氣 2. 隔絕 3. 壓縮 4. 排氣。
可製造出約10^{-2} Torr 的壓力。

氣鎮
oil

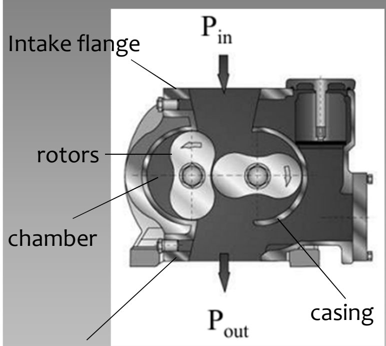
Rotary-Vane-Pump.mp4





Two-stage type

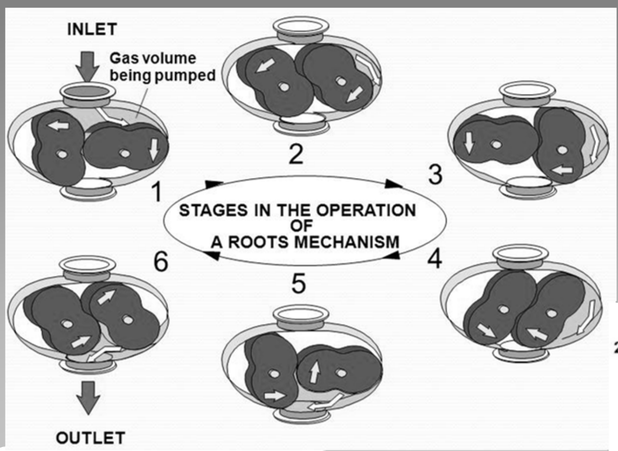
Roots pump



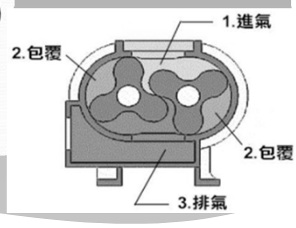
Roots Pump Two Lobe.mp4

Roots Pump Three Lobe.mp4

- 1848年，由Isaiah Davies發明了設計原理，到了1954年，由 Francis Roots和Philander Roots 兩兄弟製作出來。起初Roots pumps 被當作旋轉鼓風機來抽送空氣 ，之後才被拿來用在真空引擎上。
- 又稱機械式助力幫浦
- 搭配於油式真空幫浦或乾式幫浦來使用。
- 中度真空之抽氣效率佳
- 大氣至低真空度之抽氣效率不佳
- 無單獨使用，需搭配上述之真空幫浦使用。

