THERMAL SENSORS

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SEP
Science Enhancement Programme

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education. For further information, visit www.sep.org.uk

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THERMAL SENSORS

INTRODUCTION

The student material About thermal sensors gives an introduction to the different types of thermal sensor and to the functioning of some temperature sensors, but it does not go into detail and does not cover the complete range.

Temperature sensors are one of the first types of sensor that students will come across, but probably in non-electronic forms – the **alcohol in glass** or **mercury in glass thermometers**. Here there is an opportunity to let your students see the range of devices available and be able to **calibrate** and use a couple of them.

Two other thermometers, the **infrared laser pointing thermometer** and the **infrared ear thermometer**, are the most modern types that you are likely to get access to. Neither is very expensive and both are available from Shaw Scientific Education (UK) Limited. These rely on measuring the energy associated with the incident infrared radiation of particular wavelengths falling on a pyroelectric crystal in a set time. With the ear thermometer this time is typically between 0.1s and 0.3s. The crystal builds up a charge as a result and this is related to the temperature of the object being examined. Some years ago Kynar film was made available to schools in the UK. This material is **pyroelectric** and is sensitive to infrared radiation. If it becomes available cheaply again, it might be worth investigating its use.

Whilst the **liquid crystal forehead temperature strips** are of interest, explaining how they work is best left to a later date.

THE ACTIVITIES

Although just measuring a **thermistor's** resistance and matching this to a temperature is no longer a common method, it is one means of doing so. Such a method also makes it very clear that **with most thermistors there is a very non-linear relationship between their resistance and temperature.**

A more common set-up is with a **potential divider network**. However, due to this non-linearity, deciding the ideal resistor to place in series with the thermistor is not that easy. In fact the choice of resistor will vary according to the range of temperature that one wishes to sense over. In the students' experiment a sensible choice is 47kΩ. Although details of how a potential divider network functions are provided, complete with calculations to show how the voltage output range with a sensor varies with the resistor chosen, many students would not greatly appreciate this. For them it may be best to just demonstrate how this range is affected by the choice of resistor.

The **band-gap sensor** LM35DZ is rather special in that its voltage output, for a range of supply voltages, is 0V at 0°C and 1.0V at 100°C, varying linearly in between. Hopefully the students will realise how handy this is.

All the activities involve the heating of water (to boiling if required) and so an appreciation of the hazards is required. Students should be wearing safety goggles, be provided with beaker tongs, and instructed to stand rather than sit.

Whilst the students will be calibrating the sensors over a range from 0°C to 100°C, it will prove useful to raise the issue of **fixed points** which have defined temperatures, rather than utilising (calibrated) temperature measuring instruments.

Results obtained

Thermistor

Temperature /°C	Resistance /kΩ
0	534.9
24	159.2
33	106.0
53	48.5
68	25.7
85	14.1
100	7.73

Temperature /°C	Voltage /V
1	0.54
23	1.29
35	1.98
59	3.44
77	4.33
100	5.21

Temperature /°C	Voltage /mV
1	508
21	1165
33	1670
52	2950
68	3780
83	4500
92	4995

Band-gap sensor

Temperature /°C	Voltage /V
0	0.00
23	0.23
38	0.38
62	0.61
89	0.85
97	0.93

Temperature /°C	Voltage /mV
0	32
21	229
31	300
41	410
65	627
78	748
97	938

__Note:__ The displayed resolution of the temperature on the computer screen will not actually be correct. Although this can be dealt with in setting up PicoScope it is better to leave it as it is, and discuss the issue with students

Other possible activities using different types of sensor

One sensor which was considered for use is the **Temperature Sensing Resistor** PRC100 (RS Components Ltd RS 341-452) which has a resistance at 0°C of 100Ω and a resistance at 100°C of 138.5Ω. Its change of resistance is linear over the range -40°C to +150°C. It is made of wire of an alloy of nickel, copper, manganese and iron. This could be experimented with but is quite expensive to purchase. Similarly, students could investigate the use of a **diode as a temperature sensor** (the *Dr DAQ* built-in sensor is a semiconductor diode, for example) or indeed the platinum resistance film sensor.

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THERMAL SENSORS: TECHNICAL NOTES

USING A BAND-GAP LM35DZ TEMPERATURE SENSOR

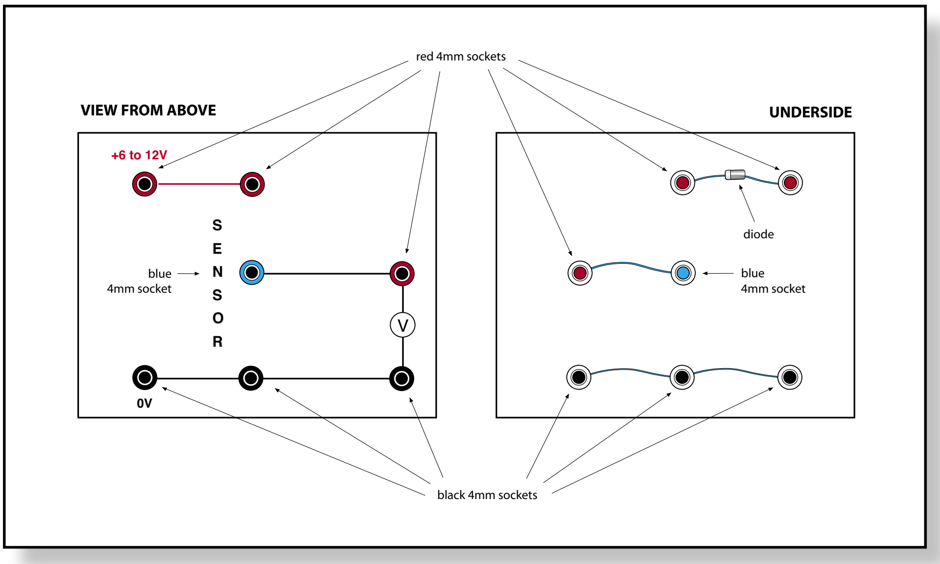
(I) USING THE LM35DZ WITH A MULTIMETER

Note: ***Many components and items of equipment are commonly available in science departments, or can be obtained from a wide range of suppliers. Where equipment and components are listed with a supplier and product code, these are less widely available and are the versions used when the activities were developed, so any sample results will be based on them. It may be possible to obtain the same or equivalent equipment or components from other suppliers.***

