SPECTROMAG SUPERCONDUCTING MAGNET AND OPTICAL SYSTEM

GENERAL OPERATING PROCEDURES

OXFORD

SPECTROMAG SUPERCONDUCTING

MAGNET AND OPTICAL SYSTEM

GENERAL OPERATING PROCEDURES

System Includes :

Supplied to :

Project Engineer :
Project number :
(Please use this number for communications with the company concerning this system).

OXFORD INSTRUMENTS LIMITED
EYNSHAM
OXFORD
OX8 1TL
ENGLAND

TELEPHONE (0865) 882855
TELEX 83413
FAX (0865) 881567

MASTER\1.1\MAGNET.MAN
AJB DEC 1989

SYSTEM SPECIFICATION AND BRIEF DESCRIPTION.

Please use this brief specification / checklist to ascertain the relevance of particular sections of the following manual to the system purchased. The manual is a general document defining standard procedures and giving information about the more common pieces of equipment produced by Oxford Instruments as well as the necessary pieces of ancillary tools and apparatus. The final section of the manual will deal with any system-specific procedures and information, including the system wiring diagram, and should be read in conjunction with the main body of the manual.

Cryostat.

MD range : MD10 / MD15 / MD25

Magnet.

Solenoid / Split pair.
Horizontal bore / Vertical bore.

Magnetic field	__ Tesla at 4.2 Kelvin.
	__ Tesla at 2.2 Kelvin.
Cold bore	__ mm
Cold split	__ mm
Leads	Fixed / Demountable.

Variable Temperature Insert (VTI).

Fitted / Not fitted.

Temperature range		__ / __ Kelvin.
Sample space	standard	23 x 13 mm.
	non standard	_ x _ mm

Lambda Point Refridgerator.

Fitted / Not fitted.

I M P O R T A N T

This operating manual is intended to help the user set up and operate an Oxford Instruments Superconducting Magnet and Cryostat.

The front pages define the system components supplied hence refer to the relevant sections in the manual.

Before attempting to operate the system, PLEASE READ THE INSTRUCTIONS.

Ensure that any packing bungs (if fitted) are removed from the system before operation - instructions and information are generally stuck to the outside of the cryostat when packing bungs have been fitted - the main exception to this is when an Oxford Instruments installation has been ordered.

This product is guaranteed for 1 year against defective materials and workmanship under the general conditions of sale as detailed in the Company's order acceptance.

The guarantee does not apply to damage caused by failure of the operator to follow the recommended operating instructions. This point should particularly be remembered when dealing with the wiring.

Glass and quartzware when provided with the system is covered by our guarantee for a period of three months, except where damage is caused by freezing aqueous samples.

Systems fitted with optical windows on sample cells have had the window seals thermally cycled from room temperature to nitrogen boiling point six or more times, however they may be destroyed if they are heated above 40° centigrade. For 500 Kelvin inserts the sample space should be at reduced pressure. It is recommended that the spare cells are kept below 10° centigrade, e.g. in a domestic refrigerator.

CONTENTS

ILLUSTRATIONS

SECTION 1. SAFETY

1.1. INTRODUCTION

A superconducting Magnet System can be operated easily and safely provided the correct procedures are obeyed and certain precautions observed.

This safety section must be read and understood by everyone who comes into contact with a Superconducting Magnet System. They are NOT for the sole information of senior or specialist staff. Proper training procedures must be undertaken to familiarise effectively all persons concerned with such equipment with these requirements. **Also since the field from the magnet is 3-dimensional, consideration must be given to floors above and below the magnet as well as the surrounding space on the same level.**

The installation and operation of a Superconducting Magnet System presents a number of hazards of which all personnel must be aware. It is essential that:

- Areas in which magnet systems are worked on or used, and their installation generally, are planned with full consideration for safety.
- Such premises and installations are operated in a safe manner and in accordance with proper procedures.
- Adequate training is given to personnel.
- Clear notices are placed and maintained to effectively warn people that they are entering a hazardous area.
- All health and safety procedures are observed.

These notes outline aspects of operation and installation which are of particular importance, however, the recommendations given cannot cover every eventuality and if any doubt arises during the operation of the system the user is strongly advised to contact the supplier.

It is the obligation of Oxford's customers to communicate effectively to their own customers and to users of the equipment the information in this manual regarding safety procedures and hazards associated with magnet systems.

FLOOR LOADING

Professional assistance from a civil or structural engineer should be sought when considering any installation.

1.2. THE MAGNETIC FIELD

Certain precautions must be taken to ensure that hazards will not exist due to the effect of a magnetic field on magnetic materials or on surgical implants. Typical of such effects are the following:

Large attractive forces may be exerted on equipment brought near to the magnet. The force may become large enough to move the equipment uncontrollably towards the magnet. Small pieces of equipment may therefore become projectiles, large equipment (e.g. gas bottles, power supplies) could cause bodies or limbs to become trapped between the equipment and the magnet. **Either type of object may cause injury or death. The closer to the magnet, the larger the force. The larger the equipment mass, the larger the force.**

The operation of medical electronic implants, such as cardiac pacemakers, may be affected either by static or changing magnetic fields. Pacemakers do not all respond in the same way or at the same field level if exposed to fields above 5 gauss.

Other medical implants, such as aneurysm clips, surgical clips or prostheses, may contain ferromagnetic materials and therefore would be subject to strong forces near to the magnet. This could result in injury or death. Additionally, in the vicinity of rapidly changing fields (e.g. pulsed gradient fields), eddy currents may be induced in the implant resulting in heat generation.

The operation of equipment may be directly affected by the presence of large magnetic fields. Items such as watches, tape recorders and cameras may be magnetised and irreparably damaged if exposed to fields above 10 gauss. Information encoded magnetically on credit cards and magnetic tape including computer floppy discs, may be irreversably corrupted. Electrical transformers may become magnetically saturated in fields above 50 gauss. The safety characteristics of equipment may also be affected.

To prevent situations as described above from occurring, the following general precautions are provided as guidelines. These should be regarded as minimum requirements. Every magnet site location should be reviewed individually to determine precautions to be taken against the above hazards. **Also, since the field from the magnet is 3-dimensional, consideration must be given to floors above and below the magnet as well as the surrounding space on the same level.**

Before ramping the magnet to field
The following precautions must be taken.

Ensure all loose ferromagnetic objects are removed from within 2 meters of the OVC, or 3metres for high field magnets (>11 Tesla).

At all points of access to the magnet room display warning signs that the magnet is operating.

Display warning signs giving notice of the possible presence of magnet fields and of the potential hazards in all areas where the field may exceed 5 gauss.

Ensure all electronics and interfacing equipment supplied by Oxford Instruments are placed in areas where the field level is less than 10 gauss.

The safe working field level of other equipment must be individually assessed by the system manufacturer.

After ramping the magnet to field
Do not bring ferromagnetic objects into the magnet room.

Use only non-magnetic cylinders and dewars for storage/transfer of compressed gas or cryogenic liquids. Equipment for transportation of cylinder/dewars must be non-magnetic.

1.3. FIRE AND EXPLOSION HAZARDS

In the case of fire evacuate personnel from the area, sound the fire alarm.

Water must not be used on electrical equipment and when sprayed on cryogenic liquids will rapidly freeze. The magnet ventilation may become blocked by ice with subsequent risk of explosion and the release of cryogens from the system.

The surface temperature of containers for liquid nitrogen and helium, if not vacuum insulated, may be sufficiently low to condense oxygen or oxygen enriched air. This liquid in contact with flammable substances can become explosive.

Portable fire fighting equipment must be non-magnetic and should be installed by agreement with the local fire authority.
Local emergency services must be informed of the presence of a magnet operating in their area as this may affect their procedures in dealing with fires or other accidents.
In case of a large cryogen spillage avoid direct contact with the liquid; sound fire alarm and evacuate the area.
Oil mist filters should be fitted to pumps to reduce the emission of toxic oil vapours which pose both health and explosion hazards.

1.4. THE SAFE HANDLING OF CRYOGENIC SUBSTANCES

Cryogenic liquids can be handled easily and safely provided certain precautions are obeyed. The recommendations in this section are by no means exhaustive and when in doubt the user is advised to consult the supplier.

The safe handling of cryogenic liquids requires a knowledge of the properties of these liquids, common sense and sufficient understanding to predict the future behaviour of such liquids under certain physical conditions.

The substances referred to in these recommendations are nitrogen, air and helium.

1 GENERAL SAFETY RULES

Cryogenic liquids, even when kept in insulated storage vessels (dewars), remain at a constant temperature at their respective boiling points and will gradually evaporate. The very large increase in volume accompanying this vaporisation is approximately 700:1 for helium and nitrogen and therefore:

CONTAINERS OF CRYOGENIC LIQUIDS MUST **NOT** BE COMPLETELY CLOSED AS THIS WOULD RESULT IN A LARGE BUILD UP IN PRESSURE AND THUS PRESENT AN EXPLOSION HAZARD.

In the event of a large spillage operate the fire alarm and evacuate the area.

2 HEALTH HAZARDS

Asphyxia of varying severity will occur if the magnet room is not properly ventilated. (Helium can displace air from the top of a room and cold nitrogen can displace air from lower levels).

Burns. Cryogenic substances in liquid or vapour form or as low temperature gases produce effects on the skin similar to **burns** (cold burns).

Exposed or insufficiently protected parts of the body coming into contact with uninsulated venting pipes or vessels (see ventilation section) will stick fast and the **flesh will be torn** if removed.

3 FIRST AID

If any of the cryogenic liquids come into contact with eyes or skin, immediately flood the affected area with large quantities of cold or tepid water and then apply cold compresses. Never use hot water or dry heat. MEDICAL ADVICE SHOULD BE SOUGHT IMMEDIATELY.

4 PROTECTIVE CLOTHING

Protective clothing must be worn mainly to avoid cold burns and dry leather **or PVC gloves** must be worn when handling or working with cryogenic liquids.

Gloves must be loose fitting so that they can be removed easily in case of liquid spillage.

Eyes must be protected by **goggles.**

Do not wear any metallic objects (e.g. jewellery) on those parts of the body where they may come into contact with the liquid.

5 HANDLING

Cryogenic liquids must be handled and stored in well ventilated areas.

Do not allow cryogens to come into contact with the body.

Always handle the liquids carefully - boiling and splashing will always occur when filling a warm container or when inserting warm objects into the liquid.

When inserting open ended pipes into the liquid, block off the warm end until the cold end has cooled down (otherwise cold liquid may spurt out of the open end under self-generated pressure). Never direct pipe/piping towards any person.

Beware of liquid splashing and rapid flash-off of helium when lowering equipment at ambient temperature into liquid. This operation must be carried out very slowly.

Use only metal tubing connected by flexible metal hose for transferring liquid nitrogen. For the coupling DO NOT use rubber tube, silicon rubber tube (including hospital grade tube - this explodes!) or plastic tubing e.g garden hose and including reinforced tubes e.g. for air lines - this shatters unexpectedly and may cause injury to personnel. It should be noted that polythene and nylon lines are sometimes used however this should not be taken as an implied recommendation, all lines should be tested in safe circumstances or used only after the manufacturer's recommendation.

6 EQUIPMENT

Only use containers specifically designed for use with particular cryogens and constructed of non-magnetic materials.

7 LIQUID NITROGEN

Good ventilation is essential.

Store and use in a well ventilated place. If enough gas evaporates from the liquid in an unventilated place (e.g. overnight in a closed room) the oxygen concentration in the air may become dangerously low. Unconsciousness may result suddenly without previous warning symptoms and may be fatal. For example, the evaporation of 25 litres of liquid nitrogen produces 17,000 litres of nitrogen gas (600 cu.ft.). If this vaporization takes place in a room of $53m^3$ (2,000 cu.ft.), i.e. 3 x 6 x 3m high (10 x 20 x 10ft. high) it can produce a very dangerous situation if the room is not ventilated. Appropriate multiplication of these parameters will indicate actual site conditions.

Minimise contact with air

Since liquid nitrogen is colder than liquid oxygen, the oxygen of the air will condense into the nitrogen and if allowed to continue for some time, the oxygen concentration may become so high that the liquid may become as dangerous to handle as liquid oxygen. This applies particularly to wide-necked dewars. **Therefore ensure that contact with air is kept to a minimum.**

Do not smoke

Rooms in which cryogenic liquids are being handled should be designated no smoking areas. While nitrogen and helium do not support combustion, their extreme cold can cause oxygen from the air to condense on cold surfaces and may increase the oxygen concentration locally. There is a particular fire danger if the cold surfaces are covered with oil or grease which is itself combustible.

8 LIQUID HELIUM

Liquid helium is the coldest of all cryogenic liquids. It will therefore condense and solidify any other gas (air) coming into contact with it, with the consequent danger that pipes and vents may become blocked.

Liquid helium must be kept in specially designed, storage or transport dewars. Dewars should have a non-return valve fitted in the helium neck at all times in order to avoid air entering the neck and plugging it with ice. Vacuum insulated pipes should be used for liquid transfer; breakdown of the insulation may give rise to condensation of oxygen.

1.5. VENTILATION OF EXHAUST GASES

Gaseous nitrogen and helium exhausted from the cryostat will displace oxygen and if not properly ventilated, the possibility of asphyxiation exists.

Cryogenic substances in liquid, or vapour form, or as low temperature gases, produce effects on the skin similar to burns (cold burns).

Exposed or insufficiently protected parts of the body coming into contact with uninsulated venting pipes or vessels will stick fast and the flesh may be torn if removed.

Exhaust systems are required in order to vent to atmosphere any discharge from the system cryostat as described below.

The static helium evaporation exits from the turret via a non-return valve. The valve prevents ambient air leaking back into the cryostat. The outlet from this valve should be vented out of the room to atmosphere or, if required, to a helium recovery system. In the event of a quench the evaporated helium will be exhausted from the manifold via the pressure relief valve(s). The amount of gas is dependent on the type of system, but for a 500MHz NMR magnet quenching with 100% helium the volume of gas at room temperature will be approximately 50,000 litres. If the system is located in a small room then a system should be provided that is capable of exhausting this gas to atmosphere or to a recovery system.

The static nitrogen evaporation will exit from one (or two) of the nitrogen ports. This gas should be vented out of the room to atmosphere.

1.6. ENVIRONMENTAL SAFETY

It is the responsibility of the user to ensure that all equipment, services, data links or personnel passing through the affected space are adequately protected and that access to the area is controlled. Access doors leading into the affected areas must be capable of being secured against unauthorised entry and fitted with warning signs. It is also recommended that local barriers be erected around the magnet and be fitted with warning signs. Care must be taken to advise personnel who have access (in particular security or cleaning staff who often have their own keys) of all the risks associated with magnetic fields and systems operating with cryogens.

SECTION 2. DESCRIPTION OF THE SYSTEM

2.1. GENERAL DESCRIPTION

Spectromag and ODMR systems from Oxford Instruments are mounted in a vacuum insulated cryostat (one of the MD range - see page 14 for diagram of basic cryostat).

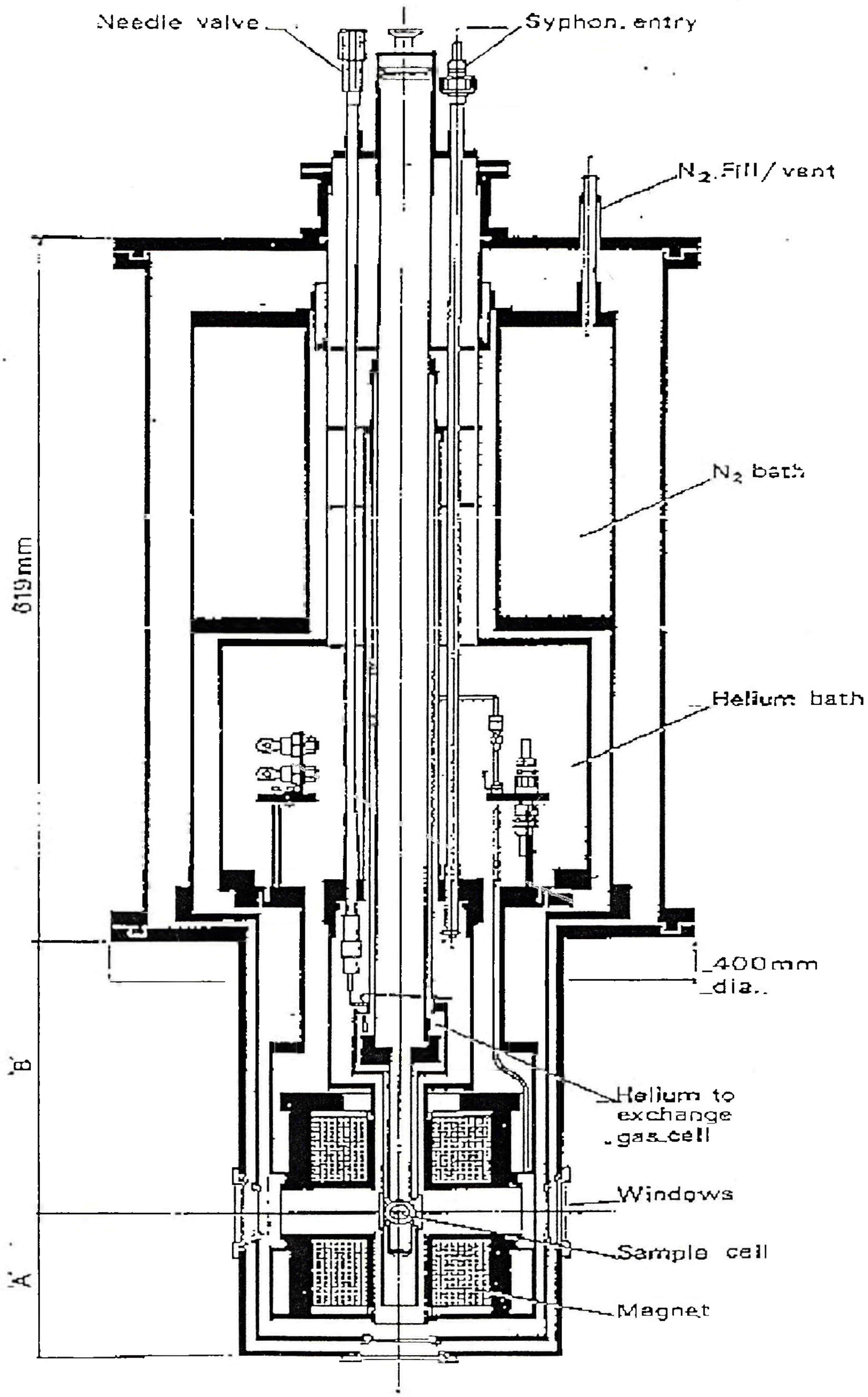
1. SM1 and SM2 systems are solenoids mounted in a tail-set allowing horizontal access. SM1 access is at either room temperature, or 80K with a room temperature window set, or at 5K with room temperature and 80K windows. At the lower temperatures extra radiation shielding is necessary reducing the sample space diameter. SM2 access is through windows to a (4.2K to 300K reduced bore) variable temperature insert.

2. SM3 and SM4 systems incorporate split pair magnets with vertical access through the split, giving a sample access of 23 x 13 mm, allow horizontal bore access, and for the SM4 horizontal and vertical split access, through windows. They both include a (1.5K to 300K) Variable Temperature Insert (VTI).

3. ODMR systems consist of higher homogeneity split pair magnets and allow sample access of a variety of sizes. It is similar to the SM4.

4. Special systems e.g. for gyrotron studies are made in a variety of forms, and may include such features as lambda point fridges, high field or homogeneity magnets and will generally be based on a spectromag type system.

A detailed description of the system components follows.



SM4 SPECTROMAG SCHEMATIC DIAGRAM

2.2. MAGNET TAILS DESCRIPTION

The magnet is mounted with its field horizontal, unless stated otherwise on the cover sheet, in a set of 'tails' which bolt onto the base of the main cryostat.

The magnet is an integral part of the helium tail, usually being welded into position. The inner vacuum chamber of the variable temperature insert (where this is part of the system) is indium sealed directly onto the magnet.

The magnet/tail/insert assembly is presented into the MD dewar from below, and is indium sealed into position. Addition of the outer tail shields then completes the system. A drawing showing the overall tail dimensions is shown on page 10 and the table below gives the dimensions not shown on the drawing.

The optical windows fitted as standard to systems are quartz with a useful optical range of approximately 90% from 0.2 to 2.5 µm. The windows are as large as possible within the system's mechanical constraints. The radiation shield windows may be replaced with re-entrant bore tubes if appropriate and all windows may be replaced by windows of alternative materials. See Section 2.4.1 on page 15

VTI systems only, (e.g. SM2, SM3, SM4 + special systems).

The insert assembly has common vacuum with the main cryostat. The inner sample space pot is varied in temperature by controlling the balance of heat leaks and cooling power around the sample. Below 4.2 Kelvin control of temperature is achieved by controlling the vapour pressure. Above 4.2 Kelvin a dynamic flow of expanding helium gives cooling power. Controlled electrical power input to a heater, which is mounted on the sample rod, gives stability at higher temperatures (with suitable control electronics the temperature range is 1.5 to 300 Kelvin. Above about 100 Kelvin the main bath boil-off may rise slightly.

Reference to drawing on page 10.

Dimension	5/6T	7T
A	97mm	130mm
B	207mm	250mm

2.3. CRYOSTAT DESCRIPTION

The cryostat is of a vacuum insulated, all metal contruction with intermediate temperature radiation shielding. The outside surfaces of the helium and nitrogen vessels are wrapped with single or multilayer superinsulation to reduce emissivity. The outer vacuum case (OVC) of the dewar will be fitted with an evacuation valve incorporating a pressure relief safety feature that will operate in the event of a cryogen leak to the vacuum space. In addition there is a drop-off plate at the base or side of the dewar.

The syphon entry port has an associated cone located within the cryostat. A tube runs from the cone to the bottom of the cryostat and ensures that all liquid nitrogen can be removed from the helium reservoir after pre-cooling the magnet and that filling with helium is from the bottom.

All cryomagnet service ports should be sealed with the plugs provided when not in use.

In all cases the boil-off of cryogens is minimised by taking great care in the design to prevent heat entering from the following main sources:

1). Gaseous conduction.
An evacuation / pressure relief valve allows the insulating vacuum space to be evacuated to less than 10^{-4} torr.

2). Metallic conduction.
Great care is always taken to use materials of low thermal conductivity combined with mechanical strength to support the cryogens in their vacuum. The supports (usually tubes) are of minimum cross sectional area and maximum effective length within overall size constraints. Neck tubes are thermally anchored with a copper thermal link to the top of the nitrogen vessel and good use is made of the enthalpy of the exhausting gas to minimise incoming conducted heat.

3). Radiation.
The radiation load is reduced to reasonable values by the introduction of intermediate temperature radiation shields. These are usually cooled by a reservoir of liquid nitrogen surrounding the helium bath. The enthalpy of the exhausting helium gas is sometimes used to cool a radiation shield inside the nitrogen shield. The emissivity of cold surfaces can also be reduced. This is achieved using many interleaved layers of aluminium and insulation known as superinsulation.

4). Ohmic heating.
The principal sources of ohmic heating are the current leads and the superconducting switch. In some systems the current leads are made demountable to minimise the cryogen boil-off with a persistant magnet, the remainder of systems feature carefully designed current leads which do not impose a significant heat load. A great deal of development work has been done recently on superconducting switches and all systems now feature low-loss switches.

2.4. MD SERIES CRYOSTAT DESCRIPTION

The MD series of bath cryostats for liquid helium has been developed around a series of standard modules. The cryostats are available with a full range of variable temperature inserts and superconducting magnets allowing a wide range of applications including optical, magnetic and electrical studies. Demountable 'tail' sets are supplied suitable for the particular system configuration.
The MD10 cryostat is supplied as standard with Spectromag systems.

