Cryogenic Cooling

for
Temperature Chambers
and
Thermal Platforms

Explained & Demystified

SIGMA SYSTEMS CORPORATION

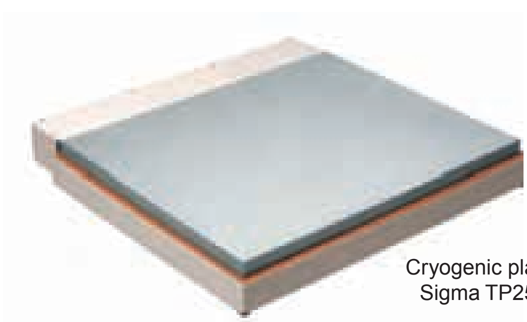
You should know...

That Sigma Systems builds temperature chambers and thermal platforms with *mechanical cooling* (refrigeration compressors), *cryogenic cooling* (liquid Carbon Dioxide, L–CO_2, or liquid Nitrogen, L–N_2) and combination units. Mechanical cooling is familiar to all of us. It's the cooling system for our home refrigerators, office air conditioners, our automobile climate control systems, and our grocer's freezer. While many temperature chamber and thermal platform applications are well suited to mechanical refrigeration, a lot of the success of mechanical refrigeration in the thermal test market is attributable to simple familiarity. Rather than take a risk with an unknown, people tend to embrace what they know and stick with it. The result is a safe choice, but not always the best choice.

Comfort and familiarity are compelling factors, but they are likely not the best criteria to use when choosing a cooling method for a thermal test or conditioning system. The purpose of this brochure is to help you become familiar and comfortable with cryogenic cooling so you can choose the right coolant and have a successful implementation if you choose cryogenic cooling. If this brochure can help you have the same comfort and familiarity with cryogenic cooling that you already have with mechanical cooling, you will be better able to make informed and comfortable decisions about the type of cooling system you need in your thermal platform or temperature chamber.

The scientific world holds that there really is no cold, just less heat. We're going to refer to low temperatures as cold. While the concepts of superheat, latent heat, etc. make the real physics of heat transfer much easier to understand, those concepts require development that is beyond the scope of this paper. For most people, the idea that something can be "superheated" at –265°C is preposterous. (Helium vapor at –265°C is superheated.) This paper is just not voluminous enough to successfully make the argument that such terms are reasonable. Our objective here is to give users and potential users of cryogenic cooling in thermal platforms and temperature chambers the basic information they need to make good decisions and have successful operations. To this end we may take a bit of license and leave a few theoretical details aside. The audience for this paper is not the theoretician, but the ever pressed test maintenance technician, and individuals buying or supervising the use of cryogenic chambers and platforms. The discussion of cryogenics for our purposes does not need to be complicated and only the relevant details will be discussed.

Cryogenic chamber
Sigma M256



Cryogenic platform
Sigma TP2555

Mechanical platform
Sigma TP1085M

Mechanical chamber
Sigma M256M

1 How we cool things

Cooling is simply the process of taking some of the heat energy away. There are lots of ways to cool things. Some methods are far more efficient than others. We'll use a kitchen pan to explain the method that's used in temperature chambers and thermal platforms. While this may all seem a bit unscientific, the concept is important to understanding why cryogenic, and mechanical cooling, work as well as they do.

Imagine putting an empty pan over a fire. Get the pan really hot… way over the boiling temperature of water. Take the pan off the fire. Pour a cup of water in the pan. Note that as the cool water absorbs heat from the pan, it heats quickly and when it gets to it's boiling temperature, it bubbles and boils. The pan will be quickly cooled by the boiling (evaporating) water. However, as soon as the boiling stops, the pan and water don't get any cooler for awhile. Instead, the pan and water will come to the same very warm temperature. Here's what happened:

When you first put water in the pan, the large difference in temperature between the pan and the water caused a lot of heat to transfer to the water. The water got warmer and quickly got to its boiling temperature. As more heat transferred from the pan to the water, instead of getting hotter, the water boiled and the process of boiling (vaporization) absorbed the newly arriving heat. In fact, the heat that was absorbed by the vaporization process (boiling) was substantially greater than the heat that was absorbed just heating the water to the boiling point. Once the pan was cooled below the water's boiling point, adding more water only cooled the pan a small amount as the remaining heat was diluted in more water. The significant cooling was done when the water was being vaporized.

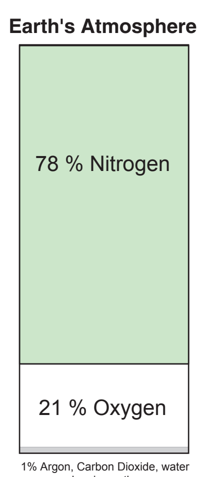
Every liquid requires substantial heat energy to vaporize and become a gas. If we can find a way to make a liquid vaporize, it will absorb heat in doing so. The temperature at which a liquid boils (vaporizes) is affected by the pressure it's under. Because the vaporization temperature of every liquid is determined by the pressure it's under, we can keep it from vaporizing by raising its pressure, or make it vaporize by lowering its pressure.

To cool our temperature chamber, or thermal platform, we bring a pressurized liquid inside, then reduce it's pressure by passing it through a throttling device. If we do it right, the liquid will vaporize when the pressure is reduced and absorb the heat we want to take away. We'll then move the vapor, which contains our unwanted heat, out of the chamber or platform. If we continue this process, it will continuously cool our chamber or platform. In this brochure, we'll discuss using liquid Nitrogen ($L–N_2$) and liquid Carbon Dioxide ($L–CO_2$), the cryogenic liquids most commonly used as coolants.

2 How safe is cryogenic cooling?

Common cryogenic coolants do not harm the Ozone layer, are not flammable, and are not poisonous. Using cryogenic cooling is likely a lot safer than driving to work. The common coolants, Carbon Dioxide, and Nitrogen, are normal components of our breathable air. In fact, about 78% of our atmosphere is Nitrogen, so it's safety is pretty well demonstrated. Carbon Dioxide is the fizzy part of soft drinks, so it better be safe. With all that said, there are some things to consider when using cryogenic cooling.

Cryogenic coolants are usually very cold and under pressure. Use of proper hoses designed for cryogenic temperatures is essential. Simple training is appropriate to make certain that operators know the appropriate precautions and how to handle potentially cold fittings and valves with gloves and safety glasses. The risks are real, but probably less than putting gasoline into your car.



Spent cryogenic coolant can displace breathable air. Your chamber or platform will have an exhaust port from which most of the cryogenic coolant vapor will be vented. In most cases, rooms are large enough and sufficiently well ventilated that the introduction of the vapor into the room breathing air is not a problem. However, if coolant usage is high and/or the air volume low and ventilation poor, then there is the chance that too much of the breathable Oxygen in the room will be displaced. All Sigma chambers and platforms have exhaust ports designed for easy attachment to a vent system so the spent coolant can be vented out–of–doors. In facilities where there is any doubt whatsoever, it is prudent to use a simple and inexpensive Oxygen level monitor to confirm a healthy environment for workers.

3 What is mechanical cooling and what is cryogenic cooling?

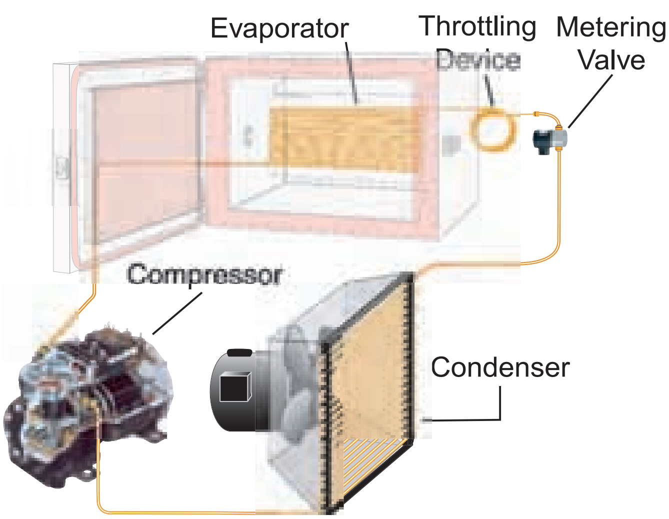
The only, and very significant, basic difference between mechanical cooling and cryogenic cooling is that mechanical cooling systems use a closed system which recovers and reuses the coolant vapor, whereas traditional cryogenic cooling systems use an open system that expels the spent vapor into the atmosphere.

