NITROGEN BOILING POINT APPARATUS MODEL ITL-M-18205

User Maintenance Manual/Handbook

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GUARANTEE

This instrument has been manufactured to exacting standards and is guaranteed for twelve months against electrical break-down or mechanical failure caused through defective material or workmanship, provided the failure is not the result of misuse. In the event of failure covered by this guarantee, the instrument must be returned, carriage paid, to the supplier for examination and will be replaced or repaired at our option.

FRAGILE CERAMIC AND/OR GLASS PARTS ARE NOT COVERED BY THIS GUARANTEE

INTERFERENCE WITH OR FAILURE TO PROPERLY MAINTAIN THIS INSTRUMENT MAY INVALIDATE THIS GUARANTEE

RECOMMENDATION

The life of your **ISOTECH** Instrument will be prolonged if regular maintenance and cleaning to remove general dust and debris is carried out.

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The company is always willing to give technical advice and assistance where appropriate. Equally, because of the programme of continual development and improvement we reserve the right to amend or alter characteristics and design without prior notice. This publication is for information only.

⚠ CAUTIONARY NOTE

ISOTECH PRODUCTS ARE INTENDED FOR USE BY TECHNICALLY TRAINED AND COMPETENT PERSONNEL FAMILIAR WITH GOOD MEASUREMENT PRACTICES.

IT IS EXPECTED THAT PERSONNEL USING THIS EQUIPMENT WILL BE COMPETENT WITH THE MANAGEMENT OF APPARATUS WHICH MAY BE POWERED OR UNDER EXTREMES OF TEMPERATURE, AND ARE ABLE TO APPRECIATE THE HAZARDS WHICH MAY BE ASSOCIATED WITH, AND THE PRECAUTIONS TO BE TAKEN WITH, SUCH EQUIPMENT.

HEALTH & SAFETY INSTRUCTIONS

1. Wear appropriate protective clothing.

2. Operators of this equipment should be adequately trained in the handling of hot and cold items and liquids.

3. Do not use the apparatus for jobs other than those for which it was designed, i.e. the calibration of thermometers.

4. Do not handle the apparatus when it is hot (or cold), unless wearing the appropriate protective clothing and having the necessary training.

5. Do not drill, modify or otherwise change the shape of the apparatus.

6. Do not dismantle the apparatus without disconnecting it from the supply and leaving time for it to reach ambient temperatures.

7. Do not use the apparatus outside its recommended temperature range

8. The apparatus is protected by an over temperature circuit, ensure correct settings at all times.

NITROGEN BOILING POINT APPARATUS

This device is intended for use with liquid nitrogen refrigerant supplied from a storage dewar with a transfer device. It may also be used with liquid argon. The user is cautioned NOT to use this apparatus with liquid oxygen except upon receipt of specific preparation instructions from Isotech; otherwise the danger of fire, explosion, etc., is present. Do not remove labels which read:

⚠ WARNING - NOT FOR OXYGEN SERVICE

The apparatus is intended for use by technical professionals skilled and trained in the technique (and understanding the hazards) of storing, transferring, and otherwise handling liquid cryogens, including, but not limited to, liquid nitrogen, liquid argon, liquid oxygen.

This equipment is intended for use in the calibration of Standard Platinum Resistance Thermometers (SPRT's) such as Isotech's model 909, Leeds and Northup and YSI Models 8163 and 8167, etc. It may be used to calibrate other thermometers having similar diameter, length and immersion characteristics. It provides an environment for the comparison of a thermometer under test with another thermometer having a known calibration, at the boiling temperature of liquid nitrogen or liquid argon, if appropriate.

UNPACKING THE COMPARATOR

DO NOT DISCARD ANY PACKING MATERIAL UNTIL ALL PARTS HAVE BEEN LOCATED AND IDENTIFIED AS SOME PARTS ARE SMALL!

Because of the fragility of some parts, the Comparator is shipped in an incompletely form.

You should find in the package:

- 1 x Flanged stainless steel dewar flask labelled WARNING: NOT FOR OXYGEN SERVICE.
- 1 x Stainless steel lid for dewar flask complete with gas manifold, pressure gauge and various Swagelok fittings.
- 1 x Cylindrical copper block drilled with 3 deep holes and a central threaded hole, and partially covered with a porous blanket.
- 3 x Individually-numbered thermometer tubes with block-support collars attached.
- 1 x Block retaining disc.
- 1 x Stainless steel cap screw ¼ - 20 x ¾ inch (to secure block retaining disc)
- 1 x Level float assembly.
- 1 x Large “O” ring.
- 6 x Stainless steel cap screws ¼ - 20 x ¾ inch (for lid).
- 1 x Copy of this manual.