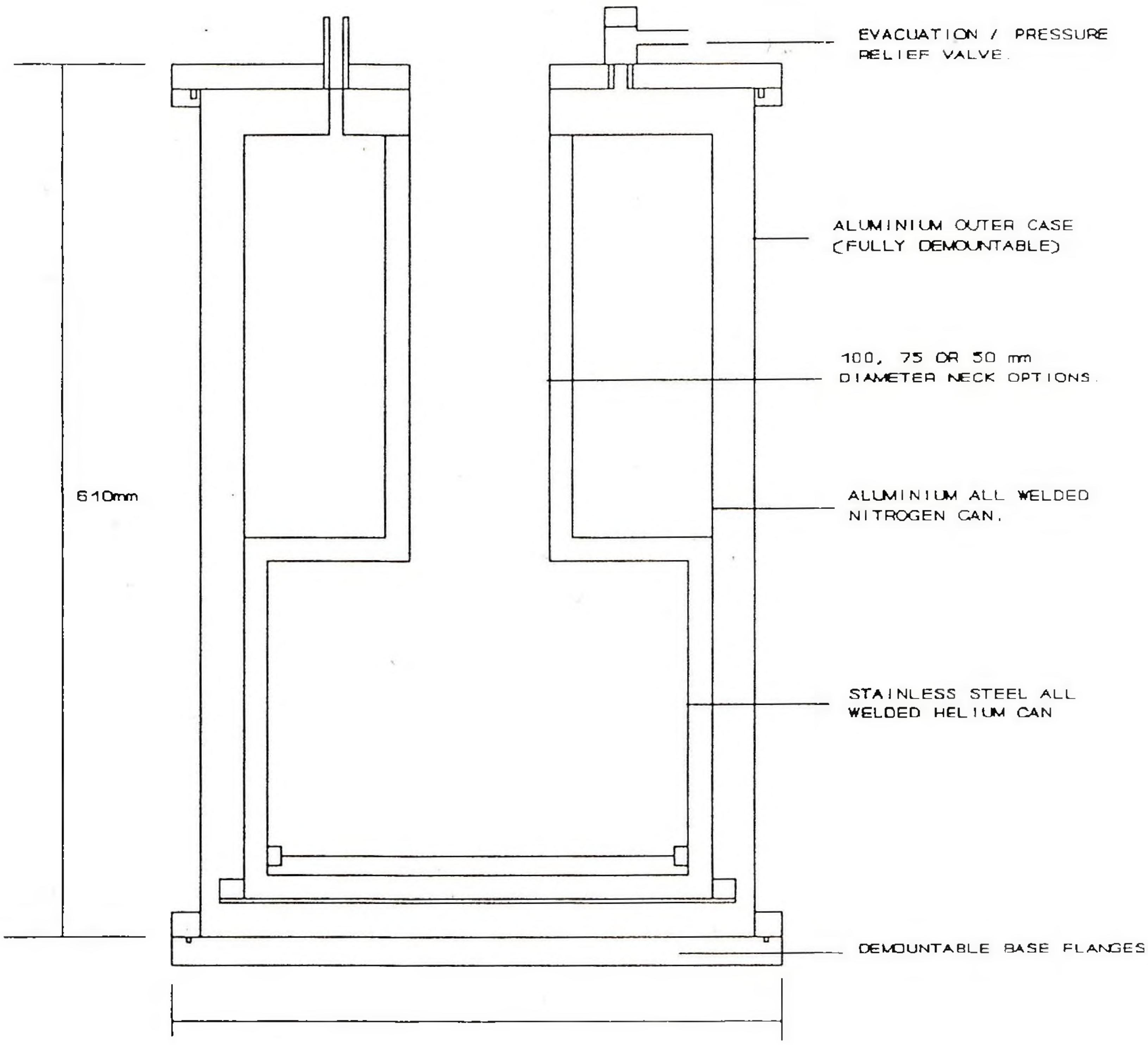
Specifications:

Cryostat	MD10	MD15	MD25
Outside diameter:			
Body (mm/ ")	356/14	418/16.5	540/21.25
Flanges (mm/ ")	400/15.75	462/18.18	587/23.125
Height (mm/ ")	610/24	610/24	890/35
OVC flange bolt details			
Equispaced	8xM6	8xM6	12xM8
P.C.D. (mm/ ")	387/15.125	498/19.625	572/22.5
Cryogen volumes (litres):			
LHe (useful)	8.5	13	23
LN2	11	17	45
Cryogen hold times for typical system (hours):			
LHe (useful)	30	50	90
(total incl. tails)	45 approx.	65 approx.	105 approx.
LN2	24	32	70
Typical System Weight Kg	75-100	150-200	250-300

Note: It must be emphasised that these figures are variable due to:

1). Variations in boil-off due to:
   - a). Radiation load increases due to windows on optical systems.
   - b). Additional services e.g. Lambda point fridge, VTI, special wiring etc. add to conducted heat load.
   - c). Operational considerations: obviously a static magnet at field will have a lower cryogen boil-off than the same system with a Lambda point fridge working, a VTI at 300K, and a magnet doing fast sweeps.
   - d). Manufacturing variations - generally small!

2). Variations in cryogen volume and system weight due to:
   - a). Different tail sizes.
   - b). Large magnets displace a great deal of helium - a large ODMR split pair may displace 10-15 litres!



SECTIONAL VIEW OF MD SERIES HELIUM BATH CRYOSTATS

For information on the various diameters, mounting bolts and P.C.D.s and approximate cryogen volumes/hold times etc. see data in the specifications section on page 13.

2.4.1. Window materials

NOTE: Not all systems are fitted with windows - windows are generally only fitted to some optical MD based systems with tails and some special optical systems.

Window material.	Transmission. (Percent)	Transmission range (micro-metres)
Spectrosil B	90	0.2 - 2.5
	80	>100 (turns on at 40)
Spectrosil WF	80	0.2 - 4
Sapphire	80	0.2 - 5.4
Calcium Fluoride (High thermal contraction requires special mounting procedures giving reduced sample space)	90	0.2 - 9
KRS 5 (High thermal contraction requires special mounting procedures giving reduced sample space)	60	0.6 - 36
Zinc Selenide	60	0.6 - 20
Polythene	80	209 - 1000
Clear mylar	>50	0.1 - 0.8
	>50	>100

2.5. RE-ENTRANT OPTICAL BORE TUBES

Re-entrant bore tubes are used to reduce the number of optical windows used on a spectromag. The aim being to reduce the reflection and transmission losses caused by light passing through multiple windows a particular problem when using laser beams, where any misalignment of the windows causes severe scattering problems.

The normal configuration of windows through the access of a spectromag for example, is:

> OVC (2 mm thick), Rad tail (2 mm thick), VTI rad shield (1 mm), sample cell (2 mm). This is then repeated passing out through the other side of the access.

A re-entrant tube through the access directly replaces both radiation shield windows, thus reducing the amount of window material passed through by nearly 43%. This has obvious advantages when using expensive window materials.

Construction

The re-entrant tube consists of a copper tube inserted through the access and held in place by six screws, hence it is easily demountable but in good thermal contact with the tail rad shield, the end nearest the sample cell is blanked off, apart from a clearance hole which coincides with the cell window, this ensures the maximum amount of radiation is absorbed.

Theoretical and Experimental Boil-Off

The static boil-offs on a SM4 standard spectromag with all its windows are:-

Main Bath	=	230 - 250 cc/hr
Cell	=	80 cc/hr

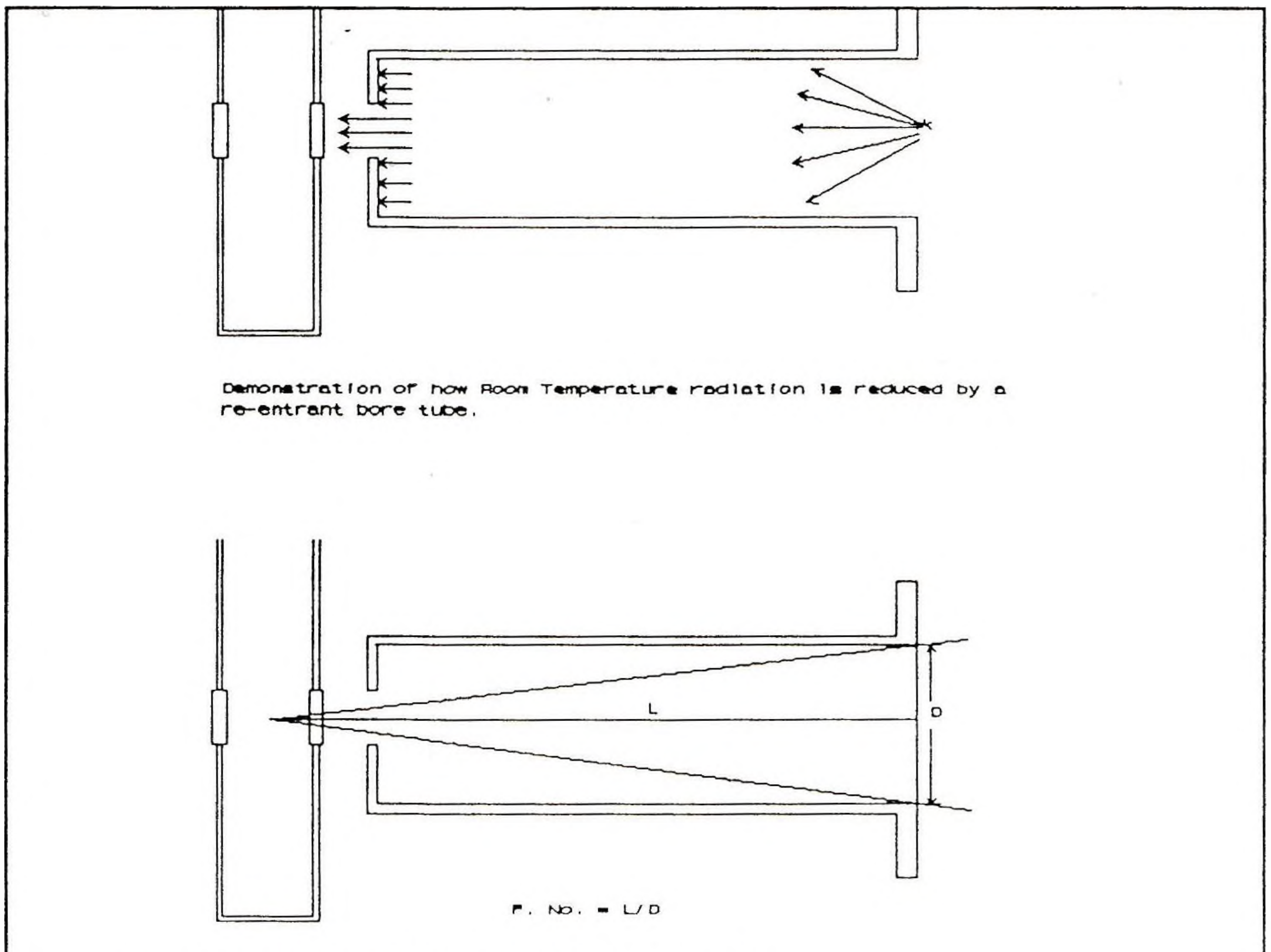
Since we no longer have any 77 K windows then it is reasonable to expect the cell boil-off to have increased. Fortunately the heat load is much less than one would immediately expect due to the solid angle correction factor. The radiation hitting the front of the tube is travelling in all directions, hence the longer the tube the more radiation that is absorbed by the tube, until in the limit only the radiation travelling directly through the tube passes through. (see figure on page 17). Hence, theoretically, re-entrant bore tubes will add approximately 24 cc/hr to the static boil off, which is easily acceptable.

Often there is only a negligible increase in boil-off this depends very much on the emissivity on the sample. If the customer had a black sample, for example, then most of this radiation would be absorbed and hence give the higher boil off calculated for re-entrant bore tubes over windows.

Disadvantages

The main disadvantage with using re-entrant bore tubes is the restriction in F number or optical access. This may not be a problem for experiments using a laser beam as the light source for example but could be a problem on scattering experiments where the angle available for light collection is critical. The best solution on some systems could be a re-entrant bore tube for the incident light source and windows for the scattered light on the exit accesses. The effect on F No. is shown below.

	Bore (Access parallel to field)	Split (Horizontal)	(Vertical
SM3	Yes	No	No
SM4	Yes	Yes	Yes
5&6 Tesla	2.8	4.0	4.0
7 Tesla	3.2	5.25	5.3
Bomem - 7 Tesla	2.95	4.2	4.3



RE-ENTRANT BORE TUBE F NUMBERS

2.6. SUPERCONDUCTING MAGNET

The magnet consists of a number of concentric solenoid sections together with compensating coils including shimming coils (when required to achieve the specified level of homogeneity). Each section is wound from multifilamentary superconducting wire formed from Niobium Titanium (NbTi) filaments surrounded by a stabilizing matrix of copper. High field magnets i.e. those with maximum fields of greater than 11 Tesla will be fitted with inner coil sections of Niobium Tin (Nb_3Sn). All sections are constructed to the MAGNABOND system, an integration of proprietry techniques, developed by Oxford Instruments, to give a structure which is both physically and cryogenically stable under the considerable Lorentz forces generated during operation. All the constituent sections of the magnet are connected to allow series energisation except when independently excited shims are fitted.

2.6.1. The Superconducting Switch

A superconducting switch consists of a length of superconducting wire non-inductively wound with an electrical heater. The superconducting switch, as supplied, has this length of superconductor wired in parallel with the entire magnet. The superconducting wire is made resistive by raising its temperature using the heater. The switch is then in its open state and current, due to a voltage across the magnet terminals, will flow in the superconducting magnet windings in preference to the resistive switch element. The switch is in its closed state when the heater is turned off and the switch element becomes superconductive again.

The process of establishing persistent mode operation of the magnet consists of energising the magnet to give the required field with the switch in the open state, closing the switch and then reducing the current flowing through the magnet current leads to zero, leaving the magnet in its previously energised state. The current flowing in the magnet windings remains constant as the magnet lead current is reduced, the current flowing in the closed switch then being the difference between the magnet and lead currents.

Magnets are occasionally constructed for fast sweep applications without a switch, the advantages of this being, firstly, the boil-off is reduced whilst sweeping as switch heater current is not required (although modern switches have a very low heater dissipation, typically 30cc/hr) and, secondly, all the power supply current is forced through the magnet and is not shunted by the switch (0.1 Amps is a typical maximum shunt current (10 volt sweep with 100 ohm switch). This leads to non-linearity between the power supply current and the field, which may be important for some applications. **If a switch is fitted it should not be removed** as the inductance of the magnet coupled with the power supply output capacitors can constitute a tuned circuit and 'ring' after a step voltage change without the damping effect of the switch. This may be of sufficient amplitude to activate the protection circuitry in the power supply causing the system to shut down. This is likely to be most evident when sweeping through zero at a high rate.

2.6.2. Magnet Quench Protection

Protection resistors, and diodes if appropriate, are provided for all magnet sections, restricting the development of potentially high voltages in the event of a magnet quench (rapid conversion from the superconducting to the normal resistive state). The resistors also dissipate some of the energy stored in the magnet during de-energisation, thereby reducing the energy dissipation within the magnet windings. The resistors are mounted on baffles attached to the magnet support structure or on plates above the magnet itself and hard wired or coupled to the magnet via an electrical connector. The connector will also incorporate the wiring for the superconducting switch heater, making it impossible to run the magnet without the protection circuit attached.

If barrier diodes are used in the protection circuit then, under limited voltage conditions, e.g. energisation, all the current passes through the magnet and ensures proportionality between energisation current and magnetic field they also reduce heat loads from the protection resistors and hence reduce system boil off. Under quench conditions, the barrier voltage is exceeded and the protection circuit shunts a proportion of the current away from the magnet windings.

2.6.3. Magnet Electrical Access

Single current terminals or coaxial pairs are provided on the cryostat for attachment of room temperature current leads. Internally the current leads take the form of brass tubes shunted at their lower end by superconducting wire and cooled by helium gas from the main reservoir of liquid helium.

Current terminal pairs are wired as follows:

Centre or red terminal = +ve = start of magnet
Outer or black terminal = -ve = end of magnet

IMPORTANT On no occasion should the current leads inside the cryostat be modified or any electrical connectors be unscrewed or removed. Serious damage to the magnet may result.

The magnet temperature and lambda point refrigerator performance (if fitted) are generally monitored with Allen-Bradley carbon resistors. An appropriate ten pin electrical seal is provided on the cryostat OVC, service neck or magnet support plate.

The superconducting switch heater will also be wired to a ten pin electrical seal.

2.6.4. Equivalent Circuit of a Superconducting Magnet.

A Superconducting magnet can be considered to be a pure inductor, however connections from the power supply to the magnet will of course be resistive and a small voltage will be dropped along the length of the leads and at the cryostat terminals. This voltage will be proportional to the current in the leads.

The switch will shunt a small amount of the magnet current whilst there is a voltage across the magnet i.e. when the field is changing. This current is minimised by running the magnet up slowly and using a high resistance (100Ω) switch, a worst case may be 10 Volt run-up through 100Ω i.e. 0.1 Amps. For experiments requiring an extremely linear field vs. current ratio, such as VSM measurements, a switch may not be fitted. The protection circuitry is generally fitted with special diodes and will not pass current until a certain voltage is exceeded. This is generally 4 Volts, however some special magnets and those designed for fast ramping may have a "protection voltage" of 10 Volts or more. Some small magnets and magnets designed for very infrequent running up and down may have no diodes (i.e. 0 Volt protection). In this case the protection circuit will dissipate power whenever a voltage is present across the magnet terminals.

To run the magnet up to field a voltage must be applied to the magnet leads to overcome the inductance of the coil. The magnitude of this voltage will govern the speed at which the magnet will run-up, this is defined by the equation:

$$V_{mag} = -L \frac{dI_{mag}}{dt}$$

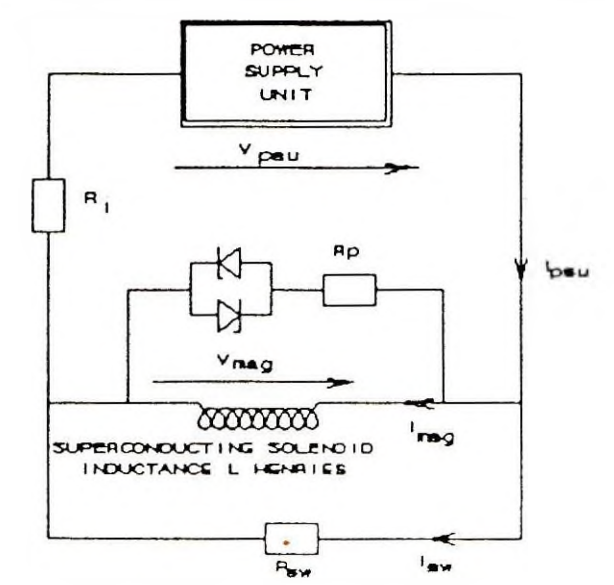
$$(V_{mag} = V_{psu} - I_{psu}.R_1)$$

L is the magnet inductance, given in the specifications.

For magnetic circuits with no iron (i.e. they are linear) the magnetic field at any point is proportional to the magnet current i.e.:

$$B = k\ I_{mag}$$

k is the magnetic field to current ratio given in the specifications section.



EQUIVALENT CIRCUIT OF A TYPICAL MAGNET

2.7. 1.5K TO 300K VARIABLE TEMPERATURE INSERT

This section is only applicable to systems supplied with a VTI e.g. Spectromags SM2, SM3, and SM4, ODMR systems, standard systems which include a VTI; usually based on SMD cryostats, and some special systems.

The Variable Temperature Insert (VTI) is either held by the magnet support (SMD based systems) and then hangs vertically down to the magnet bore, being an easily removable single item, or it can be indium sealed onto the top of the magnet, which is itself welded into the helium tails (spectromag based systems). This second type system has a common vacuum with the main cryostat. The sample is supported inside the insert where its temperature can be varied over the range 1.5K to 300K, using liquid helium coolant drawn from the helium reservoir in the dewar.

The liquid helium is drawn from the main reservoir through a needle valve. This valve is adjusted from the top of the cryostat and is used to control or stop the flow. From the valve, the helium is piped to the base of the sample space, from which it exits through an exhaust port at the top.

Temperature control of the sample in the range 4.2K - 300K is achieved by using a suitable temperature controller (e.g. the ITC-4) to balance the cooling power of the flowing helium by electrical heater power, using a feedback from a suitable temperature sensor. Both the heater and sensor are generally mounted on the sample rod (spectromags) or on the heat exchanger (SMD based systems). Spectromag temperature sensors are usually Rhodium Iron and need to be mounted as close as possible to the null field region of the magnet to keep any magnetoresistive effects as small as possible.

Temperatures in the range 1.5K to 4.2K are obtained by reducing the vapour pressure of static helium liquid, which is collected in the sample space. The volume has been designed to give extended hold times in this mode.

The needle valve has been designed to operate in the continuous or dynamic mode as well as static, it is vacuum insulated for optimum performance which allows it to sit at any equilibrium temperature and so act as a true Joule-Thomson valve. By 'cracking' the needle valve open and pumping on the sample space helium is drawn from the main bath. As it passes the needle, flash evaporation occurs producing cold superfluid helium hence temperatures in the range 1.5-4.2K may be obtained. The advantage of the dynamic mode over static is that experiments may be carried out at reduced temperatures for extensive periods. It has the disadvantage of a greater helium consumption (approximately twice as much) because one is constantly trying to cool new helium from 4.2K, also the base temperature will not be as low as in static mode although this depends a great deal on the speed of the pump and connecting lines.

Accurate pressure control and therefore temperature control may be achieved, if desired, by using a manostat, see Section 3.10 on page 46.

The variable temperature insert top plate carries all the electrical connections necessary for VTI operation, together with connectors available for connections to customer's experiments, and the needle valve actuator. On MD cryostat based systems the VTI top-plate will also be the magnet top plate so this plate also has the ports for cryogenic services and magnet connections.

A further advantage of the vacuum insulated needle valve is that if blockages occur the needle valve can be easily unblocked without having to warm up the entire system. This is achieved with a localised heater and temperature sensor mounted on the needle valve body. See wiring diagrams in section 5.5 on page 74 for appropriate pin positions and the 'Checks for Blockages' instructions in section 3.10 on page 45.

The sample rods fitted as standard to SM3 and SM4 type spectromags have the heater and control sensor attached to them. This is considered the best configuration because thermal contact with the sample is more direct. The sensor is a 27 ohm Rhodium Iron with a 40 ohm non-inductive resistance heater for controlled heat inputs.

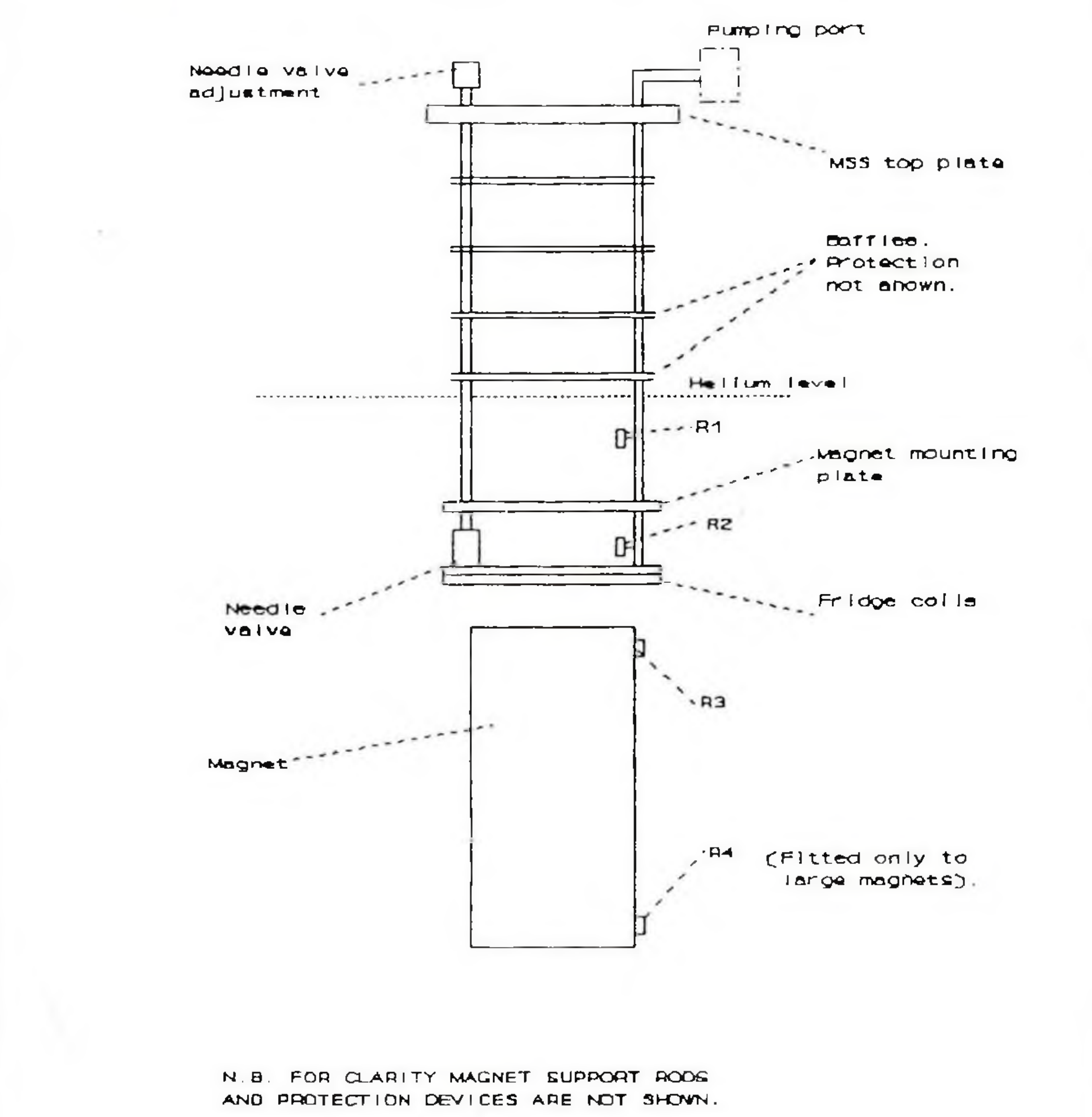
2.8. LAMBDA POINT REFRIGERATOR

This section is only relevant to systems fitted with a lambda point fridge (for running a magnet with a pumped (2.2 Kelvin) specification.