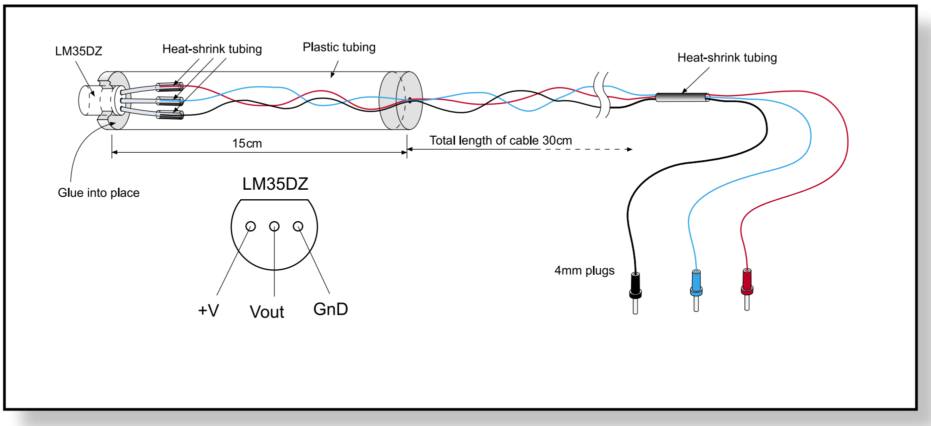
Equipment:

6V battery
multimeter/voltmeter
bunsen burner with tripod, gauze, and heat-proof mat, or other appropriate heating arrangement
beaker 250ml
connecting leads
thermometer –10 to 110°C
beaker tongs
temperature sensing unit – see construction notes
band-gap sensor – see construction notes
white trunking
3 x red 4mm socket
3 x black 4mm socket
1 x blue 4mm socket
equipment wire black
equipment wire red
equipment wire blue
diode 1N4001
LM35DZ precision centigrade temperature sensor (Maplin UF52G)
heat shrink sleeving 1.5mm i.d.
plastic tubing (eg, W Hobby TBFS10)
sealant
rapid adhesive (such as Araldite, or similar)

Note: *the marked band on the diode is nearest the central top red 4mm socket.*



Temperature sensing unit construction



Band-gap sensor construction

When assembling the band-gap sensor be careful to ensure that the soldered connections between it and the coloured wires are insulated with heat shrink sleeving. The LM35DZ is simply glued into the end of the plastic tubing but it is essential that this glueing seals this end of the tube to prevent water ingress. Seal the other end of the tube with white bath sealant.

(II) USING WITH PICOSCOPE AND DRDAQ

Note: *The activity notes and technical notes are for DrDAQ and associated computer equipment, but other datalogging equipment could also be used, with modification of the student activities Word version.*

Note: *If the computers are connected to a network you may need to provide some additional notes for the students on their use with DrDAQ and PicoScope*

Equipment (additional):

computer
*DrDAQ** and associated connecting cable , plus PicoScope software (Pico Technology)

*It is useful to mount *DrDAQ* onto half square-section downpipe using Velcro. Then link *DrDAQ's* **V** terminal to a red 4mm socket, its **R** terminal to a 4mm blue socket, its **DO** terminal to a 4mm yellow socket and its **GND** terminal to a 4mm black socket.

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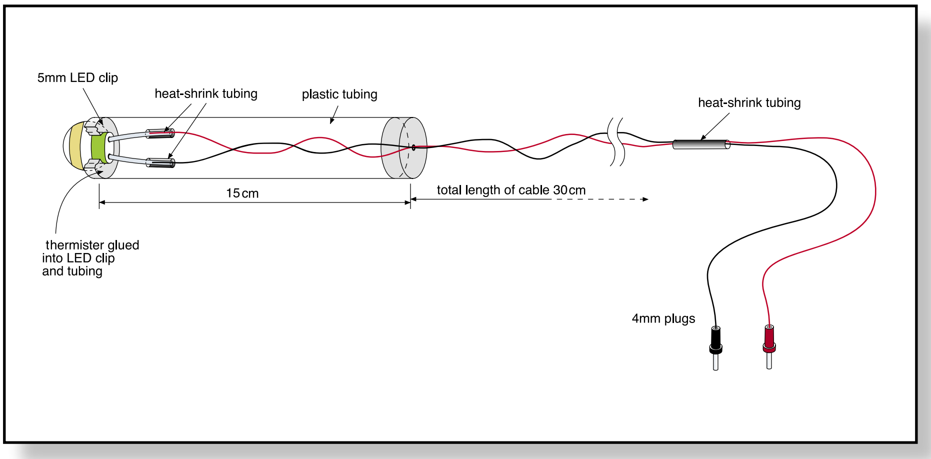
USING A THERMISTOR AS A TEMPERATURE SENSOR

(I) USING WITH A MULTIMETER ON ITS RESISTANCE RANGE

Equipment:

multimeter
beaker 250ml
beaker tongs
-10 to 110°C thermometer
thermistor sensor – see construction details
bunsen burner, tripod, gauze, heat-proof mat or other form of appropriate heating
plastic tubing (eg W Hobby TPFS12)
thermistor 150kΩ
rapid adhesive Araldite
5mm led clip
bath sealant
heat shrink sleeving 1.5mm i.d.
equipment wire black
equipment wire red
4mm plug black
4mm plug red



Thermistor sensor construction

To prevent shorting of the thermistors leads it is essential that their connections with the red and black wires are insulated with the heat shrink sleeving. Glue the led clip into the top of the plastic tubing. Now fit the thermistor into the top of the led clip and glue it into place such that the glue also seals this end of the tube. Seal the other end with bath sealant.

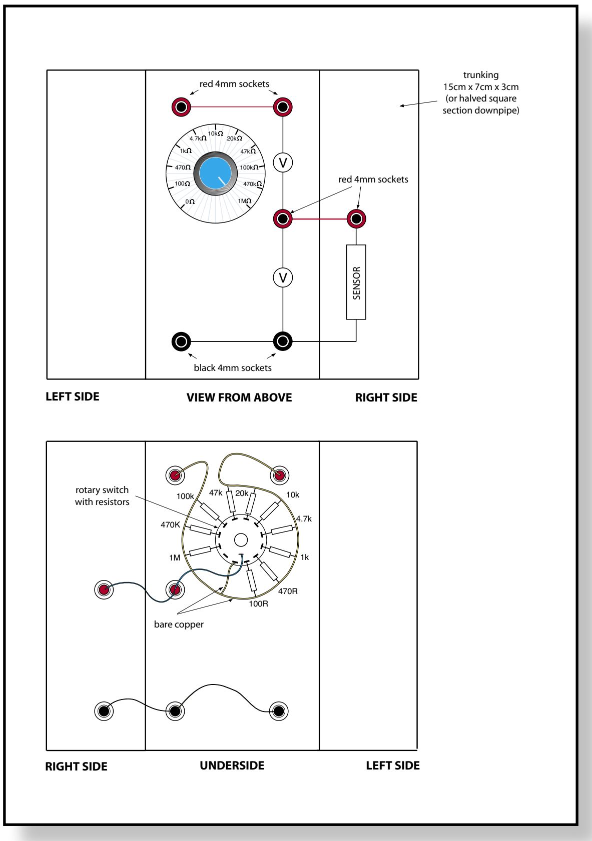
(II) USING A THERMISTOR TEMPERATURE SENSOR WITH A POTENTIAL DIVIDER NETWORK AND A VOLTMETER TO MEASURE TEMPERATURE

Equipment (additional):

6V battery
universal potential divider unit – see construction diagram
connecting leads
plastic trunking
3 x 4mm black socket
4 x 4mm red socket
rotary switch 1 pole 12 way
collet knob (eg Maplin YG40T)
L C cap – blue (eg Maplin QY01B)
resistor M100R - 0.6W *
resistor 470R - 0.25W
resistor 1K - 0.25W
resistor 4.7K - 0.25W
resistor 10K - 0.25W
resistor 20K - 0.25W
resistor 47K - 0.25W
resistor 100K - 0.25W
resistor 470K - 0.25W
resistor 1M -0.25W
copper wire 18swg tinned

Note – *the 100Ω resistor needs to be of higher power rating than the others.*

For polar graph paper (to make potentiometer scale) – go to freeware site at http://www.engj.ulst.ac.uk/sidk/graph/graph.htm for download of programme to print polar and many other kinds of graph paper.