If any parts are missing, please inspect the packing materials carefully. If parts are not found, please call Isotech or your nearest supplier.

ASSEMBLING THE COMPARATOR

WARNING: Particular caution much be exercised when building and handling the assembly. The thermometer wells are necessarily thin-walled, to prevent excessive transfer of ambient heat into the refrigerant. They are stainless steel tubes, 9.35mm (¾ inch) OD x 0.89mm (0.035 inch) wall thickness. Even a slight bend will prevent full insertion of an SPRT of the usual 7.36mm (0.290 inch) sheath diameter. Take all necessary precautions. For example, after assembly of the tubes, do not set the lid-edge down on to a surface with any tube touching the surface.

Assembly Step 1: The copper block is intended to hold the three thermometer wells (referred to hereafter as tubes), as shown in the drawing. There is a unique position for each tube and, to this end, parts have been numbered correspondingly. Insert the tubes into the holes with a firm slow downward push (be certain to avoid side-loading which would bend the tubes). "Slow" is advised because the tubes are a very close fit in the holes, and it is necessary to allow entrapped air to leak out as the tubes are inserted. Referring to the drawing, the collars silver-soldered on to the tubes are set into the annular recesses machined into the block as the tubes are fitted.

Assembly Step 2: When the tubes are seated in the holes in the block, place the block retaining disc between the tubes so that it rests on all three collars. Pass the ¼ - 20 x ¾ inch cap screw through the clearance hole in the retaining disc and screw it into the copper block finger-tight. Over-tightening could result in distortion of the thermometer tubes and must be avoided.

Assembly Step 3: Attach the lid passing the Swagelok fittings of the manifold over the tubes and adjusting the relative positions of lid and block to give a gap of 115mm (4 ½ inches) between them. Secure the Swageloks to the tubes very carefully to avoid crimping but sufficiently well to support the copper block.

WARNING: The tubes are particularly susceptible to bending during and after attaching the copper block to the lid. Do not subject the assembly to any sidewise static force or pendulum-like acceleration. Do not allow the block to hang from the tubes other than with its axis vertical. The safest place to rest the assembly is to suspend it in the dewar.

Check the integrity of the tubes by inserting a rod 7.62mm (0.300 inch) in diameter successively into each tube. It should pass into the tube to a depth of about 390mm (15 – $^{3}/_{8}$ inch) measured from the open end of the tube. No resistance should be felt. The rod should be felt to bottom in this position.

Assembly Step 4: Locate the level float assembly. Note that it comprises a light stainless steel tube 3mm ($^{1}/_{8}$ inch) in diameter with a foam cylinder cemented to one end, and a plastic cylinder on the other, the tube passing through a plastic guide-tube. Ensure that the stainless steel tube is not bent, and is free to slide through the guide for its full length under its own weight.

The drawing shows a Swagelok fitting (SW1) intended to locate the level-float assembly. To fit the assembly, remove the plastic cylinder from the end of the float tube. Insert the guide-tube into the $^{3}/_{8}$ inch hole in the Swagelok fitting from the bottom (the copper block side of the lid). Tighten the nut on the Swagelok fitting finger-tight. Secure the plastic cylinder on the upper end of the stainless steel tube with a spot of suitable adhesive. Check once again that the tube slips freely through the guide for its entire length.

Assembly Step 5: Ensure that the "O" ring is in its proper channel at the top of the dewar flange, as in the drawing. It is not necessary or advisable to lubricate the "O" ring. With the dewar vertical and bottom-down, lift the assembly prepared in Steps 1 to 4, and insert it into the dewar. Complete the assembly by bolting the lid to the dewar flange with the six ¼ - 20 x ¾ inch cap screws.