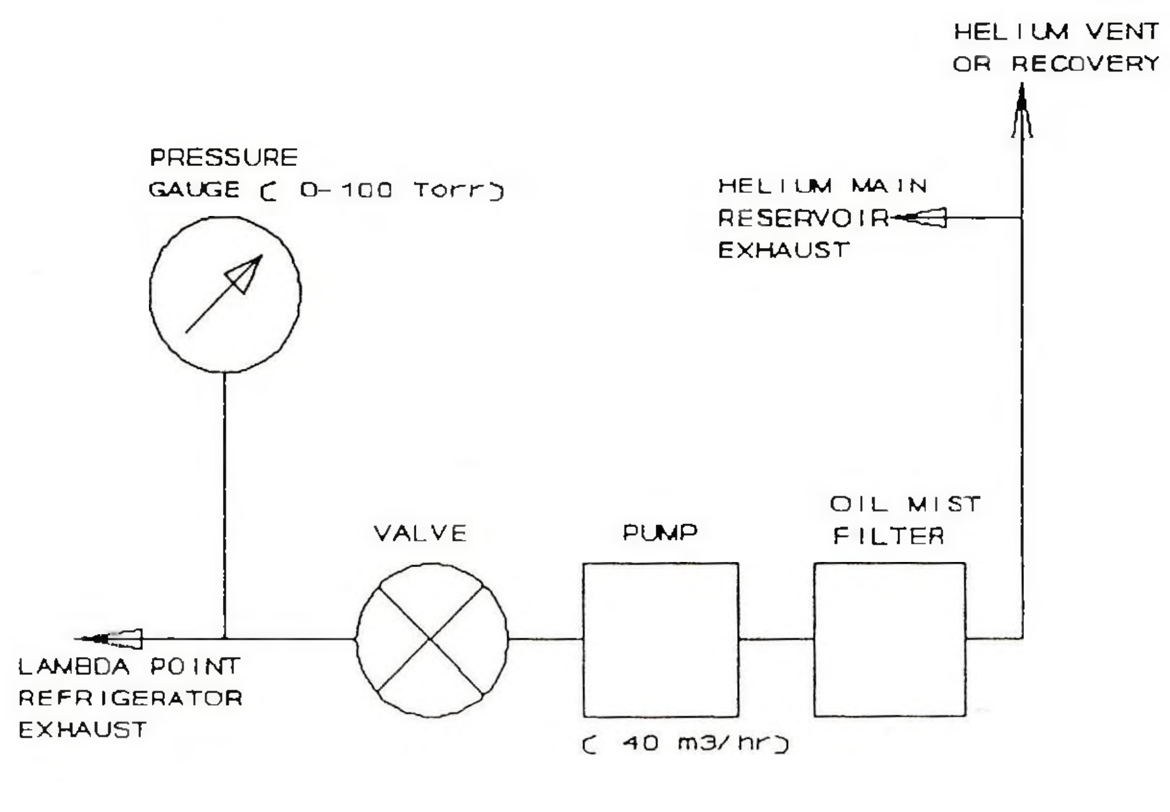
The Lambda point refrigerator, shown schematically on the enclosed diagram, allows the temperature of the lower portion of the helium reservoir to be reduced to 2.2 Kelvin, if fitted. The normal method of producing subcooled helium would be to pump on the helium exhaust line, thereby reducing the vapour pressure of the helium and therefore its temperature. This has the disadvantage that all access to the helium reservoir is prevented, and all access ports have to be vacuum tight rather than merely gas tight, in order to prevent ice formation and contamination of the helium recovery system. Consequently it is not possible to refill the cryostat whilst operating at reduced temperatures.

The Lambda point refrigerator cools the helium around the magnet to 2.2K by conduction and convection, without any reduction of pressure in the reservoir. It consists of a needle valve fed from the main helium bath, and connected via a cooling loop to an exhaust port that exits the cryostat through the main bath. By pumping against the needle valve a cooling effect is produced. The loop then cools the surrounding helium by conduction. The cooler and therefore denser helium sinks to the bottom of the cryostat and is replaced by liquid at 4.2K. The cooling continues until just before the Lambda point (2.17K) is reached, when a layer of helium at approximately 2.2K accumulates at the bottom of the cryostat. Further cooling simply causes the gradient between the 2.2K helium and 4.2K helium to move further up the helium bath.

In order to monitor the temperature of the helium, carbon sensors are provided, usually 10 cm above the lambda plate and above the magnet. Electrical access to these is achieved by a 10 pin connector on the magnet support top plate. Temperature is best measured using a digital multimeter to monitor the sensor resistance. Use the highest resistance range possible to minimise self-heating of the resistor.



SCHEMATIC OF A LAMBDA POINT REFRIGERATOR.



LAMBDA POINT REFRIGERATOR PUMPING CIRCUIT.

SECTION 3.- OPERATING THE SYSTEM

3.1. TYPICAL INSTALLATION REQUIREMENTS.

The requirements below include some items that may be purchased in Oxford Instruments standard spares kits.

PHYSICAL.

Suitable Hoist or Crane	Typically 250 kg minimum safe working load to allow lifting height of 3 metres.
Lifting sling and shackles	To suit eye bolts.
Trolley with wheels	Necessary if lifting equipment is not in laboratory. The system must be removable from the trolley for magnet running.
Wooden or non-magnetic platform	Strong enough to stand the system on. It should be 25 cm high and is needed if it is suspected that the floor has steel reinforcing.
Personnel protection	Hazard warning signs, barriers and controlled entry systems as applicable to the environment. See sections 1.2 and 1.6
Electricity supply	Single phase, several sockets needed (a three phase supply may be needed for large pumps and some power supplies). PS120-10 needs 3.5KVA - We suggest 220/240 Volt supply.

TOOLS AND ACCESSORIES.

Spanners	Open ended. Metric.
Allen Keys	Metric set.
Screw Drivers, pliers, sidecutters etc.	
Hot Air Gun	
Electrical Soldering Iron	75 and 25 Watts preferably.
Digital Multimeter	With low current Ohms range.
Roll of Mylar Adhesive Tape	
Roll of Aluminium Adhesive Tape	
Tube of Vacuum Grease	
Pair of Cotton Gloves	
Boxes of Tissues and lint free cloth	For polishing metal surfaces.
'Scotchbrite' etc.	For polishing stainless steel at Indium seal joint faces.
'Brasso' etc.	For polishing copper surfaces.
'Inhibisol' etc. degreaser	
Indium Wire (1 mm diam.x 2 metres)	Except on welded-in systems.
Rubber Bladders	2 needed.
Rubber and Plastic Tubing	0.375/0.5/0.625 ins (10/12.5/16 mm) bore diameters. 10 metres total required.

VACUUM DEVICES. (see section 4.1 for more information).

Single Stage Rotary Pump	60-80 m^3/hr typ. (40m^3/hr min.) capable of evacuating to less than 0.1 mbar. (For lambda fridge systems).
Single Stage Rotary Pump	18 cubic metres per hour capable of evacuating to less than 0.1 mbar. (For Variable Temperature Insert systems).
Oil mist filters	Fitted to all pump exhausts to eliminate possible carcinogenic vapours.
High Vacuum Pump with Penning gauge	Capable of evacuating to less than 10^{-6} mbar. (Can be diffusion pump fitted with Nitrogen cold trap, or turbomolecular pump). Pumping port should be 50mm diameter minimum.
Leak Detector	For checking indium joints.
Pressure Gauges	0 to 1000 mbar logarithmic scale or 0 to 100 mbar and 0 to 1000 mbar linear scale. Gauges to be connectable to NW25 flanges.
Gas Flow Gauges	0 - 2.5 litres/min Helium gas. 0 - 25 litres/min Helium gas.

CRYOGENIC VESSELS AND FITTINGS.

Liquid Nitrogen	In self pressurising dewar. (100 litres typically)
Liquid Helium	In self pressurising dewar. (100 litres typically)
Helium gas	For flushing system. Can use gas for storage dewar or from a gas cylinder.
Helium Transfer Tube	OI standard diameter is 0.375 ins (9.6 mm).
Laboratory Clamps	To suit rubber tube.

Vacuum Fittings :-

NW10 Clamp
NW10 "O" Ring Carrier
NW10 Christmas tree fitting
NW25 Valves
NW25 Clamps
NW25 "O" Ring Carriers
NW25 Tees
NW25 Elbow
NW25 Christmas tree fitting
NW25/10 Adaptor
NW40 Clamp
NW40 "O" Ring Carrier
NW40/25 Adaptor
Pumping Lines NW25 each end, 2.5 metres long, 20 mm or preferably 25mm bore.

PS120-10HS PSU: This requires cooling water with temperature stability $\pm$0.5°C, flow of 2l/min at 0.3 bar and will dissipate 150 Watts.

3.2. EVACUATING THE CRYOSTAT OVC

In order to maintain the thermal isolation of the liquid helium it is necessary that a high vacuum be maintained within the cryostat outer vacuum case (O.V.C.).

IMPORTANT In many cases the thin wall contruction of the helium reservoir will not support an external pressure differential of one atmosphere. The helium reservoir must therefore never be evacuated unless the OVC is first evacuated.

The recommended pumping equipment consists of an oil diffusion pump of 50mm (2 inch) diameter or, even better, a turbomolecular pump fitted with a liquid nitrogen cold trap. This pump should be backed by a rotary pump of not less than 12-15 m^3/hr pumping speed, fitted with a gas ballast facility. All connecting lines should have an internal diameter of not less than 25mm (1 inch) and be as short as possible. Tubes must NOT have been used previously to carry or pump helium.

a) Connect the valve on the cryostat top flange to the pumping equipment. Using the rotary pump, evacuate the cryostat slowly (approx half hour) to prevent any possible collapse of internal shielding, until the pressure is less than 0.05 mbar.

b) Switch over to the diffusion pump and evacuate the cryostat to less than 5×10^{-4} mbar. Continue pumping at least overnight to ensure the removal of residual gases trapped in the superinsulation.

Inspecting the vacuum:-

If the cryostat is already evacuated and it is desired to inspect the pressure only, the pumping tube should be evacuated and the diffusion pump operating before the O.V.C. valve is opened. If the pressure is greater than 10^{-3} mbar with the system warm, the cryostat should be evacuated overnight with the diffusion pump to less than 5×10^{-4} mbar. It is recommended that the cryostat is always pumped overnight before use.

Flushing the vacuum space:-

If the vacuum space has been accidentally contaminated with helium gas or moisture evacuation can be improved by flushing the space. **NOTE: Never vent cryostats with helium gas as this will 'stick' in the superinsulation.**

i) Using rotary pump, evacuate cryostat to less than 1 mbar.

ii) Admit an atmosphere of DRY nitrogen gas, preferably through a 1mm orifice, and pump out to less than 1 mbar.

iii) Repeat (ii) several times, then pump to less than 0.05mbar.

iv) Switch over to the diffusion pump as in (b) above.

Mylar windows

Mylar film, if used as a window material, is slightly porous to helium gas above 80K.

Keep helium gas away from mylar windows in vacuum case. Seal windows will show a leak if tested with a helium leak detector.

For cryostats with mylar on the sample space, the vacuum space should be continuously pumped.

Ice Blocks

If a VTI is fitted to the system it is wise to fill it with helium gas. This ensures that the VTI does not get blocked by ice as the system is cooled. This can also be done on the lambda point fridge and any other 'Dead' spaces in the system.

3.3. TRANSFER TUBE AND STORAGE DEWAR ADAPTER FOR LIQUID HELIUM

The transfer tube optionally provided with the system is of a stainless steel construction. It takes the form of a tube surrounded by a second tube with a vacuum of better than 10^{-4} mbar maintained between them. The assembly of the two tubes usually takes the form of a large 'n' shape.

For detailed instructions on initial filling and topping-up the reader is referred to sections 3.6 and 3.7 (on pages 34 and 35) respectively.

Occasional repumping of the tube will be necessary in service, particularly during the first few months while the materials in the tube are still outgassing.

3.3.1. The ST9 Syphon Evacuation Fitting

To evacuate an Oxford Instruments standard syphon, an ST9 fitting is needed to operate the vacuum valve.

1 Remove the nylon dust cap from the transfer tube valve. Connect the ST9 fitting to the pumping system described in Section 3.1 (page 28).

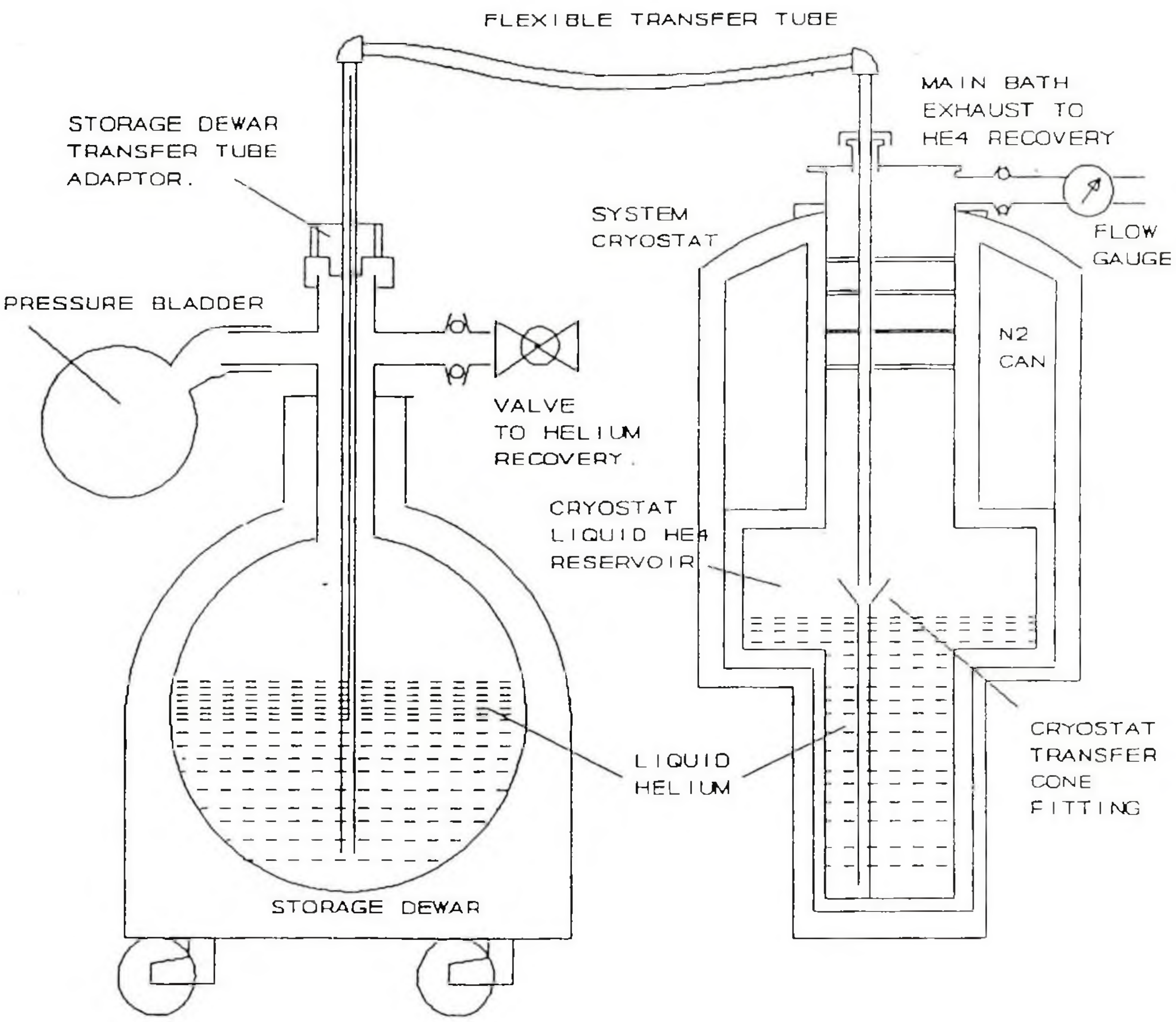
2 Place the ST9 fitting over the transfer tube valve. Evacuate the pumping lines and check the system for leaks.

3 Using the screwdriver in the fitting, open the transfer tube valve. Pump out the syphon to 10^{-4} mbar or better.

4 Close the transfer tube valve using the screwdriver fitting, shut the pump and remove the ST9.

5 Replace the dust cap.

Note: **The cryostat overpressure relief valve should be in position and not restricted. The flow meter, if used, should be capable of high flow rates and should not introduce a flow restriction.**



SCHEMATIC OF LIQUID HELIUM TRANSFER.

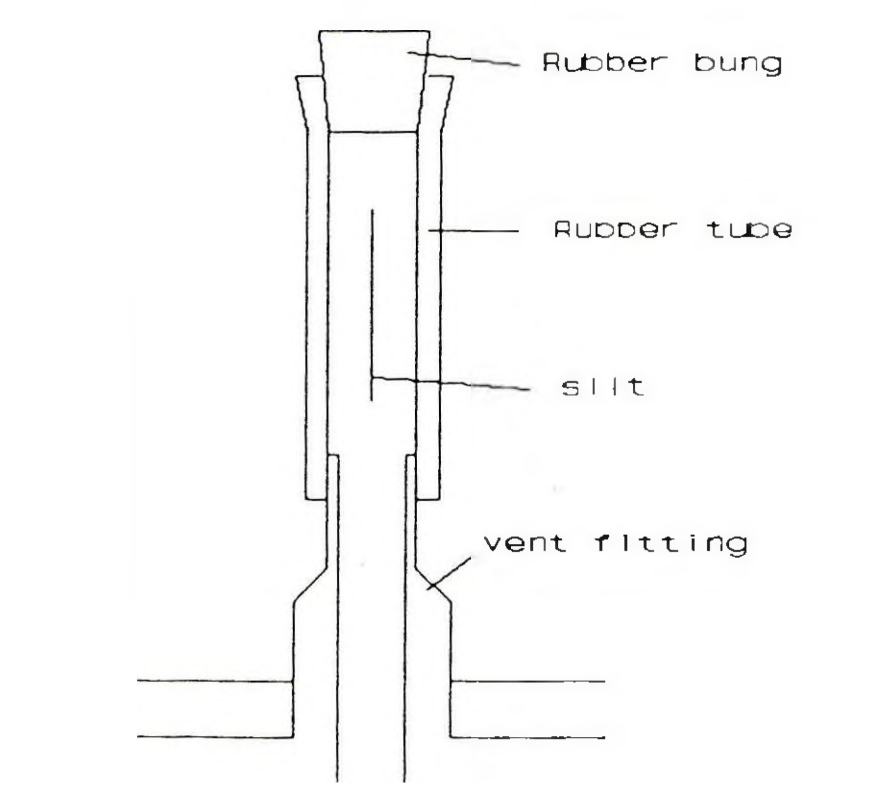
3.4. FILLING THE LIQUID NITROGEN CONTAINER.

This section is not relevant to vapour shielded dewars.

Connect one of the three filler/vent tubes of the liquid nitrogen container to a storage vessel using flexible polythene pipe. Transfer the liquid nitrogen by pressurising the storage vessel to approximately 0.25 atm. above atmospheric pressure. Violent boiling will occur initially until the radiation shield has cooled down. When liquid nitrogen sprays out of the filler tubes release the pressure on the storage vessel to stop the transfer.

The storage vessel can be pressurised using a valve on the outlet. By using an electronically controlled valve, the liquid nitrogen container can be filled and the level maintained using a Liquid Nitrogen Level Controller. **Inspect the liquid nitrogen at intervals appropriate to the overall system hold time.**

All Oxford Instruments cryostats are fitted with overpressure relief valves which are not customer removable. **Information only:** For magnets going into systems without this protection at least one of the liquid nitrogen fill/vent tubes must be connected to a oneway valve (e.g. a Bunsen valve), as a precuation against ice blockage. The problems caused by ice formation in the filling tubes can be reduced by slipping 0.25m (10 in.) lengths of plastic tubing over them. These tubes also prevent any overflow of liquid nitrogen from cooling the top flange and its 'O' ring. This can be important if an autofilling system fails to stop the nitrogen transfer when the tank is full.



BUNSEN VALVE

3.5. PRECOOLING THE MAGNET

IMPORTANT: **FOR Nb_3Sn (High field; ≥12 Tesla) MAGNETS ONLY:** Control the flow of LN_2 to the helium tank, to slowly precool and thereby protect the magnet, by connecting a restriction to the cryostat exhaust line (e.g. the one way valve provided or 12 inches (300mm) of 1/4 inch (6mm) bore tube) and transferring the LN_2 at an overpressure of approximately 260 torr.

Before filling the cryostat with liquid helium, the magnet must be cooled to a temperature below 100K. To do this, fill the liquid helium container with liquid nitrogen, completely above the magnet. Use a length of 10 mm (3/8 in.) diameter stainless steel tubing inserted into the transfer tube entry port. Allow the liquid nitrogen to remain for one or two hours and then fill it completely again.

The liquid nitrogen should then be removed. Insert the 10mm stainless steel tube into the transfer entry fitting and ensure that it is firmly fitted into the cone on the top of the magnet. Blow out all the liquid nitrogen by pressurising the liquid helium container with helium gas to not more than 0.25 atmospheres overpressure, the blown out nitrogen may then be fed into the nitrogen can.

Monitor the background in the OVC with a leak detector connected to the OVC pumping line to check for low temperature leaks from the main bath to the OVC.

It is important that all the liquid nitrogen is removed. Failure to do this properly will make filling with the liquid helium difficult, and may impair the performance of the magnet. When all the nitrogen has been removed, release the pressure in the liquid helium bath and evacuate the liquid helium container using a rotary pump, (if during pump down a pause is seen in the range 70-100 mbar then liquid nitrogen is still present) and then fill it with helium gas. Repeat this procedure at least two times in order to thoroughly purge the magnet of nitrogen. As an indication that all the liquid nitrogen has been removed, check that it is possible to evacuate the liquid helium container to a pressure less than 10 mbar.

At this point, ensure that any needle valves operate freely and if possible, ensure that gas can be pumped through the needle valve pickup tubes. Fill the helium reservoir with 1 atmosphere pressure of helium gas.

3.6. INITIAL FILLING WITH LIQUID HELIUM

Note: **See also the instructions for the storage dewar.**

1). Check that the transfer tube has the correct leg lengths and diameters to be compatible with the cryostat and storage dewar. Connect the cryostat and storage dewar to the helium recovery system or put a oneway valve on the cryostat exhaust port. Position the liquid helium storage vessel so that the transfer tube can be inserted easily and is close to the cryostat to be filled.

