Heliox Sorption Pumped ^{3}He Refrigerator Systems

Principles of Operation and Control

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1 Introduction

This manual is designed to introduce you to the Heliox range of liquid helium cooled, sorption pumped ^{3}He refrigerators manufactured by Oxford Instruments. If you have bought a complete system from Oxford Instruments, separate manuals will have been supplied describing the other components. Please ensure you have reviewed the information supplied in all of the manuals provided before you attempt to operate your system.

1.1 Properties of ^{3}He

^{3}He has a critical temperature of approximately 3.3 K. At temperatures below this, ^{3}He can be liquefied at sufficiently high pressures. This means that all ^{3}He refrigerators operated in ^{4}He cryostats require a pumped ^{4}He stage to condense the ^{3}He, the details of this condensation stage, usually referred to as the "1 K pot" will be provided for the various Heliox insert types in section 1.3.

Once condensed, the temperature of the liquid ^{3}He can be reduced by pumping the vapour above the liquid surface. The temperature dependence of the vapour pressure is shown in figure 1.

The strong temperature dependence of the vapour pressure means that a very efficient pump is required to attain the lowest possible temperature.

1.2 Sorption Pumped Systems

At low enough temperatures gases adsorb to cold surfaces. If a material with a very large surface area can be cooled to a sufficiently low temperature then this material can be used as a pump. Oxford Instruments' Heliox range of inserts use such sorption pumps to lower the vapour pressure above the ^{3}He surface and so attain low temperatures. The use of an internal pump also has the benefit of connecting the ^{3}He pot to the pump by the shortest (and coldest) pumping line possible.

1.3 The Heliox Range of Inserts

Oxford Instruments manufacture a range of liquid helium cooled, sorption pumped ^{3}He refrigerators for various experimental applications. The specifics of each type of insert will be outlined in the sections below

1.3.1 The HelioxVL

The HelioxVL ^{3}He refrigerator that can be used in a liquid helium storage dewar, in a typical Oxford Instruments superconducting magnet magnet system, or in a large sample space dynamic variable-temperature insert (VTI). It has an outer diameter of less than 50 mm so that it will fit into a wide range of cryogenic systems and it is simpler to operate than a conventional ^{3}He system. The sample is changed by warming the entire insert to room temperature, but because the insert is so small the sample change time

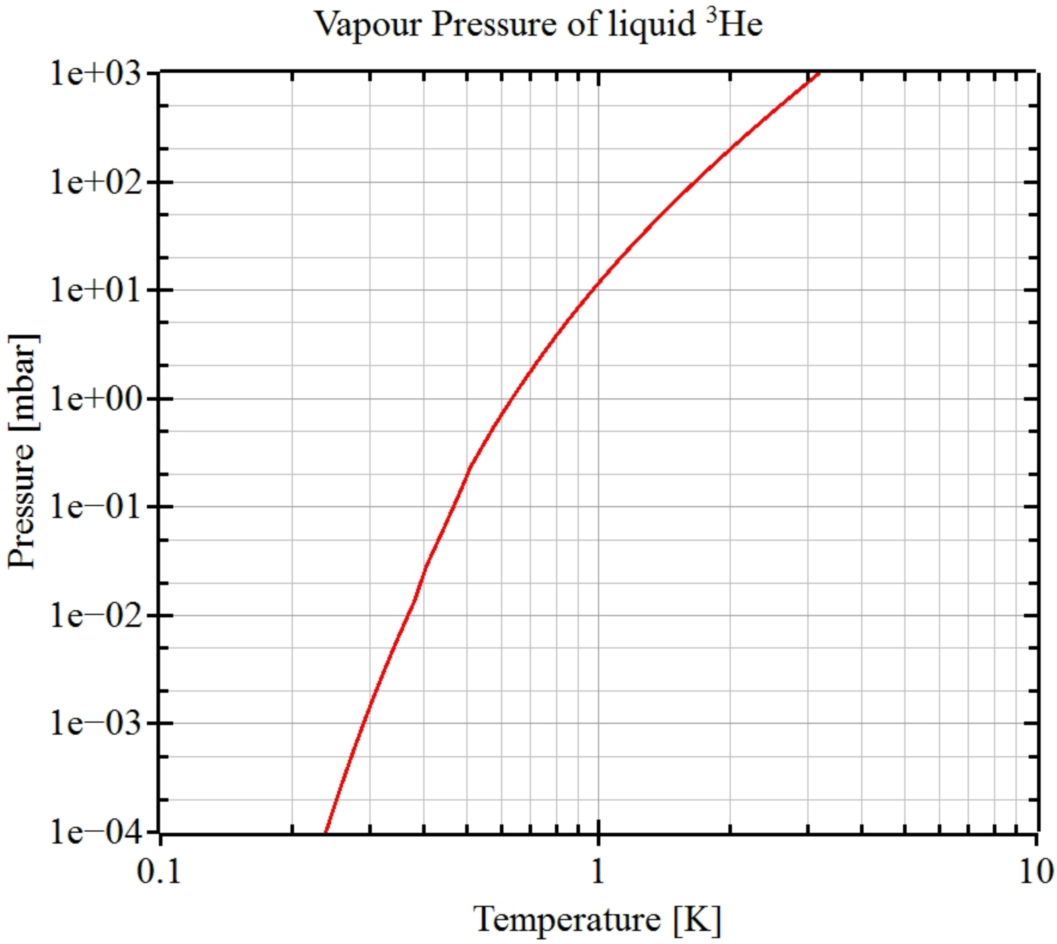

Figure 1: Graph showing the vapour pressure of ^{3}He as a function of temperature.

is not much longer than that of a top loading system. Some of the important parts of the insert are shown in figure 2.

The insert has a sliding seal, which allows it to be loaded slowly into the liquid helium without losing the boil-off gas or allowing gross contamination to enter the neck of the vessel and collect as ice. Full and efficient use is made of the enthalpy of the cold gas, and the amount of liquid boiled during the loading process is minimised. The inner vacuum chamber is sealed by a greased cone seal, allowing the system to be used by relatively inexperienced personnel.

Caution: Anyone working with the HelioxVL insert must be familiar with the precautions they must take to ensure their own safety and the safety of those people working around them.

