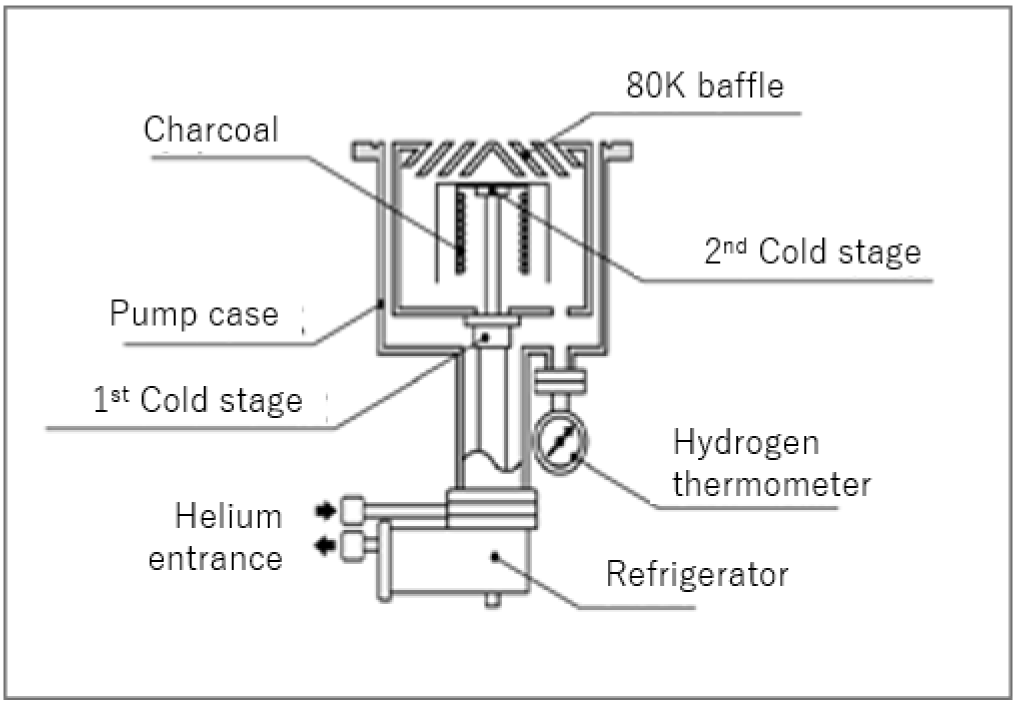
Cryopumps

Mechanism of Cryopump.

Higher vacuum with two-stage.

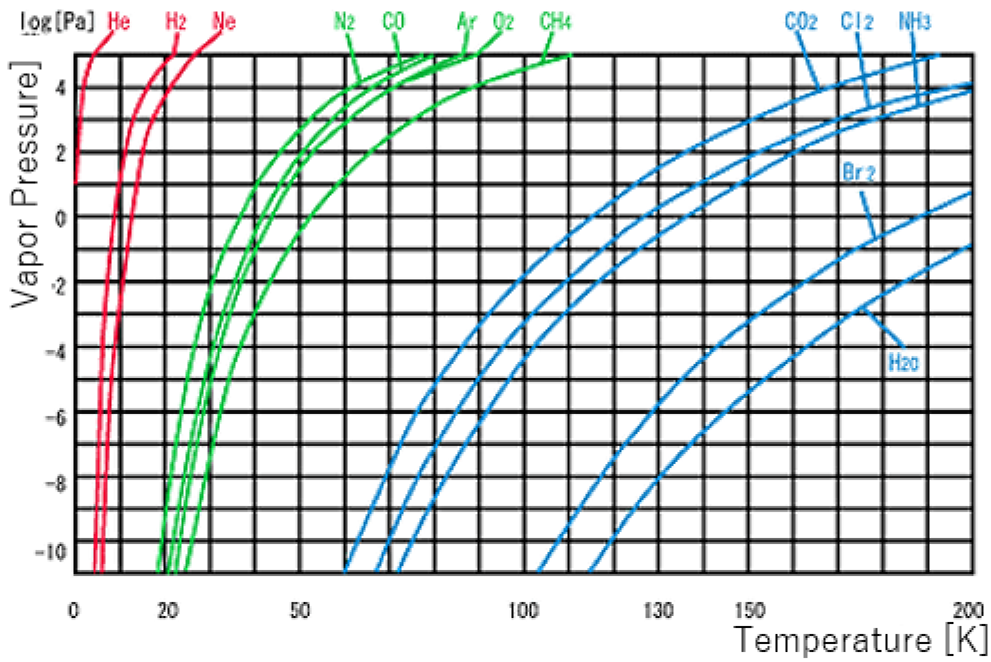
Cold stage is a two-stage type. The cooling capacity of the first stage is large, and it can cool to 80 K (Kelvin) or less. First-stage exhausts mainly the moisture and the second stage exhausts molecules such as N2, O2, Ar, and H2 by cooling even further to obtain a higher vacuum.