2). Remove the plug from the cryostat transfer tube entry port and also from the top of the storage vessel. Insert the transfer tube legs into the cryostat and, slowly, into the storage dewar, allowing it to cool gradually. Ensure that the end of the transfer tube in the cryostat is fitted into the cone on top of the magnet. In this way, cold gas and then liquid is introduced at the bottom of the magnet which is then cooled by the enthalpy of the gas as well as by the latent heat of evaporation.

3). Start transferring the liquid helium by pressurising the storage vessel. (This is generally done by gently squeezing a rubber bladder). The transfer rate should be such that the vent pipe is frozen for not more than 2 m (6 ft.) of its length. The initial transfer rate should be equivalent to about 10 litres of liquid per hour. This rate can be increased as the magnet cools and the boil-off reduces. Typically the cool-down from 77K to 4.2K will take between 10 and 60 litres depending on the system size and the care taken in the transfer.

By monitoring the Allen-Bradley sensors, when the magnet temperature falls below 10 Kelvin, the transfer rate can be further increased in order to fill the liquid helium container. This should occur when a further 10 to 50 litres of liquid have been transferred, depending on the size of magnet and dewar.

4). When the liquid helium reservoir has been filled, stop the transfer by releasing the pressure in the storage vessel. Remove the transfer tube and replace the plug. **Inspect the liquid helium level at appropriate intervals.**

3.6.1. Typical Volumes of Liquid Helium required for Cooldown.

The volumes of Liquid Helium given below should be regarded as a guide only, they are critically dependent upon transfer rate and include filling to approximately 50%, (it is not so efficient on Helium if a cryostat is filled from warm to the 100% level).

SMD8 Cryostat and 5T magnet	35 litres
7T Spectromag (MD10 Cryostat)	25 litres
SMD10 Cryostat and 12T magnet	50-60 litres
VSM or NMR Cryostat and 8T magnet	60 litres

3.7. REFILLING WITH LIQUID HELIUM

The cryostat should be refilled before the level reaches the 10% mark (if a helium level meter is in use). In refilling, care should be taken not to evaporate the liquid in the cryostat with the hot gas which initially comes through the transfer tube. (N.B. Failure to take care can cause the magnet to quench).

The correct procedure is as follows:

1) Insert one leg of the transfer tube into the storage vessel, but leave the other one outside of the cryostat. The cryostat syphon entry fittings (the O-ring and the knurled ring) should be undone and slid onto the transfer leg to go into the cryostat, reseal the cryostat entry with the bung provided. Pressurise the transport dewar in the normal way, as if transferring helium. After about a minute liquid will issue from the transfer tube, indicated by a blue tongue of vapour. (Prior to this a white vapour plume will have been seen for about 20 seconds).

2) Quickly release the pressure in the transport dewar and insert the open end of the transfer tube into the cryostat.

3) Lower the transfer tube until it reaches the bottom of the necktube. DO NOT push the tube into the cone on top of the magnet. Transfer liquid helium in the usual way.

If the helium level has fallen below 5% and the magnet is still energised there are two courses of action open:

(i) If the level is below 0% or if the user is not certain that a careful transfer can be done DE-ENERGISE THE MAGNET, refill and then re-energise the magnet.

(ii) Refill the dewar, but be careful as the syphon is introduced and as the transfer starts.

The cryogen boil-off test results are given in the specifications (section 6.3).

3.8. OPERATING THE MAGNET

A magnet power supply is needed to energise the magnet. Typically an Oxfod Instruments PS120-10 power supply would be used, however any power supply with the necessary current rating to achieve the full field of the magnet, and a voltage suitable to allow field sweeping at the desired rates may be used. The following instructions are general. Read the relevant PSU handbook for specific information. The magnet field strength is determined by the current available (the Tesla/Amp ratio is given in the specifications), while the voltage determines the rate of change of field (the inductance is also given in the specifications).

The magnet can be operated manually or under control of a computer. Three modes of magnet energisation exist namely:

Constant voltage. This allows the solenoid to be swept to a set current or zero at a rate dictated by a constant voltage at the power supply terminals, the voltage drop in the current leads and the inductance of the solenoid. This will not give a constant rate of energisation with increment of time and is therefore not of any interest for VSM experiments.

Current control mode with voltage limit. This allows the solenoid to be swept to a set current or zero at a constant rate of change of current, which with resistor diode protection allows a constant rate of energisation. If the rate of energisation demands more voltage at the power supply than is set on it, then the power supply will limit at that voltage but will continue to sweep to the set current.

Current control mode with voltage trip. This is a similar mode as voltage limited constant sweep rate but in the event of the voltage limit being reached, the power supply will trip and the solenoid will de-energise at the rate allowed by the negative voltage limit set at the power supply.

IMPORTANT Before initial use, and if the system has not been used for sometime the following measurements should be made, and compared with the quoted values.

1. Magnet continuity.
2. Magnet to cryostat isolation.
3. Magnet to switch heater isolation.
4. Switch heater resistance.
5. Switch heater to cryostat isolation .

Suggested sweep rates are described in the specification section of this manual. (See Section 6.3).

3.8.1. Constant voltage mode

1. Connect the magnet leads and persistent mode switch heater leads. Check for electrical isolation from the cryostat.

2. Switch on the magnet power supply.

3. With the switch heater off, sweep the power supply to the current required. The sweep rate used is not critical. When the required current is reached measure the voltage at the power supply output terminals. This is the resistive voltage drop in the magnet leads and should be noted.

4. Sweep the power supply back to zero amps. This will sweep the leads down to zero amps.

5. Turn the persistent mode switch heater on, wait 30 seconds for the switch to open.

6. Turn the positive voltage setting to a value that is the resistive voltage drop plus the required magnet charging voltage. Allow the power supply to sweep the magnet to field.

7. Turn the switch heater off and wait 30 seconds.

8. Turn the negative voltage setting on the power supply to 0.5V and allow the power supply to sweep down. This will cause the leads to run down, leaving the magnet in persistent mode.

To take the magnet out of persistent mode:

1. With the switch heater OFF sweep the leads to the previously set current.

2. Turn the switch heater ON, wait 30 seconds.

3. Sweep the power supply back to zero amps. The sweep rate is not critical. The magnet will then sweep down to zero current. Turn the switch heater off to conserve helium.

3.8.2. Current control mode with voltage limit or trip

1. Connect the magnet leads and persistent mode switch heater leads. Check for electrical isolation from the cryostat.

2. Switch on the magnet power supply.

3. Set the power supply to constant current mode, with voltage limiting or trip.

4. Set the output voltage limits to the required level on the power supply.

5. Set the current for the required field on the power supply and the current sweep rate. (N.B. this may change several times during a sweep, the actual sweep rates are defined in the specifications section).

6. Turn the switch heater ON wait 30 seconds. Start the sweep to field by allowing the current output of the power supply to start sweeping on the power supply.

7. When the magnet has reached field and the voltage at the power supply has died away to the voltage drop in the current leads, turn the switch heater OFF. Wait 30 seconds, then sweep the current from the power supply back down. The sweep rate is not critical. This will cause the leads to run down leaving the magnet in persistent mode.

If the ramp rate is too high the voltage across the magnet will exceed the set positive voltage. This will either cause the power supply to continue energisation but at a rate dictated by the set voltage, or trip and allow the magnet current to decay at a rate dictated by the negative set voltage. The mode in which the power supply is set will dictate which of these two cases will apply.

To take the magnet out of persistent mode:

1) With the switch heater OFF, run the leads to the set current.
2) Turn the switch heater ON and wait 30 seconds.
3) Re-set the current sweep rate required for de-energisation and allow the power supply current to sweep down. The magnet will sweep to zero amps at the prescribed rate providing it is less than that allowed by the negative voltage setting.

IMPORTANT: If the magnet has been left in persistent mode and the power supply disconnected, briefly short circuit the output current terminals of the power supply before re-connecting.

Extreme care must be taken to ensure that the current leads are re-connected with the correct polarity. If any doubt exists as to the correct polarity, it is preferable to use the emergency de-energisation procedure, rather than attempt to de-energise the magnet in the conventional manner.

3.8.3. Running the magnet with a PS120-10 Power supply.

The following instructions assume that an OXFORD INSTRUMENTS PS120-10 magnet power supply is being used.
The instructions that follow are sufficient to cover the basics of running a magnet. For more detailed instructions and description, consult the power supply instruction manual.

The PS120-10 allows operation of the magnet either manually or under control of a computer (using the RS232 link, of IEEE interface if the optional converter is fitted).

IMPORTANT: Before initial use, and if the system has not been used for some time the following measurements should be made, and compared with the quoted values.

1) Magnet resistance
2) Magnet to cryostat isolation
3) Switch heater resistance
4) Switch heater to cryostat isolation
5) Magnet to switch heater isolation

1. Before connecting the PS120-10 to the electricity supply, connect the magnet current leads and the persistent mode switch heater lead to the terminals inside the rear cover of the power supply.

2. Connect the leads to the cryostat magnet terminals and the appropriate ten pin seal. Check for electrical isolation from the cryostat. Switch on the magnet power supply.

3. The power supply will initialise by displaying 'PASS', then 0.00.

4. Select the mode of display required, this can be in Amps or Tesla by pressing the button labelled CURRENT/FIELD (the ratio of these is set in the software for a given magnet).

   Set the current or magnetic field to which the magnet is to be energised by pressing the RAISE and LOWER buttons on the ADJUST panel while depressing the SET POINT button on the DISPLAY panel. Set the rate of change in a similar way by pressing RAISE and LOWER while depressing the SET RATE button. Please consult the running rates in Section 6.3 of this manual for advised energisation limits. The SET RATE can be changed while the magnet is being energised so the SET POINT can be the value desired ultimately.

5. If the magnet is equipped with a persistent mode switch, press the HEATER ON button on the SWITCH HEATER panel. The button should be held down for about five seconds until the indicator light remains on when the button is released.

6. The magnet energisation can now be started by pressing the SET POINT button on the SWEEP CONTROL panel. The current or field will be seen to increase on the digital display and the output voltage will have been seen to kick over to the voltage needed to overcome the magnet impedance on the analogue meter.

7. When the set point has been reached, the switch heater can be turned off by pressing the HEATER ON button again. After waiting about ten seconds for the switch to become superconducting, press the ZERO button on the SWEEP CONTROL panel. The current in the magnet leads will decrease to zero leaving the magnet, still energised, in persistent mode. The rate at which the leads alone can be swept is faster than the magnet and leads, this is automatically taken into account in the power supply software.

8. The magnet can be taken out of persistent mode by using the following procedure:-

   Pressing the SET POINT button on the SWEEP CONTROL panel (the switch heater is left 'off'). The current leads will be swept at a fast rate to the Set Point value. Turn the switch heater current 'on' by pressing the HEATER ON button for five seconds until the indicator light remains on when the button is released.

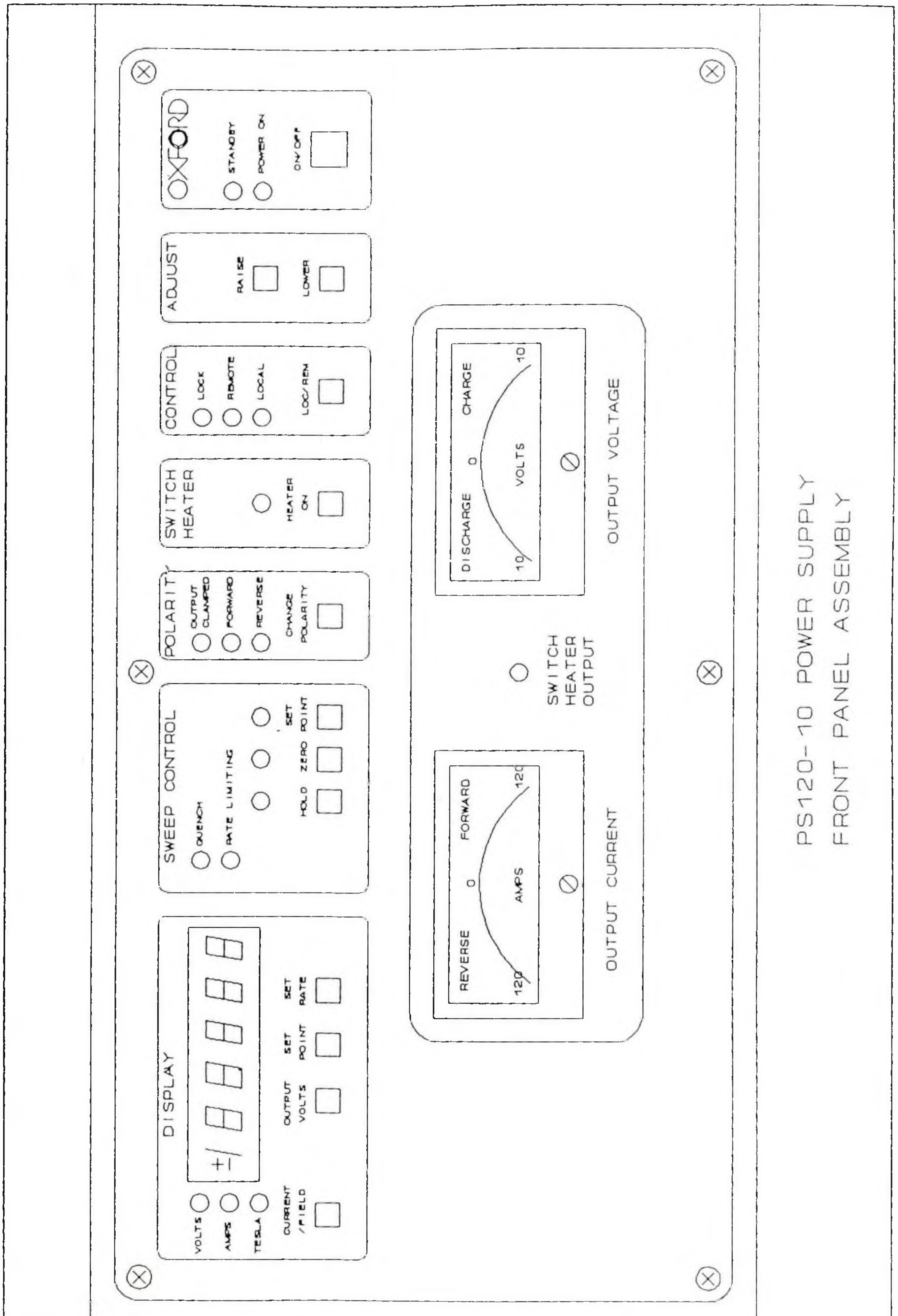
   Press the ZERO button on the SWEEP CONTROL panel and the magnet will start to de-energise. The Set Rate can be increased during the sweep without stopping.

If it is desired to change the value of magnetic field, sweep the current leads to the present current or field of the magnet, open the switch by turning on the heater. Press the SET POINT button and RAISE and LOWER to change the Set Point to the new desired value. Make changes to the Set Rate of sweep in a similar manner. Press the SET POINT button on the SWEEP CONTROL panel and the magnet will either energise or de-energise to the new field.

If the voltage needed to drive the magnet at a given rate is such that the maximum voltage of the power supply will be exceeded, the power supply will deliver its full voltage and the RATE LIMITING light will illuminate, on the SWEEP CONTROL panel. The sweep will continue, but at a slower rate than intended.

In the event of a magnet quench, the power supply will trip to zero amps and the QUENCH light will illuminate.

A diagram of the front panel layout is shown in the diagram on page 41.

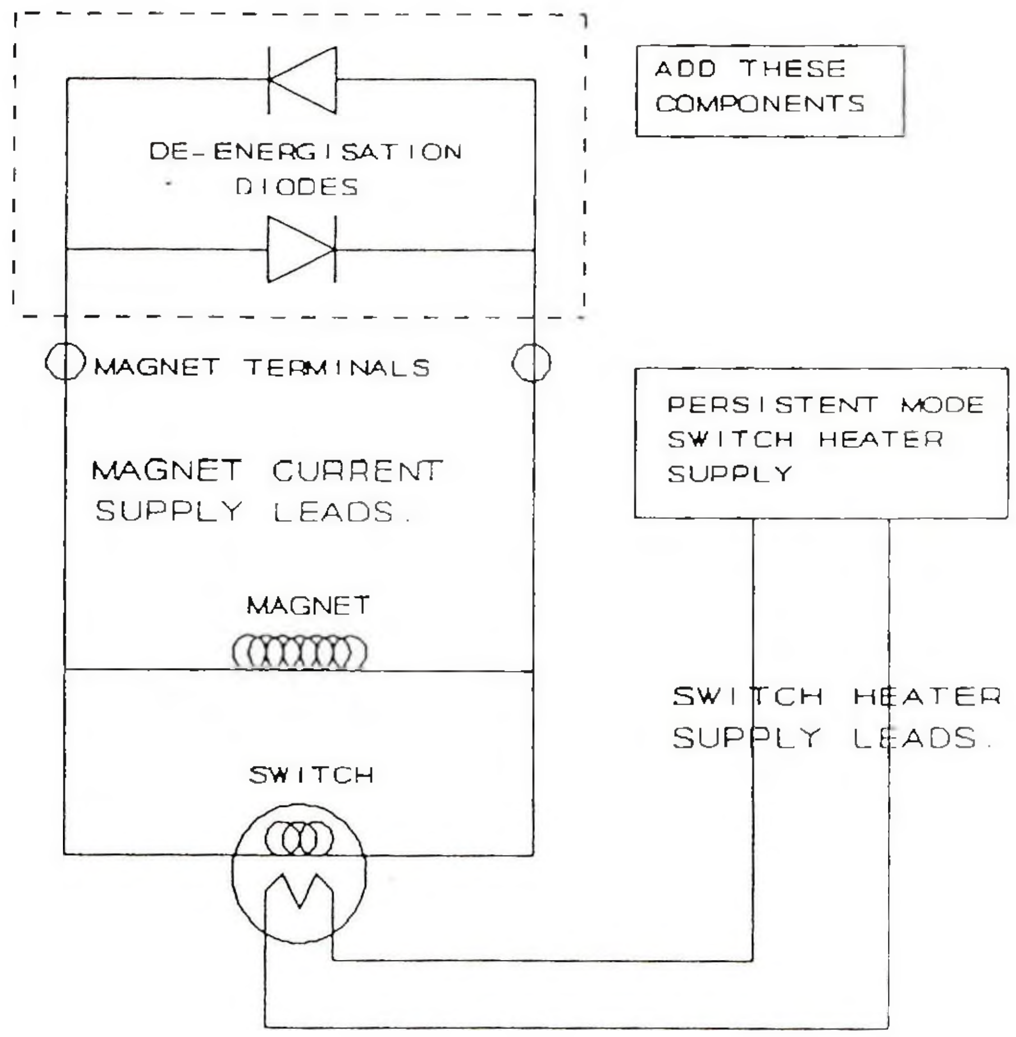


OXFORD INSTRUMENTS PS120-10V POWER SUPPLY

3.9. EMERGENCY DE-ENERGISATION PROCEDURE

IMPORTANT: AT NO TIME SHOULD THE MAGNET TERMINALS OF A PERSISTANT MAGNET BE HELD, BECAUSE IN THE EVENT OF THE MAGNET QUENCHING HIGH VOLTAGES COULD BE DEVELOPED. EXERCISE GREAT CARE IN THIS PROCEDURE.

In an emergency, for instance when no power supply is available or when the polarity of the current leads is unknown, the magnet may be de-energised by carefully connecting a pair of diodes across the terminals as shown in the figures following. Activate the switch heater using either the power supply or from a separate 6 volt battery. The switch heater current required is given in the magnet specifications. The magnet will de-energised at a rate determined by the forward voltage drop of the diode. The de-energisation will be slow, eg about 100 minutes using silicon diodes. Care should be taken not to disconnect the diodes before de-energisation is complete. The diodes must be capable of carrying the full operating current of the magnet and must be fixed to an adequate heatsink.



EMERGENCY DE-ENERGISATION CIRCUIT DIAGRAM

3.10. OPERATING THE VARIABLE TEMPERATURE INSERT

THIS SECTION ONLY APPLIES TO SYSTEMS FITTED WITH A VTI e.g. SM2, SM3, SM4 AND SPECIAL SYSTEMS.

Operating above 4.2K

Above 4.2K, the insert can be operated in two modes, namely gravity feed or pumped feed. The former is obviously easier, since no pump is required but provides limited flow and therefore cooling power.

A. Gravity Feed

It is recommended that the insert exhaust and pot are initially evacuated with the needle valve closed, and vented to an atmosphere of helium gas, to minimise the chances of a blockage when the needle valve is first opened.

a) Connect the insert exhaust port to the helium vent/recovery system.

b) Open the needle valve to give the required flow and cooling power.

c) Once the required temperature has been attained, restrict the flow until the temperature settles at a value just below that required, or continues to drift slowly downwards.

d) Set the required temperature on the temperature controller and use the heater to bring the insert to the required value.

B. Pumped Feed

a) Connect the insert exhaust to a suitable pump (approx. 450 l/min).

b) Initially evacuate with the needle valve closed.

c) Open the needle valve to give the required cooling power.

d) Operation and control as for A above.

Operation below 4.2K

Temperatures below 4.2K are achieved by pumping against the needle valve, thereby reducing the vapour pressure and therefore the temperature of the helium. Operation can be either continuous or single shot, the latter providing the ultimate base temperature.

Subsequent instructions assume that the insert has been cooled to 4.2K.

(i) Continuous operation

Operation is basically as for operation above 4.2K, except that the needle valve is merely cracked open with the pump running. Temperature control is achieved by controlling the pumping pressure via the manostat, the operation of which is described in its own manual. This method will provide a base temperature of 1.5K - 2K, depending on the heat input from the sample and support rod.

(ii) Single shot operation

This mode involves filling the insert pumping pot with helium, closing the needle valve, and then pumping on the helium to reduce its pressure and therefore temperature. It allows the ultimate base temperature to be reached, but obviously the size of the pot restricts the operating time before the helium is exhausted.

With the insert at 4.2K, turn off the pump and revert to gravity feed operation (see Section A above). Fully open the needle valve and allow the pot to fill completely. Left unattended the helium would fill the pot to the same level as the helium in the main bath. However, it is advisable to restrict the flow before this level is reached, as it would cause the helium to run up the insert exhaust line, and therefore increase the helium boil off. During the filling the helium boil off from the pot should be monitored, and the filling curtailed when a sharp increase in flow indicates that the helium is entering the exhaust line.

Once the pot is full, disconnect the exhaust from the vent/recovery line and connect to the pump through the manostat. Firmly close off the needle valve and begin pumping, controlling the pressure through the manostat if required. When the base temperature has been attained, the operating time is limited by the capacity of the pot. It is possible to slowly bleed helium into the pot whilst maintaining pumping to prolong this time, although this will tend to restrict the base temperature.

If the pot should run out, simply crack open the pot with the pump running, and refill the pot. Subsequent refills will prolong the hold time as a greater thermal mass is cooled.

Changing samples

a) Warm insert to approx. 300K.

b) Place gas filled bladder on sample space evacuation port, and open valve to ensure an overpressure of helium in the sample space.

c) Remove sample holder and immediately seal sample space with baffle set provided.

d) To replace sample holder, follow the same procedure, noting that it may be necessary to rotate the sample holder as it enters the sample space.