There is no need to make indium seals during the sample changing procedure. There are no indium seals on the insert at all. An exchange gas sorption pump is mounted on the 1 K plate; it is used to pump the exchange gas from the inner vacuum chamber

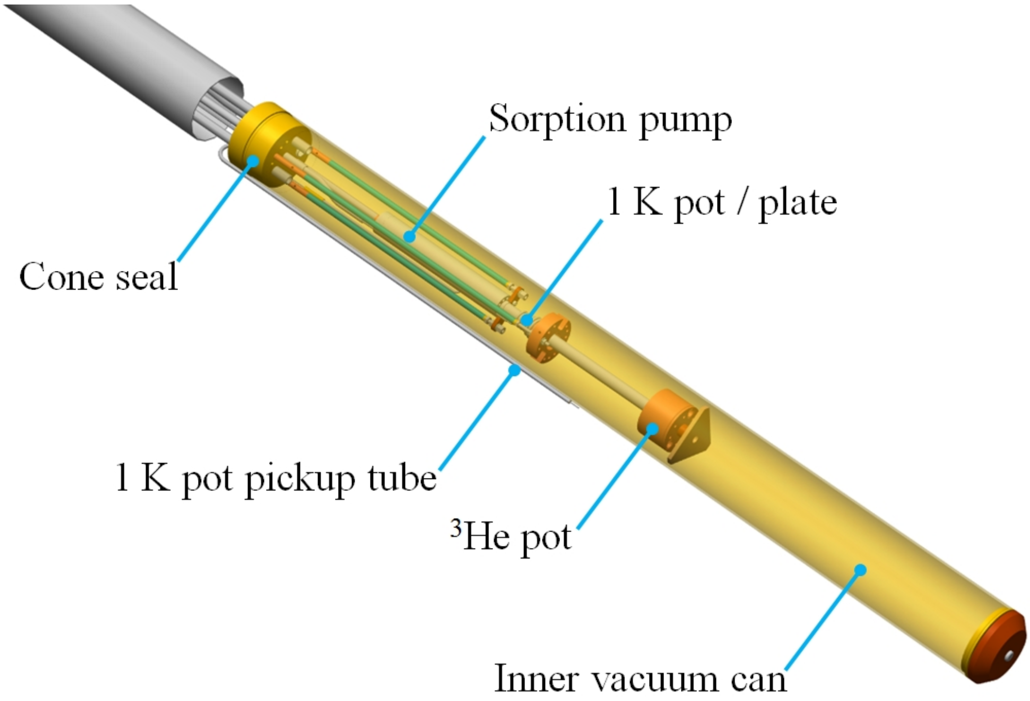

Figure 2: A drawing showing the general layout of the HelioxVL insert.

automatically during the cooling procedure.

The two experimental ports give line-of-sight access through the insert from room temperature to the sample space. They will either be left empty for you to install services for your experiment or they will contain one or more of the configured options you may have selected for your system. It is important, if you are fitting your own services, to heat sink them effectively to minimise the effect on the system performance.

The charge of ^{3}He is sealed into a self contained storage vessel so that it is not necessary to remove the valuable gas from the insert when it is warmed to room temperature. This reduces the complexity of operation of the system. The (nominal) 2.7 litre charge is stored at a pressure of approximately 2 bar (absolute). The storage vessel is fitted with a pressure relief device.

The sample is mounted in vacuum on the base of the ^{3}He pot, figure 2. Once the sample has been mounted, the inner vacuum can should be sealed and evacuated, and then a small amount($\sim$ 1 cm^3) of ^{4}He exchange gas added. The insert may then be cooled by lowering it slowly into the liquid helium reservoir.

1.3.2 The HelioxTL

The HelioxTL is a ^{3}He refrigerator with a central access tube that allows samples, mounted on a probe, to be loaded directly into the liquid ^{3}He. The HelioxTL insert is designed to be operated in a suitable liquid helium cryostat. Some important parts of the insert are shown in figure 3.

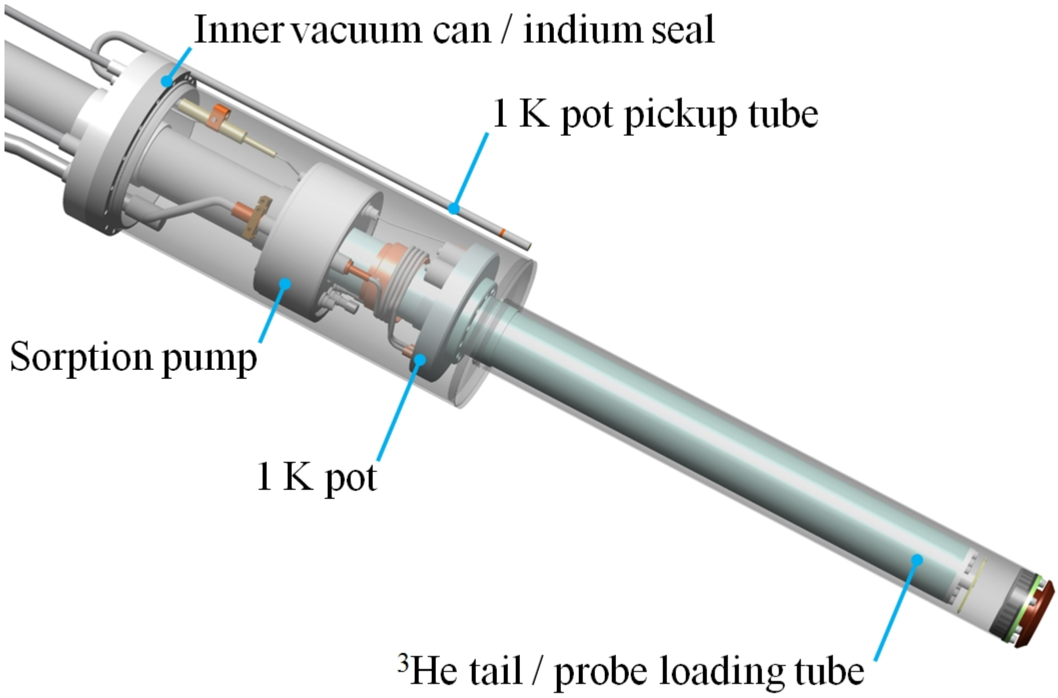

Figure 3: A drawing showing the general layout of the HelioxTL insert.

The top loading probe is used to load the sample into the ^{3}He, and it stays in the insert while the experiment is carried out. It is fitted with a vacuum lock to prevent air entering or ^{3}He escaping from the system.

One end of the probe is at room temperature; the other may be at any temperature between 0.3 K and 100 K when the system is running. The probe is designed to give a very high degree of thermal isolation from room temperature, since a heat load of the order of 10 μW may be sufficient to affect the base temperature. The experimental wiring and the other services are mounted on the probe.

As the ^{3}He tail is designed to fill with liquid, the HelioxTL system requires a significant charge of ^{3}He to operate ($\sim$ 18 litres) and so has a room temperature storage tank for this gas.

When the sample probe is ready to be introduced into the refrigerator, the ^{3}He sorb should be warmed slightly to provide some exchange gas to aid the pre-cooling of the probe as it is lowered.

1.3.3 The HelioxVT

The HelioxVT system is a ^{3}He refrigerator designed to operate in an Oxford Instruments variable temperature insert (VTI). The VTI may form part of a superconducting magnet system, or part of a stand alone cryostat. Some of the important parts of the insert are shown in figure 4.