Assembly Step 6: Place the assembly where is will be used. The dewar must be supported firmly so that it cannot be knocked over accidentally. A knock-over may (a) cause enough sideways acceleration to bend the thermometer wells (b) result in spilling dangerously cold cryogen. A preferred way of supporting the dewar is to provide a 130mm (5.125 inch) diameter hole in a bench top and suspend the dewar through the hole, resting on the lower surface of its flange. The dewar should be positioned rotationally so that (a) its cryogen transfer system tube conveniently meets the appropriate fitting in the dewar lid (b) the level float is accessible to the operator (c) the pressure gauge dial is in full view of the operator.

Assembly of the comparator is now complete!

The drawing shows a right-angle tube connection ("Fill port") on the dewar lid, provided for connection of a cryogen transfer tube (not furnished).

Normally, cryogen transfer is accomplished from a cryogen storage vessel by means of an insulated tube, using the internal pressure of the storage vessel to cause the liquid to pass. Systems for pressurising a storage vessel may be obtained if required, from manufacturers of the vessels.

WARNING: Dewars furnished for storage purposes should be fitted with blow-off valves which limit the pressure in the vessel to approximately 10 psi. The blow-off valve is located on the vessel side of the shutoff valve. The user should NOT INSERT a shut-off valve in the transfer line between the vessel shut-off valve and the Comparator dewar (to avoid dangerous pressure build-up in the line in the event of accidental line blockage). If a downstream shut-off valve is required, another blow-off valve must be provided, appropriately situated in the line before the shutoff valve. The line from the storage vessel to the Comparator dewar may be 9.5mm ($^3/_8$ inch) diameter flexible tubing, appropriately insulated with, for instance, a wrap of flexible sheet Styrofoam.

The drawing also shows a VENT FITTING, SW2. This is also a Swagelock fitting, and may be left open to vent boiled-off gas. If it is desired not to vent this gas to the work area, a suitable tube connection to another area can be made.

WARNING: Venting large quantities of nitrogen or argon into a confined space can reduce the partial pressure of oxygen in the environment of the confined space, in the extreme case leading to oxygen deprivation.

Furthermore, the drawing shows a SPARE Swagelock fitting (SW3). This fitting may be plugged with a short length of 9.5mm ($^3/_8$ inch) diameter rod or may be used for a user-elected purpose, e.g., an automatic level control sensor. (Isotech does not furnish an automatic level control system, to avoid the temperature fluctuations which would occur if fresh cryogen were added automatically during the course of a measurement).

The pressure gauge shown in the drawing is furnished as a warning device only, and does not represent an automatic safety feature.

WARNING: In the event that the vent, or a tube intended to vent the boiled-off cryogen remotely should become restricted or plugged, the pressure may rise in the comparator dewar, and the gauge will indicate this. Immediately cut off any transfer of new cryogenic liquid and take action to assure that the dewar is vented. Dewars such as this one are rated at about 3 atmospheres of safe internal pressure, but Isotech does not test for this nor make any representation regarding safe internal pressure. The Comparator is intended to operate with no pressure differential to atmosphere.

The use of a gas manifold, as fitted, is not strictly essential. However, its function (described below) is to augment accuracy and to reduce operating time.

The manifold is intended to allow the air around the thermometers in the respective wells to be replaced with an atmosphere of helium gas. At -100°C, the respective thermal conductivities of air and helium are in a ratio of

approximately 1 to 5. Thus, attainment of the block temperature by the thermometers is much facilitated by surrounding them with a helium atmosphere.

The drawing also indicates a suitable gas handling arrangement with which to transfer helium to the thermometer wells. Two or three thermometers are placed in the wells; if two, then the third port must be closed by a glass or metal rod 7.3 mm (0.29 inch) in diameter. The Swagelock fittings are closed onto the thermometer tubes finger-tight. The wells are evacuated using a mechanical vacuum pump ("Vac" in drawing) and then filled with approximately 1 atmosphere of helium ("He" in drawing).