Checks for blockages

This is not a common occurence, especially with careful operation, but if necessary a check can be made to see if the needle valve is blocked as follows:

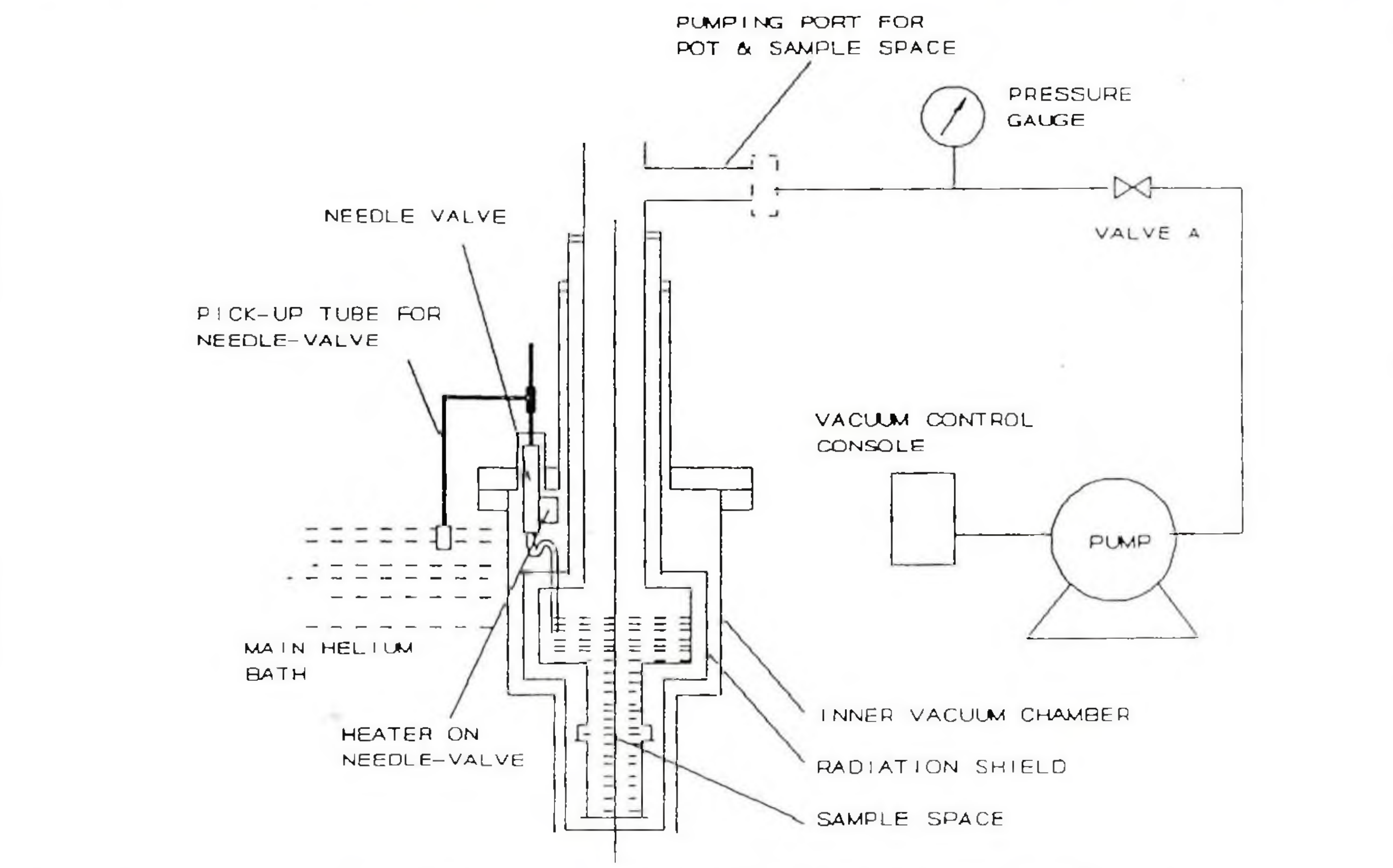
(i) Connect a pump and a pressure gauge to the pumping line as in the following figure.

(ii) Close the needle valve and pump on the pumping line. Close valve A and record the pressure.

(iii) Open the needle valve and observe the pressure on the pressure gauge. If there is no increase in pressure then the needle valve is blocked.

(iv) The needle valve is vacuum insulated and carries a small heater. Blockages may then be released by gently heating the needle valve via the heater. A temperature sensor is also provided as excessive heating (above approx. 30C) will corrupt the indium vacuum seals and may damage the heater. (See section 5.5 on page 74 for circuit diagram). In any case the most likely cause of a blockage, Nitrogen, will melt at far lower temperatures and ice should only need 10C to melt reasonably quickly.

The heater resistance is 68 ohms and a 15 volt supply should be connected across it. The monitoring sensor is a 270 ohm Allen Bradley, see figure in section 5.5 on page 74.



SYSTEM FOR CHECKING FOR A BLOCKAGE IN A NEEDLE VALVE

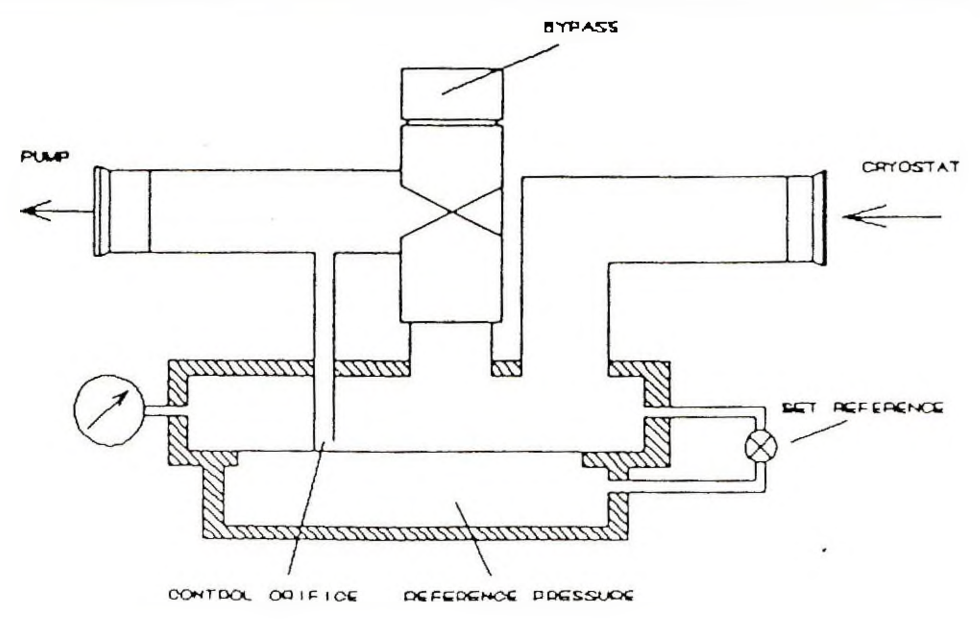
Operation of a Manostat

The Oxford Instruments manostat is an automatic pressure controller designed specifically to control the pressure in a cryostat reservoir or heat exchanger when operating below atmospheric pressure. The liquid cryogen, helium or nitrogen, is below its (atmospheric pressure) boiling point, thus a constant temperature can be maintained by the manostat. The pressure control operates by the comparison of vapour pressure over the liquid with a fixed reference pressure. As the cryostat pressure falls below the reference pressure, the diaphragm closes the control orifice thereby carrying the pumping speed to maintain a constant vapour pressure. In helium cryostats temperatures of better than $\pm$0.01 K can be maintained over the range 1.5K - 4.2 K for long periods. (Refer to the cryogenic data in section 4.2.2, page 66 showing helium-4 vapour pressure vs. temperature graphs)

Operation

For temperature control in the range 1.5K - 4.2K with liquid helium first connect the manostat to the cryostat with a 'T' piece, the third connection being to the helium recovery system.

1). Check the reference isolation valve is open.
2). Close the bypass valve and connect the pump.
3). Start the pump.
4). Slowly open the bypass valve and observe the cryostat pressure decrease on the pressure gauge.
5). When the cryostat pressure reaches the required level, close the bypass valve and the reference isolation valve.
6). The manostat will now adjust the pumping speed to maintain a constant over the liquid helium in the cryostat.
7). a) To increase the pressure, first isolate the pump. Open the reference isolation valve and monitor the pressure until the required pressure level is reached. Close the reference isolation valve and recommence pumping.
b) To reduce the pressure, open the reference isolation valve and the bypass valve and proceed as in (4) above.



SCHEMATIC OF A MANOSTAT

3.11. OPERATING THE LAMBDA POINT REFRIGERATOR

This section is only applicable to systems fitted with a lambda point fridge (for running a magnet with a pumped (2.2 Kelvin) specification).

IMPORTANT When operating the Lambda point refrigerator, boil off from the main helium reservoir will decrease and may reach negligible proportions. It is important therefore that precautions are taken to ensure that there is no chance of the cryostat 'sucking back', thereby introducing contaminants into the helium. It is recommended that the system is linked with the Lambda fridge exhaust pump connected to the main helium exhaust. The oil mist filter prevents possible contaminants entering the cryostat. Also ensure that there is sufficient liquid helium in main reservoir to achieve and maintain low temperature operation of the magnet.

A pump of minimum 700 l/min (40 m^3/hr) and preferably 1000-1300 l/min (60-80 m^3/hr) displacement should be connected to the lambda fridge pumping port using a 25mm pumping line. The pressure gauges should be connected to the exhaust port on the cryostat, not on the pump inlet. With the needle valve closed, evacuate the pumping lines. Crack open the needle valve sufficient to maintain the pressure at approximately 50 torr. Monitor the temperature using the carbon sensors R_1, R_2, R_3. R_2 and R_3 will show a reducing temperature whilst R_1 should maintain approximately 4K. The valve should be throttled back to 35 torr at a temperature of about 3K.

Once at 2.2K, as measured by R_2, the flow can be reduced to give approximately 15-20 torr pressure. The aim is to provide just sufficient cooling power to maintain the gradient between sensors R_1 and R_2.
If the phase boundary begins to move upwards, the flow should be reduced and vice-versa if sensor R_2 shows signs of warming. When adjusting the flow, take into consideration the long time constant of the system and also that greater cooling power will be required if the magnet is being energised or de-energised, to counteract the power dissipation in the current leads and superconducting switch. The lambda fridge can be used with the magnet energised.

Note: On physically very large systems a fourth temperature monitoring carbon resistor (Allen-Bradley) is sometimes fitted to the base of the magnet (See System Wiring Diagrams in Section 6.3).

A typical lambda point refrigerator performance characteristic is shown overleaf.

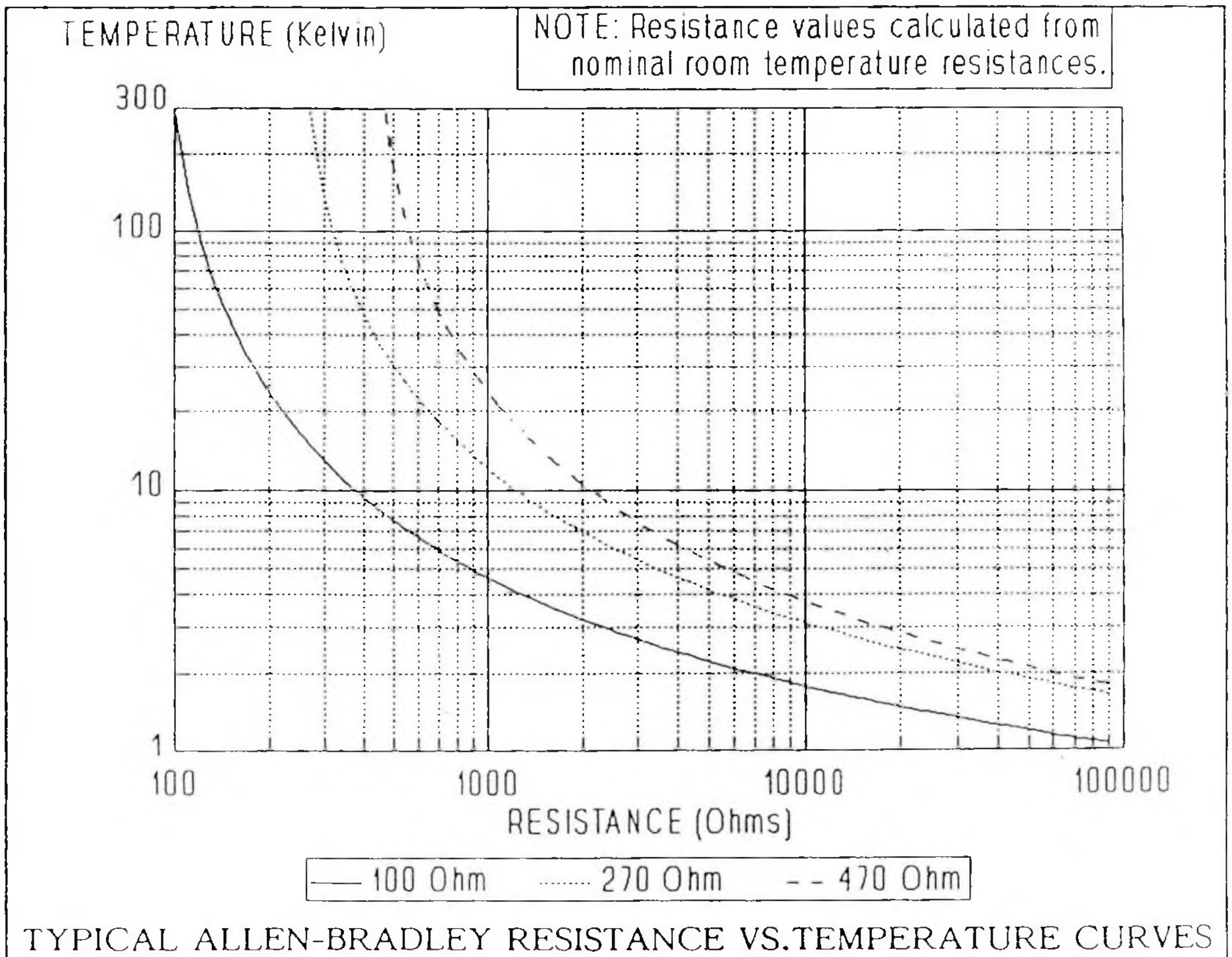
Useful Allen-Bradley Resistances at various temperatures (see also graph overleaf). 100 ohm nominal Allen-Bradley Sensor - see also section 4.2.3 on page 67 for a more comprehensive set of data.

300K	77K	5K	4.5K	4.2K	4K	3.5K	3K	2.5K	2.2K	2K
100Ω	123Ω	830Ω	1KΩ	1.1KΩ	1.2KΩ	1.5KΩ	2.2KΩ	3.2KΩ	4.5KΩ	6KΩ

Typical Test Results

Approx. Temp.K as indicated by: R2	R1	Approx. time after starting (min)	Pressure (mbar)	Flow l/min gas
4.2	4.2	0	1000	-
3.4	4.2	20	50	> 15
3.1	4.2	25	-	-
3.05	4.2	30	-	-
2.5	4.2	40	-	-
2.35	4.2	50	-	-
2.3	4.2	60	30	-
2.2	4.2	65	22	15

Pumped using Edwards ISC 450B single stage pump.



TYPICAL ALLEN-BRADLEY RESISTANCE VS.TEMPERATURE CURVES

3.12. SYSTEM CLOSEDOWN

Temporary Closedown

If the system is to be left unattended for any length of time (eg over a weekend period) it is preferable, but not absolutely necessary to de-energise the magnet. However, the following precautions MUST be taken to ensure the safety of the system.

1 Ensure that the cryostat contains sufficient helium to last for the required period.

2 Ensure that the nitrogen reservoir is full, and arrangements have been made to ensure topping up if necessary.

3 Ensure that there is no chance of the helium or nitrogen exhaust ports becoming blocked or iced up. The helium exhaust should be connected to a helium recovery system or vented through a one-way valve.
In order to minimise helium consumption the lambda point fridge needle valve should be firmly closed and the fridge evacuated.

Warming the system

Before warming the system, it is imperative that there is no trapped volume of gas or liquid within the cryostat. In particular the lambda point fridge exhaust port needle valves should be opened and linked to the main bath exhaust. (Alternatively the valve can be closed off and the fridge pumped out continually during the warming procedure).

Having adopted the above precautions, and with the magnet de-energised the system can simply be allowed to run out of liquid helium and nitrogen, and left to warm up. If a rapid warm up is desired either transfer the helium out of the cryostat into a transport dewar or insert the blowing out tube into the transfer tube entry port and gently pass DRY helium gas through it. This will boil-off the remaining liquid. Remove the liquid nitrogen by passing a stainless steel tube through one of the filler tubes and blocking off the other two fillers. This will pressurise the container and blow out the liquid.

Having removed all the cryogenic liquids the system can be warmed by softening the vacuum. Leave for 1 hour to let the magnet warm towards 77K. Slowly allow 1 bladder full of DRY nitrogen gas into the OVC or admit it until approximately 10 millibar is reached, close off the evacuation valve.

Non preferred method: With the vacuum valve closed, blow some helium gas into the pipe attached to the valve. Place a rubber bung on the end of the pipe, then open the valve and close it again. This technique ensures that only a small amount of helium gas enters the vacuum space, so that the warming up process is not too violent. Ensure that the relief valve is unobstructed. This technique is very effective, but afterwards great care must be taken to flush the helium out of the superinsulation. Do not under any circumstances attempt this method with vapour shielded dewars as they contain very large quantities of superinsulation making flushing difficult.

3.13. DISASSEMBLY OF VTI (SMD BASED SYSTEMS)

Once the VTI has been removed from the warmed-up system (by undoing the six bolts on the top flange and lifting the insert out as a unit) it is a fairly simple matter to disassemble the unit.

Unscrew the bolts and separate the indium seal flange halves using jacking screws in the holes provided. slide the stainless steel tail off. A copper radiation shield will then be exposed which should then be removed (some special VTI systems do not have a radiation shield if the sample is in vacuum for high temperature operation and sample space has to be maximised). Radiation shields are held in place by screws at the top end.

Re-assembly is the reverse of the above procedure, taking care not to damage or trap any of the wiring.

Care must be taken with the indium seals in the unit. The indium wire, which has a 1mm outside diameter, is fitted into an internal corner with the seal made by the indentation of an external sharp corner. The joint in the indium wire is made by bending one end of the wire sharply outwards and laying the other end across the corner of the bend. The wire is soft enough to allow the compression of the double thickness into a cold weld (see Section 4.1.4 on page 63 for more information on indium seals).

3.14. DISMANTLING THE SYSTEM

1. With the cryostat at room temperature fill all vacuum spaces with dry nitrogen gas or dry air, starting with the sample space and leaving the O.V.C. (outer vacuum can) until last.

2. Disconnect all wiring from the top of the cryostat, remove the sample holder, nitrogen level sensor and helium sensor.

3. Unscrew the four screws of the 1/4" vac valve on the sample space and remove the valve (see figure on page 54).

4. Unscrew the two sets of screws on the 'top hat' (large black ring and collar) (see figure on page 54) remove assembly with 'O' rings.

5. With the cryostat on blocks on the floor (blocks are to prevent the cryostat from sitting on its base window). Unscrew the 6-8 screws on the O.V.C. tail. NOTE ORIENTATION.

6. Lift the cryostat vertically upwards, using lifting eyes provided, leaving the tail on the floor.

7. Support the copper radiation shield and unscrew the 6-8 screws, holding it in place, lower when free. Try not to scratch the aluminium tape on the magnet. NOTE ORIENTATION. Place in a safe place upside down.

8. With the magnet suspended from a crane you must check the bottom of the magnet. Sometimes the copper cell shield protrudes through the base of the magnet, in this case wood packing must be used to avoid squashing this shield (see figure on page 55).

9. Before setting the magnet down it is advisable to loosen all the bolts between the collar and the helium can (see figure on page 55). Note - where the jacking screws are, i.e. two tapped holes between the bolts opposite each other. Find some suitable screws from the spares kit.

Lower the magnet until it almost touches the packing on the floor. Next remove all the scews and screw in the jacking screws to force the flanges apart. Tighten each screw a bit at a time until the magnet drops down onto the packing. Carefully lift away the cryostat. NOTE ORIENTATION.

Magnet Wiring

This can vary from system to system, but in most cases the protection circuit can be unplugged by using two 10 pin connectors or, for 120A magnets, one 10 pin connector and one 12 way plug/socket pair. Unplug the circuit and remove the protection plate and pillars (see wiring diagram at the end of the manual).

1. Unsolder main current leads from magnet current terminals with powerful soldering iron using ordinary multicore solder.

Removing Insert from Magnet

1. Break the coupling on the syphon cone and unscrew all the bolts connecting the insert with the magnet and jack apart slowly (see figure on page 56).

2. Remove the insert from the magnet and place horizontally on a table or bench. Unscrew the four counter sunk screws on the copper shield and slide off. NOTE ORIENTATION.

3. If the sample cell is going to be removed and replaced use the same procedure as before in breaking indium seals. Check orientation of new cell. See diagram on page 57.

4. Next, clean all of the indium seals with a plastic tool and a carbon tetracloride (or similar solvent) soaked paper towel. (NEVER use a razor blade or wire wool).

Reassembly

1. Reassemble in the order of disassembly making indium joints as shown in Section 4.1.4 on Page 63. Clean all flanges with degreaser. Note - as each part is assembled, check alignment and that there are no touches between each shield.

2. When making an indium seal tighten the bolts in a circular order, round and round, until there is no more give. (Using standard Allen key wrenches go about as tight as you can get without pain to the fingers). Leave the indium to relax for 15 minutes and once around again. Sometimes they give a little, other times they do not, depending on the spring of the flange.

3. Check that the cone is in the correct place under the syphon entry.

- Check that the wiring of the magnet is ok, no shorts to ground on the leads.
- Warning: P.V.C. tape and most heat shrink cracks at helium temp so use 'PTFE' insulation/plumbing tape or PTFE tube.
- When making the indium seal from the helium can collar to the helium can do not lower the helium can onto the indium wire but lower to 1/8 above the indium wire. Use the screws to align the flanges and lift the magnet onto the indium. It is easy to knock the indium out of place otherwise and it is difficult to see if anything is wrong until the end.

4. Most Oxford cryostats have orientation marks on all the flanges. Sometimes the marks are not very obvious, they are normally a letter stamp or centre punched dots. It is important that the cryostat is assembled in the same orientation as when it was built.

If any problems are encountered please telephone the Oxford Instruments Agent's service department or Oxford Instruments directly.