Universal potential divider construction

(III) USING WITH PICOSCOPE AND DRDAQ

Note: *The activity notes and technical notes are for DrDAQ and associated computer equipment, but other datalogging equipment could also be used, with modification of the student activities Word version.*

Note*: If the computers are connected to a network you may need to provide some additional notes for the students on their use with DrDAQ and PicoScope.*

Equipment (additional):

computer
*DrDAQ** and associated connecting cable (Pico Technology)
PicoScope software (Pico Technology) – updates free on their website.

*It is useful to mount *DrDAQ* onto half square-section downpipe using Velcro. Then link *DrDAQ's* **V** terminal to a red 4mm socket, its **R** terminal to a 4mm blue socket, its **DO** terminal to a 4mm yellow socket and its **GND** terminal to a 4mm black socket.

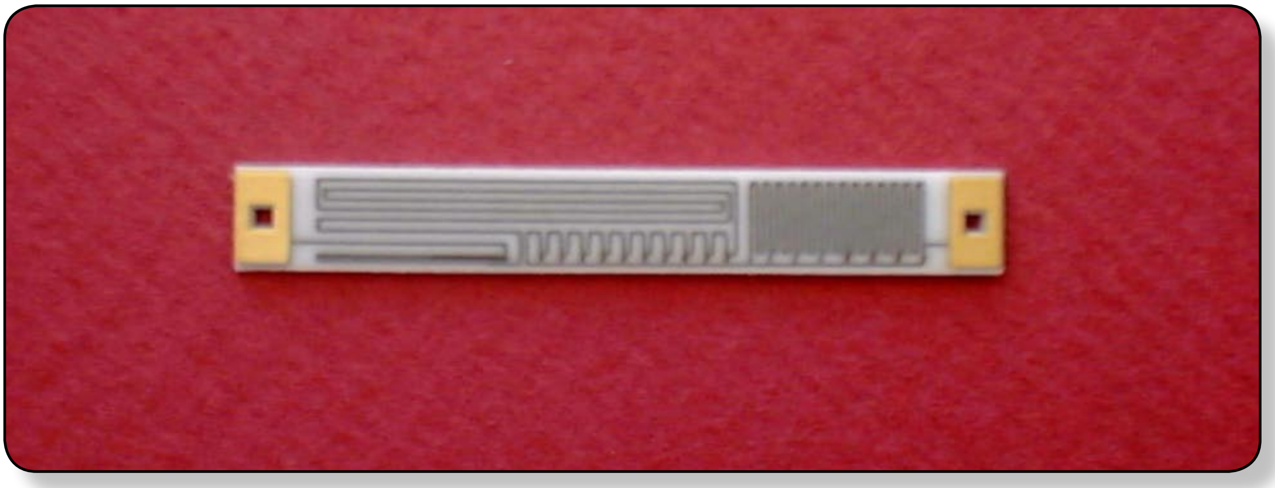
About thermal sensors

Temperature is a very widely measured quantity. It may be measured in order to control the temperature of a room or building, a furnace or a hot-plate. In the medical field it is frequently an indicator of well-being or illness.

Alcohol in glass and mercury in glass thermometers

Types of thermal sensor and how they work

One of the oldest forms of temperature indicator – a **thermometer** – is that of the **alcohol in glass** and **mercury in glass** type, each dependent on the linear expansion of the liquids alcohol and mercury with rise in temperature. However, there are many other ways of sensing and measuring temperature.



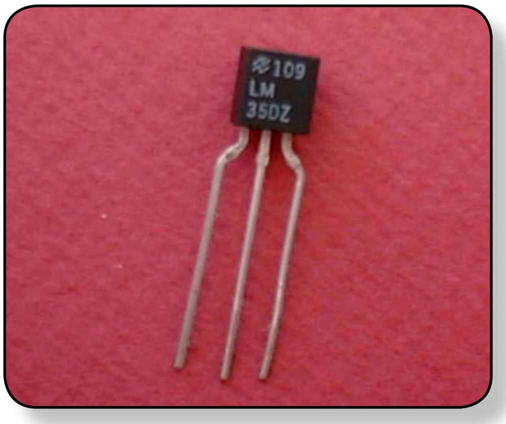
Platinum film resistance detector

The **platinum resistance thermometer** originally consisted of a coil of platinum wire mounted on a ceramic former. As its temperature rose, so its resistance increased also. Modern versions now consist of a supporting base on which a conductive track of platinum 'ink' is placed, much like that of a strain gauge. They are known as **platinum film resistance detectors**. They are very robust and are often used in hazardous environments such as in space. As their change of resistance is quite small for a given temperature change, amplification is employed. Their small mass makes them very responsive to temperature changes.

About thermal sensors

Thermistors

Thermistors – temperature sensitive resistors – are made up of mixtures of many substances, frequently oxides of cobalt, copper, iron, manganese, nickel or uranium, or a sintered mixture of selenides and sulphides. They can be used over wide ranges of temperature, with the smallest bead type also being quick to respond to temperature changes. Two main varieties exist, the **n.t.c** (negative temperature coefficient) which decrease in resistance as the temperature rises, and the **p.t.c.** (positive temperature coefficient) which increase in resistance as the temperature rises. One of the thermal sensor activities makes use of a thermistor.



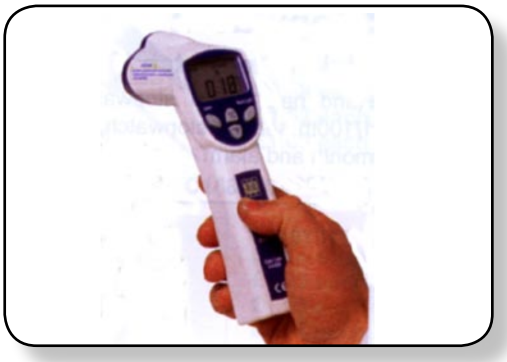
Band-gap sensor

Towards the end of the 20th century a group of temperature sensors called **band-gap sensors** were developed, and the LM35 used in one of the thermal sensor activities is a well-known example. Their design is such that 'conversion' from a voltage output to a temperature is very straightforward.

semiconductor diode

Semiconductor diodes can also be used as temperature sensors, as the diode's resistance is also temperature dependent. Like the bead thermistor, their small mass allows them to respond quickly to any temperature changes.

