# Application Notes

## Sensor installation

Measurements undertaken with accurately calibrated thermometers are of little use unless attention is given to sensor mounting. When mounting sensors, consideration must be given to thermal contact, temperature range, strain effects and unwanted heat loads.

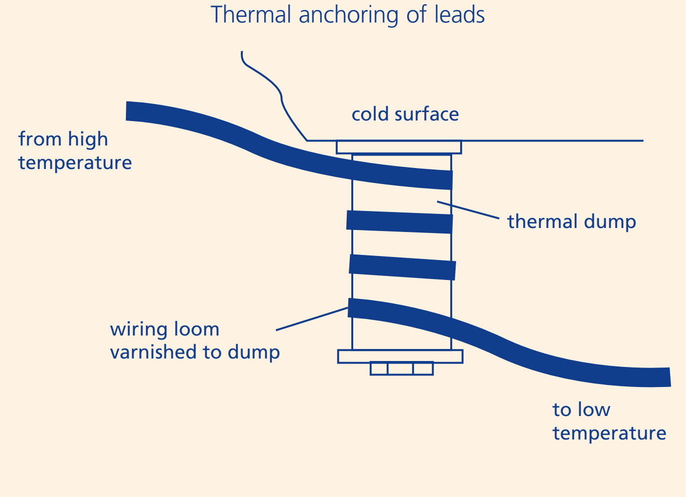
Cylindrical sensors are best mounted in a hole in the object to be measured, with a radial clearance of at most 0.1 mm. For temperature environments not exceeding 300 K, a thermally conductive grease (Type 'N' grease, A4-902) is recommended. For applications above 300 K, a high temperature sensor cement (C4-105) should be used. See Laboratory Essentials for specified consumables.

Thermocouples are usually brought into contact with the object to be measured using a clamp. Enhanced thermal contact is achieved by wrapping the junction in either indium (to 300 K), lead (to 500 K), or aluminium or copper tape.

Silicon diodes are very delicate and must be handled with care. The top face of the sensor must not be touched as this could result in damage to the diode chip or the 25 µm gold wire. The sensor may be mounted on a surface using GE low-temperature varnish (C5-101).

Sensors should never be mounted on a surface exposed to thermal radiation from room temperature. If necessary a covered mounting bracket should be fabricated. It is extremely important to ensure that the wiring for the sensor does not introduce unwanted heat loads. This is accomplished by thermally anchoring the leads on to the object to be measured. Additionally, wires should be anchored to intermediate stages in the cryostat to reduce conducted heat loads from room temperature. The simplest way is to wrap them around a copper post which is held at a known temperature. GE varnish is used to make sure that they are in good thermal contact with the post. Although its thermal conductivity is poor, it gives a large area of contact. See Figure below.

Thermal anchoring of leads




The same techniques can be applied to systems working at millikelvin temperatures. A heat load of 0.1 µW is enough to produce noticeable warming at these temperatures.

In a dilution refrigerator the wiring is typically fixed at the following temperatures:

- 4.2 K, cooled by the liquid helium bath, where the majority of the heat is absorbed
- 1.2 K, on the 1 K pot
- 0.6 K, on the still
- 50 mK, on the cold plate
- on the mixing chamber, to cool the wires to the same temperature as the experiment

If the wires are in gas or liquid – for example, if the experiment is carried out in liquid helium or helium gas in a variable temperature insert, the gas flows over the wires before it leaves the cryostat. This cools them effectively, and it is only necessary to make sure that sufficient length of wire is in contact with the cold gas. Allow the wires to spiral around some convenient mechanical support, such as a pumping line or support leg.

If it is important that the capacitance between the wires and ground is very low (for example, less than 100 pF), alternative methods of heat sinking have to be considered. One method is to clamp the wires firmly, and another is to encapsulate them in epoxy resin.

## Sensor mounting at milli-kelvin temperatures

When measuring milli-kelvin temperatures it is essential that the sensor is in intimate thermal contact with the part of the apparatus whose temperature is to be measured. It is not always sufficient to attach the sensor to the refrigerator itself because there may be a significant temperature difference between the sample and the cold point of the refrigerator, especially when the experimental heat load is high. It is also possible that there will be significant temperature differences across the sample itself. The important parameter is the effectiveness of the heat transfer from the sample to the sensor.

In general good thermal contact (to a solid thermometer or holder) is obtained by face to face contact between two clean copper surfaces. Gold-plating the copper surfaces will improve thermal contact. The surfaces should be pressed together using a screw thread (or similar clamping method), so that there is a large force between them. It is important to avoid the presence of any superconducting materials in the thermal path because they are very good thermal insulators. Many solders become superconducting at milli-kelvin temperatures. In some cases it may be acceptable to suppress the superconductivity using a small magnetic field (<0.1 T). Superconducting transitions of a few common materials are listed in the Cryogenic Reference section. Non-superconducting solder is available.