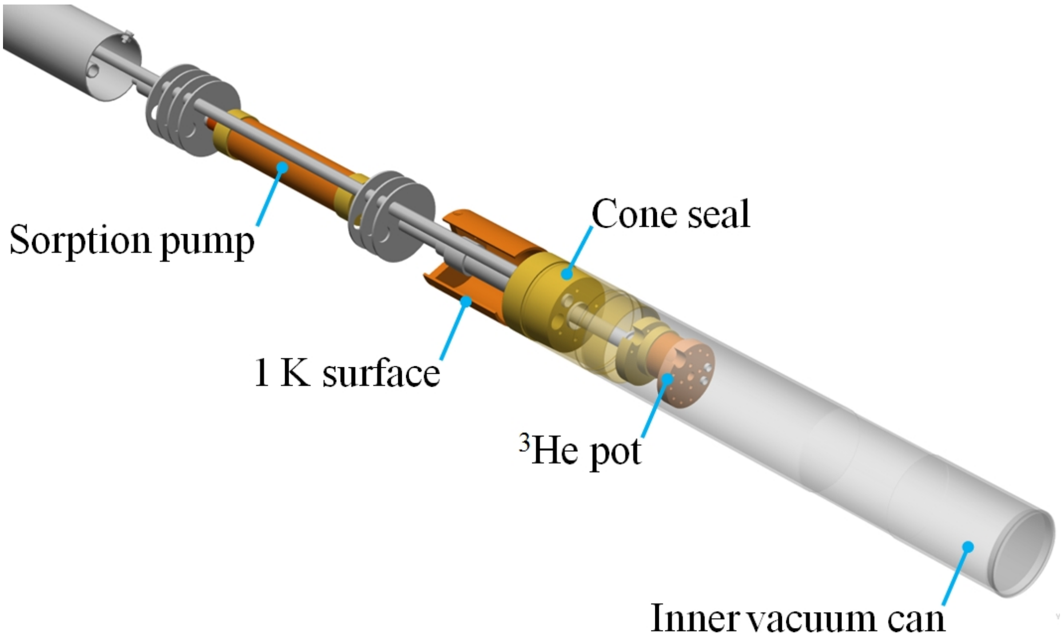

Figure 4: A drawing showing the general layout of the HelioxVT insert.

The sample is changed by warming the ^{3}He refrigerator insert to room temperature, and removing the inner vacuum can. The HelioxVT '1 K surface' is cooled to < 2 K by the VTI through exchange gas, and acts as the 1 K pot for the ^{3}He refrigerator. The HelioxVT will run in any VTI that it fits in to, but only a VTI and HelioxVT system supplied by Oxford Instruments will guarantee the optimum performance from the ^{3}He refrigerator.

The insert has a vacuum seal which allows it to be loaded into the VTI without allowing contamination of the neck of the VTI with ice. The inner vacuum chamber (IVC) is sealed using a silicon based paste applied to a cone seal, allowing the system to be used by relatively inexperienced personnel. There are no indium seals. Normal vacuum grease (as used on a HelioxVL IVC cone seal) is not used as this may leak in the superfluid ^{4}He environment of a VTI running at its base temperature.

The spare port gives line of sight access through the insert from room temperature to the sample space. You can use it to install services for your experiment. However, it is important to heat sink all of these services effectively to minimise the effect on the performance of the refrigerator.

The charge of ^{3}He is sealed into a self contained storage vessel so that it is not necessary to remove the valuable gas from the insert when it is warmed to room temperature. This reduces the complexity of operation of the system. The (nominal) 3 litre charge is stored at a pressure of approximately 2 bar (absolute). The storage vessel is fitted with a pressure relief device.

The sample is mounted in vacuum on the base of the ^{3}He pot, figure 4. Once the sample has been mounted, the inner vacuum can should be sealed and evacuated, and then a small amount($\sim$ 1 cm^3) of ^{4}He exchange gas added. The insert may then be cooled by lowering it into the VTI.

2 Heliox System Control

All Heliox sorption pumped ^{3}He refrigerators are "single-shot" in the sense that there is only a finite quantity of ^{3}He condensed into the system. Experimental heat loads are taken up by the latent heat of vaporisation of the liquid as it is transformed into vapour. Once all of the liquid ^{3}He is consumed in this way, the system will start to warm.

To cool the system again requires the "regeneration" of the ^{3}He sorption pump such that the adsorbed gas is liberated and can be re-condensed into the ^{3}He pot.

In the following sections the processes for cooling and temperature controlling Heliox ^{3}He refrigerators will be described.

2.1 ^{3}He Regeneration

In order to run the refrigerator, the ^{3}He charge must be condensed. This is achieved by warming the ^{3}He sorption pump, using its inbuilt heater, to a temperature $\sim$ 30 K such that it cannot pump helium gas (any gas previously adsorbed in the pump will be released). This raises the pressure of the ^{3}He gas in the insert. Simultaneously, the 1 K pot (or VTI) is run to ensure there is a cold surface for the gas to condense onto. The liquid ^{3}He so produced then runs down into the ^{3}He pot (or the ^{3}He tail), filling it with liquid at a temperature similar to that of the 1 K pot.

2.2 Low-Temperature Operation

To control the temperature of the ^{3}He pot between the lowest attainable temperature and a temperature approximately equal to that of the 1 K pot it is most efficient to control the temperature, and therefore the pumping efficiency, of the ^{3}He sorption pump. As can be seen from figure 1 varying the vapour pressure above the liquid surface can control the temperature of the ^{3}He without supply an additional heat load to the ^{3}He pot, thus maximising the low-temperature hold time.

Closed loop control of the ^{3}He pot temperature can be achieved by servo-controlling the ^{3}He sorption pump heater to control the ^{3}He pot at a set point.

2.3 High-Temperature Operation

To control the temperature of the ^{3}He pot at temperatures above that of the 1 K pot it is most efficient to apply electrical power directly to the ^{3}He pot heater. To provide cooling the ^{3}He sorption pump is warmed to $\sim$ 15 K to partially release the ^{3}He charge from the sorption pump, thus providing a thermal link (through the gas) between the 1 K pot and the ^{3}He pot.

Closed loop control of the ^{3}He pot temperature can be achieved by servo-controlling the ^{3}He pot heater to control the ^{3}He pot at a set point.

2.4 Rapid Cool Down

The initial cool down of the insert, or recovery from high-temperature control to run experiments at low-temperatures, is best accomplished by admitting ^{4}He "exchange-gas" into the inner vacuum can. Oxford Instruments' Heliox inserts provide a small sorption pump inside the inner vacuum can along with a heater to enable the ^{4}He exchange to be adsorbed or de-sorbed into the inner vacuum can space as desired. For Heliox VL or TL inserts, this pump is attached directly to the 1 K pot. For the Heliox VT insert the pump is attached to the IVC flange.

Closed loop control of the ^{4}He sorption pump can be achieved by servo-controlling the ^{4}He pot heater to control the ^{4}He pot at a set point (in the case of the Heliox VT, this is achieved by heating the VTI).

2.5 The Mercury iTC Heliox Controller

The routines for regeneration, for high- and low-temperature control, and for rapid cool down described above have been implemented in the firmware of the Oxford Instruments' iTC Heliox Controller, which is based around the Mercury iTC temperature controller. The details of the operation of the iTC temperature controller can be found in the relevant manual. The details of the customisation of the iTC for use with a Heliox will be covered in the following sections.

The front panel display of the iTC Heliox controller is as shown in figure 5. The display panel is a touch screen and can be used to input the required ^{3}He pot set point temperature, as shown in figure 6. Temperature control set points can also be sent to the controller remotely, as described in section 3.3.1.

When a new set point is entered the actions taken by the Heliox controller are determined by the new set point and by the current state of the system.