In 1822 the German physicist Thomas Seebeck discovered that when two wires made of different metals are twisted together, a small voltage is generated between the wires' free ends. This is the basis of the **thermocouple thermometer.** As they are very cheap to make and again have fast response times, they are in very common use in a vast range of temperature sensing applications.

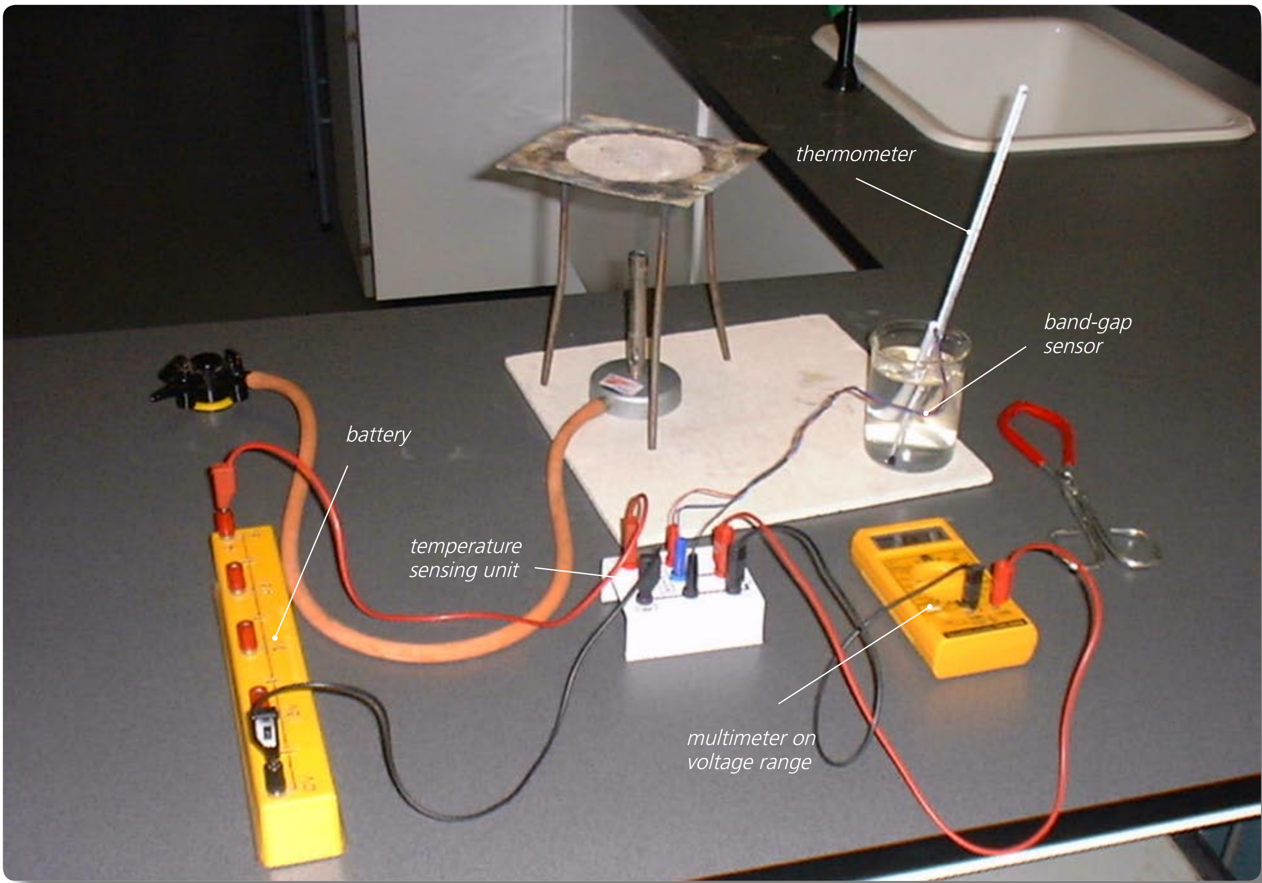


Laser pointing Infrared thermometer
(courtesy Shaw Scientific Education (UK) Limited)

If you have been to the doctor or to hospital recently you may have had your temperature taken by an **infrared temperature sensor** placed in your ear. This uses the infrared radiation given off by warm and hot objects to assess their temperatures. Remote use versions of these have **laser pointers** attached to highlight what is being pointed at and sensed.

Activity (i): Using the LM35DZ with a multimeter

Procedure



The LM35DZ connected to a multimeter

SAFETY NOTE: Safety goggles need to be worn whilst you are conducting these activities. It is also much safer to stand alongside a beaker of water being heated as, if the hot water was knocked over, you would be able to move out of the way more quickly than if seated.

Calibration

- Connect the red +6 to 12V socket of the **temperature sensor unit** to the +6V socket of the battery and the black 0V socket of the unit to the 0V socket of the battery.
- Plug the **band-gap temperature sensor's three coloured leads**/plugs into their respective coloured sockets on the temperature sensing unit.
- Finally, connect the **multimeter** (or **voltmeter**) set to a **2V range** to the voltage output sockets of the temperature sensing unit. It should appear as shown above.
- Set up a bunsen burner, tripod, gauze and heat-proof mat, or other form of appropriate heating.
- Place melting ice into a beaker and insert the temperature sensor together with a thermometer, gently give the melting ice a stir. After a minute or so give the melting ice another gentle stir and note its temperature and the voltage output in your table.

Activity (i): Using the LM35DZ with a multimeter

- Remove the temperature sensor and thermometer and empty out the ice. Two-thirds fill the beaker with water from the tap. Put the temperature sensor and thermometer back into the beaker, give the water a stir and leave for about a minute. Stir the water again, note its temperature and the voltage output in your table.
- Remove the temperature sensor from the beaker. Place the beaker, together with the thermometer, on the tripod and heat gently for a few minutes until the water has reached a temperature of around 40°C.
- Remove the beaker with the beaker tongs and place it on the heat-proof mat. Put the temperature sensor into the heated water and stir gently. Leave it for a minute or so, stir gently again and record the temperature and the voltage output in your table.
- Repeat this process to obtain another three sets of readings of temperature and voltage output, the last near or at the boiling point of water. Turn off the Bunsen burner if it is no longer needed.
- Now plot a graph of voltage output (Y-axis) against temperature (X-axis) and incorporate a best-fit line. You could do this manually or by entereing your results into a graphing package or spreadsheet.

You will now have calibrated the temperature sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown temperature.

Using the calibrated temperature sensor

- Place the **temperature sensor** into a **beaker of water of unknown temperature** (do not insert a thermometer) and record the voltage output. Using your calibration 'curve', note down what you think its temperature must be.
- Now measure the unknown temperature using the thermometer.

Activity (i): Using the LM35DZ with a multimeter

Results

Temperature /°C	Voltage output /V

Questions

What do you notice about the voltage output values and the related temperatures? Look carefully.