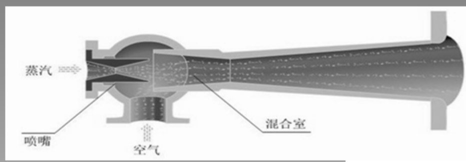


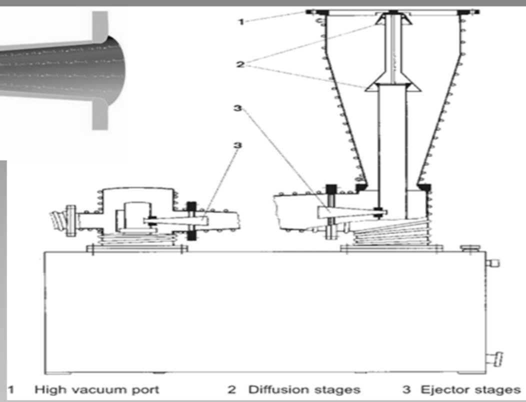
進氣
隔絕
壓縮
排氣



動力學幫浦

Oil vapor ejector pump



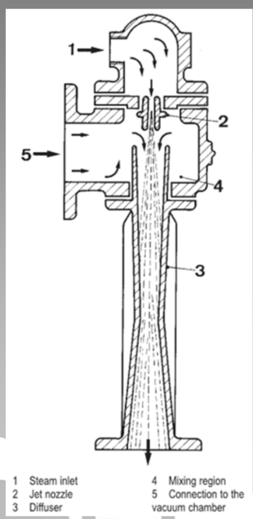


利用高速運動之蒸氣分子，經碰撞把動量給待抽氣體，並將待抽氣體排往較高壓力之區域。

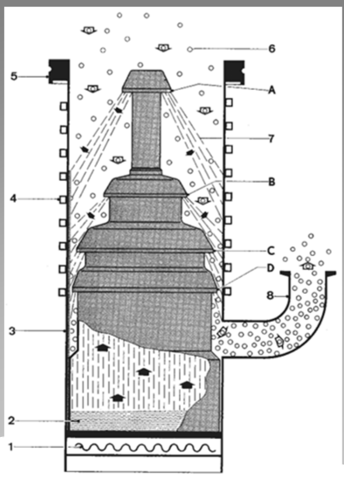
Ultimate pressure ~ 10^{-3} mbar

vapor jet pump.mp4

Water jet pump/Steam ejector pump



Diffusion pump



- Cheap, Robust
- Oil back stream, Cold trap
- Vapor ejector pump
- Need a fore pump
- Slow heat up (~0.5 hr)
- Cooling down (~2 hr)
- Ultimate pressure: $10^{-6} \sim 10^{-8}$ Torr

1 Heater	6 Gas molecules	A Nozzles
2 Boiler	7 Vapor jet	B
3 Pump body	8 Backing vacuum connection	C
4 Cooling coil		D
5 High vacuum flange		

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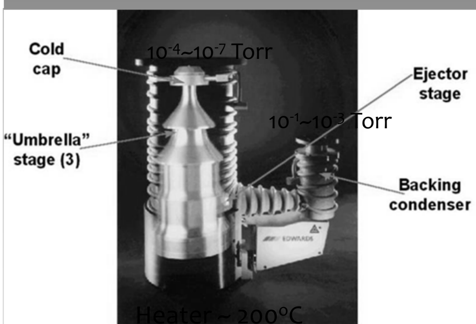

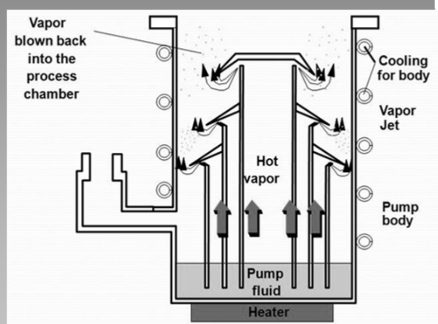

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Ex.: Edwards standard diffstak

省電、低耗能
抽氣速率：135~ 2000 L/sec (N_2)
Ultimate pressure: 7x10^{-8} mbar
(fluid: DC704EU)

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Turbomolecular pump (TMP)
分子渦輪幫浦

分子渦輪幫浦的理論在1913年被Gaede提出來，幫浦的抽氣機制乃是上游的氣體分子與快速移動的固體邊界碰撞後獲得高速並改變方向而移動至下游，此快速移動的固體邊界通常為一圓型轉子，此設計一般稱為Gaede分子渦輪幫浦。

當流體處於分子流狀態時，氣體分子密度低，分子平均自由徑大於幫浦的特徵長度，氣體分子與壁面面碰撞之機率遠低於分子間的碰撞，此時利用高速旋轉的轉子或葉片間將動量傳給分子，使其獲得一額外的速度向出口排出。

轉速：36000～72000rpm

Turbo V Pump-3D inside.mp4

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◆ 油潤滑滾珠軸承：幫浦運轉時軸承會產生很大的熱量，最常見的冷卻系統為氣冷、水冷。只能直立式安裝，但不需保養。

◆ 陶瓷軸承：由於幫浦轉子在高速運轉時，其軸承所受徑向力的主要來源是迴轉的滾珠，因此使用較輕的陶瓷材料，其重量約為鋼的60%。由於離心力較小，所造成的熱也較小，因此可以增長軸承的壽命。

◆ 磁浮軸承：利用磁鐵相斥的原理讓整個軸承即轉子漂浮於空中自轉，控制系統包括一內部電池供緊急之用，當轉子突然失去電源，此內部電源可使轉子懸浮並使其慢慢減速下來。由於為無接觸摩擦的軸承因此不需潤滑、不需冷卻，具有低噪音及震動且可固定任何方向。