2.5.1 Firmware Control Routine

The control routine begins with a new temperature control setpoint `TSET` being input by the user. The logic followed by the controller can then be summarised with the pseudo-code below:

```
Input -> TSET:

if(He3PotTemp - TSET > RAPID_COOL_DELTA && He3PotTemp > RAPID_COOL_END)
{
     Rapid_Cool()
}
```

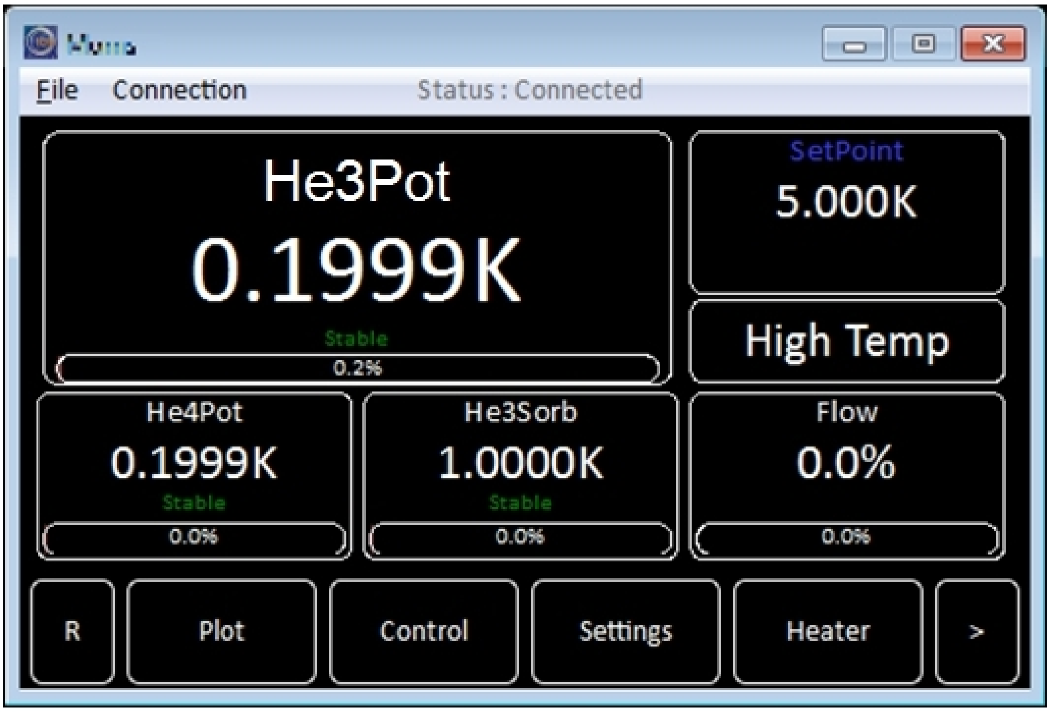

Figure 5: An image of the front panel of the Mercury iTC Heliox controller.

```
if(He4PotTemp > POT_EMPTY)
{
    Fill_Pot()
}
if(TSET > CMODE_XOVER)
{
    High_Temp(TSET)
}
else
{
    if(He3PotTemp > REGEN_ABOVE || TSET==0)
    {
        Regenerate()
    }
    Low_Temp(TSET)
}
```

Here `Rapid_Cool()` initiates the heating of the 1 K pot (or VTI) to introduce exchange gas to the inner vacuum can. `Fill_Pot()` opens the 1 K pot needle valve to increase the ^{4}He flow and accelerate the cool down of the pot, and then closes the needle valve again once the 1 K pot is 'cold'. `High_Temp(TSET)` begins the high-temperature control

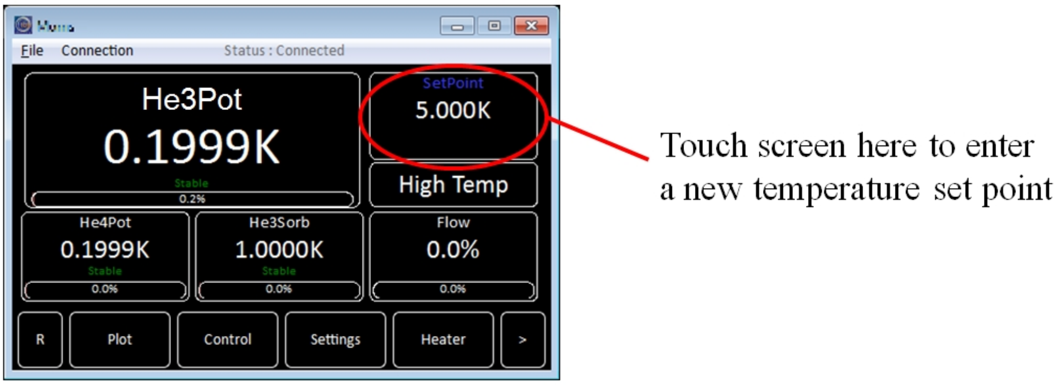

Figure 6: An image showing how the temperature control set point is updated using the touch screen front panel of the Mercury iTC Heliox controller.

routine at the set point and `Low_Temp(TSET)` begins the low-temperature control routine at the set point. `Regenerate()` re-condenses the ^{3}He charge into the pot.

As can be seen in the code, the system will re-condense the ^{3}He charge if the user is starting low-temperature control after running at a high-temperature set point, or if the special set point of 0 K is entered.

2.5.2 Firmware Control Parameters and Typical Values

There are a set of firmware parameters stored in the controller that are used in the control logic. These can be accessed from the front panel of the controller as shown in figure 7

These values will have been configured in the factory for correct operation of the Heliox insert. Typical values, along with a brief description of each parameter are given below.

```
CMODE_XOVER = 1.85
Crossover temperature between high- and low-temperature control modes

RAPID_COOL_DELTA = 10
Temperature difference required between current temperature and set point to
trigger a rapid cool

He4_SORB_RCOOL = 20
Temperature to control the He4Pot during a rapid cool

RAPID_COOL_END = 10
Stop rapid cool at this temperature (or don't start if already below it)

POT_EMPTY = 3.5
```