USING THE COMPARATOR TO CALIBRATE THERMOMETERS

Isotech practice in using the comparator is as follows;

a. Use a resistance thermometer of known calibration (not necessarily an SPRT) to monitor the establishment of the boiling plateau. This thermometer will be called a "monitor" thermometer. Connect the monitor thermometer to a resistance measuring device - an ohmmeter, for example - with an adequate resolution (0.1Ω is sufficient resolution for a 100Ω monitor thermometer).

b. Crack open the LIQUID VENT of the storage dewar withdrawal system. As the liquid enters the comparator, a substantial amount of liquid will be converted to gas until the Comparator is cold. However some of the liquid will be retained, because a phase separator has been provided immediately below the liquid entrance. It is suggested that the flow rate be low enough so that the pointer of the pressure gauge does neither move nor the level float rise show an initial rise (except for momentary displacement). Continue to fill the dewar until the level float has been lifted to a free height of about 40mm (1.5 inch) and remains there.

c. Monitor the thermometer connected to the ohm-meter. Note when the resistance of the thermometer indicates approximately the liquid boiling point, and no longer changes. (The resistance will depend upon the thermometer's calibration, but will be approximately 25% of the room temperature resistance). The time required for the boiling point temperature to be achieved and stabilized may be of the order of one hour.

d. Add enough liquid cryogen to reset the float to about 40 mm (1.5 inches) extension. Depress it gently (with a finger) to ensure that it is not frozen in place.

   When the comparator has been adequately filled and chilled, little evidence of boiling-off gas will be seen as the liquid will be retained in usable quantity for a number of hours.

   For a discussion of methods of making calibration measurements, please see appended Tutorial.

A BRIEF TECHNICAL TUTORIAL

COMPARISON CALIBRATIONS AT THE BOILING POINT OF NITROGEN (OR ARGON)

Temperature is defined by the International Temperature Scale of 1990 (ITS-90), which replaces the International Practical Temperature Scale of 1968 (IPTS 68) and all previous international scales. The scale requires the realization of a series of defining fixed points, phase equilibria of pure materials, to each of which a value of temperature has been assigned. Thus the state in which pure water exists simultaneously in its liquid, solid and vapour phases (the triple point of water) defines the temperature 273.16K or 0.01°C; the state in which pure tin, for example, exists simultaneously in its liquid and solid phases under 1 standard atmosphere pressure defines the temperature 231.928°C.

To calibrate a thermometer over the region of temperature from -189.3442°C to 0.01°C, the scale specifies a calibration at the triple point of argon (-189.3442°C), at the triple point of mercury (-38.8344°C) and the triple point of water (0.01°C). The measurements obtained are then compared with a reference function and the resulting differences used to calculate the coefficients of a deviation function, which can then be used for interpolation. An Isotech computer-program (Icarus) is available that will enable all relevant ITS-90 data to be calculated.

An alternative to the realization of the triple point of argon, employed by many laboratories (including National Laboratories) is a comparison calibration in boiling nitrogen or argon.

COMPARISON VERSUS ABSOLUTE CALIBRATION AT THE COLD END OF THE LONG-STEM SPRT RANGE

In theory, the triple point of argon is a simple point to establish. It has been realized in sealed cells by Pavese, Bonnier, Furukawa and others, particularly for capsule thermometers. Sealed cells have the drawback that, at room temperature, they exist under relatively high pressure (e.g., 3000 psi), and must be regarded as pressure vessels in handling and for transportation. Also, the cryostat required is not simple, and the prevention of heat transfer via the cell mountings and the tubes of long-stem thermometers must receive special attention. In practice, the realization of the argon triple point can be costly and complicated.

Most laboratories will elect to calibrate at this end of the SPRT range by the simpler and less costly comparison method, and Isotech model ITL-M-18205 is designed specifically for this purpose. In this method, a thermometer under test is compared to a thermometer of known calibration that is traceable to a National Laboratory. Indeed, many National Laboratories will calibrate thermometers submitted to them by comparison with their own thermometers, realizing the argon triple point itself only infrequently, and only for the calibration of their own reference SPRT's.

This policy has been announced by the National Physical Laboratory of England, in its publication "Adoption of the ITS-90", as follows*: "Most thermometers (submitted for calibration) will involve measurements at the tin and zinc freezing points, plus a comparison with NPL standards in a bath of liquid nitrogen".*

Other National Laboratories will follow similar practices.

THE EFFECT OF PRESSURE (E.G. LABORATORY ALTITUDE) ON THE NITROGEN AND ARGON BOILING POINTS

The temperature at which a pure liquid boils is that temperature at which the vapour pressure and the ambient pressure are equal.

The normal boiling point of nitrogen is -195.794°C, a mere 6.45K below the argon triple point. The normal boiling point or argon is -185.88°C. However, since these are two-phase (liquid-vapour) equilibria rather than triple points, their temperatures will vary with pressure, for example, as a function of laboratory altitude above standard sea level. Table 1 shows the variation of the nitrogen and argon boiling temperatures with altitude.