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使用注意事項

1. 加濾網於幫浦上方或改變進氣方向，以避免任何碎片可能造成幫浦葉片等之損害。
2. 渦輪分子幫浦必須由高真空側放氣。
3. 適當之電力接地，以減低電氣雜訊。
4. 不可由渦輪分子幫浦之排氣口放氣。
5. 不可選用太小之前級幫浦。
6. 不可長時間讓渦輪分子幫浦在低轉速狀態下工作。

TMP pumping station

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誘捕式幫浦

Sorption pump 吸附幫浦

- 藉由化學的吸附作用或是物理的吸收作用。
- 成本低，但是無法連續操作。

Ion pump -- History

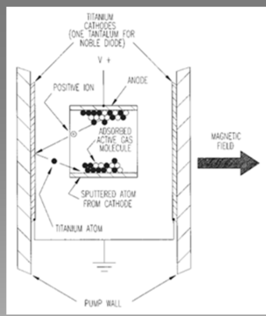
- Sputter ion pump, Ion getter pump
- J. Plucker (1858 -Germany) who found that it took ever-increasing voltages to maintain a current in a gas discharge tube. This, he rightly concluded, is due to a reduction of pressure in the tube by some mechanism involving the cathode.
- F. Penning (1937 - Holland) developed a cold cathode ionization gauge for measuring pressures in the range of 10^{-3} to 10^{-5} Torr. Due to the sputtering effect of the high voltage, ions were both buried in and "gettered" by the cathode material.
- The Penning cell has been used as a commercially available vacuum gauge ever since, but it was not until the late 1950's that its pumping characteristics were exploited by Varian Associates, resulting in the invention of the ion pump.

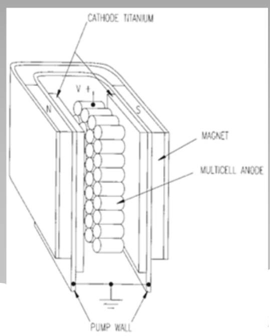
Principle

- Gas molecules are bombarded by high energy electrons when a collision occurs. A molecule may lose one or more of its own electrons and thereby is left as a positively charged ion. Under the influence of a strong electric field, the ion is accelerated into the titanium cathode. The force of this collision is sufficient to cause atoms to be ejected from the cathode and "sputtered" onto the adjacent walls of the pump. Freshly sputtered titanium chemically reacts with the active gases to form stable compounds.
- The noble gases like helium, neon, argon, krypton, and xenon, which are nonreactive. They are pumped by "ion burial" (ion burial is the "plastering over" of inert gas atoms by the sputtered getter atoms)
- These electrical potentials are usually in the range of 3,000 to 7,000 Vdc.

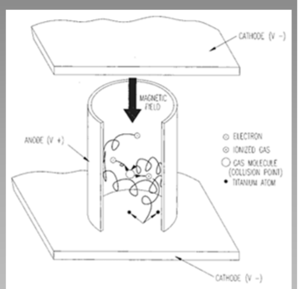
Ion pump

- In an ion pump the anode can either be a short section of metal tubing or a square, box-like structure, open at each end like a unit of an egg crate. Opposite each open end is a plate of titanium that is connected to the ground to form the cathode structure. An external permanent magnetic circuit generates a magnetic field, usually ranging from 800 to 2,000 G, parallel to the anode cell axis. A cell configured in this way is said to be a diode pump.
- To make a higher speed pump, it is now simply a matter of making a package containing more cells with a larger cathode





- This field causes the electrons to move in oscillating spiral paths (Figure 3) that increase their chances of striking gas molecules and thereby create positive ions.
- The pumping efficiency depends on the electron "cloud" density (which determines the number of ions produced) and on the sputtering yield (which determines the quantity of active getter material produced).



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Net pumping effect

In an ion pump, the net pumping effect results from the sum of different phenomena:

- The pumping action of the getter film produced by the sputtering of cathode material by ion bombardment.
- The pumping action due to the ion implantation and diffusion into the cathode.
- Gas burial on the anodes and pump walls.
- The gas re-emission from the cathode due to cathode heating and erosion.