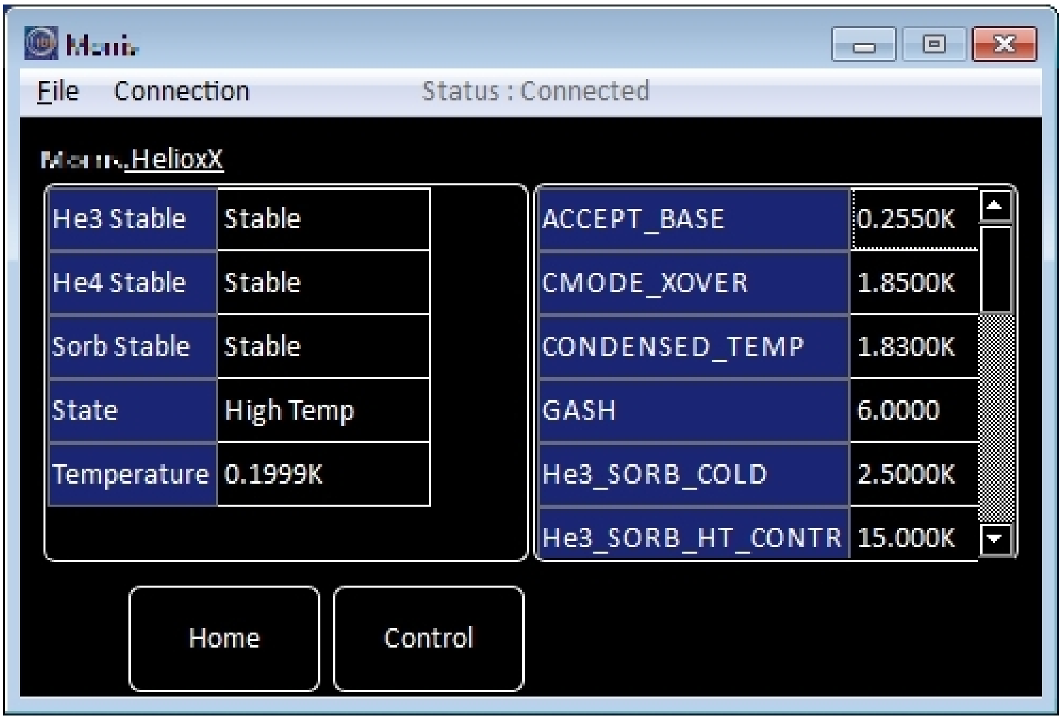

Figure 7: An image showing Mercury iTC Heliox controller settings screen.

```
Temperature above which to consider the 1 K pot empty

OPTIMAL_NV_LT = 5
The optimal needle valve flow in low-temperature operation

OPTIMAL_NV_HT = 10
The optimal needle valve flow in high-temperature operation

OPTIMAL_NV_RG = 15
The optimal needle valve flow during regeneration

REGEN_ABOVE = 1.0
If the current He3Pot temperature is above this, and a new low-temperature
control set point is entered, regenerate anyway

ACCEPT_BASE = 0.25
Accept this temperature as a valid base (when system is stable and TSET == 0)

He3_SORB_REGEN = 32
Temperature to control the He3Sorb at while regenerating
```

```
CONDENSED_TEMP = 1.8
Temperature that both the He4Pot and He3Pot have to be below (and stable) to
consider the system condensed

He3_SORB_HT_CONTR = 15
Temperature that the He3Sorb is controlled at during high temp control

T_DELTA = 0.005
Ratio of the temperature delta to the set point temperature below which
the system is considered to be at the set point.
```

2.5.3 1 K Pot flow control

As the operation of the Heliox (particularly the HelioxVT running in a VTI) is rather sensitive to the precise He flow rate through the 1 K pot "open-loop" control based solely on the 1 K pot needle valve setting is unsatisfactory. A pressure gauge is supplied with the Heliox controller that should be istalled as close as possible to the front of the 1 K pot pump, as depicted in figure 8. Using this gauge, the system PID controls the needle valve position to maintain a constant pressure (and hence flow) at the inlet to the pump.

The Heliox control parameters relating to the needle valve, `OPTIMAL_NV_LT` for example, are the pressures in mbar the system will maintain during operation.

2.6 Diagnostic Wiring

There are three diagnostic wiring connectors for Heliox ^{3}He refrigerator systems, in addition to the connection to the automatic needle valve controller. The diagnostic connectors are 10-way 1031 series Fischer connectors, the details of which are given is section 2.6.1.

The sensor(s) and heater for the ^{3}He pot are carried on connector 1, the connection information for which is summarised in table 1.

The sensor and heater for the ^{4}He pot (or VTI) are carried on connector 2, the connection information for which is summarised in table 2.

The sensor and heater for the ^{3}He sorption pump are carried on connector 3, the connection information for which is summarised in table 3.

2.6.1 1031 Series Fischer Connectors

The electrical connections to the system are made using hermetically sealed 10-pin Fischer connectors. The pin layout for these connectors is as shown in figure 9.

Table 1: Connector 1 - ^{3}He Pot Wiring

Pin #	Function	
1	3He Pot Heater	Start
2	3He Pot Heater	End
3	3He Pot Cernox	V-
4	3He Pot Cernox	V+
5	3He Pot Cernox	I-
6	3He Pot Cernox	I+
7	3He Pot RuOx	V-
8	3He Pot RuOx	V+
9	3He Pot RuOx	I-
10	3He Pot RuOx	I+

Table 2: Connector 2 - ^{4}He Pot Wiring

Pin #	Function	
1	IVC Sorb Heater	Start
2	IVC Sorb Heater	End
3	4He Pot RuOx	V-
4	4He Pot RuOx	V+
5	4He Pot RuOx	I-
6	4He Pot RuOx	I+
7		
8		
9		
10		

Table 3: Connector 3 - ^{3}He Sorption Pump Wiring

Pin #	Function	
1	3He Sorb Heater	Start
2	3He Sorb Heater	End
3	3He Sorb Allen-Bradly	V-
4	3He Sorb Allen-Bradly	V+
5	3He Sorb Allen-Bradly	I-
6	3He Sorb Allen-Bradly	I+
7		
8		
9		
10		

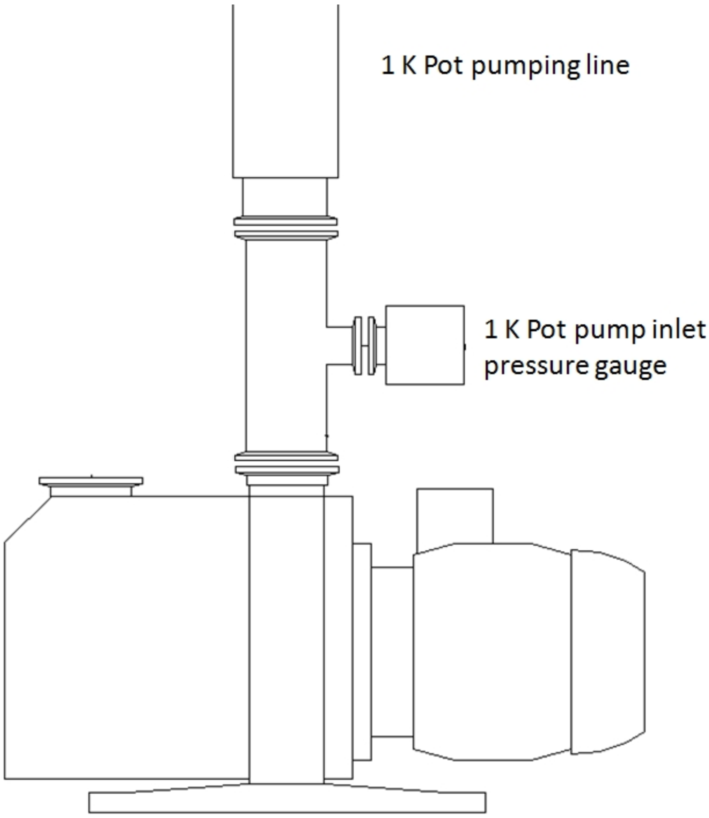

Figure 8: A drawing showing the pressure gauge at the inlet of the 1 K pot pump.