LEGEND
1-TRANSFER TUBE ENTRY
2-He LEVEL PROBEENTRY
3-CURRENT TERMINAL
4-10 PIN SEAL ELECTRICAL ACCESS
5-MAIN EXHAUST PORT
6-25 MM SAFETY VALVE
7-O.V.C VAC/RELIEF
8-N2 FILL/VENT
9-N2 BLOW OFF
10 EYE BOLT

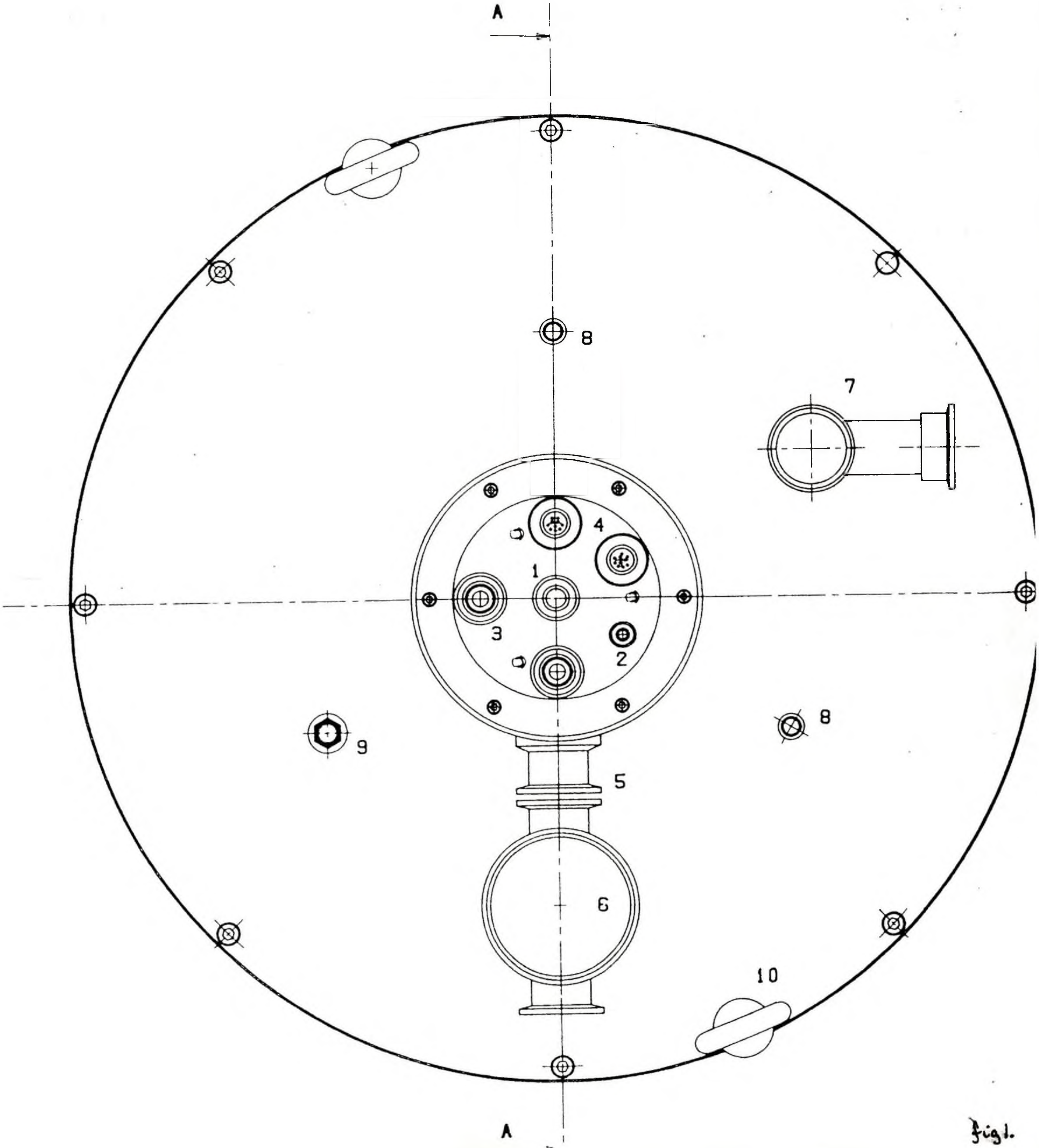
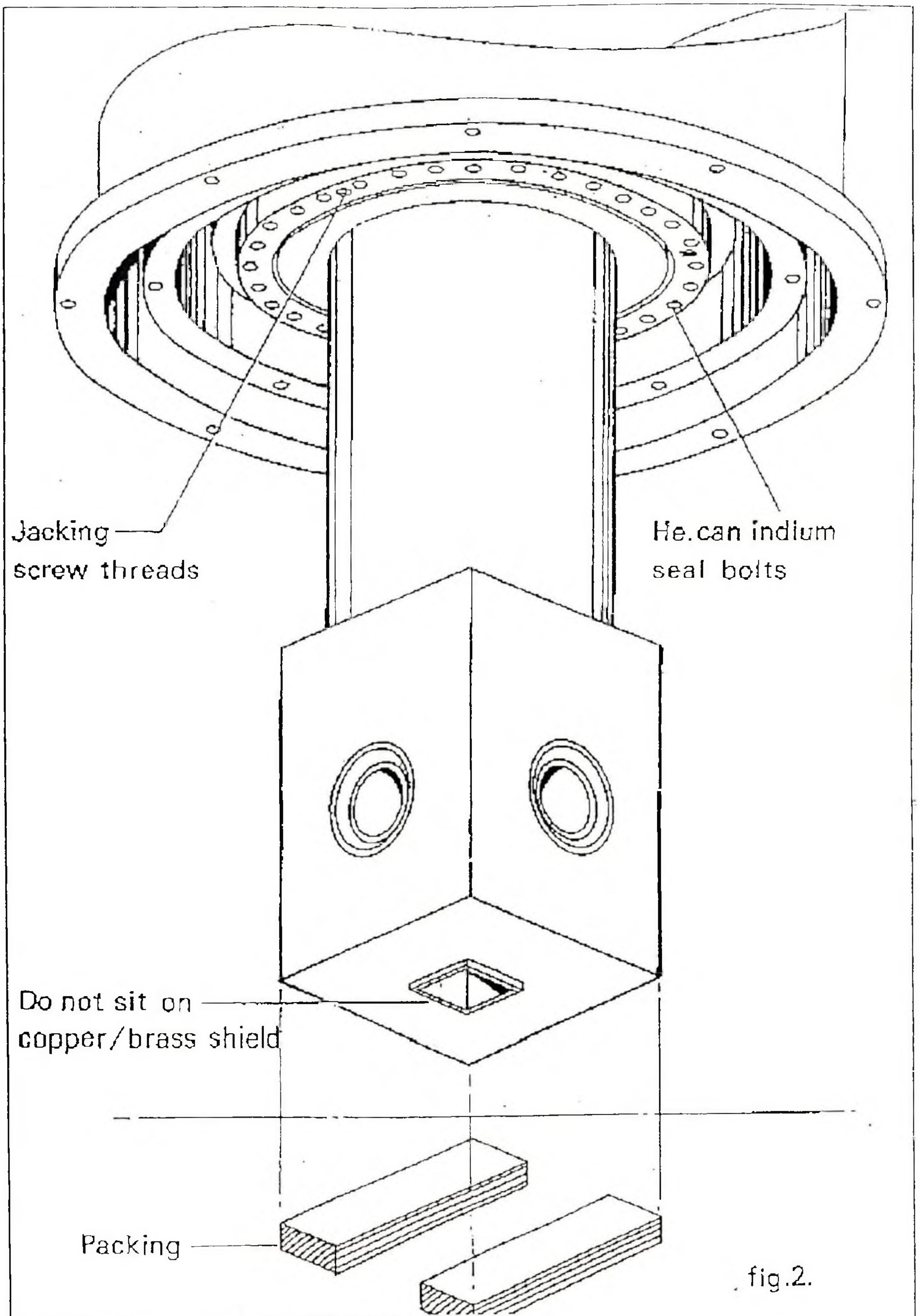
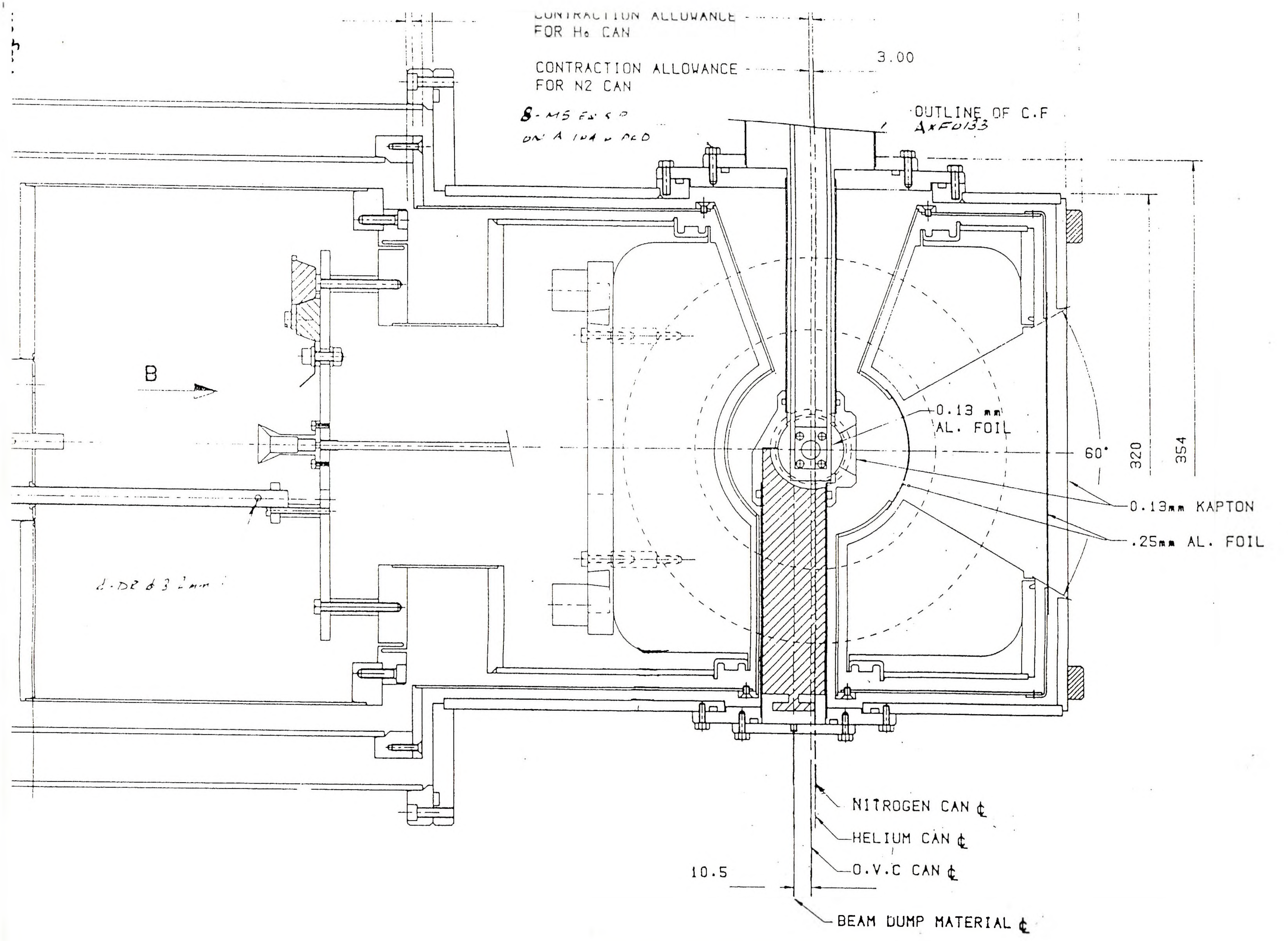


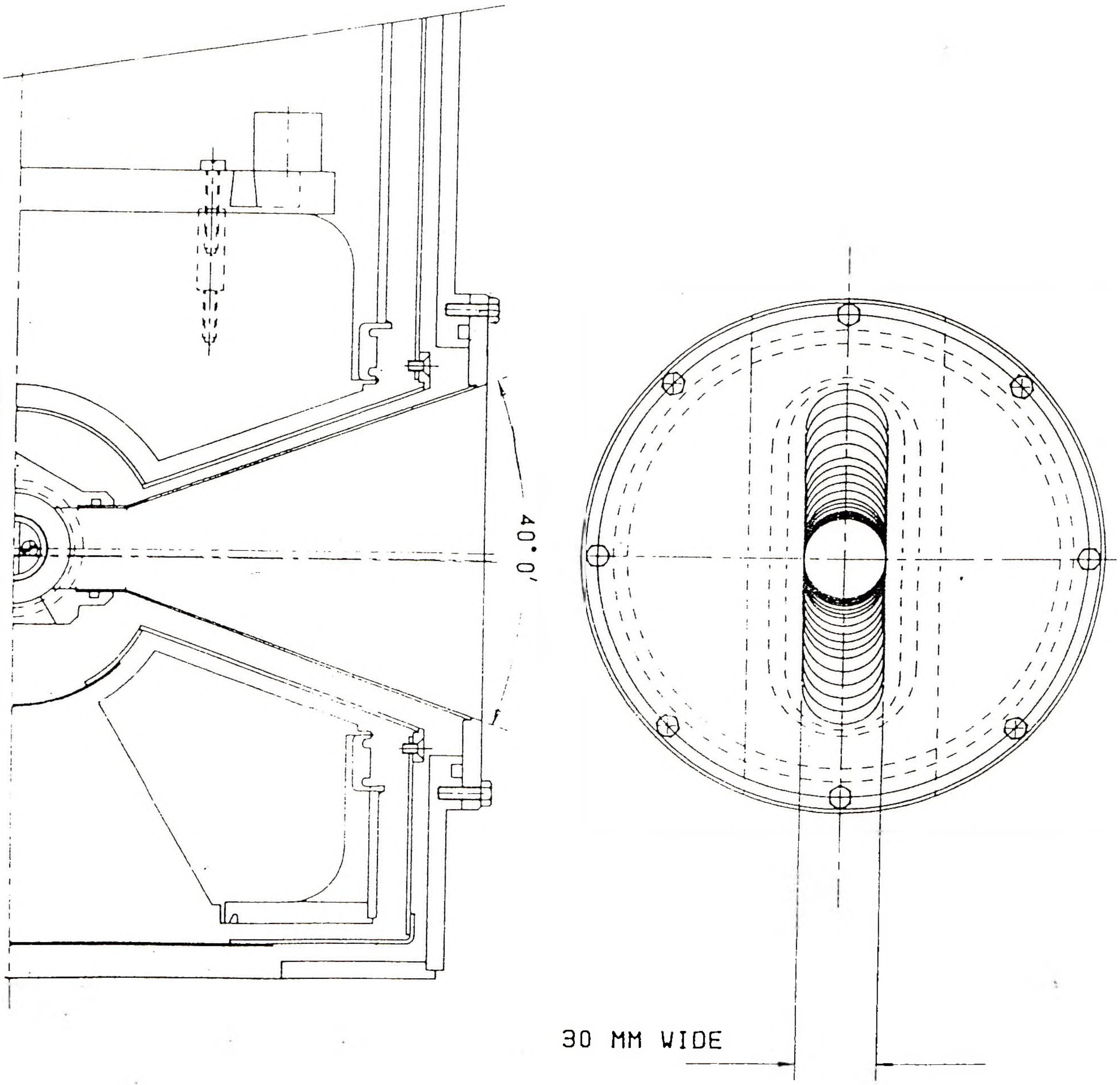
fig1.



MAGNET FLANGE DISASSEMBLY



CONTRACTION ALLOWANCE FOR He CAN
CONTRACTION ALLOWANCE FOR N2 CAN
3.00
OUTLINE OF C.F
B
0.13 mm AL. FOIL
60°
320
354
0.13mm KAPTON
.25mm AL. FOIL
NITROGEN CAN ¢
HELIUM CAN ¢
O.V.C CAN ¢
10.5
BEAM DUMP MATERIAL ¢



SCRAP SECTION OF TAIL
FOR BEAM ACCESS.

3.15. FAULT FINDING

SYMPTOM	LIKELY CAUSES	SOLUTIONS
Lack of vacuum in OVC	Leak on pumping system	Shut dewar OVC valve and check pumping system base vacuum.
	Leak on dewar	Obtain mass spectrometer and identfy source of leak. Check all 'O' rings for cleanliness.
	Excessive moisture in OVC	Pump and reflush with dry nitrogen several times, then re-pump.
OVC gets frosty on nitrogen cooldown.	Loss of vacuum or original poor vacuum	Repump OVC, check for OVC leaks including leaks to main bath with detector.
Heat exchanger pressure does not rise when needle valve is opened at nitrogen precooling stage	Blocked needle valve or capillaries	Warm heat exchanger to 300K and try again. Warm up whole system. Thoroughly flush needle valve with dry helium gas.
Transfer tube gets frosty	Loss of tube vacuum	Repump.
Transfer tube shows ice "spots"	Internal capillary touches outer tube	Continue to use if feasible. Replace if not.
Liquid helium will not collect in main reservoir	Poor OVC vacuum (cold) or not all liquid nitrogen removed	Repump OVC. If successful remake indium seals on main reservoir. Stop helium transfer and remove nitrogen remaining in main reservoir.
Needle valve jammed or no cooling at heat exchanger when open	Needle valve or capillaries blocked with ice or solid nitrogen. Heat exchanger is activated	Warm up system. Reduce heater output to zero on temperature controller.
Heat exchanger temperature shows difficult cooling with excessive helium consumption at heat exchanger exhaust	Radiation shield is touching heat exchanger	Disassemble and check radiation shield positioning. Evacuate sample tube immediately or put main vacuum on pump.
OVC becomes frosty and helium boil off increases when sample exchange gas is entered.	Leak from sample tube to main vacuum	Disassemble and remake window seals. Leak test at room temperature.
Poor temperature stability on automatic set point control	Incorrect PID settings. Excessive helium flow through heat exchanger	See Test for correct PID and flow values.
Sample rod is jammed in sample tube	Ice or solid air blockage in sample tube	Evacuate sample tube if possible. Flush repeatedly with warm gas. If unsuccessful gently warm to 300K

SECTION 4. CRYOGENIC PROPERTIES AND TECHNIQUES

4.1. VACUUM REQUIREMENTS AND INFORMATION

4.1.1. Introduction

Vacuum pumps are used most commonly in laboratory scale cryostats and superconducting magnet systems for the following purposes:

(i) to pump out the vacuum insulation spaces in the cryostat and transfer tube,

(ii) to pump out the exchange gas space,

(iii) to set up a pressure gradient along the helium flow line so that the flow of helium through the cryostat can be controlled,

(iv) to reduce the vapour pressure over liquid helium surfaces where temperatures below 4.2K are required,

(v) to pump out the nitrogen from a precooled helium vessel.

All gases, except helium, hydrogen and neon, will condense on surfaces cooled to below about 60K. Therefore, once liquid helium at 4.2K is introduced into a thin walled metallic vessel surrounded by a vacuum, all the residual gases which are normally present will condense or 'cryopump', reducing the pressure in the vacuum space by one or two orders of magnitude. Therefore, the function of a vacuum system is to reduce the pressure in the vacuum space to a point where the thermal insulation is sufficiently good to allow liquid helium to be introduced to the vessel. This pressure for laboratory scale systems is around 10^{-4} torr (mm Hg) or 10^{-1} microns.

In cryostats with only liquid nitrogen, the coldest surface is 77K, above the temperature for effective cryopumping. If the cryostat is not pumping continuously, a sorption pump is mounted on the liquid nitrogen reservoir. It is activated by heating and becomes effective when liquid nitrogen is introduced.

To reach this pressure both a mechanical rotary pump and an oil diffusion pump are generally required. The rotary or backing pump is used to reduce the pressure to a point where the diffusion pump can start to operate (about 1 torr or less), the diffusion pump will then take the pressure down to 10^{-5} torr or less.

WARNING: Oil mist filters should be fitted to rotary pumps to prevent possible emission of toxic carcinogenic fumes.

4.1.2. Vacuum pumps

1. Rotary pump

If the rotary pump's sole function is to back a small oil diffusion pump, then a single stage rotary pump with a base pressure of about 10^{-2} torr and a pumping speed of about 50 litres/minute is adequate. If the rotary pump is also to be used for reducing the vapour pressure over a liquid helium surface it is necessary to choose a higher speed pump, up to about 300 litres/minute.

It is preferable to use pumps fitted with a gas ballast facility. This permits the removal of the relatively large quantities of condensable vapours from the vacuum insulation space of a cryostat where they may accumulate during transportation or if the cryostat is left unused for some time.

2. Diffusion pumps

A one inch oil diffusion pump is sufficient for pumping laboratory scale cryostats. Typically, an air-cooled pump with a pumping speed of about 10 litres/second for air and an ideal ultimate pressure of about 10^{-7} torr is used.

It is essential to use a cold trap in conjunction with the diffusion pump. This helps to remove water vapour from the cryostat by cryopumping. In addition, it prevents back streaming of oil vapour from the pump to the cryostat. There are two types of trap commonly in use, liquid nitrogen filled traps and thermo-electric (Peltier effect) cooled baffles, the latter require less attention and are better for very long-term unattended operation.

3. Two stage rotary pumps

In some cases, it is possible to dispense with the diffusion pump and to replace the rotary/diffusion pump combination with a two stage rotary pump. Base pressures of 10^{-4} torr for a small pump can be achieved in ideal conditions, but in practice the pressure in the cryostat will probably only be 10^{-2} to 10^{-3} torr.
The advantage of this system is its simplicity, but it has the disadvantage that if a base pressure of only 10^{-2} or 10^{-3} torr is reached, more cryopumping is necessary when helium is introduced. This leads to higher helium losses during transfer. In addition, frosting may occur if the cryostat is used above 60K.

NOTE : THE PERFORMANCE OF BOTH ROTARY AND DIFFUSION PUMPS IS ADVERSELY AFFECTED BY POOR PUMPING LINES. THESE SHOULD BE MADE OF METAL, WITH A MINIMUM OF 5/8 INCH (16mm) INTERNAL DIAMETER, AND SHOULD BE AS SHORT AS POSSIBLE.

4.1.3. Accessories

Oil mist filter

This is used to prevent oil from contaminating the helium recovery system and the flow meter. Contamination will occur if a rotary pump is used to pump on liquid helium or to produce the flow in continuous flow cryostats. The filter normally contains replaceable paper elements.

Vacuum gauges

High vacuums are normally measured using a combination of Pirani and Penning type gauges. Typically, the Pirani gauge operates in the range 760 torr to 10^{-3} torr, and the Penning in the range 10^{-2} torr to 10^{-7} torr. The exchange gas pressure can be adequately measured using a simple, 0-760 torr, capsule or dial gauge. Helium vapour pressure in vessels operating below 4.2K can be measured reasonably accurately using a vacustat which typically operates in the range from 10 torr to 10^{-2} torr.

Manostat

Relevant mainly to systems with a Variable Temperature Insert (VTI). The Oxford Instruments manostat is an automatic pressure controller designed specifically to control the pressure in a cryostat reservoir or heat exchanger when operating below atmospheric pressure. The liquid cryogen, helium or nitrogen, is below its (atmospheric pressure) boiling point, thus a constant temperature can be maintained by the manostat.

The pressure control operates by the comparison of vapour pressure over the liquid with a fixed reference pressure. As the cryostat pressure falls below the reference pressure, the diaphragm closes the control orifice thereby carrying the pumping speed to maintain a constant vapour pressure. In helium cryostats temperatures of better than ± 0.01 K can be maintained over the range 1.5-4.2 K for long periods. (Refer to the cryogenic data in section 4.2.2, page 66 showing helium-4 vapour pressure vs. temperature graphs)

Other useful accessories

(i) A multi-meter for checking circuits, reading volts and ohms etc.

(ii) A mass spectrometer helium leak detector with 10^{-11} torr litres/sec sensitivity.

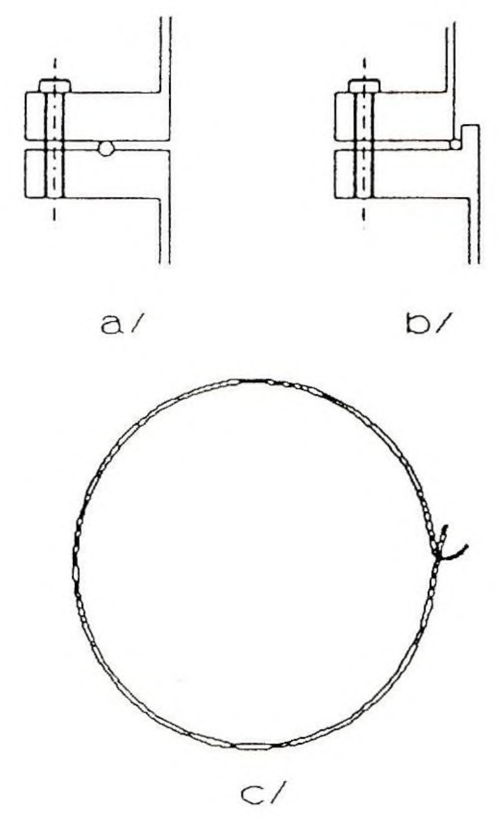
(iii) Facilities for hard and soft soldering.

4.1.4. Indium seals

Demountable indium seals

The indium seals used in cryostats manufactured by Oxford Instruments are of two main types, as illustrated in the figure. The wire, which has a diameter of 1mm, may be retained in a groove 0.5mm radius and the seal made by the pressure of a flat surface upon it (figure (a)) or it may be fitted into a corner with the seal made by the indentation of a sharp corner (figure (b)). In both instances, the joint in the indium wire is made by bending one end of the wire sharply outwards and laying the other end across the corner of the bend as shown in figure (c). The wire is soft enough to allow the compression of the double thickness into a cold weld.

Before fitting the seal ensure that the groove and the mating surfaces are clean and free from grease, if necessary a grease solvent such as inhibisol or acetone can be used for cleaning. Because of the softness of the indium wire care must be taken not to exert excessive pressure on the seal when tightening the bolts. Sufficiently pressure can be applied by tightening the bolts with a spanner or Allen key held between the thumb and forefinger about 3 cms from the bolt head. When remaking a seal, always remove the old compressed indium wire and replace with fresh wire.



INDIUM SEALS

4.1.5. Bunsen valve

A simple and safe way to terminate tubes from a helium container not connected to a low pressure recovery system is by means of a Bunsen valve (see Section 3.4, Page 32).

A piece of rubber tubing, 5-10 cm long, is fitted to the outside of the emerging tube, a rubber stopper is placed in the other end and a small slit 15mm long is made in the rubber tube. A slight over pressure builds up in the tube allowing helium to escape through the slit and preventing air from entering the exhaust vent.

Due to the low latent heat of vaporization, and high gas to liquid ratio (700:1) rapid and violent expansion will occur if, for example, the container vacuum should fail. Therefore, pressure relief devices should be adequately sized for helium containers.

4.1.6. Liquid helium transfer

Owing to its low latent heat of vaporization, liquid helium must be transferred by means of a vacuum insulated transfer tube. The annular vacuum space is evacuated to approximately 10^{-4} torr. This further cryopumps to at least 10^{-6} torr in use and provides good thermal insulation. (See page 31, Schematic of liquid helium transfer).