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Re-emission

- As the number of gas molecules implanted into the cathode increases, the re-emission of them due to the ion bombardment increases.
- As a consequence, the net pumping speed decreases until an equilibrium condition between ion implantation and gas re-emission is reached. In this condition, the ion pump is "saturated" and the net pumping speed, due only to the gettering action of the material sputtered from the cathode, is about half the pumping speed of the unsaturated pump.

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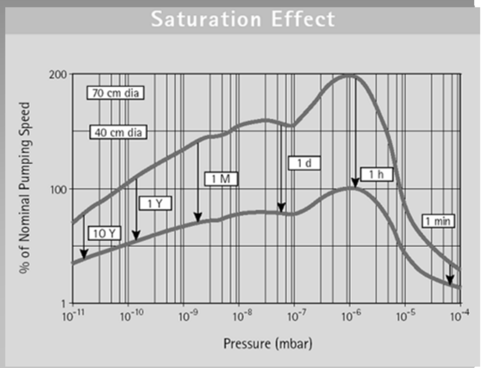
- The "nominal" pumping speed is defined as the maximum point on the pumping speed curve for a saturated pump; the reference gas is usually nitrogen.
- The time required to saturate an ion pump is inversely proportional to the pressure at which the pump is operated. Thus, the lower the pressure, the longer the time before the pump saturation occurs.



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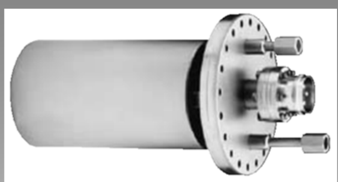
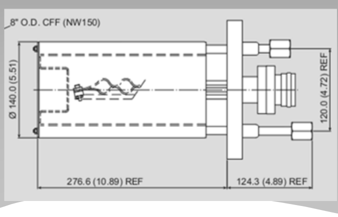
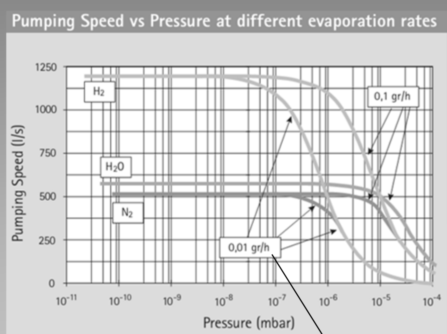
Ti sublimation pump







Evaporation rate

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Short summary

- No foreline needed
- low 10^{-11} Torr range
- oil-free, vibration-free, cost-effective
- robust
- The ion pump instead captures and stores gas.
- Gas species dependent
- Ti sorption pumping when electric power is off.
- Memory effect, outgas
- Saturation effect
- At some point in time the pump must be reconditioned or replaced.

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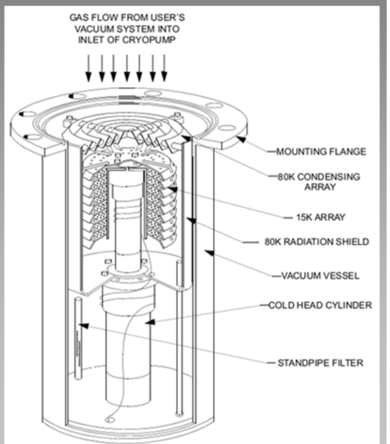
Cryogenic pump 冷凍幫浦

CTI 8 Cryopump CTI 8F Cryopump CTI On-Board 10

Cryo-Torr Cryopump Model	8	>8F	>10
Pumping Speeds - liters/sec.			
Water Vapor	4,000	4,000	9,000
Air	1,500	1,500	3,000
Hydrogen	2,500	2,200	5,000
Argon	1,200	1,200	2,500
Capacity - std. liter			
Argon	1,000	1,000	2,000
Hydrogen (5x10^{-6} Torr)	12	8	24