2.7 Generic Sensors

The Heliox insert is supplied with diagnostic temperature sensors at various positions to monitor the behaviour of the system and to allow the Mercury iTC to automate operation. As standard the insert is supplied with generically calibrated temperature sensors, which means they come from a batch of similar sensors the average characteristics of which have been determined. Individual sensors may deviate from the mean by a small amount, but the generic sensors are sufficiently accurate to control the system.

If accurate determination of the temperature at the sample position is required then fully calibrated sensors can be added to the sample stage.

2.7.1 P- and R-series Ruthenium Oxide Temperature Sensors

Ruthenium oxide temperature sensors are useful at temperatures in the range $0.02 < T < 20\,\mathrm{K}$. Oxford Instruments has two series of ruthenium oxide temperature sensors, the P- and R-series the characteristics of which are shown in figure 10.

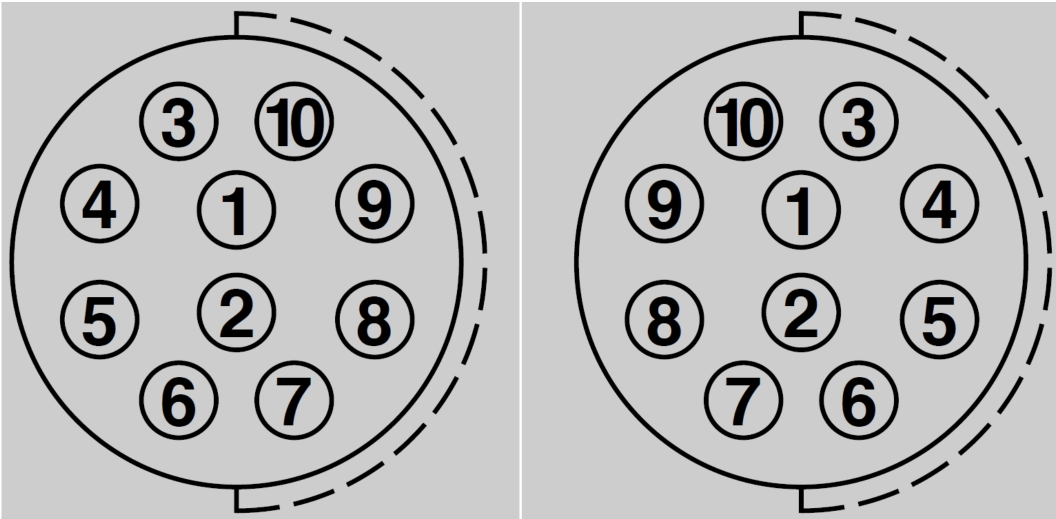

Figure 9: A drawing showing the pin configuration in Fischer 1031 series 10-way connectors for both plugs (left) and sockets (right).

2.7.2 Allen-Bradley Temperature Sensors

Allen-Bradley carbon resistors can be used as temperature sensors in the range $4 < T < 300$ K. Oxford Instruments supplies two types of Allen-Bradly sensors with diffenrent room temperature resistances: the 100 Ω and the 270 Ω sensor, the characteristics of which are shown in figure 11.

3 Remote Operation

The Remote Interface (RI) interacts with the Mercury iTC Heliox controller using the Transmission Control Protocol (TCP), part of the Internet Protocol Suite, as the transport layer. This section will describe the functionality available through the RI and give some examples of implementations in various programming languages.

3.1 Prior to Using the Remote Interface

As stated above, the communication to the RI is *via* TCP. In order to establish a connection to the RI you also need to know the *Internet Socket Port Number* over which the communication will take place: this set to 7020. Access to this port should be configured on your local network.

In order to open a connection to the RI you must also know the Internet Protocol (IP) address of the Mercury iTC Heliox controller. These details can be obtained from the `Settings>>Ethernet` menus on the controller, figure 12.

Note: If you see that DHCP is "ON" then the controller is using the Dynamic Host Configuration Protocol to be automatically assigned an IP address. It is possible that

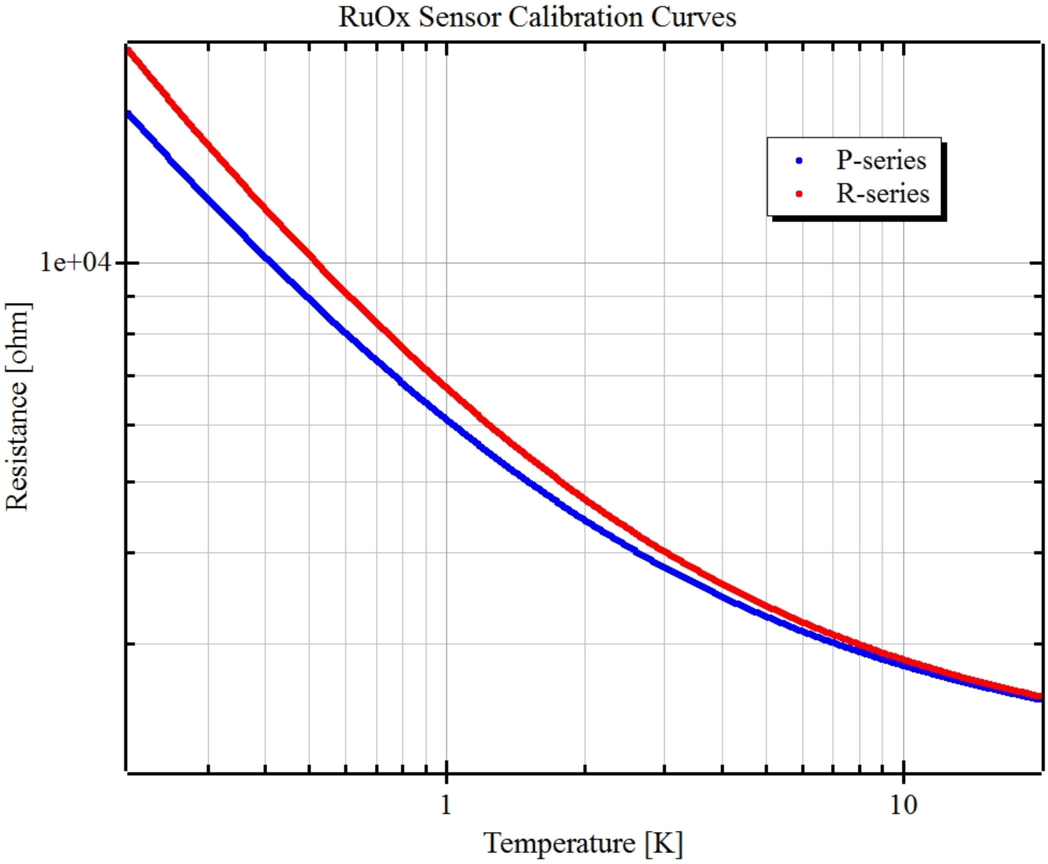

Figure 10: A graph showing the typical resistance *Vs* temperature characteristic of the P- and R-series ruthenium oxide temperature sensors.

this IP address could be changed automatically by the DHCP server when the current lease expires and this may mean that you will lose the ability to communicate with your system unexpectedly during an experiment. You may prefer to ask your network administrator to assign the controller a static IP address.