4.1.7. Helium gas recovery

A helium gas recovery system is desirable for the following reasons:

a) There may be a financial saving depending on the volume of helium used,
b) it prevents the cryostat from becoming contaminated with ice and air,
c) it conserves the earth's helium supply.

A typical recovery system consists of a low pressure gas holder, a compressor and a high pressure gas storage facility. The low pressure gas storage is connected to the cryostat helium exhaust vent and is usually in the form of a gasometer or gas bag. The compressor pumps the gas into high pressure gas cylinders (or bottles) for storage. The compressor should be specifically made for use with helium because of the large quantity of heat released in compressing the gas.

NOTE: a) The cost-effectiveness of a gas recovery system is a function of the amount of helium used and the cost of installation of a recovery system. This must be calculated for each system or each laboratory and advice cannot be given in general terms.

b) To prevent air entering the cryostat, the low pressure gas holder should be maintained at a pressure slightly above atmospheric - a pressure of a few centimeters of water is sufficient. Failure to do this may lead to the formation of ice and solid air in important entry and exhaust ports of the cryostat.

4.2. USEFUL CRYOGENIC DATA

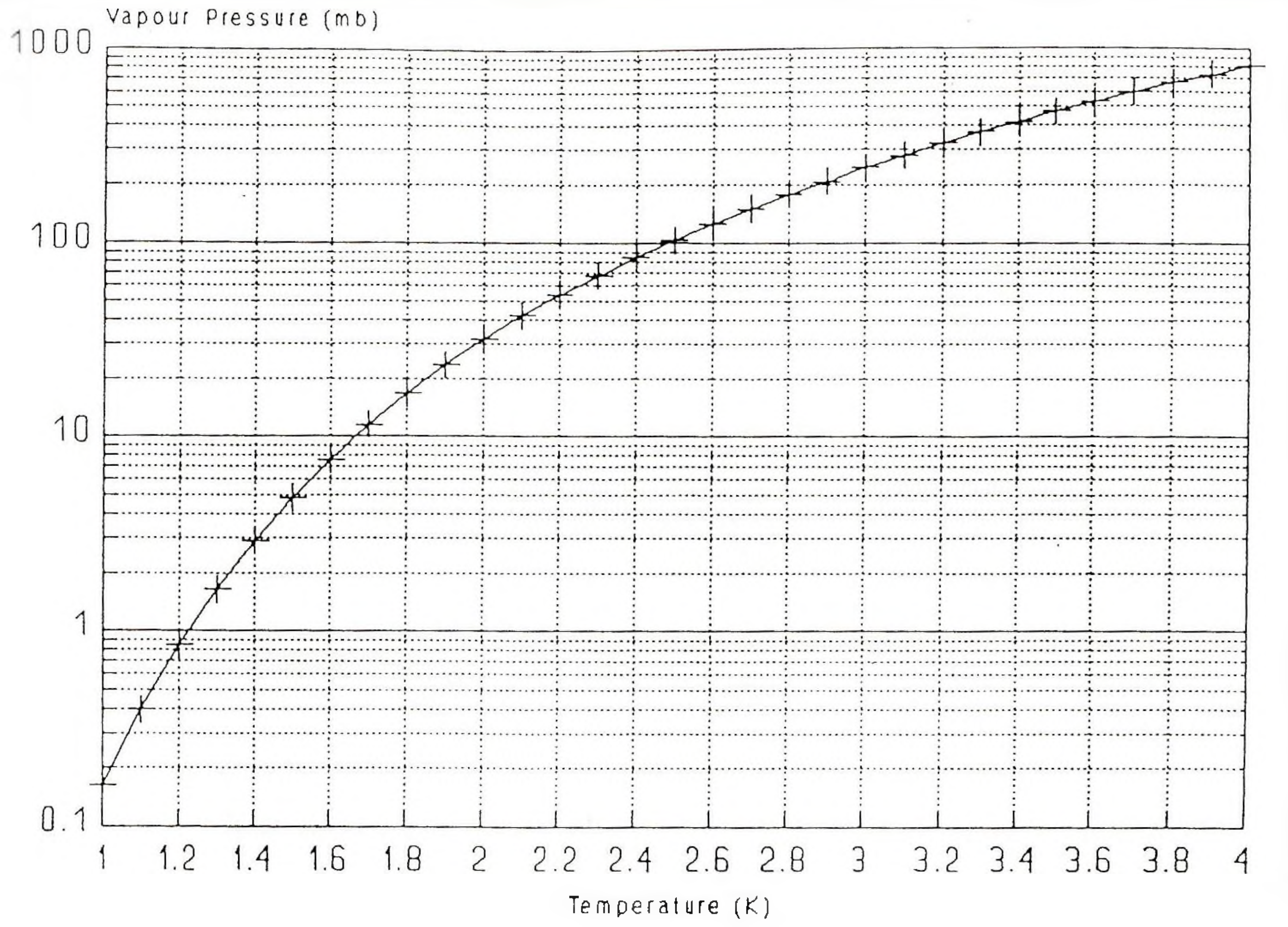
4.2.1. Physical data - tabulated

	Liquid Nitrogen LN2	Liquid Helium LHe4
Normal boiling point (deg. K)	77.3	4.2
Latent heat of vaporization (Joules/grm)	198	20.9
Amount of liquid evaporated by 1 Watt (litre/hour)	0.023	1.38
Liquid density at normal boiling point (g/ml)	0.808	0.125
Gas density at NTP (g/ml)	1.25×10^{-3}	1.79×10^{-4}
Gas at STP to liquid volume ratio	648:1	700:1
Enthalpy change of gas (J/gm).		
4.2K - 77K	-	384
77K - 273K	234	1542
Boil-off conversion factor for l/min of gas to cc/hr of liquid.	88	91

Amount of cryogenic fluid required to cool metals (litres/Kg)

Cryogen		He4	He4	N2
Initial temperature of metal		300K	77K	300K
Final temperature of metal		4.2K	4.2K	77K
Using the latent heat of vaporization only	Al	66.6	3.20	1.01
	St St	33.3	1.43	0.53
	Cu	31.1	2.16	0.46
Using the enthalpy of the gas		Al	1.61	0.220.64
	St St	0.79	0.11	0.33
	Cu	0.79	0.15	0.29

4.2.2. Helium-4 Vapour Pressure versus Temperature Data



HELIUM-4 VAPOUR PRESSURE VS. TEMPERATURE GRAPH

ACTUAL DATA (Torr/mmHg and mb).

Temp. (K)	Pressure (mmHg)	Pressure (mb)	Temp. (K)	Pressure (mmHg)	Pressure (mb)	Temp. (K)	Pressure (mmHg)	Pressure (mb)
0.9	0.0422	0.0563	2.4	63.573	84.757	3.9	554.72	739.56
1.0	0.1210	0.1622	2.5	77.788	103.70	4.0	614.68	819.50
1.1	0.2959	0.3945	2.6	94.040	125.37	4.1	679.15	905.45
1.2	0.6325	0.8433	2.7	112.47	149.95	4.2	748.45	997.86
1.3	1.2219	1.6291	2.8	133.22	177.62	4.3	822.41	1096.4
1.4	2.1776	2.9032	2.9	156.43	208.56	4.4	901.01	1201.2
1.5	3.6335	4.8443	3.0	182.24	242.96	4.5	984.36	1312.3
1.6	5.7406	7.6535	3.1	210.78	281.01	4.6	1072.6	1430.0
1.7	8.6612	11.547	3.2	242.19	322.89	4.7	1165.8	1554.2
1.8	12.561	16.747	3.3	276.61	368.78	4.8	1264.1	1685.3
1.9	17.600	23.466	3.4	314.17	418.86	4.9	1367.7	1823.4
2.0	23.919	31.890	3.5	355.03	473.33	5.0	1476.6	1968.6
2.1	31.610	42.143	3.6	399.33	532.40	5.1	1590.9	2121.0
2.2	40.675	54.229	3.7	447.25	596.29	5.2	1780.8	2374.2
2.3	51.253	68.331	3.8	498.98	665.26			

4.2.3. Allen-Bradley and Rhodium-Iron Temperature Sensor Characteristics

(a). Typical values of temperature versus resistance for an Allen-Bradley carbon resistor with nominal resistance at room temperature of 100 ohms.
(b). Typical values of resistance versus temperature for a 4-wire Rhodium Iron sensor with a nominal resistance of 27 ohms at 273 Kelvin.

Temperature (Kelvin)	Allen-Bradley Resistance	Rhodium-Iron sensor
500	-	51.4Ω
475	-	48.2Ω
425	-	42.8Ω
373	-	37.5Ω
323	-	32.2Ω
300	100Ω	29.8Ω
280	100.5Ω	27.8Ω
260	101Ω	25.7Ω
240	102Ω	23.74Ω
220	103Ω	21.73Ω
200	104Ω	19.69Ω
190	105Ω	18.67Ω
180	105.5Ω	17.66Ω
170	106Ω	16.64Ω
160	107Ω	15.87Ω
150	108Ω	14.53Ω
140	109Ω	13.46Ω
130	110Ω	12.37Ω
120	112Ω	11.38Ω
110	114Ω	10.24Ω
100	116Ω	9.2Ω
95	118Ω	8.7Ω
90	119Ω	8.18Ω
85	120Ω	7.68Ω
80	122Ω	7.19Ω
75	124Ω	6.72Ω
70	126Ω	6.27Ω
65	128Ω	5.82Ω
60	132Ω	5.43Ω
55	135Ω	5.05Ω
50	140Ω	4.73Ω
45	145Ω	4.43Ω
40	150Ω	4.17Ω
35	158Ω	3.94Ω

Data continued overleaf.

(Continued.)

Temperature (Kelvin)	Allen-Bradley Resistance	Rhodium-Iron sensor
30	170Ω	3.75Ω
28	175Ω	3.67Ω
26	180Ω	3.60Ω
24	190Ω	3.53Ω
22	200Ω	3.45Ω
20	210Ω	3.36Ω
18	225Ω	3.28Ω
16	241Ω	3.18Ω
14	269Ω	3.07Ω
12	300Ω	2.95Ω
10	350Ω	2.81Ω
9	390Ω	2.73Ω
8	440Ω	2.65Ω
7	520Ω	2.56Ω
6	625Ω	2.45Ω
5.5	700Ω	2.4Ω
4.5	950Ω	2.28Ω
4.2	1100Ω	2.25Ω
4	1200Ω	2.22Ω
3.75	1300Ω	2.19Ω
3.5	1500Ω	2.16Ω
3.25	1800Ω	-
3	2250Ω	-
2.8	2400Ω	-
2.6	3000Ω	-
2.4	3600Ω	-
2.2	4500Ω	-
2	6000Ω	-
1.9	7000Ω	-
1.8	8000Ω	-
1.7	10000Ω	-
1.6	12500Ω	-
1.55	14000Ω	-

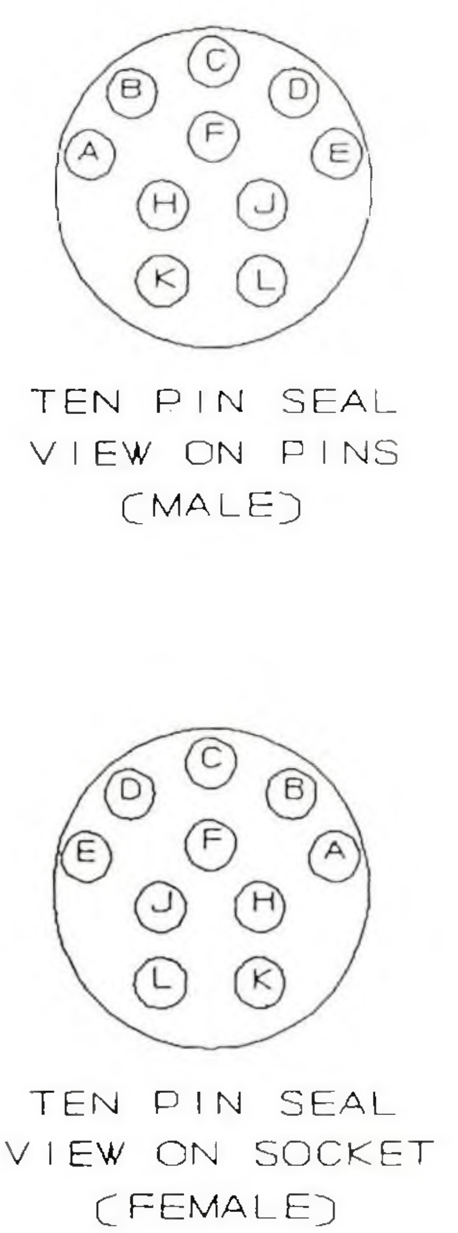
Approximate % error due to magnetic fields:

Sensor	Allen-Bradley Resistor			Rhodium-Iron	
Field	2.5T	8T	14T	1T	3T
2K	0.5	1.5	4	0.13	0.88
4.2K	0.5	3	6	0.13	0.79
50K	-	-	-	0.14	0.84
77K	0.1	0.5	1.5	-	-

SECTION 5.- ELECTRICAL WIRING

5.1. GENERAL WIRING NOTES

Wiring to sensors in cryostats requires great care to avoid large heat leaks and maintain accuracy of measurement. Electrical leads are generally coiled to maximise length, and usually made from copper in the case of heater leads or constantan in the case of measurement leads. Four wire measurements for high accuracy resistance sensing should be used whenever possible.

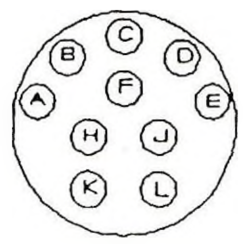


10 PIN SEAL WIRING.

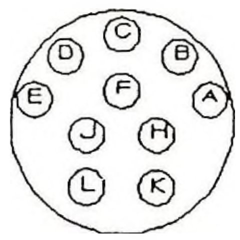
10 Pin seals are used extensively throughout equipment manufactured by Oxford Instruments for small signal (<5a) connections. For standard connections, see the wiring diagrams on the following pages and for system-specific wiring details see section 6.3.

5.2. HELIUM LEVEL PROBE WIRING DIAGRAM

Please see Helium Level Meter manual for more detailed information concerning installation and operation of cryogen level meters. The 10 pin seal for demountable helium level probes are mounted on a 3/16" tube, generally with a curved section immediately below the connector, or, in the case of some fridge systems, they may be mounted on a straight 3/8" tube.



TEN PIN SEAL
VIEW ON PINS
(MALE)



TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

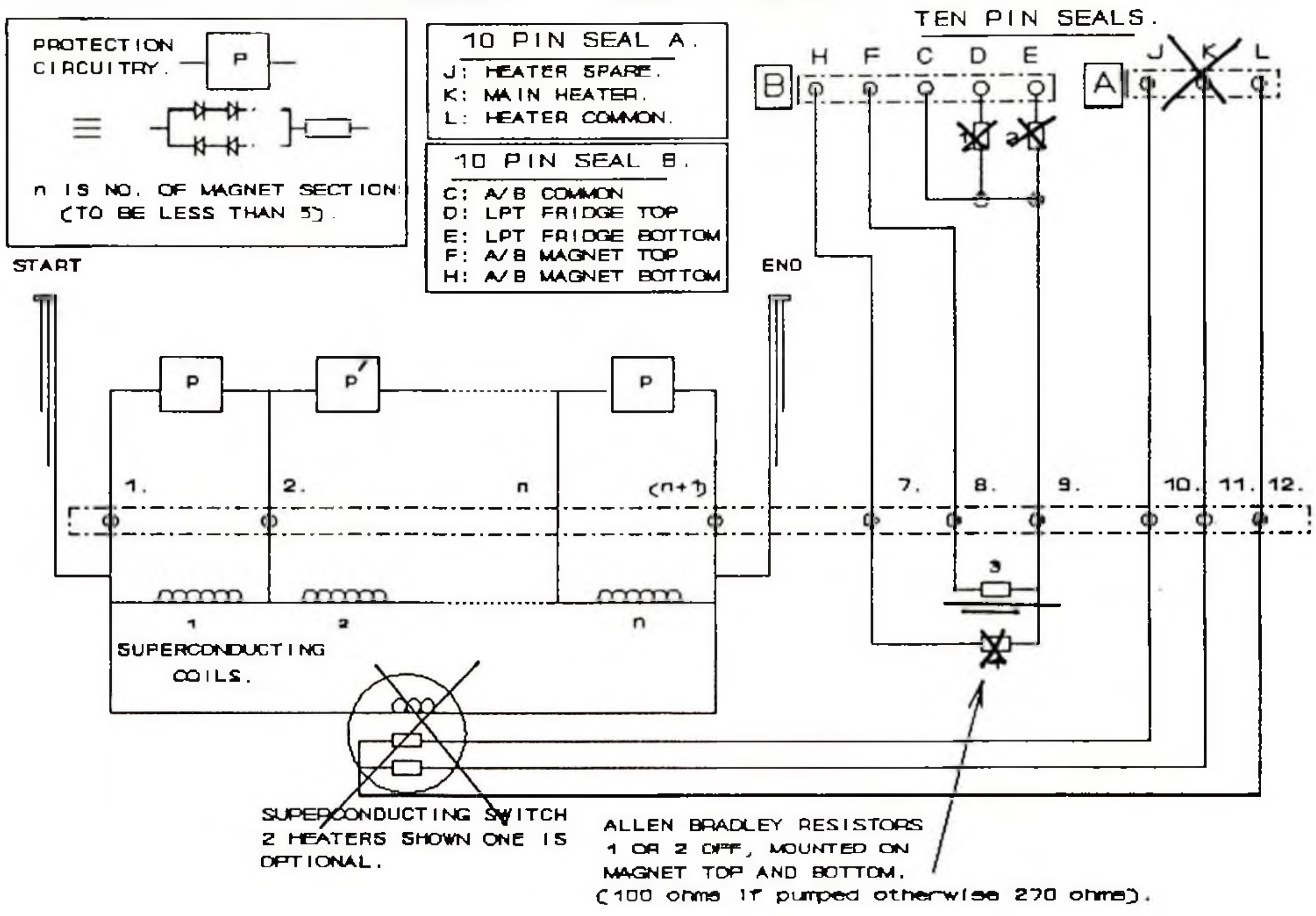
		WIRE GAUGE	WIRE TYPE
A	I+ LEAD TO HELIUM LEVEL PROBE	41	COPPER
B	V+ LEAD TO HELIUM LEVEL PROBE	44	COPPER
C	NOT USED		
D	V- LEAD TO HELIUM LEVEL PROBE	44	COPPER
E	I- LEAD TO HELIUM LEVEL PROBE	41	COPPER
F	SPARE		
H	SPARE		
J	SPARE		
K	SPARE		
L	SPARE		

ALL LEADS SPECIFIED ARE INTEGRAL TO THE PROBE, EXTERNAL INTERFACING AT ROOM TEMPERATURE MAY BE WITH LARGER WIRE GRADES FOR MAXIMUM STRENGTH.

HELIUM LEVEL PROBES ARE GENERALLY ONLY FITTED TO SYSTEMS WHEN A HELIUM LEVEL METER HAS ALSO BEEN ORDERED.

HELIUM LEVEL PROBE WIRING DIAGRAM.

6.3. SPECIAL SYSTEM MAGNET WIRING DIAGRAM



GENERAL MAGNET WIRING DIAGRAM.

THE 10 PIN SEALS FOR THE MAGNET TEMPERATURE SENSORS AND THE SWITCH ARE MOUNTED ON MAGNET SUPPORT TOP PLATE (SMD BASED SYSTEMS), ON THE HELIUM SERVICE NECK (VSM, NMR, CRYSTAL PULLER, AND GYROTRON DEWARS) OR ON THE CENTRAL TOP HAT ASSEMBLY (MD BASED SYSTEMS, INCLUDING SPECTROMAGS AND MOSSBAUER SYSTEMS).

CARBON SENSOR OPTIONS

RESISTORS 1,2 ONLY FITTED TO MAGNETS WITH LAMBDA POINT FRIDGE. X
RESISTOR 4 ONLY FITTED TO PHYSICALLY LARGE MAGNETS (AT BASE). X
RESISTANCE VALUES: 100 OHMS FOR PUMPED (2.2 Kelvin) MAGNETS
220 OHMS FOR UNPUMPED (4.2 Kelvin) MAGNETS

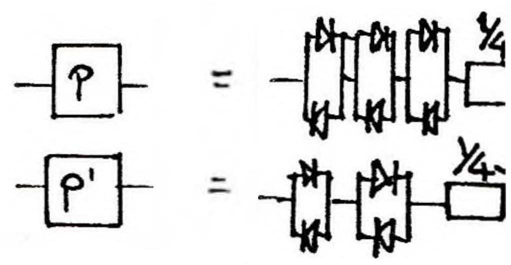
SWITCH OPTIONS:

SWITCH FITTED X
SPARE HEATER FITTED ____
HEATER RESISTANCE ____
SWITCH RESISTANCE ____

PROTECTION CIRCUITRY

NO. OF SECTIONS 2 x [P] + 2 x [P′]
DIODE CURRENT RATING:120A/75A 120A
NO. OF RESISTORS PER SECTION 1
RESISTOR VALUES ¼ Ω

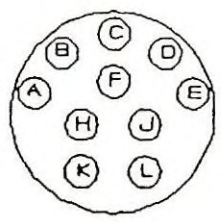
PROTECTION SECTION NO.	MAGNET COIL NUMBERS.	NO. OF DIODE PAIRS/SECTION.
1	1A, 1B	3
2	2A, 2B	2
3	3A, 3B	2
4	4A, 4B	3
5		



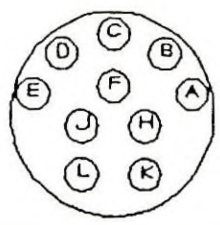
5.5. VTI HEATER WIRING DIAGRAMS

THIS SECTION ONLY APPLIES TO SYSTEMS FITTED WITH A VTI e.g. SM2, SM3, SM4 AND SPECIAL SYSTEMS.

Systems fitted with a Variable Temperature Insert (VTI) are equipped with a needle-valve heater to allow the removal of ice blockages. The Allen-Bradley carbon resistance sensor allows the temperature to be monitored during warming to prevent the heater burning out. The ten pin seal is located on the VTI top plate (SMD based systems), on the top hat assembly (MD based systems, including Mossbauer and Spectromag systems), or less commonly, on the Outer Vacuum Chamber for VSM/NMR cryostats with an integral VTI.



TEN PIN SEAL
VIEW ON PINS
(MALE)

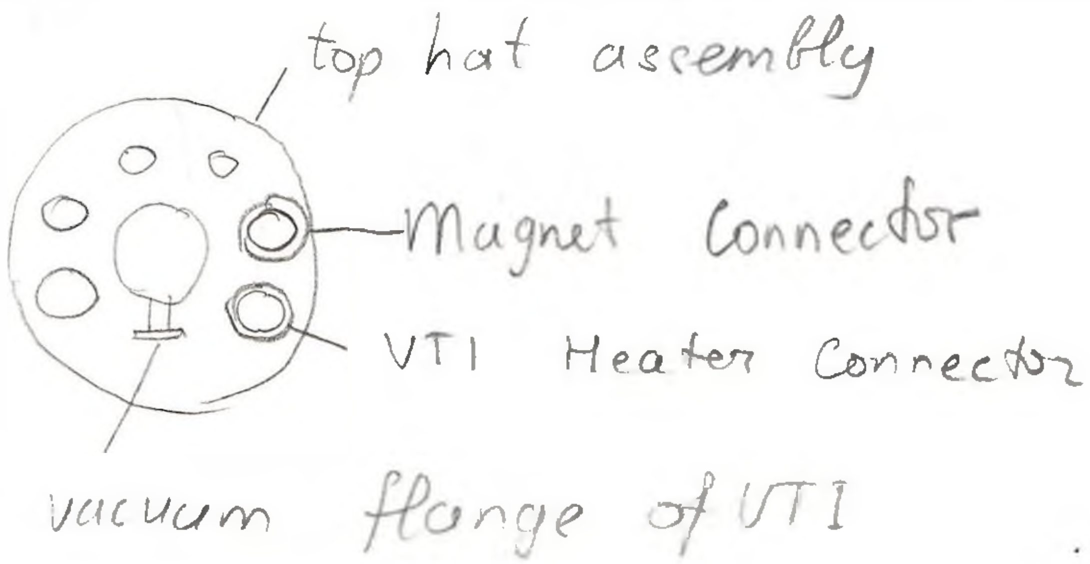


TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

PIN	CONNECTION	CONNECTING WIRE MATERIAL	GAUGE
A	68 OHM HEATER RESISTOR	Cu	36
B	IN COPPER HEATER BLOCK	Cu	36
C			
D			
E			
F			
H	270 OHM CARBON SENSOR	CONST	36
J	(ALLEN - BRADLEY)	CONST	36
K			
L			

NOTES: 1. GAUGE IN S.W.G. (STANDARD WIRE GAUGE)
2. MATERIAL COPPER: Cu
CONSTANTAN: CONST.