1.What is a cryopump?

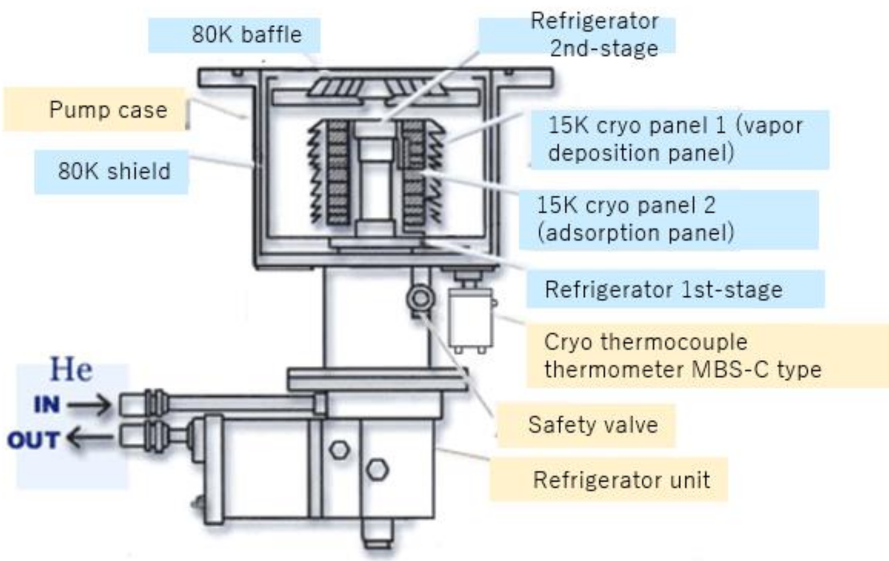
A cryopump is vacuum pump that traps gases and vapors by condensing them on a cold surface. For efficient evacuation under ultra-high vacuum, the vapor pressure for condensation, or the equilibrium pressure for adsorption must be less than 10^{-8}Pa.**Figure 1** shows vapor pressures of different gases.
According to this figure, if the cryocooled surface such as cryo-surface and cryopanel is cooled below 20K, the vapor pressure of the gas becomes below 10^{-8}Pa, provided the vapor pressure is lower than that of nitrogen. The lightest gases such as hydrogen, helium, and neon are not condensed at 20K, therefore instead of relying on condensation alone, adsorbent made of special porous materials are provided to adsorb them. By cooling down the adsorbent below 20K, those

gases are adsorbed efficiently, and thereby a cryopump can achieve ultra-high vacuum.
There are two ways to "cryocool" the surface of the cryopump. One is a use of coolant such as liquid nitrogen(LN2, 77K) or liquid helium(LHe, 4.2K), and the other is a small closed cycle helium refrigerator.



2.Basic Principle and Structure

Let's take a look at CRYO-U8H as an example.
The refrigerator for CRYO-U cryopumps normally has two-stages. While the 1st stage has a large refrigerating capacity down to below 80K, the refrigerating capacity of the 2nd stage is small but cools down to 10 to 12K. Both 15K cryopanel(1) and 15K cryopanel(2) are mounted on the 2nd stage of the refrigerator, and shielded from the temperature radiation by the 80K shield and 80K baffle mounted on the 1st stage.