Does your graph show the voltage output to be
(a) **linearly related to** the temperature
and
(b) **directly proportional to** the temperature? Explain.

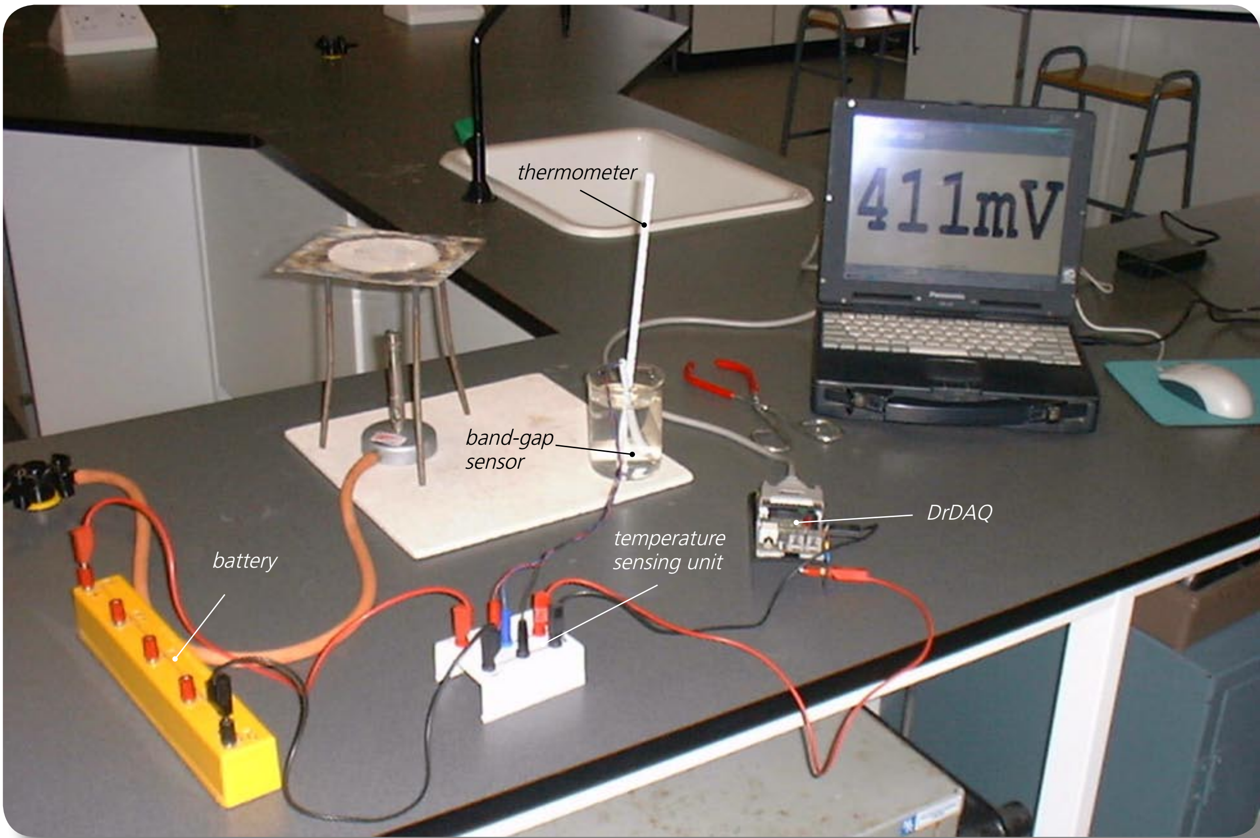
How close was your estimate of the water's temperature?

Why wouldn't a prediction of an unknown temperature be so reliable if the voltage output obtained for it was way beyond those used to produce the calibration 'curve'?

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ

This equipment allows you to have the digital meter reading directly as a thermometer, giving a temperature in degrees Celsius. (This is not possible with an ordinary multimeter or millivoltmeter).

Procedure



Band-gap temperature sensor set up to use with PicoScope on DrDAQ

SAFETY NOTE: Safety goggles need to be worn whilst you are conducting these activities. It is also much safer to stand alongside a beaker of water being heated as, if the hot water was knocked over, you would be able to move out of the way more quickly than if seated.

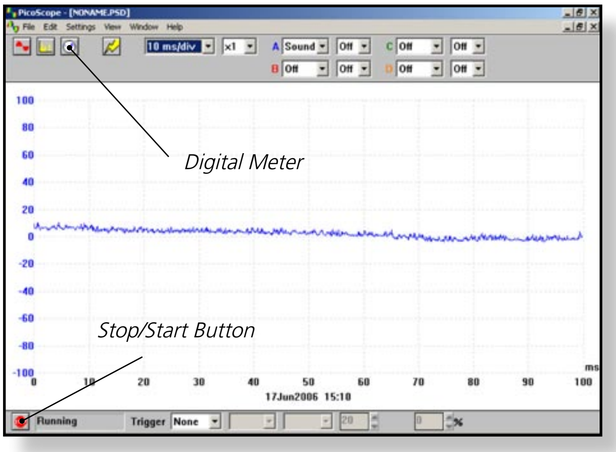
Before the computer is switched on check that *DrDAQ* has been plugged into the computer.

Calibration

Note: If you are connected via a network you may need to obtain additional instructions.

- Connect the red +6 to 12V socket of the **temperature sensor unit** to the +6V socket of the battery and the black 0V socket of the unit to the 0V socket of the battery.
- Plug the **band-gap temperature sensor's three coloured leads/plugs** into their respective coloured sockets on the **temperature sensing unit.**
- Connect the red voltage output socket of the temperature sensing unit to the **V** socket on *DrDAQ* and the black Voltage output socket to the **GND** socket of *DrDAQ*.

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ



DrDAQ opening screen

- Switch on and load the PicoScope software. If necessary, enlarge by clicking the in the top right-hand corner of the screen to provide a full screen display as shown with the program already running.

Note: If the program appears to have frozen at any time then it can usually be unfrozen by pressing the F10 function key. If this does not succeed then close down the program by pressing the Ctrl, Alt and Delete keys simultaneously, and then restart the program.

Digital Voltmeter display

- Click the **STOP** button in the bottom left-hand corner of the screen. Close down the Oscilloscope mode by clicking the lower of the two Xs in the top right-hand corner of the screen.
- Now click on the **Digital Meter** icon in the Toolbar, select **Volts** and **DC Signal** and then click the **GO** button to put PicoScope into **Display Voltmeter mode**. You should get a display like that shown, though not necessarily of that value.