The application you create to communicate with the RI can be constructed in any development environment provided access to the TCP port is possible, throughout the rest of this manual the features of the RI will be explained in detail to enable software to be constructed to access the RI in any programming language. However, Oxford Instruments have created *Oxsoft IDK* which you may find already provides the functionality you require.

3.2 Details of Communicating with the Remote Interface

All commands sent to the RI application layer are encoded as ASCII text. Commands can either be to request data (READ commands) or to define the state of the system

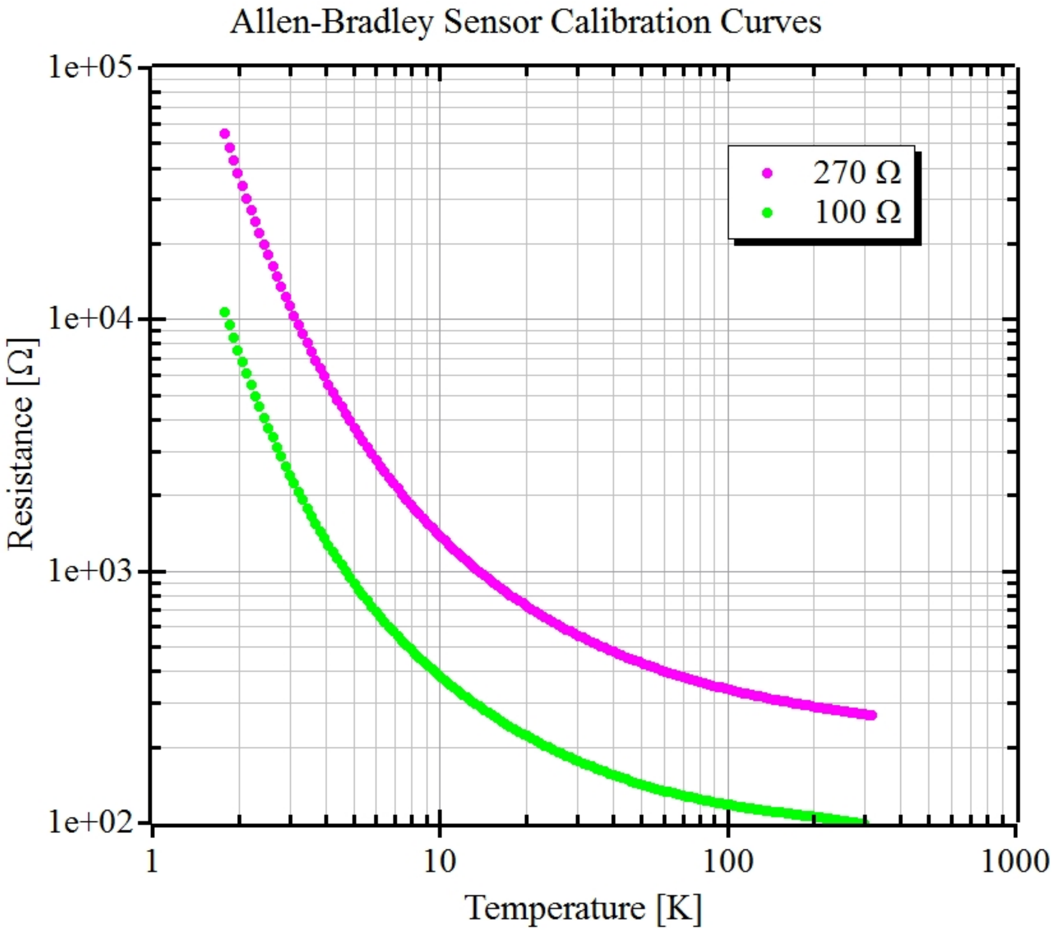

Figure 11: A graph showing the typical resistance *Vs* temperature characteristic of Allen-Bradley temperature sensors.

(SET commands). The remote interface provides verification to all commands (STAT response).

All commands should be terminated with a carriage return and line-feed (CRLF); ASCII characters 13 (0x0D) and 10 (0x0A).

The syntax for the communication is hierarchical and similar in concept to the SCPI protocol. Commands are constructed from keywords as follows:

`<VERB>:`

Where the verb is either READ or SET.

`<VERB>:<NOUN>`

Where the noun is either SYS when the command is addressed to the controller itself, or DEV if the abstracted "Heliox" type or a specific system component (such as an individual temperature measurement board) is to be addressed.

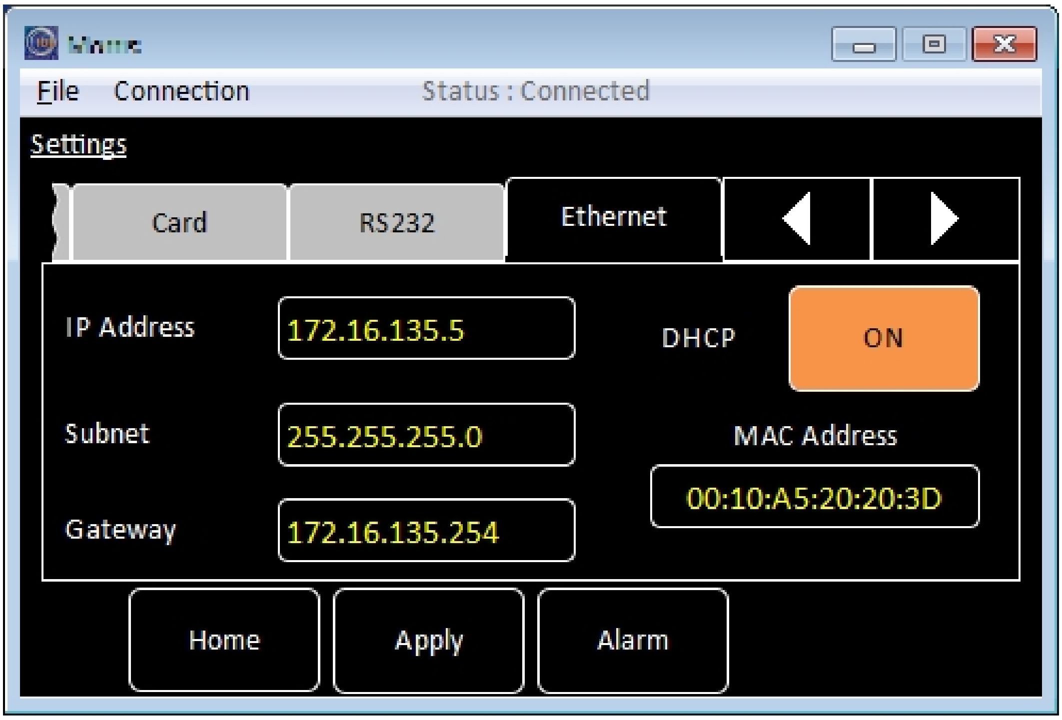

Figure 12: Determining the IP address of the Mercury iTC Heliox controller.

The command key words should be separated with a colon; ASCII character 58 (0x3A).