For this table, the pressure (p/mm Hg)-temperature (t/°C) relationship has been computed from the Antoine vapour pressure equation

$t = (B/(A - \log p)) - C$ (Eq. 1)

In which, for nitrogen, A = 6.4946, B = 255.68, C = 266.558, and for argon A = 6.6165, B = 304.277, C = 267.328.

Table 1; The Boiling Point of Nitrogen & Argon at various altitudes

Feet of Altitude	Pressure/mm Hg	Nitrogen Boils °C	Argon Boils °C
-1000	787	-195.50	-185.54
0	760	-195.80	-185.88
1000	733	-196.11	-186.22
2000	707	-196.41	-186.56
3000	681	-196.72	-186.90
4000	656	-197.02	-187.24
5000	632	-197.33	-187.58
6000	609	-197.63	-187.92
7000	586	-197.93	-188.26
8000	564	-198.24	-188.60
9000	543	-198.53	-188.94

(Pressure-Altitude data from "Pressure-Altitude Tables Based on the United States Standard Atmosphere", W. Brombacher, NACA Report No. 538,1948)

THE METHODOLOGY OF COMPARISON CALIBRATION

Comparison calibration is done by placing two thermometers in an isothermal situation at an approximately known temperature. One of these thermometers (the standard) must have a known calibration (such as is obtained from a UKAS or National Laboratory), and a table of calibration values which includes the range under consideration.

Method 1

After the two thermometers have reached a condition of thermal equilibrium with the bath, the resistance of the standard thermometer is measured, the resistance of the unknown is measured, and the resistance of the standard is measured again, to assure that no change in temperature has taken place (possibly caused, for example, by change in ambient pressure). The temperature of the bath, t_b, is then determined from the measured resistance and the calibration table for the standard, and the measured resistance of the unknown at the same temperature is said to be its resistance at t_b.

It is possible to take account of slow, steady drifts by taking a succession of measurements at regular intervals, alternately with each thermometer. The contrasting feature of a "thermostatically-controlled" bath is that temperature fluctuations occur as the control function operates. In this case, each measurements should be an average value taken over a sufficient number of control cycles to avoid the possibility of swings of equal magnitude but in opposite directions between successive instantaneous measurements leading to an erroneous interpretation.

Method 2

Outlined below is a potentially more satisfactory way than Method 1 to perform a calibration transfer, if there is available a resistance-measuring bridge or an instrument equipped with appropriate terminal connections and the facility to allow the ratio of two resistances to be determined. Examples are Guildline model 9975 and Automatic Systems Laboratories F16, F17 and F18 bridges.

With a thermometer to a calibrated and a standard thermometer (with a known calibration) immersed in (and in thermal equilibrium with) the bath, the temperature (t) maybe found from the standard's calibration data, being that value corresponding to the resistance Rs determined by comparison with a known fixed resistance.

A measurement if the ratio, r, of the resistance (Ru) of the thermometer intended for calibration to that (Rs) of the standard thermometer will then furnish the calibration point (t, Ru). In principle, a transfer of calibration carried out in this manner depends not only on equality of temperature of the thermometers at the time of the transfer but also on this temperature being identical to the value, t, determined by comparison of Rs and the fixed resistance.

In this context there is no advantage immediately evident over Method 1. However, if the two measurements relate respectively to slightly different bath temperatures (and therefore, marginally different values of Rs and Ru), the ratio r can, in certain circumstances, be construed still to apply to that value of Rs used for temperature determination and, consequently, can yield a value of Ru belonging to that temperature, without introducing significant error. The condition that renders r relatively insensitive to small temperature differences is that the two thermometers have similar rates to change of resistance with temperature. For example, a discrepancy of 1°C in a bath temperature of about -200°C is equivalent to a calibration measurement error no greater than a few mK for any thermometers that would qualify as standards, within the constraints defined by ITS-90. However, spatial uniformity of temperature is still vital.

By way of illustration the results are presented below of some calculations on the correspondence between 17 thermometers calibrated at various times. The thermometers represented a fair selection of Leeds and Northrup 8163 and 8167 thermometers, of various ages and provenance. The reference standard for each comparison was one of two Leeds and Northrup Model 8163 thermometers having long and honourable histories and current NIST calibrations.