With a mechanically cooled system, the equipment for the recompression and cooling of the spent coolant vapor to convert it back to a reusable liquid is part of the chamber or platform system. With at least one compressor, two heat exchanger coils, a fan, and lots of process controls, these systems are complicated and expensive. Cryogenic cooling systems leave all the complication of compressing and liquefying the coolant to the coolant supplier. The photographs below show the basic components used to build a cooling system for a typical cascaded mechanically cooled temperature chamber and those required to build a cryogenically cooled temperature chamber.

Mechanical cooling systems are handy because they are self contained. However, mechanical cooling systems are limited by the capacity of the compressors which are in turn limited by your available power, space, and tolerance for noise and heat. They are more expensive, complicated, and do a lot less work than equivalent cryogenic systems.

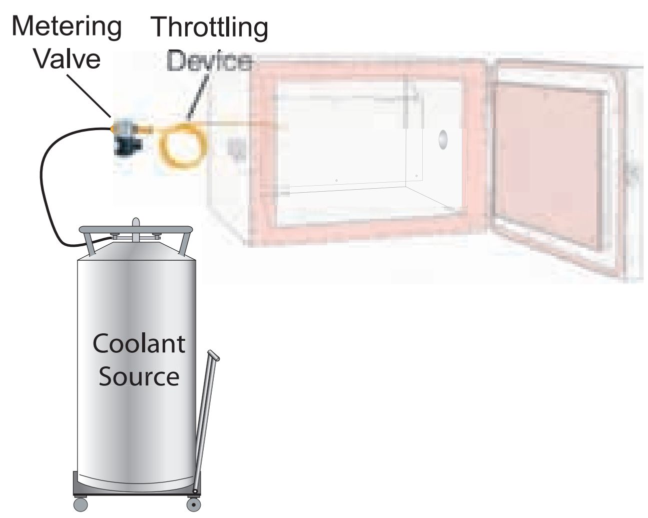
With cryogenic cooling, someone else does all the compressing and liquefying for you. You simply buy it, use it, and discard it into the atmosphere. The system is simpler, faster, better performing and less expensive to buy.

Typical Mechanical Cooling System



Parts that go into a typical cascade mechanical refrigeration system: condenser, heat exchanger, evaporator, fan motor, fan, fan shroud, lots of copper tubing, lots of solder joints, centrifugal oil remover, electronic relays, thermostats, pressure sensors, .lters , hi-pressure by-pass, over pressure accumulator, foam insulation for copper tubing, mechanical compressor, meter valves, throttling device (capillary tube) and more.

Typical Cryogenic Cooling System



Parts for a typical cryogenically cooled system: metering valves, mounting bracket and injector tube

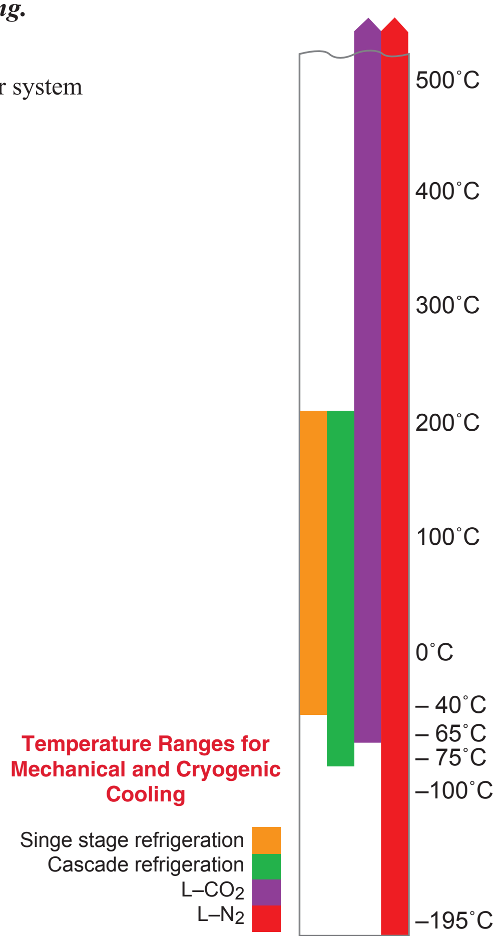
4 The advantages of cryogenic cooling...

Cryogenic cooling offers real advantages when compared to mechanical cooling.
These are the most important:

- Lower initial equipment cost – you won't pay for a complicated compressor system
- Lower maintenance costs – fewer and less expensive parts to maintain
- Lower temperatures possible – down to –195°C
- Higher temperatures possible – up to 500°C
- Much faster temperature transitions for much better productive throughput
- Smaller and lighter equipment requires less space
- Less electrical power required
- Less heat dissipated into the room
- Less noise – no compressor or condenser fan noise
- Drier – no interior moisture accumulation during cooling

Cryogenic cooling is the only choice when you require fast temperature change (ramp) rates, or temperatures beyond the limits of mechanical refrigeration. While mechanical refrigeration is limited to approximately –35°C (single stage) or –65°C (cascaded 2 stage), and slow to reach those limits, cryogenic coolants can easily and quickly achieve –175°C and lower. High temperatures, well over the mechanical refrigerant degradation limits of approximately 200°C are practical and common for systems using cryogenic cooling.

Because the cryogenic coolant is prepared by your vendor and delivered in a bottle, you won't need to provide power, space, or maintenance for compressors, fans, etc. Without all the extra hardware associated with mechanical refrigeration, your working environment will be cooler and quieter.

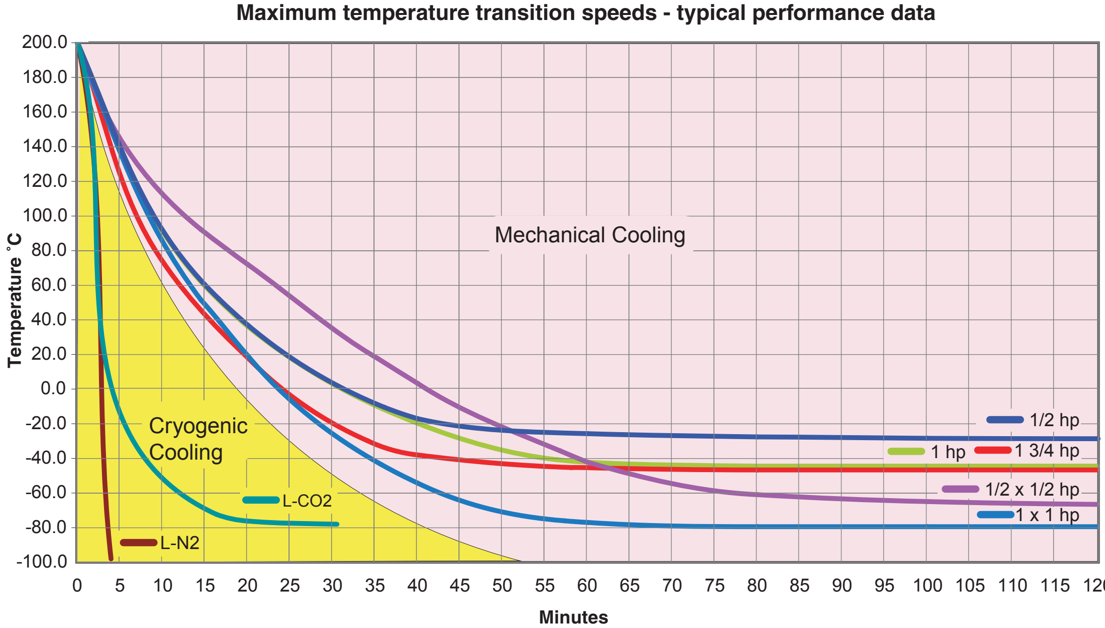


Temperature Ranges for Mechanical and Cryogenic Cooling

Comparison of Relative Maximum Temperature Transition Speeds

M90 & M90M & M90MM temperature chambers

Maximum temperature transition speeds - typical performance data



5 The costs of cryogenic cooling... Seeing the Big Picture

In situations where the required temperatures and performance are within the range of mechanical refrigeration, the #1 argument against cryogenic cooling is the continuing cost of providing the expendable liquid coolant. The argument is commonly made that the cost per hour of L–CO_2 or L–N_2 for operating a cryogenically cooled chamber or platform is much higher than the hourly cost of electricity to operate an equivalent mechanically cooled unit. The argument is true, but incomplete.