As you see in Fig.1, the vapor pressure of water vapor becomes below 10^{-8}8 Pa at temperature of below 130K, and thus water vapor is pumped as a result of condensation on the 80K baffle and 80K shield. The next group of gases, nitrogen, oxygen, argon, and other gases of similar molecular weight are pumped at the exposed surface of 15K cryopanel(1) at the second stage, which is kept below 20K. The third group, mainly hydrogen, helium, and neon will not condense at 20K and will not be pumped efficiently by the metal surface because the equilibrium vapor pressure for cryosorption will be too high. To improve this situation, cryopumps have adsorbent of porous materials such as charcoal on the 2nd stage cryoarrays. The adsorbent is bonded to the inner surface of the 15K cryopanel(1) to prevent it from being covered with condensable gases. Outside surface of 80K shield, 80K baffle, and 15K cryopanel(1) are specular finished in order to reflect radiant heat from room temperature. The inner surface of 80K shield is blackened to reduce the radiation heat transfer to the 15K cryopanel attached to the 2nd stage. In order that a cryopump to operate properly, both 80K shield and 80K baffle should be kept below 130K and 15K cryopanel to be kept below 20K.

In order to monitor those temperature, K(CA) thermocouple for 80K shield, and hydrogen vapor pressure gauge(H2VP) or CRYO METER MBS for 15K cryopanel are installed to the cryopumps. (The standard for the electromotive force at 130K of K(CA) thermocouple is -5.5mV.)

3.Regeneration and Pressure Relief Valve

Cryopumps are not continuous throughout pumps such as oil diffusion pumps and turbo molecular pumps. As a cryopump keeps gases inside on 15K cryopanels by condensation and adsorption, it needs to be degassed and regenerated on a regular basis. During this regeneration process, the cryopump is warmed up, and condensed or adsorbed gases are turned into gas again. If large amount of gases are pumped, there is a risk of explosion. In order to prevent the explosion danger, all cryopumps feature a pressure relief valve.

The operating pressure of the pressure relief valve has been set at 20kPa(gage).
For safety reasons, DO NOT BLOCK the pressure relief valve, and DO NOT MODIFY it for other purposes.
Also never use it as a purge valve in a regeneration process because refuse in purge gas may stick to the sheet of the pressure relief valve and may cause a leakage.

4.Cryopump System

Cryopump system consists of

《1》Cryopump Unit（incl. Cold Head）

《2》Compressor Unit

《3》Flexible Hose（2）

The connection of the cryopump system is shown in **Figure 3.** In addition, rough pump (customer-supplied) is necessary to operate and regenerate cryopumps. (Cryopumps cannot start from the atmospheric pressure.)