WIRING FOR VTI NEEDLE-VALVE



6.2. MEASURED FIELD PROFILE

The magnet was plotted with a Hall probe in a test cryostat which contains a set of room temperature insert tails. The Hall probe is calibrated against an NMR probe in an NMR magnet to ensure the accuracy of the measurements (an NMR probe being accurate to at least 1×10^{-6} while the Hall probe is only accurate to at best 1×10^{-4}). (Magnets $\leq 1 \times 10^{-5}$ homogeneity in a 10mm dsv are plotted exclusively by NMR probe).

The field plots obtained are shown overleaf. It should be noted that the 'distance along the axis' is relative to the test cryostat not the magnet, the actual field centre is given on the specification sheet (Section ?, Page ?).

The limits for the homogeneity to conform to the required specification. The maximum variation in field in a 10 mm diameter spherical volume are shown on the graph overleaf.

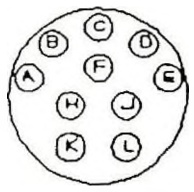
6.3. CRYOSTAT PERFORMANCE

Helium consumption (static)	cc/hr
Nitrogen consumption	cc/hr
Helium hold time (static) at 4.2K	hours
Nitrogen hold time	hours

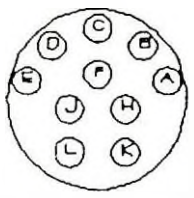
* recommended daily top up

5.6. SAMPLE ROD WIRING DIAGRAMS

A Rhodium-Iron sensor is provided as standard on a spectromag, Carbon-Glass (or other) sensors are provided when specifically requested.



TEN PIN SEAL
VIEW ON PINS
(MALE)



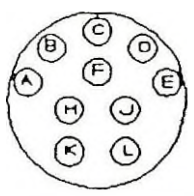
TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

PIN	CONNECTION		CONNECTING WIRE MATERIAL	GAUGE
A		25 OHM FILM HEATER	Cu	34
B			Cu	34
C	V–		Cu	36
D	V+	500 OHM CARBON-GLASS SENSOR	Cu	36
E	I+		Cu	36
F	I–		Cu	36
H				
J				
K				
L				

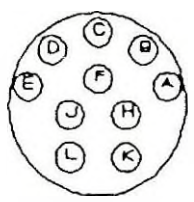
NOTES: 1. GAUGE IN S.W.G. (STANDARD WIRE GAUGE)
2. MATERIAL COPPER: Cu
CONSTANTAN: CONST.

CARBON-GLASS SENSOR WIRING DETAILS

This diagram is valid



TEN PIN SEAL
VIEW ON PINS
(MALE)



TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

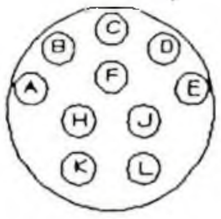
PIN	CONNECTION		CONNECTING WIRE MATERIAL	GAUGE
A		~~25 OHM FILM HEATER~~	Cu	34
B		50 OHM WIRE HEATER	Cu	34
C	V+		Cu	36
D	V–	27 OHM RHODIUM-IRON SENSOR	Cu	36
E	I+		Cu	36
F	I–		Cu	36
H	V+			
J	V-	100 OHM SENSOR		
K	I+			
L	I-			

NOTES: 1. GAUGE IN S.W.G. (STANDARD WIRE GAUGE)
2. MATERIAL COPPER: Cu
CONSTANTAN: CONST.

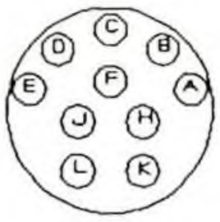
RHODIUM-IRON SENSOR WIRING DETAILS

5.7. ADDITIONAL WIRING DIAGRAMS

отладочныи провод



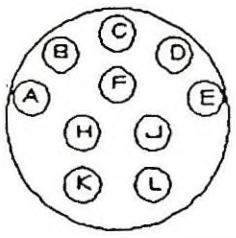
TEN PIN SEAL
VIEW ON PINS
(MALE)



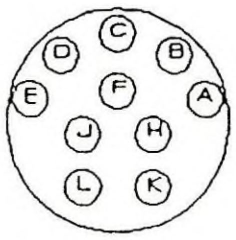
TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

PIN	CONNECTION (color)	CONNECTING WIRE MATERIAL	GAUGE
A	чёрн	1	
B	коричн	2	
C	красн	3	
D	оранж	4	
E	желт	5	
F	зелёныи	6	
H	синии	7	
J	лиловый	8	
K	серыи	9	
L	белыи	10	

NOTES: 1. GAUGE IN S.W.G. (STANDARD WIRE GAUGE)
2. MATERIAL COPPER: Cu
CONSTANTAN: CONST



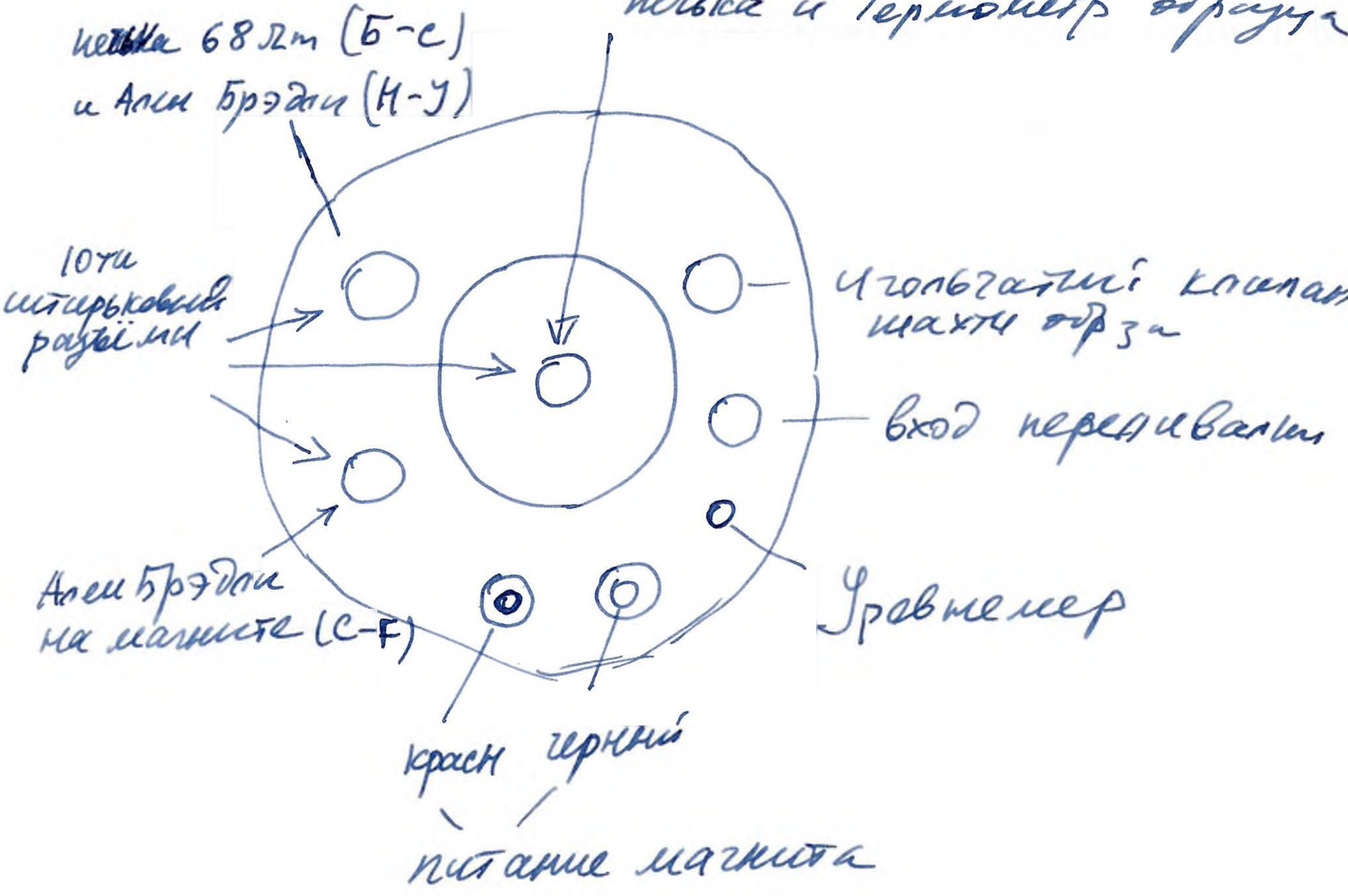
TEN PIN SEAL
VIEW ON PINS
(MALE)



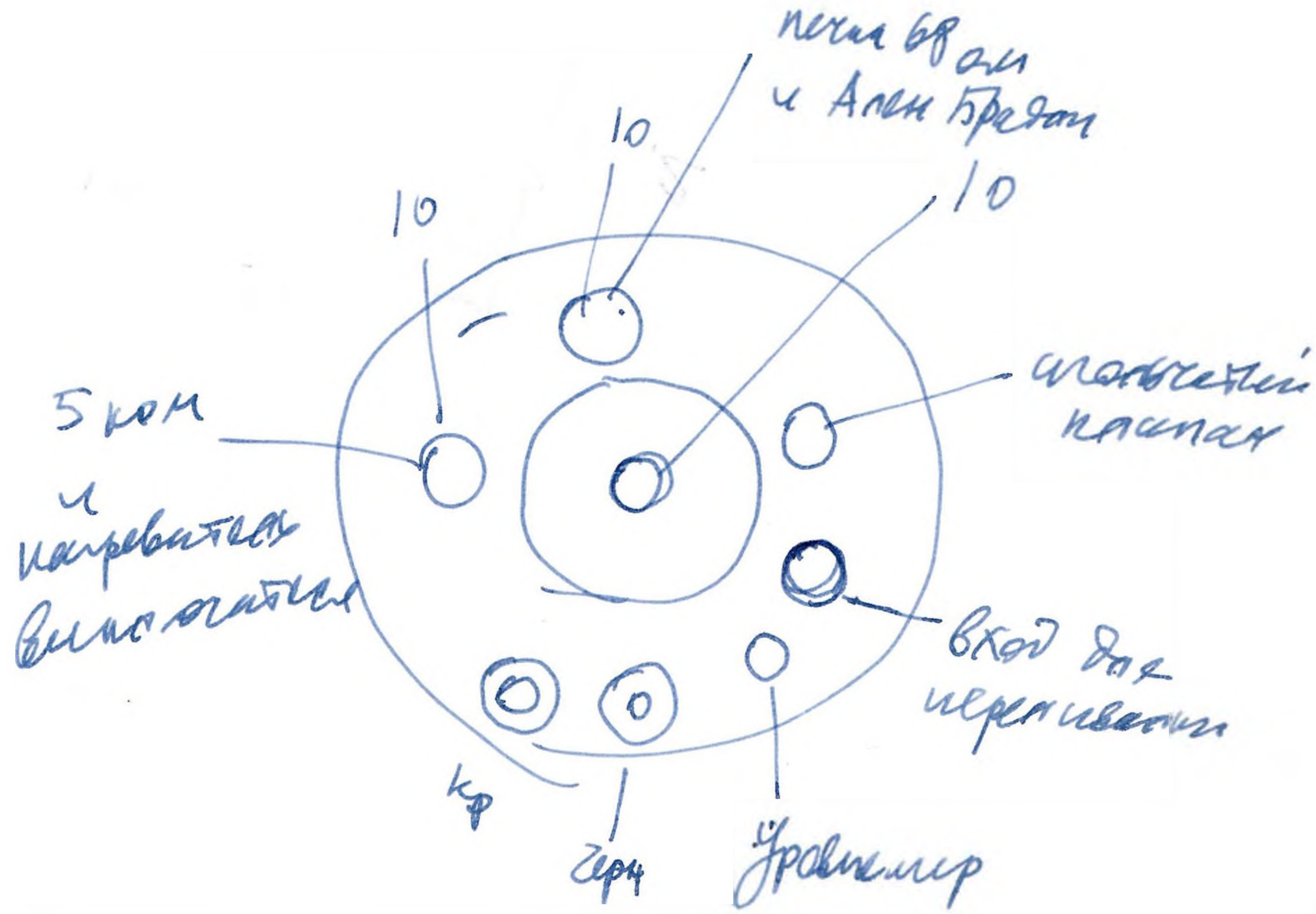
TEN PIN SEAL
VIEW ON SOCKET
(FEMALE)

PIN	CONNECTION	CONNECTING WIRE MATERIAL	GAUGE
A			
B			
C			
D			
E			
F			
H			
J			
K			
L			

NOTES: 1. GAUGE IN S.W.G. (STANDARD WIRE GAUGE)
2. MATERIAL COPPER: Cu
CONSTANTAN: CONST.


печка 68 Лт (Б-С)
и Ален Брэдли (Н-У)
печка и Термометр образца
10ти штырьковые разъёмы
игольчатый клапан шахты обр-за
вход переливалки
Уровнемер
Ален Брэдли на магните (С-F)
красн черный
питание магнита

Quanch at 9.8


10
10
10
5 ком
вход для
Уровнемер

SECTION 6.- TEST RESULTS

6.1. MAGNET SPECIFICATION

Project No: Project Name:

Maximum central magnetic field	at 4.2K	:	5	T
	at 2.2K	:	—	T
Current for central field	at 4.2K	:	75	A
	at 2.2K	:		A
Field/current ratio		:		T/A
Homogeneity (in 10mm DSV)		:		%
Other homogeneity requirements		:		
Current decay in persistent mode		:		/hr
Clear bore diameter at 4.2K		:		mm
Clear bore diameter at 77K		:		mm
Clear bore diameter at 300K		:		mm
Magnetic field centre from base of tails		:		mm
Nominal inductance		:		Henries
Superconductor type		:	NbTi	
Switch heater current for open state		:		mA (nom)

Resistance values at K

Magnet resistance Start-Finish (System*)	:		ohm (nom)
Superconductor switch resistance	:		ohm (nom)
Switch heater resistance	:		ohm (nom)
Isolation at 500 Volts :			
Magnet windings - former	:		M ohm
Magnet windings - switch heater	:		M ohm

Allen Bradley Sensors and Others

On System	pins C -		(A/B Common)
10 cm above lambda fridge	D	:	Ohms (100 nom)
On Lambda fridge	E	:	Ohms (100 nom)
On Top of magnet	F	:	Ohms (100 nom)
On Bottom of magnet	H	:	Ohms (100 nom)

(includes wiring resistance nominally 60 - 70 Ohms at 300K)

* System definition: Magnet mounted in its cryostat with full protection across it in its warm condition, i.e. before cooling. The room temperature resistance value is then the total resistance of a parallel circuit consisting of the protection circuit (if diodes are not fitted), magnet and switch. Since in general the magnet resistance is very much higher than the other two components then the switch resistance normally dominates.

Sweep time to field

-constant current :		mins (recommended for first run)
-constant voltage :		mins at 2 Volts (above lead drop)
-maximum rate	: At	Volts to field
used in test	: in	mins (Not recommended for everyday use)

6.1.1. Magnet Current and Settings

I a) Charging Rates for Constant Current Energising

1st run, after commissioning only, 2nd and all subsequent runs including runs after the system has been warmed up.

	Current/A			Rate/A min^{-1}	Approx Time/mins		
	1st Run	:	2nd Run		1st Run	:	2nd Run
PS120	-	:	-	12		:	
	-	:	-	6		:	
	-	:	-	2.4		:	
	-	:	-	1.2		:	
	-	:	-	0.6		:	
	-	:	-	0.24		:	
				TOTAL		:	

pump down to 2.2K then:

-	:	-	2.4		:	
-	:	-	1.2		:	
-	:	-	0.6		:	
-	:	-	0.24		:	
			TOTAL		:	

(Current for Field listed in magnet specification)

b) Voltage Setting for Constant Voltage Energising for runs after initial commissioning run (see above).

___ Volts above lead IR drop.

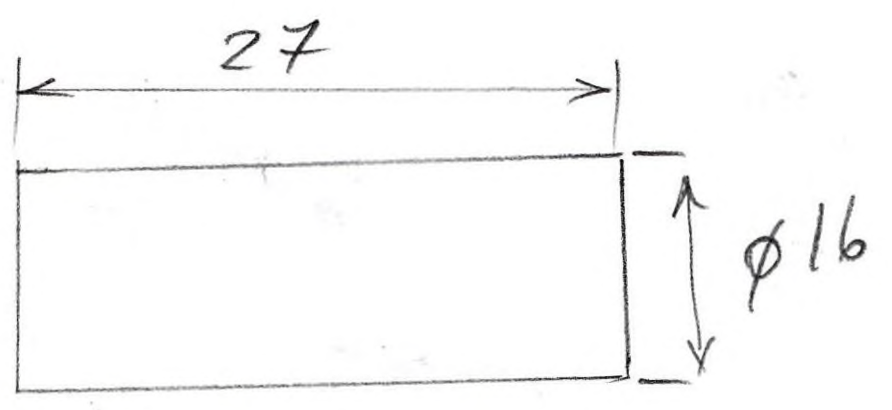
II Run leads down at following rates (magnet persistent)

Field to 0 A at 15 Amp/min

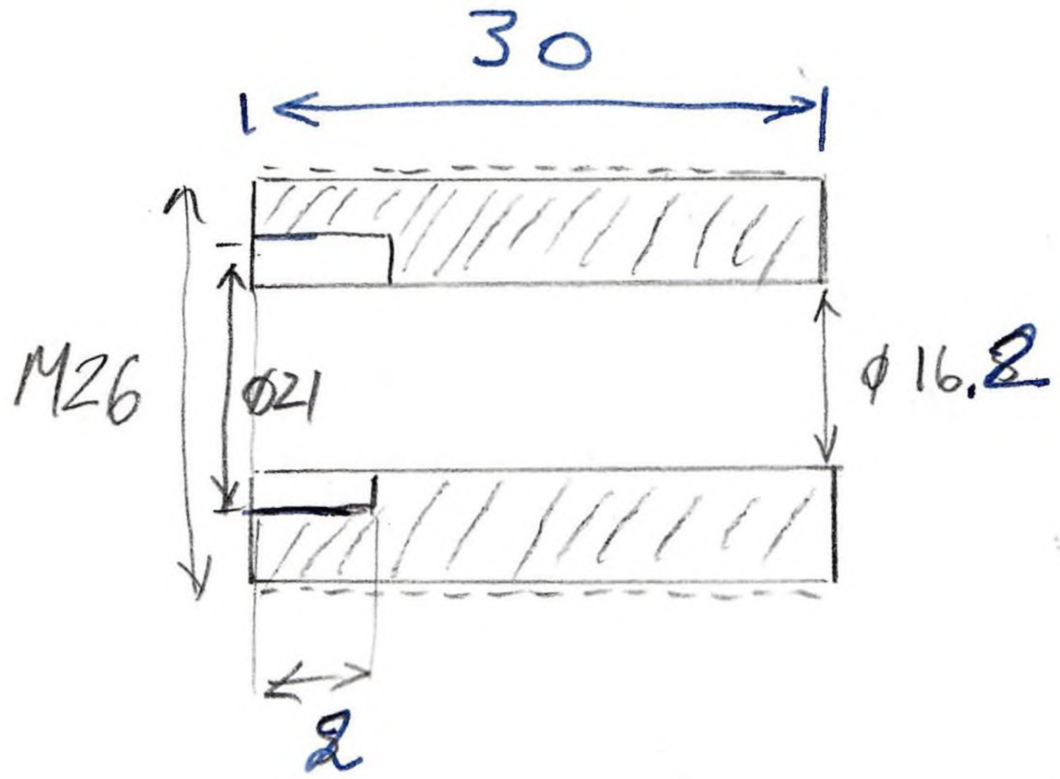
III Run leads up at same rates

IV Magnet may be run down at ___ A min^{-1} or at reverse of charging rates.

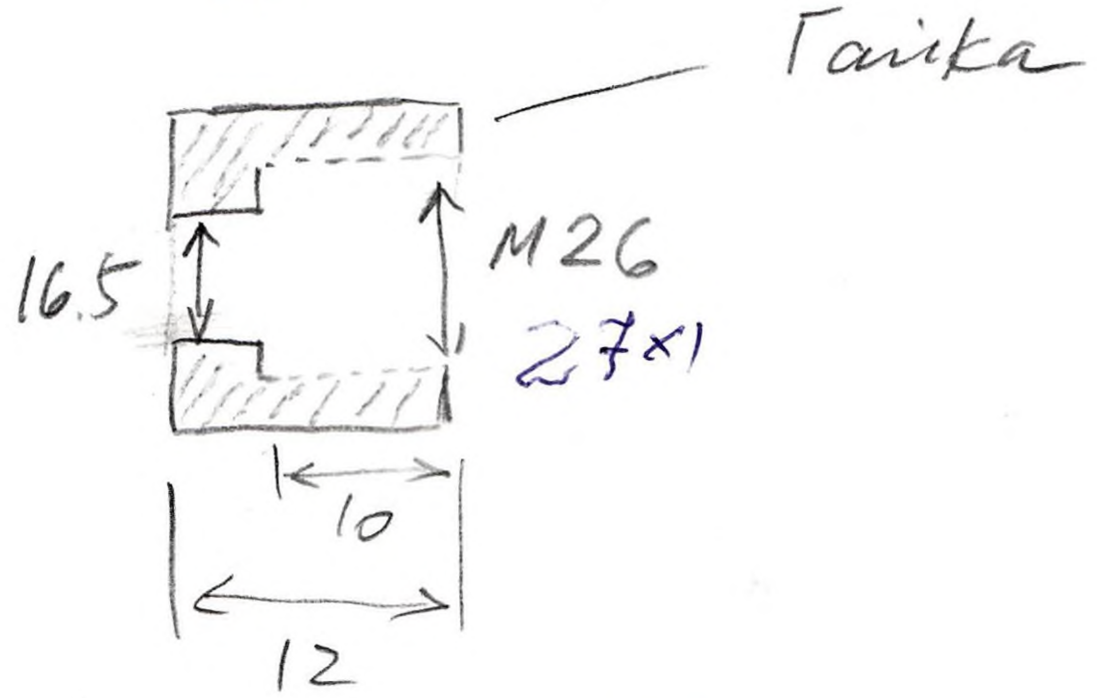
6.4. FIELD PLOTS.



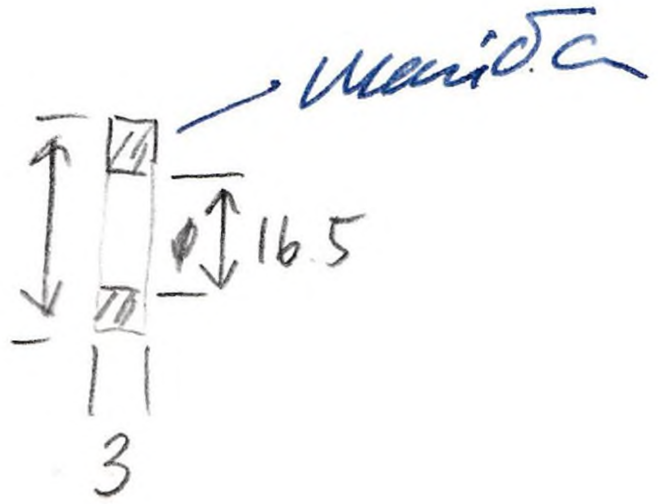
27
ϕ16



30
M26
Ø21
ϕ16.2
2



Гайка
16.5
M26
27×1
10
12



шайба
ϕ16.5
3

Oxford Instruments Limited
Eynsham, Oxford OX8 1TL, England
Telephone (0865) 882855.
Telex 83413. Fax (0865) 881567