If the primary objective of your testing profile is to test continuously for hours without any need for rapid temperature changes, then mechanical refrigeration is probably the best choice. However, if your objective is to complete a lot of tests in a short time, or to test and ship the greatest amount of product in a day or shift, then cryogenic cooling, even with it's higher hourly coolant cost, may well be the best choice.

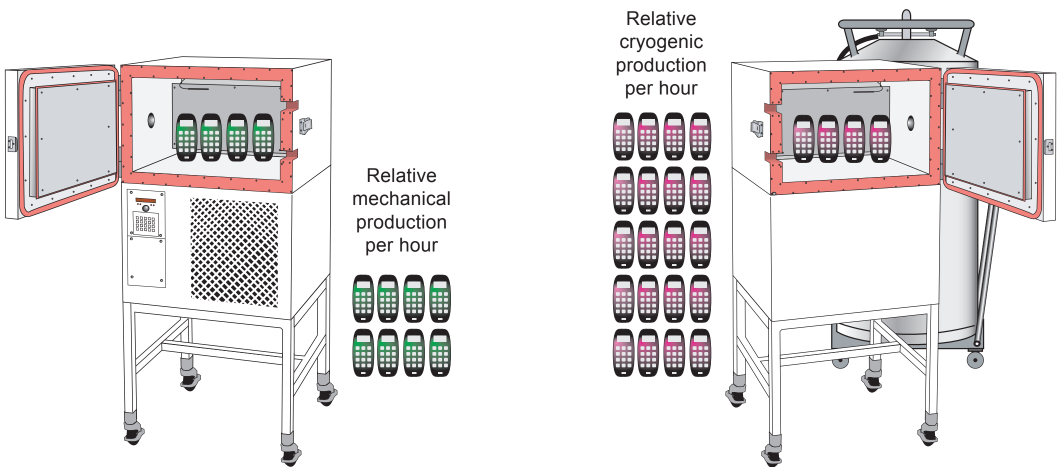
Cryogenic cooling systems are very simple and therefore cost a lot less than mechanical systems to buy and maintain. Depending on your usage, the money you save on the initial equipment purchase may well be more than you'll ever spend on coolant. And… you'll have the benefit of better performance.

Cryogenic cooling systems also have a very high cooling capacity and can cool very rapidly. If you take advantage of that performance, you will save a lot of time and money. Consider that your lab, or factory, has a limited amount of equipment, space, and people. Your temperature testing is probably the slowest part of the production and testing process. If each test station has to have certain expensive equipment, and cutting test time in half would halve the number of test stations required, then the cost of the cryogenic coolant becomes less of an issue. If halving the number of test stations can also allow the same work to be done by half as many operators, the cost savings are even greater and accumulate every hour. Expendable coolant cost per operating hour may be an insignificant factor in the "total picture".

If your company is growing, there will likely come a time when you will outgrow your current lab, building, or factory and have to move into a larger facility. Using cryogenic cooling may save your company vast amounts of money by so substantially improving productive throughput that you can avoid buying or leasing new land and buildings. If you have a whole fleet of mechanically cooled chambers and platforms requiring you to move twice as often and support twice as much space, equipment, and people as you'd need with cryogenic cooling… are you saving anything?

The actual cost of running any particular platform or chamber will depend on the load, temperature profile, and other factors. Your Sigma Systems representative or sales engineer can help you make estimates. Because Sigma Systems makes both refrigerated and cryogenically cooled products, we don't have much of a stake in which you choose, except that we want to be sure you get the best solution for your needs. We encourage you to take a close look at the real benefits of cryogenic cooling when doing a cost comparison with mechanical refrigeration. We sell a lot of mechanically cooled products to insistent customers who we know would be better served by cryogenic products. Take a hard look before you decide. Let us know if you want advice or help.

Comparison of Relative Production Output for Mechanical versus Cryogenic Cooling in Units per Hour



Push your production capabilities to the maximum with a Sigma *Double Stack* cryogenic chamber

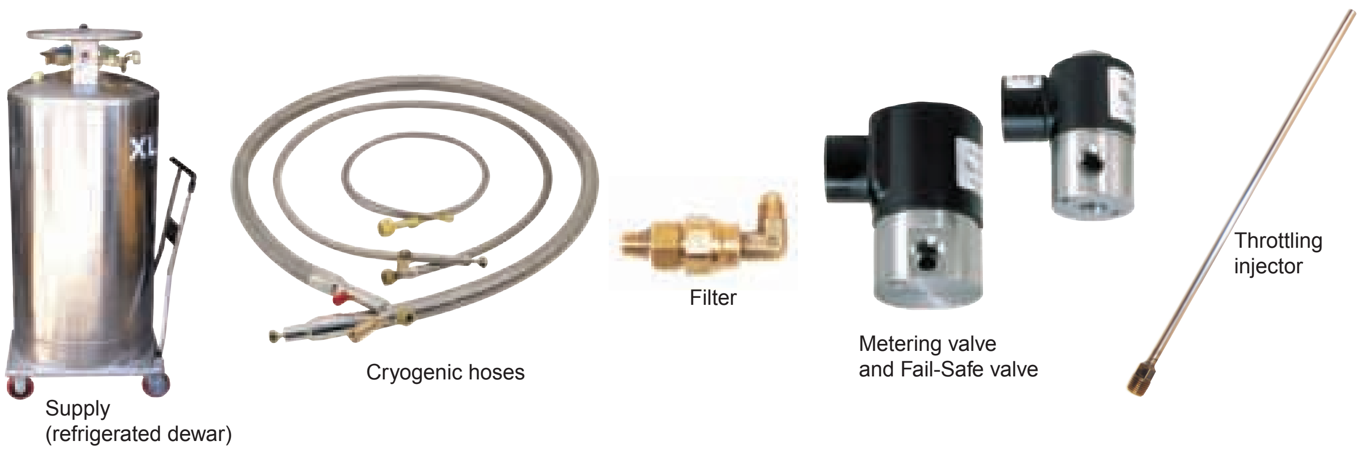
6 The parts of a cryogenic cooling system

A cryogenic cooling system consists of:

- A supply vessel (either a tank or a pipe from a bulk system)
- A suitable connection hose
- A filter
- An optional electrically operated fail–safe valve
- An electrically controlled metering valve
- A throttling injector.

It's all pretty simple. The first item, obtaining a supply of coolant, is your job. Section 10 tells you what you need to know. Sigma will take care of the rest of the list so that you get a carefully designed and matched system that's safe, reliable, efficient, and precise. Sigma cryogenic hoses are carefully matched to the needs of our chambers and platforms. Every system includes a filter to make sure that the coolant metering system is not fouled or compromised by contaminants. The metering valves used in Sigma chambers and platforms are specially designed and built to our rigid specifications to assure long life with minimal noise. The throttling injector is uniquely sized to provide proper flow and good dispersion.

A common optional component of a cryogenically cooled system is a fail–safe system with redundant valve. The system includes a separate temperature sensor & control that shuts down the system should the temperature get beyond specified limits. Should the problem be a mechanical failure of the primary cryogenic control valve, the redundant valve will close to shut off the flow of cryogenic coolant. Fail–safe systems *with redundant solenoid coolant valves* should be fitted to all cryogenically cooled systems that will be operated without constant operator supervision.