Each of the 17 thermometers was calibrated relative to the standard thermometer at the boiling point of oxygen (it might equally have been done at the boiling point of nitrogen, or of argon) by using the standard thermometer as the standard resistor and the unknown thermometer as the unknown resistance of a Guildline Model 9975 Precision Current Comparator. In addition, each unknown thermometer was calibrated at two fixed points of the ITS-90, the triple point of mercury and the triple point of water, and a table calculated from this data at intervals of 1°C over the range from -200°C to -179°C, using the Isothermal Technology Icarus MS-DOS interpolation program.

From the table of resistance ratio for each thermometer, for each 1°C interval between -200°C and -179°C, are calculated the increments of resistance ratio, and then the distribution of increments for the same temperature interval for each of the thermometers. Table 2 provides a summary of the results. (The detail is available, and will be sent to any reader on request). From this information, it was possible to derive the mean and range of increment for the group at each temperature, and the standard deviation at each temperature in terms of increment and of temperature. In addition estimates were made of bath temperature uncertainties that are tolerable, at nominal values of -186°C and -196°C, in order that calibration uncertainty for a particular thermometer be maintained within about 1mK.

Table 2; Resistance-ratio Increment Data for 17 Thermometers between -200°C and -179°C

1 Temp °C	2 Mean Increment per °C	3 Range of Increments	4 2 Standard Deviation Level of Increment Population	5 2 Standard Deviation Level in °C	6* Calibration Error (°C) for Unaccounted Deviations in Bath Temp
200	.004304	.000003	.00000150	.0003665	
199	.004310	.000004	.00000174	.0003772	.00115
-198	.004316	.000004	.00000172	.0003849	.00077
-197	.004322	.000003	.00000150	.0003896	.00039
-196	.004326	.000004	.00000177	.0003917	.00000
-195	.004333	.000003	.00000165	.0003915	.00038
-194	.004333	.000004	.00000177	.0003894	.00077
-193	.004336	.000003	.00000162	.0003856	.00115
-192	.004338	.000004	.00000193	.0003805	
-191	.004340	.000003	.00000137	.0003743	
-190	.004341	.000003	.00000150	.0003674	
-189	.004342	.000003	.00000140	.0003601	.00106
-188	.004342	.000003	.00000165	.0003526	.00071
-187	.004342	.000003	.00000158	.0003452	.00036
-186	.004342	.000003	.00000154	.0003384	.00000
-185	.004341	.000003	.00000165	.0003323	.00033
-184	.004340	.000002	.00000118	.0003273	.00065
-183	.004339	.000002	.00000139	.0003238	.00087
-182	.004338	.000003	.00000150	.0003219	.00130
-181	.004337	.000002	.00000112	.0003220	
-180	.004334	.000003	.00000160	.0003244	
-179	.004333	.000003	.00000140	.0003294	

* Over the temperature range of column 1, the calibration error per degree deviation of bath temperature from its assumed value is not particularly sensitive to the temperature itself.

Comment

It is clear that the thermometers reported on have very closely matching characteristics, which fact appears to render superfluous knowledge of the precise temperature of the bath. However, the extent of agreement between characteristics is not discernible without detailed measurements. In any event, care must be taken to assess the demands imposed on the measurement environment by the calibration accuracy required for a thermometer with given or approximately known, characteristics.

For industrial resistance thermometers, there will generally be a considerable difference in the slope of the resistance/temperature characteristics from that of an SPRT calibration standard. However, the calibration accuracy required is unlikely to be at the level of a few mK, thus providing wider latitude in acceptable bath temperature deviation than would otherwise be the case.

The methods, with appropriate modifications, are obviously applicable to other types of thermometer, e.g. thermocouples.

Useful References

H. Preston-Thomas, The International Temperature Scale of 1990, Metrologia 27, 3-10 and 107 (correction) (1990). Isotech will furnish a copy of this paper upon request.

H. E. Sostmann, Fundamentals of Thermometry Part I, pp 1-18, also Practical Calibration of Thermometers on the International Temperature Scale of 1990, pp 19-30, Isotech Journal of Thermometry, Vol. 1 No. 1, (1990)
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NITROGEN BOILING POINT APPARATUS DIAGRAM