All commands will generate a response, if the command or verb or noun is impossible to interpret the command will return:

```
INVALID | <VERB>:INVALID | <VERB>:<NOUN>:INVALID
```

If the user does not have the required permission to change or read the parameter being addressed the command will return:

```
DENIED
```

3.3 Remote Interface Commands

Hardware commands will have the form

```
<VERB>:<NOUN>:<UID>
```

where UID is the unique identifier of the system component being addressed. If the UID does not exist in the system being addressed the command will return:

```
NOT_FOUND
```

If the command is directed to a system sub-component, then the type of hardware is specified

```
<VERB>:<NOUN>:<UID>:<HW-TYPE>
```

where HW—TYPE defines the hardware referred to by the UID. The hardware may have a status, or other parameters that could be read / set

```
<VERB>:<NOUN>:<UID>:<HW-TYPE>:<PARMS>
```

where PARMS defines the parameter of interest; additionally a given piece of hardware could contain many data streams — these are accessed as“signals”

```
<VERB>:<NOUN>:<UID>:<HW-TYPE>:SIG:<S-TYPE>
```

where S—TYPE defines the signal to be accessed. A signal will be returned as a value, followed by a SI unit prefix (n, u, m, k, M etc.) if necessary, followed by the units (A, V, mB, K etc.). Not all signals are available on all hardware types (most needle valves do not perform temperature measurements for example). If the function is not applicable to the device being addressed the command will return:

```
N/A | NOT_FOUND | INVALID
```

The command sets for the iTC temperature controller are detailed in the manual for that device. The abstracted Heliox commands are an additional set of commands over the standard iTC temperature controller set, and the software control is configured such that only this superset of commands should be required for standard operation.

3.3.1 Heliox Commands

```
<VERB>      [READ | SET]
<NOUN>      [DEV]
<UID>       [HelioxX]
<HW-TYPE>   [HEL]
<S-TYPE>    [STAT | TEMP | TSET]
```

And so the current ^{3}He pot temperature can be read back from the controller with:

```
READ:DEV:HelioxX:HEL:SIG:TEMP
```

A new set point (350 mK in this example) can be entered with:

```
SET:DEV:HelioxX:HEL:SIG:TSET:0.350
```

And the state of the system read back with:

```
READ:DEV:HelioxX:HEL:SIG:STAT
```

3.4 Testing the Connection

The RI connection can be tested using Telnet, figure 13. Connection is established with the command:

```
telnet xxx.xxx.xxx.xxx yyyy
```

where `xxx.xxx.xxx.xxx` is the IP address of the controller and `yyyy` is the port number (7020) to connect on.

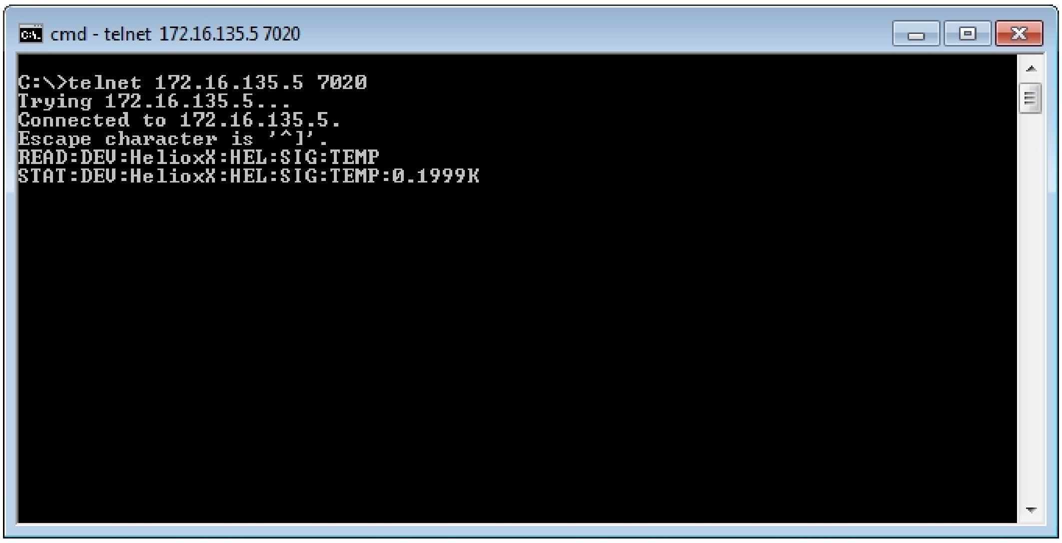

Figure 13: Testing the remote interface connection to the Mercury iTC Heliox controller with Telnet.

4 Setting up the System

If you purchased a complete system from Oxford Instruments, then the system should arrive fully configured. If you plan to use your own pumps, or if the system is being retro-fitted into an existing system then some of the parameters may need to be updated to attain optimum performance.

4.1 Regeneration Parameters

Prior to cooling the system the parameters `CONDENSED_TEMP` and `ACCEPT_BASE` should be set to an unrealistically low value, e.g. 0.1 K. This will ensure the system never completes the regeneration routine and allows time for the various parameters to be optimised.

A set point of 0 K should then be entered and then system cooled. The controller will wait for the ^{3}He pot to cool and then attempt to regenerate. The temperature that the

^{3}He sorption pump will be controlled at during regeneration will have been optimised in the factory and will not need to be changed, but the OPTIMAL_NV_RG setting may need to be adjusted. The flow through the 1 K pot needle valve should be adjusted to give the lowest possible ^{3}He pot temperature (note: this does not necessarily correspond to the lowest possible ^{4}He pot temperature, particularly on systems running in VTIs). This will ensure that the maximum fraction of the ^{3}He charge is condensed.

At this stage CONDENSED_TEMP should be set to a value slightly above this minimum temperature, with a $\delta T \sim 200$ mK, to allow for small variations in performance. The system will then commence its cool down towards its base temperature, where the low-temperature parameters can be determined.

4.2 Low-Temperature Operation Parameters

As discussed in section 1.1, the minimum ^{3}He pot temperature will be obtained when the ^{3}He sorption pump is as cold as possible. OPTIMAL_NV_LT should now be adjusted to minimise the ^{3}He pot temperature. Once the minimum temperature is found ACCEPT_BASE should be set to a value slightly above this minimum temperature, with a $\delta T \sim 20$ mK, to allow for small variations in performance. Note: the minimum temperate and optimum flow found in this way assume that there is no experimental heat load to be applied to the ^{3}He pot. If your experiment will generate a significant heat load (~ 100 μW or more) then the additional ^{3}He boil off that this will generate will apply a large heat load to the sorption pump (the heat of adsorption is $>>$ than the latent heat of vaporisation). In this case the OPTIMAL_NV_LT may need to be increased to ensure the sorption pump temperature is maintained at as low a possible a value during operation.

4.3 High-Temperature Operation Parameters

In high temperature operation OPTIMAL_NV_LT should be chosen to be the lowest flow at which the 1 K pot temperature can be maintained below ~ 3 K during operation. This is to ensure that the IVC exchange gas sorption pump stays cold. Choosing the lowest possible value for OPTIMAL_NV_LT will minimise ^{4}He consumption during operation, so if you know you plan to only operatre the system up to 20 K it would make sense to optimise OPTIMAL_NV_LT at that temperature rather than, say, 80 K.