7 Combining cryogenic cooling with mechanical refrigeration

Sigma Systems temperature chambers can be fitted with both cryogenic cooling and mechanical refrigeration. Typically a toggle switch is fitted to select either or both cooling systems. With some optional wiring additions to the chamber, sophisticated Sigma controllers can handle both cooling systems under program control. Systems with both cooling systems are known as "cryogenically boosted mechanical refrigeration systems", or "boosted systems", even though such systems can use the cryogenic coolant without the mechanical refrigeration.

Combining cryogenic and mechanical cooling can provide some of the benefits of each system. The cryogenic cooling will typically be able to effect faster temperature transitions, and/or reach lower temperatures, and the mechanical refrigeration system can maintain a low temperature for a lower cost. However, there are drawbacks to such systems.

Boosted systems are less efficient because the refrigeration evaporator inside the chamber is an additional thermal load. The additional load results in both slower performance and increased cryogenic coolant consumption. The refrigeration evaporator is also an impediment to air flow. Because of the unrestricted air circulation path, cryogenic only cooled chambers have better air flow than the same model chambers with mechanical refrigeration evaporators in the air circulation path.

Boosted systems require special care to make certain that the mechanical refrigeration system is turned off any time that the temperature is below the normal limits of the mechanical refrigeration. Operating a mechanical system at temperatures below its normal limits can return liquid refrigerant to the compressor and quickly damage or destroy it. Furthermore, chambers with mechanical refrigeration have a 200°C upper limit to prevent degradation of the refrigerant which is always present, even during the heating cycle.

In summary, boosted systems are best suited for applications where the speed and load handling capacity of cryogenic cooling can be used to do the primary cooling and the mechanical refrigeration system can be used to hold low temperatures for extended times. Such systems offer the advantage of high performance and low long term operating costs.

8 Choosing a cryogenic coolant

The two common cryogenic coolants are liquid Carbon Dioxide (L–CO_2), and liquid Nitrogen (L–N_2). The important differences are their low temperature limit, packaging & handling, cost, and other lesser factors. In brief:

Liquid Carbon Dioxide has a boiling point of –78.4°C with a practical cooling limit of –55°C to –65°C due to low efficiency and dry ice accumulation near the lower limit. L–CO_2 has the advantage over L–N_2 in that it is typically slightly less expensive per pound and has a slightly better cooling capacity per pound at typical use temperatures. L–CO_2 also has the advantage that it can be delivered either as a refrigerated liquid under moderate/low pressure (about 300 psi) in insulated tanks known as dewars, or as a room temperature liquid in non–refrigerated high pressure *siphon* cylinders. Siphon cylinders are smaller and the increased heat already present in the L–CO_2 inside makes that form a bit less efficient. Siphon cylinders, unless aggregated into a multi cylinder manifold system, are not suitable for large chambers or very long tests as their small size mandates frequent cylinder changes. However, high pressure L–CO_2 is the only common cryogenic coolant available in non refrigerated form that can be kept indefinitely between uses.

L–CO_2 has also the advantage that it can be piped to the location of use as a gas and then liquefied by normal refrigeration at the point of use. Equipment for this purpose is commonly called a L–CO_2 *economizer*. Economizers can substantially lower costs and improve performance. Bulk L–CO_2 systems that flow refrigerated liquid to the point of use are also available.

L–CO_2 has one characteristic that can be a problem. When L–CO_2 is throttled to atmospheric pressure for cooling, it first turns to a solid known as dry ice, then sublimates to vapor as heat is absorbed. The dry ice formed in a chamber or platform is called dry ice snow as particles of dry ice are partially suspended in the vapor stream and at low temperatures can easily accumulate in corners much like blowing snow. Furthermore, dry ice accumulations may continue to cool a chamber or platform long after the controller has shut off the flow of L–CO_2, making control a bit more difficult with fast ramps to low temperatures. In temperature chambers, dry ice accumulations around irregularly shaped test loads may affect load temperatures. L–CO_2 is the ideal coolant for many applications, and especially for intermittent use. However, dry ice formation and accumulation will be apparent at –45°C, copious at –55°C, and may be problematic at lower temperatures.

Liquid Nitrogen has a boiling point of about –195.8°C. It is ideally suited for cooling to –175°C, and with some special attention, can be used for cooling to –195°C. L–N_2 is always delivered refrigerated as it cannot remain a liquid at temperatures higher than –148°C. It is essential that the L–N_2 supply be at sufficient pressure for the proper operation of Sigma temperature chambers and thermal platforms. See the L–N_2 Pressure – a discussion – section 11 of this brochure.

L–N_2 is simple to use. It has the advantage that is does not form dry ice solids, and because of its very low boiling point, it is almost always fully vaporized by the time it gets to the DUT inside a temperature chamber. As a result, gradients are low and temperatures are more accurate. Because of its wide range, predictable behavior, and simple use, L–N_2 is the cryogenic coolant preferred by the majority of users.

9 Specifying temperature chambers & thermal platforms for the coolant you choose

When you order a cryogenically cooled Sigma System temperature chamber or thermal platform you will need to specify the type of coolant you want to use. Each type of coolant requires unique flow control components that will be fitted when your chamber or platform is built. Therefore, you will need to specify your choice of coolant when you order a Sigma chamber or platform. These are the choices:

Coolant speci.cation For Chambers:	**Coolant Source**
High pressure L–CO_2	Room temperature siphon cylinders
Low pressure L–CO_2	Refrigerated dewars, bulk systems, and economizers
L–N_2	Refrigerated “pressure building” dewars or bulk delivery system
For Platforms:	
L–CO_2 (all types)	Room temperature siphon cylinders, Refrigerated dewars, bulk systems, and economizers
L–N_2	Refrigerated “pressure building” dewars or bulk delivery system

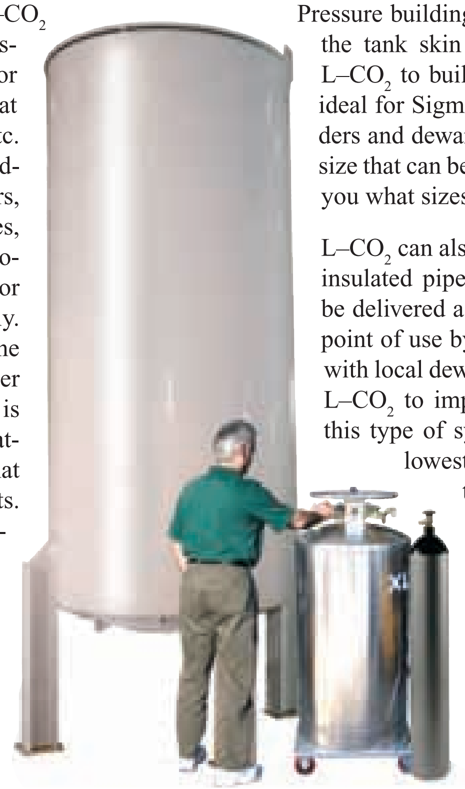
Chambers can be supplied with an option for dual coolant systems. Conversion kits are available for chambers and platforms should it be necessary to change coolants.

High pressure CO_2 cylinder. L–CO_2 and L–N_2 dewars with ‘trolleys’ makes moving the dewars very easy

10 Cryogenic coolant & delivery systems – how to specify what you need

Obtaining cryogenic coolants is not difficult. L–CO_2 and L–N_2 are typically available from any industrial gas supplier such as Airgas, Praxair, or BOC Gases. These are the same companies that sell gases for medical use and for welding, etc. Because these companies sell a lot of gas, including liquefied gases, to a wide variety of customers, they have a large assortment of formats, sizes, pressures, delivery vessels, etc. To get the cryogenic liquid that you need for your chamber or platform, it is important that you specify carefully. Sometimes, even when you specify correctly, the supplier will try to convince you that some other form would be better. Unless the supplier is intimately familiar with Sigma chambers and platforms, it is best to make sure you know what you're doing and then be firm about your requests. Your supplier's experience may be general, theoretical, or practical, but with another vendor's equipment. In any event, this brochure is specific in detailing what is needed for Sigma equipment, and why. Stay with our recommendations and you will have a more successful test experience.