At very low temperatures there is a large thermal resistance ("Kapitza resistance") between liquid helium and any solid. When even a small amount of heat is supplied to the sample, its temperature quickly rises to a value much higher than that of the $^3He/^4He$ mixture. The most effective way to ensure good thermal contact between the sample and the mixture is to mount the sample directly onto a mixing chamber that has been designed with a very large surface area to make good thermal contact with the mixture.

## Twisted pairs

Electrical noise is often picked up by an electrical circuit, and if sensitive measurements are being made the noise may make it difficult to detect a signal. The noise can also contribute to radio frequency heating of the sensor in ultra low temperature systems. One way of reducing the electrical noise pick up is to arrange the wires in twisted pairs. The wires are twisted together for their whole length, so that the currents induced by flux passing between the wires in each twist is cancelled by that in the next twist.

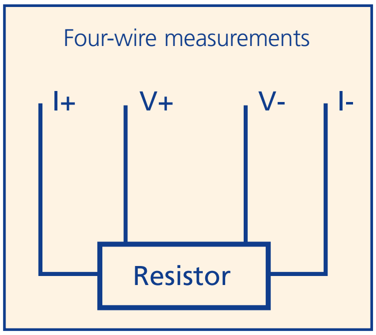
## Thermo-electric voltages

If two dissimilar metals are joined together they act as a thermocouple, and small voltages (typically microvolts) can be generated. If very low voltage signals are being measured steps have to be taken to reduce the thermal voltages, so that they do not affect the readings. This is especially important at temperatures below 4 K, when very small excitation currents are required to prevent self-heating. As there are always some joints, it is important to ensure that the joints in all the wires are at exactly the same temperature. The dependence on temperature (near room temperature) of thermoelectric voltage with respect to copper (relative thermopower) is given in the table. These figures should be treated with caution, as the thermolectric properties of copper are very sensitive to purity.

**Thermoelectic voltage coefficient with respect to copper**

| Metal | μV/K |
|---|---|
| Copper | <0.3 |
| Constantan (copper-nickel) | 40 |
| Gold | 0.5 |
| Silver | 0.5 |
| Brass | 3 |
| Beryllium Copper | 5 |
| Aluminum | 5 |
| Kovar or Alloy 42 | 40 |
| Silicon | 500 |
| Copper-Oxide | 1000 |
| Cadmium-Tin Solder | 0.2 |
| Tin-Lead Solder | 5 |

## Four wire measurements




Cryogenic resistance thermometry requires the use of the four-wire technique. Using this technique a sensor with a resistance of a few ohms can be measured accurately through leads with a resistances of several hundred ohms. Two wires are used to supply the excitation current. The other two wires are used to measure the voltage across the sensor. Since there is almost no current flowing in these wires the voltage drop along them is tiny, and their resistance can also be neglected.

All Oxford Instruments temperature controllers and monitors use the four-wire technique.

## Ultra-High Vacuum (UHV) systems

While some sensors in bare chip form or hermetic packages are reported to be suitable for use in UHV, it is always advisable to mount the sensor and wiring outside the UHV space if possible. Mounting sensors and thermally anchoring the wires is made much easier by use of greases, adhesives, varnish, insulating sleeving and fishing line, none of which are advisable in UHV.

## Accuracy in temperature measurement

The Oxford Instruments ITC500 series of temperature controllers and monitors has designated excitation currents for each sensor offered which ensure negligible self-heating over the recommended temperature range.

Semiconductor resistance sensors have a resistance which rises rapidly with decreasing temperature. In the ITC500 series the sensor current is measured at constant voltage for these sensors. This reduces the risk of self-heating since the current is automatically reduced with decreasing temperature.

The tables below summarise the capabilities of the ITC500 series temperature controllers and monitors when used with fully calibrated sensors.

| Sensor | Rhodium-Iron | Cernox |
|---|---|---|
| Temperature range for which these figures have been estimated | 1.4 – 300 K | 1.4 – 300 K |
| Display resolution | 0.1 K | 0.1 K |
| Accuracy | 0.1 K | 0.1 K |

Accuracy of measurement for sensors used with the ITC501 monitor or the ITC502 controller

| Sensor | Rhodium-Iron | Cernox |
|---|---|---|
| Temperature range | 1.4 – 300 K | 1.4 – 300 K |
| Display resolution | | |
| T≤19.99K<br>20 K≤T≤199.99 K<br>T≥200 K | 1 mK<br>10 mK<br>100 mK | 1 mK<br>10 mK<br>100 mK |
| Accuracy | | |
| T≤19.99K<br>20 K≤T≤199.99 K<br>T≥200 K | 30 mK<br>30 mK<br>100 mK | 30 mK<br>30 mK<br>100 mK |

Accuracy of measurement for sensors used with the ITC503 temperature controller

References
"Cryogenic Thermometry: A Review of Recent Progress ", L. G. Rubin, Cryogenics, Vol 10, 14-20, (1970).
"Cryogenic Thermometry: A Review of Progress Since 1970", L. G. Rubin, B.L. Brandt and H.H. Sample, Cryogenics, Vol 22, 491 (1982).
"Cryogenic Thermometry: A Review of Progress Since 1982", L. G. Rubin, Cryogenics, Vol 37, 341-356, (1997).