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Cryogenic pump 冷凍幫浦

Gas condensation on ultracold surfaces

< 20K activated carbon to absorb H_2, Ar, N_2, O_2, etc

< 80K metal surface to absorb H_2O, etc

Large pumping speed for condensing gases

No foreline needed

Corrosive resist

Gas species dependent: No pumping for He, Ne

Saturation effect, Memory effect

Huge outgas when warm

利用氣體膨脹吸熱的特性，產生極低的溫度，以達到抽真空的效果。冷凍幫浦可以創造無油且潔淨的良好真空環境。但具噪音且需定期維護。

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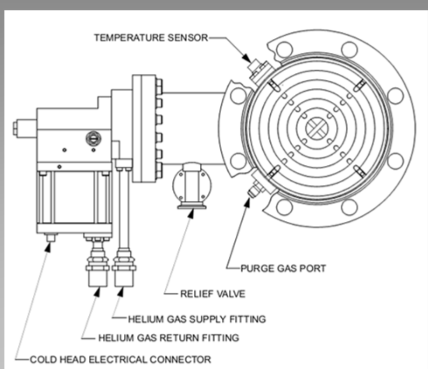

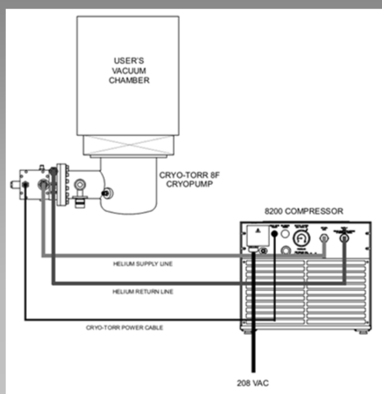

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- Cryo-Torr Cryopump consists of a cold head and a vacuum vessel. An 80K condensing array, a 15K array, cold head station heaters, and an 80K radiation shield are located in the vacuum vessel. The cold station heaters and 15K array are secured to the cold head, which is welded to the vacuum vessel. The cold head provides cooling to the three arrays. Gases are removed from your vacuum chamber, thereby creating a vacuum when they are condensed or adsorbed on the cryogenically-cooled arrays.
- The cold head consists of a two-stage cold head cylinder (part of the vacuum vessel) and drive unit displacer assembly, that together produce closed-cycle refrigeration at temperatures that range from 60 to 120K for the first-stage cold station to 10 to 20K for the second-stage cold station, depending on operating conditions. Within the drive unit displacer assembly, the drive unit actuates the displacer-regenerator assembly located in the cold head cylinder and thereby controls the flow of helium into the cold head.

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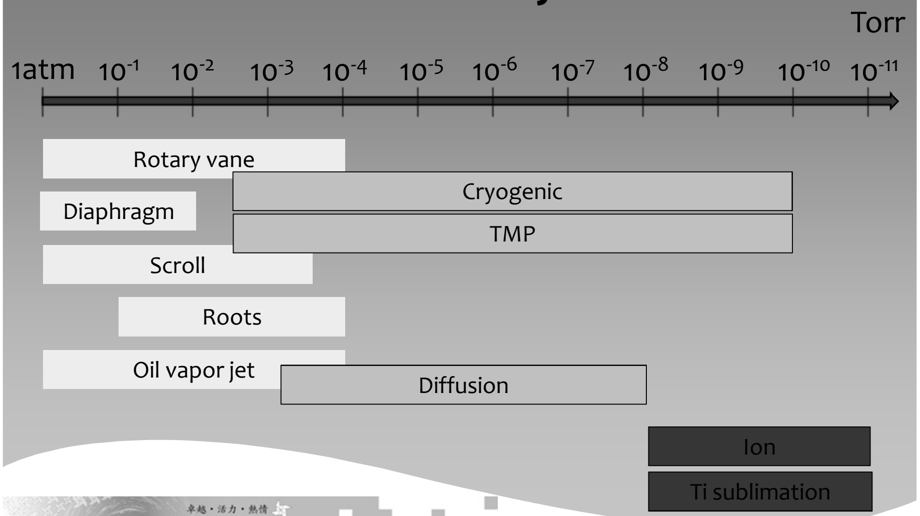
Summary



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