- Set up a bunsen burner, tripod, gauze and heat-proof mat, or other form of appropriate heating.
- Place melting ice into a beaker and insert the **temperature sensor together with a thermometer**, gently give the melting ice a stir. After a minute or, so give the melting ice another gentle stir and note its temperature and the voltage output in your table.
- Remove the temperature sensor and thermometer and empty out the ice.
- Two-thirds fill the beaker with water from the tap. Put the temperature sensor and thermometer back into the beaker, give the water a stir and leave for about a minute. Stir the water again, and note its temperature and the voltage output in your table.
- Remove the temperature sensor from the beaker. Place the beaker, together with the thermometer, on the tripod and heat gently for a few minutes until the water has reached a temperature of around 40°C.
- Remove the beaker with the beaker tongs and place it on the heat-proof mat. Put the temperature sensor into the heated water and stir gently. Leave it for a minute or so, stir gently again and record the temperature and the voltage output in your table.
- Repeat this process to obtain another three sets of readings of temperature and voltage output, the last near or at the boiling point of water.

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ

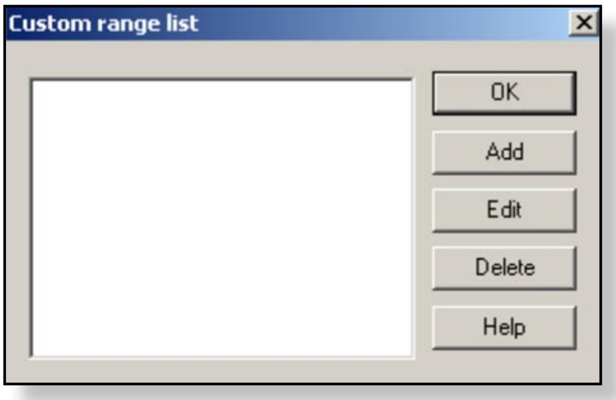
- Now plot a graph of voltage output (Y-axis) against temperature (X-axis) and incorporate a best-fit line.

You will now have calibrated the temperature sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown temperature.

Using the calibrated temperature sensor

- Place the **temperature sensor** into a **beaker of water of unknown temperature** (do not insert a thermometer) and record the voltage output. Using your calibration 'curve', note down what you think its temperature must be.
- Now measure the unknown temperature using the thermometer.

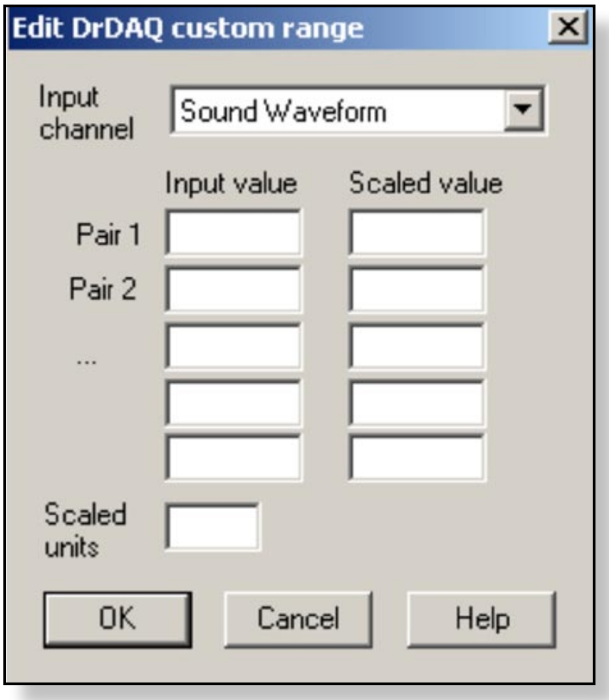
In everyday life, it would be unusual to find an instrument which had not been calibrated for direct use. With a computer-based device it is often possible to calibrate it so that it automatically displays the quantity you wish to measure directly on the screen. In this case you would want to get the computer to 'convert' the voltage input to give a temperature display on the screen. With PicoScope this is easily done by setting up a **Custom Range:**



Custom range list

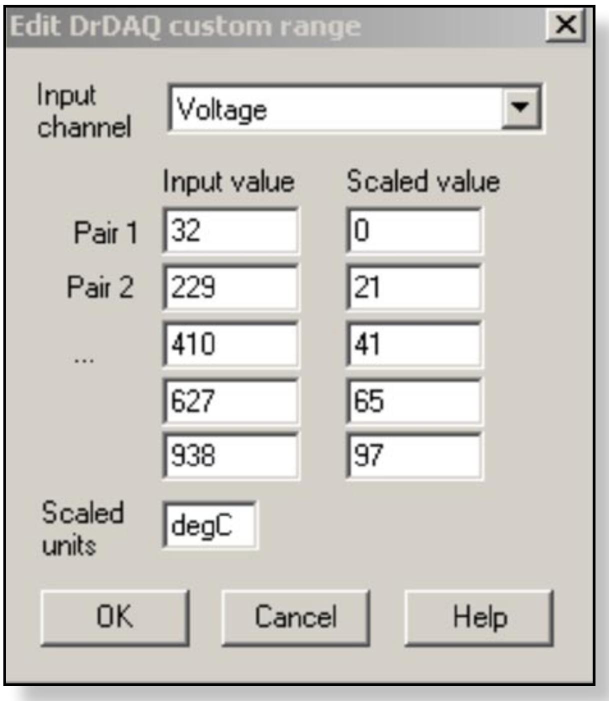
- Click the **STOP** button. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the **Custom range list** as shown.

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ



DrDAQ Custom range box

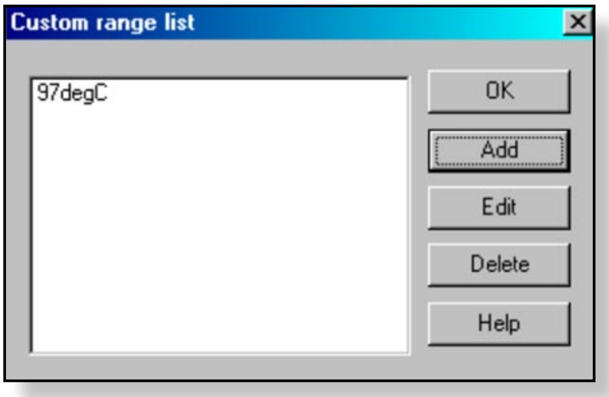
- Click on **Add** to display the Edit *DrDAQ* custom range box.



Adding values and scaled units

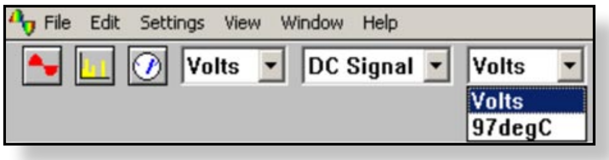
- Select the Input channel 'Voltage' by clicking on the down arrow alongside. Now type in your pairs of data into the two columns – voltage output into the **Input value column** and the temperature into the **Scaled value column**. Ensure that you input the lowest temperature and the Voltage output that this produced as the Pair 1. Make the last pair the highest temperature obtained and its corresponding voltage output. Type **'degC'** for degrees Celsius into the Scaled units box. It should appear something like the image shown.

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ



Custom range list with new range added

- Click the **OK** button. You should now see a '97degC' (or to whatever your highest temperature was) range appear in the Custom range list.
- Highlight this new range and click **OK.**



New range to select

You should now see that, when the down-arrow next to the right-hand Volts is clicked on, an extra box for this new range appears.