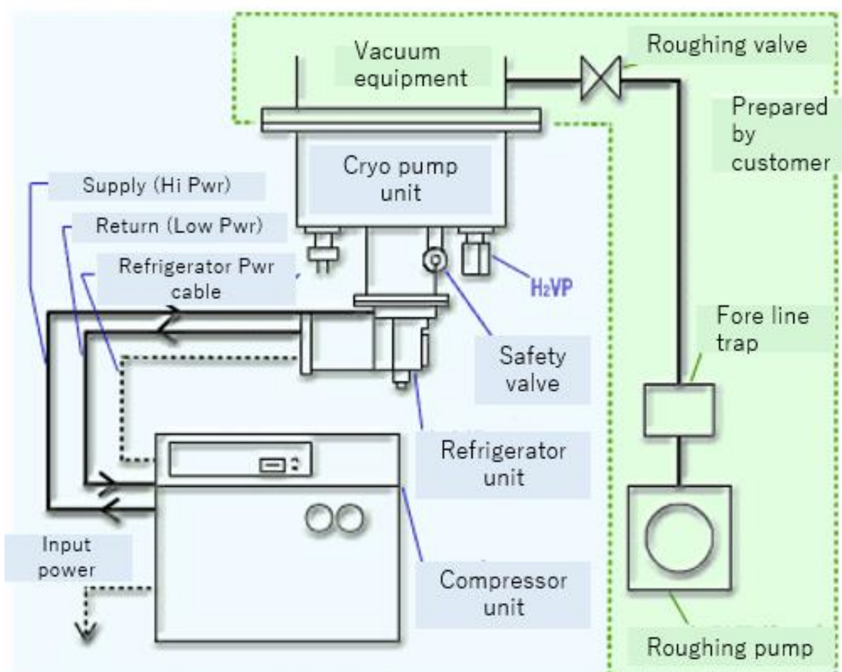


Figure3.Cryopump System

Performance Characteristics

The essential performance characteristics for cryopump operation are: ①Cooldown, ②Pumping Speed, ③Pumping Capacity, ④Maximum Throughput, ⑤Crossover Pressure, ⑥Ultimate Pressure, and ⑦Thermal Load Capacity. For details, see each section below.

1.Cooldown Characteristics

The vacuum chamber must be rough pumped before cryopumping since cryopumps cannot start its operation from atmospheric pressure. When rough pumping a CRYO-U® cryopump with a rotary pump, roughing pressure of 40Pa is sufficient since backflow of oil vapor will not occur. The residual gas will be adsorbed to adsorbent inside cryopump.Cooldown time differs depending on conditions as shown in table below.

Table 1.Factors which affects Cooldown Time

Factor	
1.Rough Pumping Pressure	HIGH
2.Pump Temperature	HIGH
3.Residual Gas Composition After Rough Pumping	DRY（Dry inside cryopump）
	WATERY
4.Contamination of Cryopump	CONTAMINATED

Cooldown time is affected by regeneration method. Use of N2 purge or Band Heater may extend the cooldown time causing temperature rise, or dry condition which hardly achieves vacuum insulation. Also, slight leakage may cause extended cooldown time or cooldown failure.(Especially due to leakage from pressure relief valve.) Cooldown time may be reduced by 10 to 15% at 60Hz compared to that at 50Hz. Generally, cooldown time is defined as the amount of time for 15K cryopanel temperature to drop to 20K or below. See Table 2 for details.

2.Pumping Speed Characteristic

2-1.Pumping Speed for Water

It is usually assumed that the water condensation probability on cryosurface is approx. one, provided that the cryosurface temperature is below 150K. In normal operation, temperature of 80K shield and baffle is below 130K(80K or below in normal use). Therefore the pumping speed for water is equivalent to ideal pumping speed of cryopump which has a diameter of 80K shield. The ideal pumping speed (s) per unit area for molecular weight M is given by:

$s=62.5/M^{1/2}(L/s/cm^2)(20℃)$

Water molecular weight M is 18, thereby the ideal pumping speed(s) is 14.7(L/s・cm^2).

Pumping speed for water(S) is given by $S=s\cdot A\ (L/s)$, provided the area of 80K shield inlet is A(cm^2). For 8-inch cryopump, the area of 80K shield inlet is approx. 275cm^2, thus, the pumping speed for water is 4000L/s. The same calculation is available for gases condensed and pumped on 80K baffle such as CO_2 and NH_4 etc.

CRYO-U8H pumping speed for water is 4000L/s. Since molecular weight of CO_2 is 44, CRYO-U8H pumping speed for CO_2 is given by:

$S_{CO_2}=S_{H_2O}\times(18/44)1/2=2560\ L/s$

Diameter	Model	Pumping Speed（L/s)
6	U6H	2100
8	U8H,U8H-U,U8HSP	4000

As you see, the capture probability(sticking coefficient) of condensing array for condensable gases is one, provided the temperature of cryosurface is below 20K. Also, cryopump pumping speed at molecular flow region is constant since the conductance from inlet to cryopanel is constant at molecular flow region.
The speed values given in brochures are pumping speed for nitrogen at molecular flow region.

Pumping speed for condensable gases of molecular weight M other than nitrogen can be calculated by following equations.