When you buy cryogenic coolant, the container in which it is delivered to you (generically referred to as a "cylinder") is rented to you. You will be charged a rental fee for the time you keep the cylinder. Sometimes the rental may be included in the price of the coolant. Ask your vendor specifically what the policy and rental rates are so you know what to expect.



Bulk tank, refrigerated dewar, high pressure CO_2 Cylinder

L–CO_2

The L–CO_2 you order needs to be "Industrial Grade" which will insure that it is reasonably free of water and other contaminants (Note - Medical Grade is not as pure and clean as Industrial Grade. It seems that the human body is more forgiving of contaminants than chambers or platforms). Be particularly careful to specify "Industrial Grade" when ordering L–CO_2 in siphon bottles. Because the coolant is kept at room temperature, it can easily include water and the siphon bottles may have rust particles inside. These contaminants are likely to cause clogs in filters, cause premature wear in metering valves, and leave a layer of performance robbing contamination in the cooling channel of thermal platforms. Always using a quality grade of liquid cryogenic coolant is essential for good performance and long service life.

L–CO_2 can be delivered as a room temperature liquid in a high pressure siphon cylinder, or as a cold (called refrigerated) moderate pressure liquid in an insulated tank called a *pressure building dewar*. Siphon cylinders are smaller, and somewhat less efficient because the fluid inside is warmer. However, because siphon cylinders are containers for room temperature liquid they can be stored indefinitely and used at will.

Pressure building dewars have a *pressure builder* circuit inside the tank skin that is used to vaporize a small amount of L–CO_2 to build the approximately 300 psig pressure that is ideal for Sigma chambers and platforms. Both siphon cylinders and dewars are available in a variety of sizes. Choose a size that can be handled in your facility. Your supplier can tell you what sizes they have available.

L–CO_2 can also be delivered via a bulk delivery system using insulated pipes connected to a bulk storage tank, or it can be delivered as a gas and then condensed into a liquid at the point of use by economizers. Economizers can also be used with local dewars and cylinders to refrigerate and subcool the L–CO_2 to improve its efficiency and purity. Cooling with this type of system provides maximum performance at the lowest possible cost per pound and is easily cost justified if the usage is high. Sigma does not make or install either bulk systems, or economizers, but is willing to work with the vendors of this equipment to assure that you get the best possible system.

L–N_2

The ideal pressure for Sigma L–N_2 cooled equipment is 90–100 psig. Pressures up to 150 psig and down to about 75 psig work nicely. Pressures over 175 psig may cause the coolant metering valve to stick closed and cause valve coil failure. Pressures lower than 75 psig will still work, but performance suffers, especially at pressures below 50 psig.

L–N_2 is delivered in refrigerated dewars as Nitrogen cannot be kept in a liquid state at room temperature. Two types of L–N_2 dewars are available, *low pressure* and *pressure building*. Low pressure dewars offer L–N_2 at typically 22 psig, while pressure building dewars offer L–N_2 at pressures of 50 – 300 psig, but most typically at 230 psig. You will need to have pressure building dewars to operate Sigma equipment. The reasons for this requirement are explained in section 11 of this brochure.

Regulating the pressure of the Nitrogen in the dewars will be your job. Section 14 explains the task and describes a Sigma Pressure Regulator that makes the job easy.

L–N_2 can also be delivered via a bulk delivery system using vacuum insulated pipes connected to a bulk storage tank. Sigma does not make or install bulk systems but is willing to work with the vendors of this equipment to assure that you get the best possible system. If you already have a bulk system, and the delivery pressure of the L–N_2 from your system is below Sigma recommendations, be sure to make this known when you order your Sigma equipment. While we recommend higher pressures for good reasons, your system is probably perfectly capable of operating our equipment if we know your requirements and can adjust for them at the time of manufacture.

11 L–N_2 pressure – a discussion

Anytime there is L–N_2 cooling, there is discussion about pressure. Sigma specifies that the optimum L–N_2 pressure for its chambers and platforms is approximately 90 psig. You should know that this specification is a compromise, the result of the balancing of a variety of contentious factors. This is the rationale for our choice.

A student of Physics can successfully argue that low pressure L–N_2 is a better coolant than L–N_2 at a higher pressure. Considering that L–N_2 is available in "low pressure" dewars at 22 psig, why does Sigma Systems specify 90 psig from "Pressure Building Dewars"?

The short answer is that L–N_2 under higher pressure will flow faster and will arrive at the chamber or platform as a *liquid* much faster than lower pressure L–N_2 which has a much greater tendency to "flash off", or vaporize, in the hose. When the higher pressure L–N_2 is injected into the chamber or platform, it disperses more evenly and finely. By using higher pressure L–N_2, the overall thermal stability of the system is vastly improved, thermal gradients within the chamber or platform are lowered, and the chance of direct impingement of the DUT by suspended Nitrogen droplets is virtually eliminated.

The somewhat longer explanation follows:

Chambers and platforms that cool with L–N_2 rely on consistent delivery of *liquid* Nitrogen to the control valve and throttling device (injector tube). If, when coolant is requested by the controller, liquid is immediately available, cooling will begin immediately, and will behave as expected by the controller.

If, as is frequently the case with low pressure systems, the L–N_2 supply is slow to respond with liquid, then cooling will not begin immediately. This has two negative impacts. First, the test is delayed simply because there is a delay in starting the cooling. If the delay is long and the test involves a number of cooling cycles, the accumulated delays can account for a substantial deterioration of test performance. Second, the delay can adversely impact the ability of the controller to maintain consistent temperatures. The control algorithm is a closed loop system that adjusts the cooling output (requests for cooling) based upon feedback from the effects of existing requests. If the response to the controller's requests for cooling is consistent, very precise control is possible. If, however, the L–N_2 delivery system cannot reliably sustain and deliver liquid coolant, then the effects of the controller's cooling requests will be very erratic, the feedback will be erratic, and control will be erratic. For precision temperature chamber or thermal platform control, it is essential that the L–N_2 delivery system deliver *liquid* Nitrogen as quickly and consistently as possible.

When L–N_2 flows through a hose, there will be some drop in pressure from one end of the hose to the other. This pressure drop will cause some of the L–N_2 to flash off inside the hose until both the hose and the moving L–N_2 are chilled to saturation at the lower pressure. With higher pressure L–N_2 the saturation temperature is a bit higher, and is easier to achieve, so liquid is sustained and delivered more quickly.

The higher pressure also achieves higher flow rates, so smaller hoses can be used. Sigma hoses typically have about half the inner diameter of most commercial hoses, so there is only half the hose mass to be cooled and only 25% as much L–N_2 mass to be cooled and kept cool. The hose itself presents a much smaller thermal path for ambient heat intrusion. These features typically cause much faster initial delivery of L–N_2, especially from a hose that has not been flowing for a time. The faster liquid delivery results in far better closed loop control.

Higher pressure also improves performance inside the chamber or platform. It is particularly important to temperature chambers because the higher flow rate through the metering injector results in better atomization of the L–N_2 in the moving air stream in the chamber. The finer liquid droplets present a substantially greater surface area and thus vaporize more quickly. The benefit is closer tolerance control, much lower temperature gradients within the chamber, and virtual elimination of micro droplet impingement of L–N_2 on the DUT surfaces.

If you will be using pressure building dewars to deliver your L–N_2, you will be controlling the pressure. Section 14 tells you how. If you have a bulk system in your facility, you have some other considerations that are detailed in section 12, below.

Note: Do not use pressure regulators with L–N_2. Conventional gas regulators will not regulate liquid pressure and will not operate at L-N_2 temperatures.

12 Using a bulk L–N_2 system with Sigma Systems equipment

Bulk L–N_2 systems rarely deliver the pressure Sigma specifies. However, thousands of Sigma temperature chambers and thermal platforms are operating successfully attached to bulk L–N_2 delivery systems.

Bulk systems usually do an excellent job of delivering liquid to the point of use. This is especially true if a vapor stripper, a device that separates vapor from liquid, is installed at or near the connection point for the Sigma equipment. Furthermore, most bulk systems feed L–N_2 from above, so gravity helps to keep vapor up on top and liquid flowing down to the point of connection.