Unknown temperature displayed in degrees Celsius

- Select this new range, place the temperature sensor into a beaker of water of unknown temperature (do not use a thermometer) and then click the **GO** button. You should now see a digital meter reading displayed directly as a temperature (not necessarily the value shown here).

- Compare the displayed temperature to the temperature obtained with a thermometer.
- Click the **STOP** button. Remove the temperature sensor from the beaker of water. Disconnect the battery from the temperature sensing unit and turn off the Bunsen burner if it is no longer needed.

To return the program to its original state, first click the down arrowalonside '97degC' and reset to 'Volts'. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list. Highlight the newly added range and click the **Delete** button to remove it. Now click the **OK** button.
To finish with the program click **File** on the Menu bar and **Exit** in its drop-down menu to leave the program.

Note: When you keyed your data into the 'Input value' and 'Scaled value' columns you were giving the computer information from which it could estimate other values that occur in between – it **interpolates.** It is doing the same job that you do with a graph and best-fit line. If the relationship between the data is a linear one then only two pairs of data items are needed, but otherwise a spread of data pairs across the range is needed.

Activity (ii): Using the band-gap sensor with PicoScope on DrDAQ

Results

Temperature /°C	Voltage output /mV

Questions

Does your graph show the Voltage output to be
(a) **linearly related to** the temperature
and
(b) **directly proportional to** the temperature? Explain.

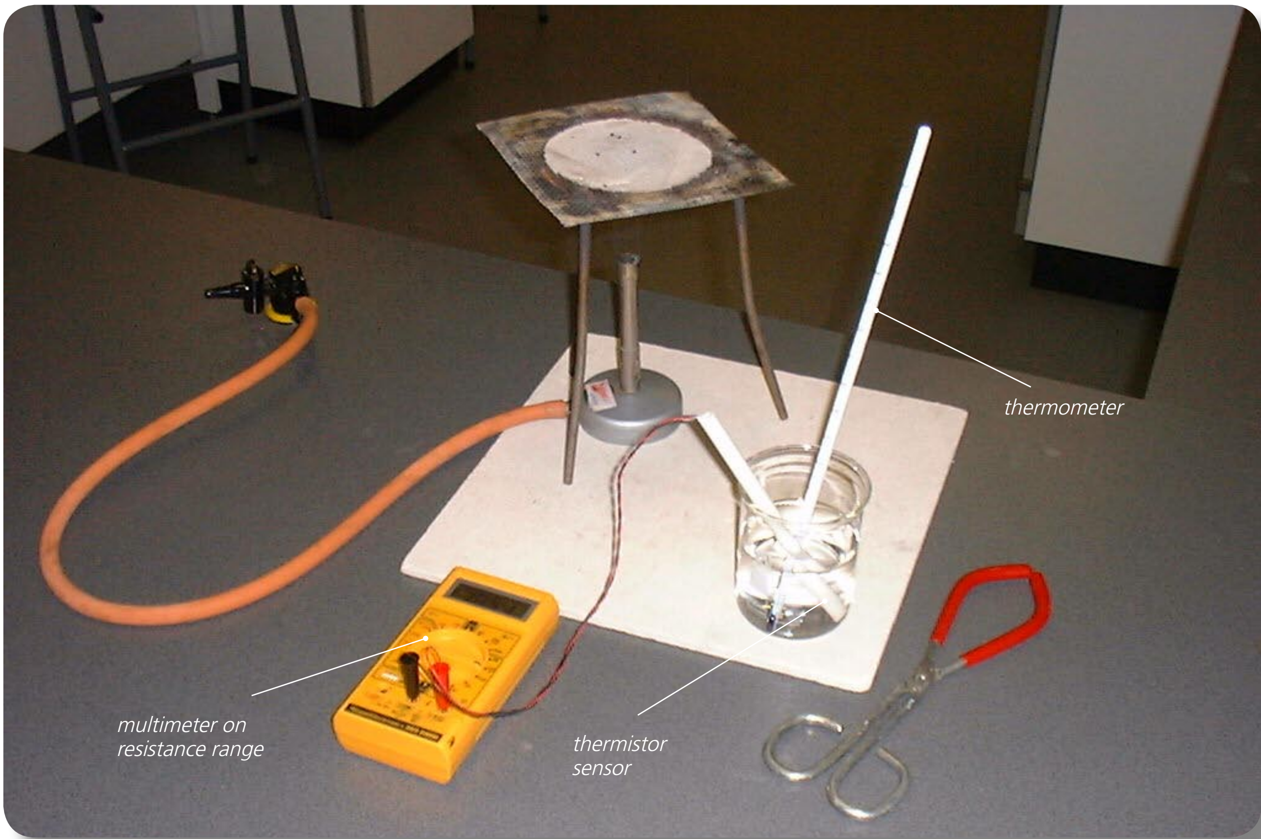
How close was your estimate of the water's temperature?

Why wouldn't a prediction of an unknown temperature be so reliable if the voltage output obtained for it was way beyond those used to produce the calibration 'curve'?

How well does the value displayed by the calibrated sensor match with the actual value?

Activity (i): Using a multimeter on its resistance range

Procedure



Set up of apparatus to measure the resistance of the thermistor at various temperatures

SAFETY NOTE: Safety goggles need to be worn whilst you are conducting these activities. It is also much safer to stand alongside a beaker of water being heated as, if the hot water was knocked over, you would be able to move out of the way more quickly than if seated.

Calibration

- Connect the **thermistor** to a **multimeter** on its **Resistance** range (initially2MΩ).

Note: 1MΩ = 1000kΩ.

- Set up a bunsen burner, tripod, gauze and heat-proof mat, or other form of appropriate heating.
- Place melting ice into a beaker and insert the thermistor sensor together with a thermometer, gently giving the melting ice a stir. After a minute or so give the melting ice another gentle stir and note its temperature and its resistance in your table. Remove the thermistor sensor and thermometer and empty out the ice. Two-thirds fill the beaker with water from the tap. Put the thermistor sensor and thermometer back into the beaker, give the water a stir and leave for about a minute. Stir the water again, note its temperature and its resistance in your table.
- Remove the thermistor sensor from the beaker. Place the beaker, together with the thermometer, on the tripod and heat gently for a few minutes until the water has reached a temperature of around 40°C.

Activity (i): Using a multimeter on its resistance range

- Remove the beaker with the beaker tongs and place it on the heat-proof mat. Put the thermistor sensor into the heated water and stir gently. Leave it for a minute or so, stir gently again and record the temperature and the thermistor's resistance in your table.
- Repeat this process to obtain another three sets of readings of temperature and resistance, the last near or at the boiling point of water. Turn off the bunsen burner if it is no longer needed.
- Now plot a graph of the thermistor's resistance (Y-axis) against the temperature (X-axis) and incorporate a best-fit line. You could do this manually or by entering your results into a graphing package or a spreadsheet.

Using the calibrated thermistor temperature sensor

You will now have calibrated the thermistor temperature sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown temperature.