$SM = SN_2 \times (28/M)^{2/1}$ (L/s)。

Table 2.Pumping Speed of Various Cryopump for Nitrogen(Value from Brochure)

Pumping Characteristic for Argon and Nitrogen (Condensable Gas)

A group of gases such as N_2、Ar、CO、O_2 and other gases of similar molecular weight are condensed and pumped at 20K or below, therefore they are not condensed on 80K baffle and shield. In general, the limit temperature that gases can be pumped by condensation is 20K. The temperature of condensing array when condensation probability of gases becomes below one at 300K is:

N2 ：approx. 23K

Ar ：approx. 27K

Also, the temperature when cryopump loses its pumping ability is:

N2 ：approx. 27K

Ar ：approx. 29K

As you see, the capture probability(sticking coefficient) of condensing array for condensable gases is one, provided the temperature of cryosurface is below 20K. Also, cryopump pumping speed at molecular flow region is constant since the conductance from inlet to cryopanel is constant at molecular flow region.

The speed values given in brochures are pumping speed for nitrogen at molecular flow region. Pumping speed for condensable gases of molecular weight M other than nitrogen can be calculated by following equations.

$SM = SN_2 \times (28/M)^{1/2}$ (L/s) ・・・・・・・(1)

SN_2：Pumping Speed for Nitrogen（L/s）

For example, CRYO-U8H pumping speed for argon is (See Table 2):

$SN_2 = 1700$（L/s） and also molecular weight of argon is 40, thus, the calculation is:

$Sar = 1700X(28/40)^{1/2} = 1400L/s$

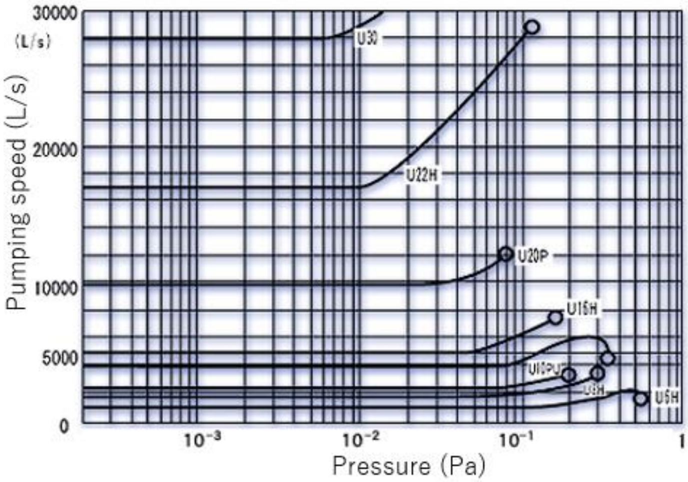


Figure 1.CRYO-U Pumping Speed for Nitrogen

Model	Pumping Speed（L/s） （L/s）
U6H	750
U8H/U8H-U/U8HSP	1700
U10P	2300
U12H	4000
U12HSP	4100
U16/U16P	5000
U20P	10000
U22H	17000
U30H	28000

Table 3.Pumping Speed of Various Cryopump for Nitrogen(Value from Brochure)

When gas flow changes from molecular flow to intermediate flow(transition flow), pumping speed increases since the conductance increases proportional to the pressure. However, since incoming heat increases as pressure increases, cryopump reaches its limit of pumping ability when the thermal load exceeds cold head refrigerating capacity. ULVAC CRYOGENICS defines the flow rate when the cryopanel reaches 20K by the thermal load as the maximum throughput.（The point marked "○" in Figure 2.） The maximum throughput may be increased with large refrigerating capacity, but it may generate temperature gradient in thickness direction since the thermal conductivity for cryoarray is limited even with a large refrigerating capacity. If the temperature of condensation array becomes too high exceeding its limit, gases will not be condensed, and then pumping capacity becomes zero. That is to say a physical limit of pumping.

2-3.Pumping Speed for Hydrogen, Helium, and Neon（Non-condensable Gas）

The next group of gases such as hydrogen, helium, and neon will not condense at 20K and will not be pumped efficiently by metal surface because the equilibrium vapor pressure for cryosorption will be too high. These gases cannot be pumped through condensation, therefore adsorbent cooled below 20K is provided to adsorb these gases. The pumping speed will decrease as the surface coverage increases. When the pumping speed is down to 80% of its starting value, the total amount of pumped gases is defined as the pumping capacity. (see below.) Pumping speed for non-condensable gases depends on the following:

(１)Adsorption Probability of Adsorbent Influenced Factors Below.