However, the lower pressure of bulk systems will result in lower performance. If the pressure is too low, some degradation of the temperature gradients in the chamber or platform is possible, and dispersion inside a chamber may suffer a bit. Sigma can make some modifications to improve performance under these conditions, but only if you make sure that your Sigma representative or sales engineer is aware of your L–N_2 delivery conditions when your chamber or platform is ordered.

13 L–CO_2 pressure - a discussion

The most significant concern when using L-CO_2 is keeping the pressure high enough to prevent the formation of dry ice in the delivery system. If the internal pressure anywhere within the delivery hose, filter, metering valve, injector connection, etc. gets below about 75 psig, dry ice particles can form. Unfortunately, subsequent raising of the pressure will not make the dry ice go away. These particles may clog the delivery system resulting in cooling failure. To prevent this occurrence, the delivery pressure must be maintained high enough so that the pressure drops associated with hoses, valves, etc. do not result in downstream pressures low enough for dry ice formation. For high pressure cylinders, the normal 800+ psig pressure is plenty if the proper hoses are used. The recommended pressure for dewars is 300 psig. In use, the dewar pressure will normally drop, but the pressure building circuit should be used to keep the pressure over 250 psig.

Note: Do not use pressure regulators with L-CO_2. Conventional gas regulators will not regulate liquid pressure.

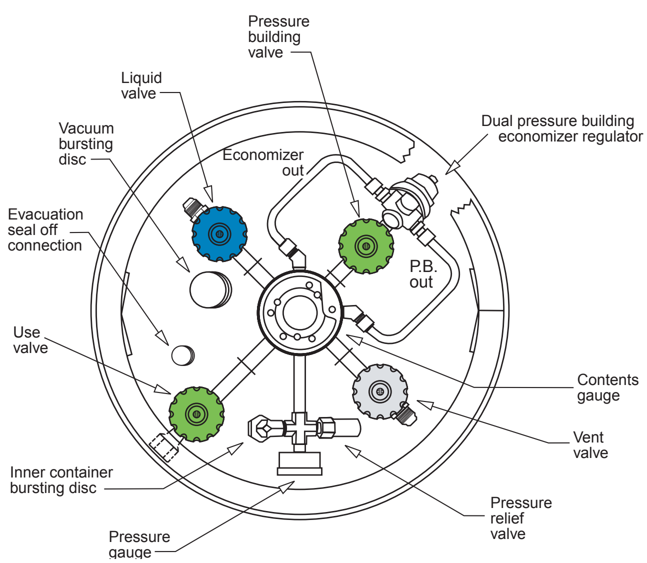
14 Controlling coolant pressure using a pressure building dewar

Excessive coolant pressures may result in failed valves and inadequate pressures may result in substandard operation. Maintaining the right pressure is not difficult when you get some experience. Taking action to increase the pressure is often not necessary as ambient heat intrusion is often enough to build the pressure to usable levels. If not, to increase the pressure, open the Pressure Building valve and allow some liquid to flow into the pressure building circuit inside the dewar. To reduce the pressure, open the Vent valve and let some of the coolant gas escape.

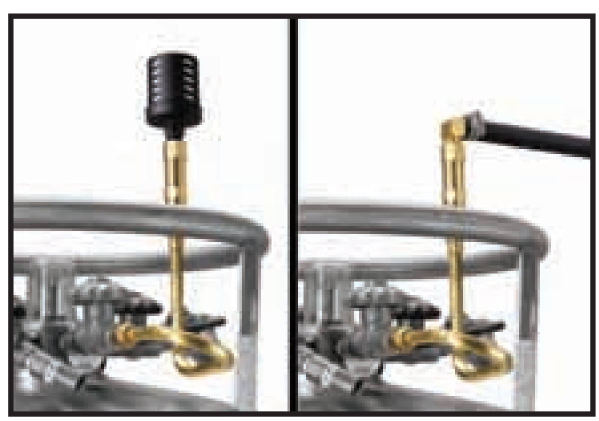
There is a widespread misconception that venting some of the coolant vapor from the dewar is wasteful. If the dewar was purchased to deliver a gas, this might be true. However, the dewar was purchased to deliver a liquid for cooling. Over time, heat will creep into the dewar and warm the coolant and increase the pressure. Venting the excess vapor is simply releasing the vapor that was formed to absorb the intruding heat. Any heat that intrudes into the dewar increases the heat content of the coolant inside and thus reduces, by the same amount, the cooling capacity of the coolant. Letting the heat out of the dewar in the form of vapor does not further reduce the cooling capacity of the coolant, it just gets the pressure down to a usable level.

While L–CO_2 dewars have relief valves set to the 300 psig that we need, L–N_2 dewars are typically fitted with 230–300 psig relief valves. While Sigma specifies 90 psig L–N_2 as ideal, any pressure from about 75 psig to 150 psig will work nicely. Pressure building dewars can be fitted with lower pressure relief valves to keep the maximum L–N_2 pressure to the 100 or 150 psig Sigma limit, but most gas vendors do not want to have to change the relief valves for each customer. A very simple solution is to get standard pressure building dewars and use a Sigma Pressure Regulator Accessory as shown in the picture. To keep the pressure optimized for immediate use, fit a Pressure Regulator Accessory to each L–N_2 dewar upon receipt. The Sigma Pressure Regulator Accessory is much quieter than vendor supplied relief valves and has a special fitting so that vented Nitrogen gas can be piped away. The Sigma Pressure Regulator Accessory can be easily moved from dewar to dewar and is tall enough that it is easily noticed by service personnel and not left behind.

Typical pressure building dewar



This is what the top of a typical Pressure Building dewar should look like. Note the pressure building circuit on the upper right section.



Sigma L–N_2 pressure regulator accessory
Shown with muffler and with venting hose

15 Cryogenic connection hoses

Cryogenic connection hoses are used to connect your Sigma temperature chamber or thermal platform to your coolant source, be it a bulk system, a dewar, or a high pressure cylinder. Getting the right size hose, with the right fittings, insulation, and safety features, is essential. Here's what you need to know.

JIC and SAE Fittings

Many of the fittings used with cryogenic coolant hoses are flare fittings in a variety of sizes. Unfortunately, and unknown to a lot of people, they are made in two types, JIC (37°) and SAE (45°). To confuse the matter even more, some folks, including some hose manufacturers, use the JIC and SAE designations incorrectly. The two can be connected, but easily leak. The photo shows ½" SAE and JIC male flare fittings that are virtually identical except for the seat taper. Sigma hoses come with the correct fittings for both the coolant source and the chamber or platform.

Sigma Standard Fittings

Most Sigma standard chambers and platforms have ¼" male SAE (45°) flare inlet fittings. Other fittings can be supplied on request

N_2 Fittings

All L–N_2 dewars have ½" SAE male flare liquid outlet fittings. This fitting is also known as a CGA–295 and is marked LIQUID. CGA is the Compressed Gas Association, the folks who set standards for this sort of thing. The vent fittings on liquid Nitrogen dewars are also CGA–295, but are marked VENT. On pressure building dewars there is also a vapor outlet (for purge gas, etc.) with a special fitting called a CGA–580 and is marked USE. It's the same as the fitting on a pressurized Nitrogen gas cylinder. Low pressure Nitrogen dewars do not typically have a vapor outlet as tank pressure is too low to be of use.

CO_2 Fittings

All CO_2 connections use a special fitting called a CGA–320. The same fitting is used for both liquid and gas on both dewars and high pressure cylinders. CGA–320 fittings use a flat face mating surface and require a washer like gasket to seal. The gasket is included with Sigma hoses.