①Characteristics, Installation Method, and Configuration of Adsorbent

②Temperature and Amount of Adsorbent

③Rate of Degassing

④Kinds and Amount of Gases Previously Adsorbed

⑤Flow Rate and Temperature of Gases

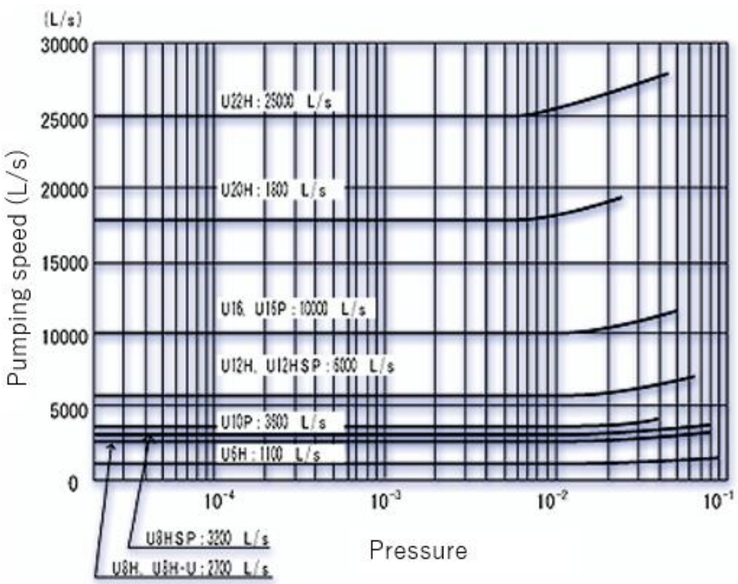
(２)Arrival Rate of Gas from Inlet to Adsorbent (Conductance)

Typically the pumping speed is determined in accordance with test results. Pumping speed for gases with large amount of adsorption such as hydrogen and neon is constant at molecular flow region. Temperature of cryopanel rises as gas flow rate increases, and the flow rate at 20K is defined as the maximum throughput. For non-condensable gases, pumping at the maximum throughput or around may be performed for a short time because the adsorption probability decreases in a short time with increasing the amount of non-condensable gases adsorbed to the adsorbent. In case of pumping hydrogen at high flow rate, it is advisable to operate intermittently rather than continuously to maintain its pumping capacity.

Hydrogen, one of non-condensable gases, is not only a component of outgas but also vital for application, therefore specifications are determined in detail. There is few data for neon because it is not used in common. Also, for helium which is hardly likely adsorbed, it is not recommended to pump them by cryosorption since they can be pumped about 1% to 0.1% of hydrogen.

Model CRYO-U	Pumping Speed (L/s)	Maximum Throughput (Pa・L/s)	Pumping Capacity (Pa・L)
-U6H	1100	1.1×10^{2}	3.1×10^{5}
-U8H	2700	2.4×10^{2}	1.0×10^{6}
-U8HSP	3200	2.4×10^{2}	1.0×10^{6}
-U10PU	3600	1.5×10^{2}	6.7×10^{5}
-U12H	6000	4.1×10^{2}	9.8×10^{5}
-U12HSP	6000	4.1×10^{2}	1.6×10^{6}
-U16	10000	4.1×10^{2}	2.4×10^{6}
-U16P	10000	4.5×10^{2}	2.4×10^{6}
-U20P	18000	5.0×10^{2}	4.6×10^{6}
-U22H	25000	1.3×10^{3}	8.5×10^{6}
-U30H	43000	7.4×10^{2}	1.5×10^{7}

Table 4.CRYO-U Pumping Performance for Hydrogen


(L/s)
30000
25000
20000
15000
10000
5000
0
Pumping speed (L/s)
U22H : 25000 L/s
U20H : 1800 L/s
U16, U15P : 10000 L/s
U12H, U12HSP : 6000 L/s
U10P : 3500 L/s
U6H : 1100 L/s
10^{-4}
10^{-3}
10^{-2}
10^{-1}
U8HSP : 3200 L/s
U8H, U8H-U : 2700 L/s
Pressure