JIC SAE

1/4" SAE Inlet used on Sigma chamber or platforms

CGA–295 / SAE male flare liquid and vent Nitrogen

CGA–580 Nitrogen gas

CGA–320 CO_2

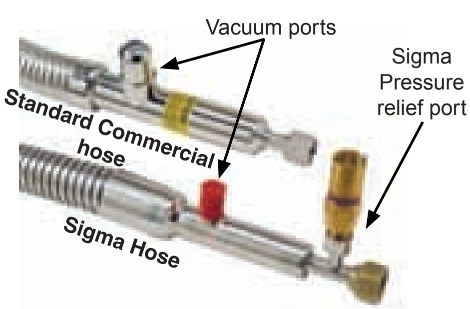
Standard Commercial Hoses

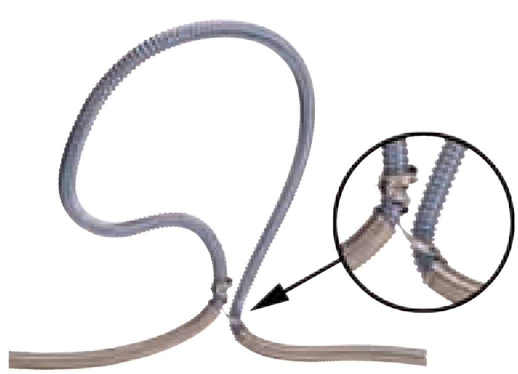
Commercially available L–CO_2 hoses are not as common as L–N_2 hoses and are not as consistent in construction. Some have integral CGA–320 supply fittings and some require tank adapters. Neither hose diameter nor outlet fittings are standardized.

Commercially available L–N_2 hoses are either "armored", or "vacuum jacketed". Armored hoses are not insulated and you must add external insulation. Vacuum jacketed hoses have an armor layer and are fully insulated by an evacuated internal tube so require no external insulation. Because of the extremely low temperature of L–N_2, hoses used for carrying it must be all stainless steel. Hoses with Teflon, rubber, or similar components become very brittle, and unsafe at L–N_2 temperatures. Standard commercial stainless steel L–N_2 hoses (non Sigma hoses) are typically ½" I.D., and have ½" female flare fittings on both ends. The end fittings can be either SAE or JIC. Oddly enough, most commercial vacuum jacketed hoses, except Sigma hoses, have ½" JIC fittings on both ends even though all L–N_2 dewars have SAE fittings.

Liquid Trapping in L–N_2 Hoses

Nitrogen cannot be maintained as a liquid at room temperature. When a chamber or platform is shut down, the metering valve in the chamber or platform will close. If the hose contains all, or almost all, liquid phase Nitrogen and an operator then turns off the valve on the dewar or bulk system outlet and traps liquid in the hose, the eventual intrusion of ambient heat into the hose will vaporize the trapped Nitrogen and exert extreme pressure on the hose. Hoses not equipped with a pressure relief will be destroyed by this pressure (Note that the evacuation port standard on vacuum jacketed hoses is not a relief valve - see picture lower left). The picture below shows the damage done by liquid nitrogen trapped in a hose without a pressure relief valve. The entire loop of hose in the picture burst through the armor cover that was split open by the extreme pressure. Very few, if any, standard commercial hoses have an integral safety pressure relief port to prevent this occurrence. All Sigma L-N_2 hoses have a safety pressure relief making operations both safer and less costly.





Without a pressure relief valve an expensive vacuum jacketed hose is ruined by trapped Nitrogen. Pressure relief valves are standard on all Sigma L–N_2 hoses.

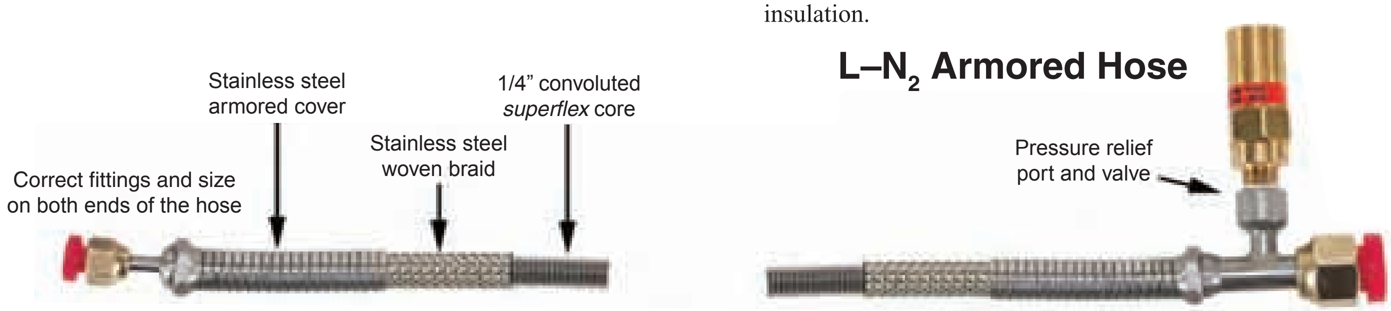
Sigma Systems L–CO_2 Hoses

Sigma L–CO_2 hoses have the correct fittings to connect any standard L–CO_2 dewar or cylinder (CGA–320 fitting) to any standard Sigma temperature chamber or thermal platform. The inner core of these hoses is Teflon with an outer braid of woven stainless steel for strength. The small inner diameter of these hoses helps to deliver refrigerated liquid phase CO_2 to the use point by keeping hose surfaces to a minimum. Hoses used for high pressure L–CO_2 from siphon cylinders do not need insulation. Hoses used for low pressure L–CO_2 from refrigerated dewars should be insulated to minimize ambient heat intrusion. Please specify insulated or uninsulated.

Sigma Systems Armored L–N_2 Hoses

Sigma armored L–N_2 hoses have the correct fittings to connect any standard L–N_2 dewar (CGA–295 fitting) to any standard Sigma temperature chamber or thermal platform. The inner core of these hoses is ¼" I.D. convoluted superflex stainless steel with an outer braid of woven stainless steel for strength and a stainless steel armored covering. The small inner diameter of these super flexible hoses reduces the volume of L–N_2 that is exposed to ambient heat influences by 75% assuring the fastest possible delivery of liquid phase Nitrogen to the cooling process.

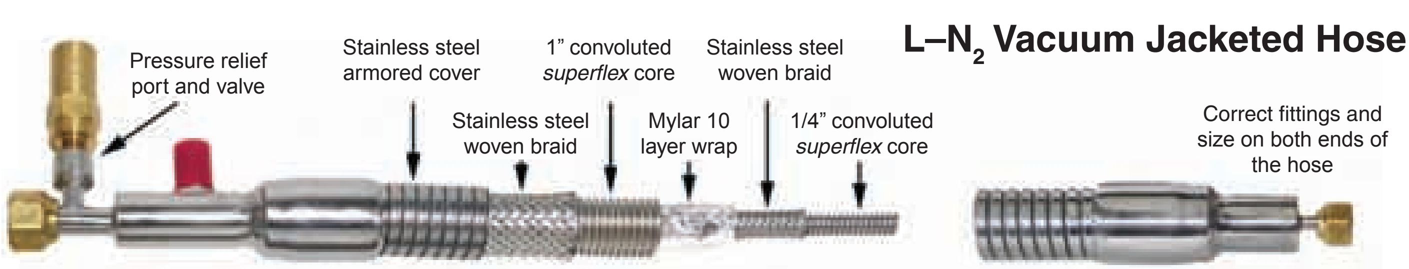
Their great flexibility allows these hoses to be more easily positioned and substantially reduces the strain on inlet fittings, filters, and valves. Armored hoses are less expensive than vacuum jacketed hoses. They are suitable for short hose lengths and occasional use or when vacuum jacketed hoses are not in the budget. Every Sigma armored superflex hose is fitted with a safety pressure relief valve so that liquid trapping is not an issue. Because there is no insulating layer in these hoses, they should always be used inside a thick layer of foam insulation. Sigma hoses are supplied with insulation.



Sigma Systems Vacuum Jacketed L–N_2 Hoses

Vacuum jacketed hoses are expensive, but are the long term winners for the lowest total cost of ownership because of their high performance and exceptionally low coolant losses to ambient heat. Because of their superior built-in insulating qualities, these hoses deliver liquid phase Nitrogen faster, and more consistently. Nitrogen consumption and test times are reduced, and temperature control is improved.

Sigma vacuum jacketed L–N_2 hoses have the correct fittings to connect any standard L–N_2 dewar (CGA–295 fitting) to any standard Sigma temperature chamber or thermal platform. The inner core of these hoses is ¼" I.D. convoluted superflex stainless steel with a surrounding layer of braided woven stainless steel for strength, a Mylar super insulation layer, a superflex convoluted outer tube to make a vacuum hose, another layer of braided woven stainless steel for strength and a stainless steel armored covering. The small inner diameter of these super flexible hoses reduces the volume of L–N_2 that is exposed to ambient heat influences by 75% assuring the fastest possible delivery of liquid phase Nitrogen to the cooling process. The O.D. of Sigma vacuum jacketed hoses is less than 1.25" and is the smallest in the industry. The great flexibility allows the hose to be more easily positioned and substantially reduces the strain on inlet fittings, filters, and valves. Sigma vacuum jacketed hoses are ideal for longer hose lengths, continuous use, and anytime that long term total cost of ownership is really considered. Every Sigma vacuum jacketed superflex hose is fitted with a safety pressure relief valve so that liquid trapping is not an issue. Because the entire hose is insulated by a very deep vacuum between the convoluted hose tube layers, condensation is not a problem.



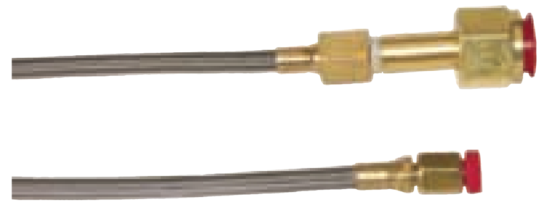
16 Sigma Systems Cryogenic Hoses

L–CO_2

Braided Stainless over Teflon L–CO_2 Hoses

3/16” ID, CGA320 dewar connection, ¼” SAE female swivel connection for Sigma thermal platform or temperature chamber. Woven braid reinforcement, available with or without insulation. (High pressure L–CO_2 does not require insulation).

Length Feet	Length Meters	Uninsulated Item Number	Insulated Item Number
1.5	0.5	36205	36705
2	0.6	36206	36706
3	0.9	36208	36708
4	1.2	36210	36710
6	1.8	36214	36714
8	2.4	36218	36718
10	3.0	36222	36722
12	3.7	36226	36726
Extension L-CO_2 hose			
10	3.0	36249	36749



L–CO_2 hoses shown without and with insulation. Both ends have the correct fittings.

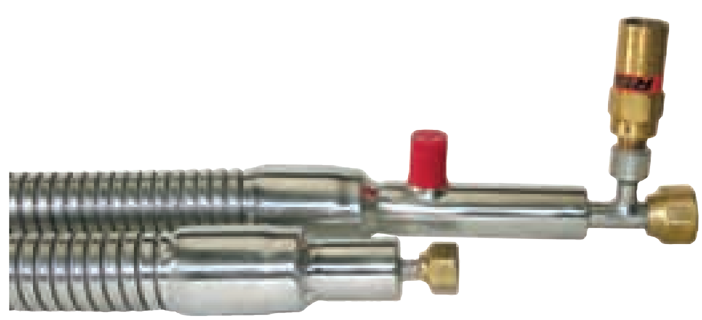
L–N_2

Vacuum Jacketed Superflex L–N_2 Hoses

Premium vacuum insulated hose for continuous use without external insulation. This hose will not sweat except at connection points. ¼” ID, CGA295 dewar connection, ¼” SAE female swivel connection for Sigma thermal platform or temperature chamber. All stainless construction, small 1.2” OD, double braid reinforcement, very small bend radius, includes pressure relief port and safety relief valve.

Length Feet	Length Meters	Item Number
4	1.2	36110
6	1.8	36114
8	2.4	36118
10	3.0	36122
12	3.7	36126
15	4.6	36132
20	6.1	36142

A Sigma vacuum jacketed hose shows its flexibility by easily coiling inside a commercially available vacuum jacketed hose.



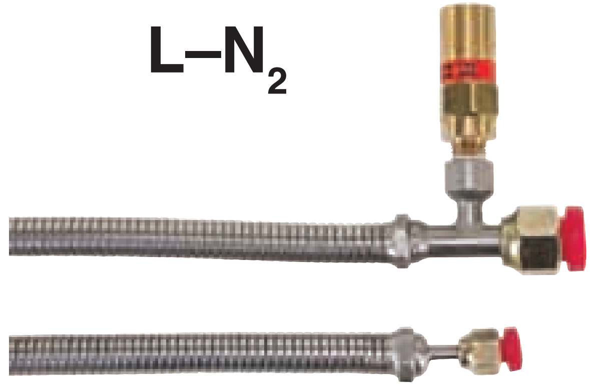
Sigma vacuum jacketed L–N_2 hose with pressure relief valve and the correct fittings on both ends of the hose.

Armored Stainless Superflex L–N_2 Hoses

¼" ID, CGA295 dewar connection, ¼" SAE female swivel connection for Sigma thermal platform or temperature chamber. All stainless construction, woven braid reinforcement, very small bend radius, includes pressure relief port and safety relief valve and insulation.

Length Feet	Length Meters	Item Number
1.5	0.5	36005
2	0.6	36006
3	0.9	36008
4	1.2	36010
6	1.8	36014
8	2.4	36018
10	3.0	36022
12	3.7	36026

L–N_2



Stainless steel armored L–N_2 Hoses with pressure relief valves come with insulation and the correct fittings on both ends of the hose.

17 Sigma Systems Cryogenic Accessories

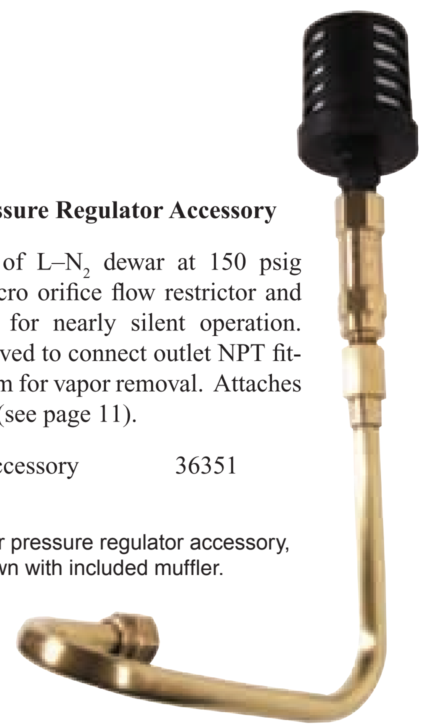
5 port L–N_2 Distribution Manifold

Features CGA295 female dewar fitting and 3 male SAE ½" flare (CGA295) outlet fittings with removable caps for two of them. Manifold has total of 5 outlet ports – two of which have plugs. Fittings and caps for the two additional ports are included.

5 port manifold 36555

5 port Distribution manifold with 3 ports installed.

L–N_2



L–N_2 Dewar Pressure Regulator Accessory

Maintains pressure of L–N_2 dewar at 150 psig or less. Features micro orifice flow restrictor and replaceable muffler for nearly silent operation. Muffler can be removed to connect outlet NPT fitting to exhaust system for vapor removal. Attaches to dewar Vent valve (see page 11).

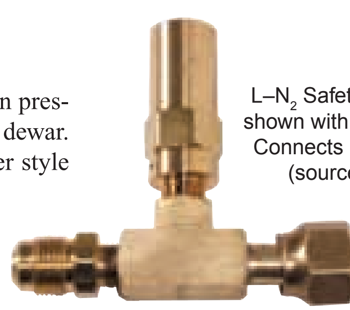
Pressure regulator accessory 36351

L–N_2 Dewar pressure regulator accessory, shown with included muffler.

L–N_2 Safety Pressure Relief "T"

Allows safe connection of hose that does not have its own pressure relief valve. Connects directly to liquid port on L–N_2 dewar. Choice of SAE or JIC outlet fittings. (Use SAE for older style Sigma hoses).

SAE/Sigma Safety "T" 36362
JIC Safety "T" 36363



L–N_2 Safety pressure relief "T", shown with pressure relief valve. Connects between your dewar (source) and LN_2 hose.

Distribution Manifold - connects one dewar to three platforms.

Fast, Efficient, & Productive thermal test equipment from the experts in Cryogenic and Mechanically Refrigerated Cooling

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