- Place the thermistor sensor into a beaker of water of unknown temperature (do not insert a thermometer) and record its resistance. Using your calibration 'curve', note down what you think its temperature must be.
- Now measure the unknown temperature using the thermometer.

Activity (i): Using a multimeter on its resistance range

Results

Temperature (C)	Resistance of thermistor (kΩ)

Questions

Does your graph show the thermistor's resistance to be
(a) **linearly related to** the temperature
and
(b) **directly proportional to** the temperature? Explain.

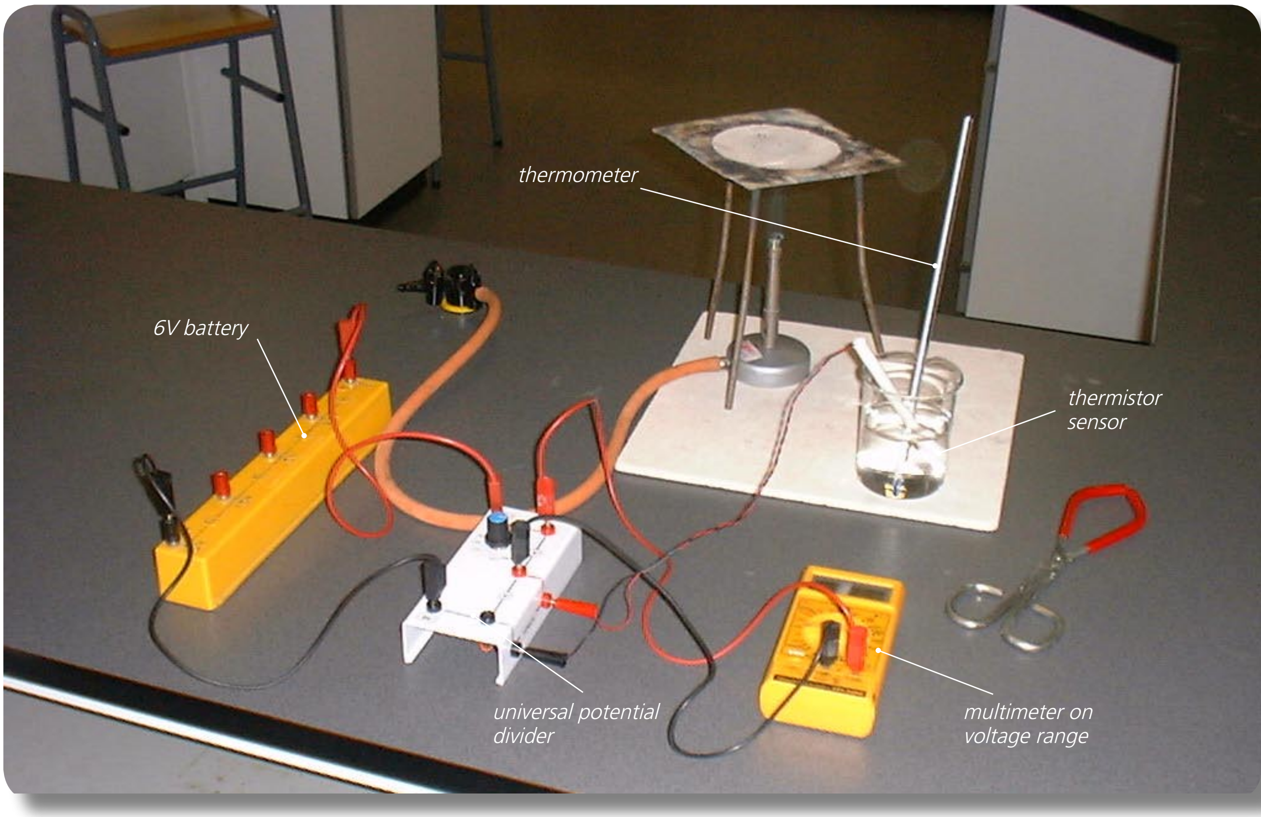
How close was your estimate of the water's temperature?

Why wouldn't a prediction of an unknown temperature be so reliable if the resistance obtained for it was way beyond those used to produce the calibration 'curve'?

Activity (ii): Using a potential divider network and a voltmeter

With the thermistor temperature sensor arranged in a potential divider network, a change in its resistance produces a change in the output voltage either across it, or across the other resistance section of the potential divider. It is the most common arrangement used with sensors.

Procedure



Thermistor set up in a potential divider network

SAFETY NOTE: Safety goggles need to be worn whilst you are conducting these activities. It is also much safer to stand alongside a beaker of water being heated as, if the hot water was knocked over, you would be able to move out of the way more quickly than if seated.

Calibration

- Set the universal potential divider unit to **47kΩ**.
- Connect the 6V battery so that its +6V socket is connected to the red+6V socket of the potential divider unit and its 0V socket to the black 0V socket of the potential divider unit.
- Connect the **thermistor** so that its black and red plugs are connected to the **black and red sensor sockets** on the side of the potential divider unit. Finally, connect a **multimeter** on its voltage range (or a voltmeter) to the **upper pair of red output sockets** on the potential divider unit.
- Set up a bunsen burner, tripod, gauze and heat-proof mat, or other form of appropriate heating.

Activity (ii): Using a potential divider network and a voltmeter

- Place melting ice into a beaker and insert the thermistor sensor together with a thermometer, gently giving the melting ice a stir. After a minute or so give the melting ice another gentle stir and note its temperature and the voltage output in your table.
- Remove the thermistor sensor and thermometer and empty out the ice. Two-thirds fill the beaker with water from the tap. Put the thermistor sensor and thermometer back into the beaker, give the water a stir and leave for about a minute. Stir the water again, note its temperature and the voltage output in your table.
- Remove the thermistor sensor from the beaker. Place the beaker, together with the thermometer, on the tripod and heat gently for a few minutes until the water has reached a temperature of around 40°C.
- Remove the beaker with the beaker tongs and place it on the heat-proof mat. Put the thermistor sensor into the heated water and stir gently. Leave it for a minute or so, stir gently again and record the temperature and the voltage output in your table.
- Repeat this process to obtain another three sets of readings of temperature and voltage output, the last near or at the boiling point of water. Turn off the bunsen burner if it is no longer needed.
- Now plot a graph of voltage output from the potential divider unit (Y-axis) against temperature (X-axis) and incorporate a best-fit line.

Using the calibrated thermistor temperature sensor

You will now have calibrated the thermistor temperature sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown temperature.

- Place the thermistor temperature sensor into a beaker of water of unknown temperature (do not insert a thermometer) and record the voltage output. Using your calibration 'curve', note down what you think its temperature must be.
- Now measure the unknown temperature using the thermometer.

Activity (ii): Using a potential divider network and a voltmeter

Results

Temperature (°C)	Voltage output from potential divider (V)

Questions

Does your graph show the voltage output from the potential divider unit to be
(a) **linearly related to** the temperature
and
(b) **directly proportional to** the temperature? Explain.

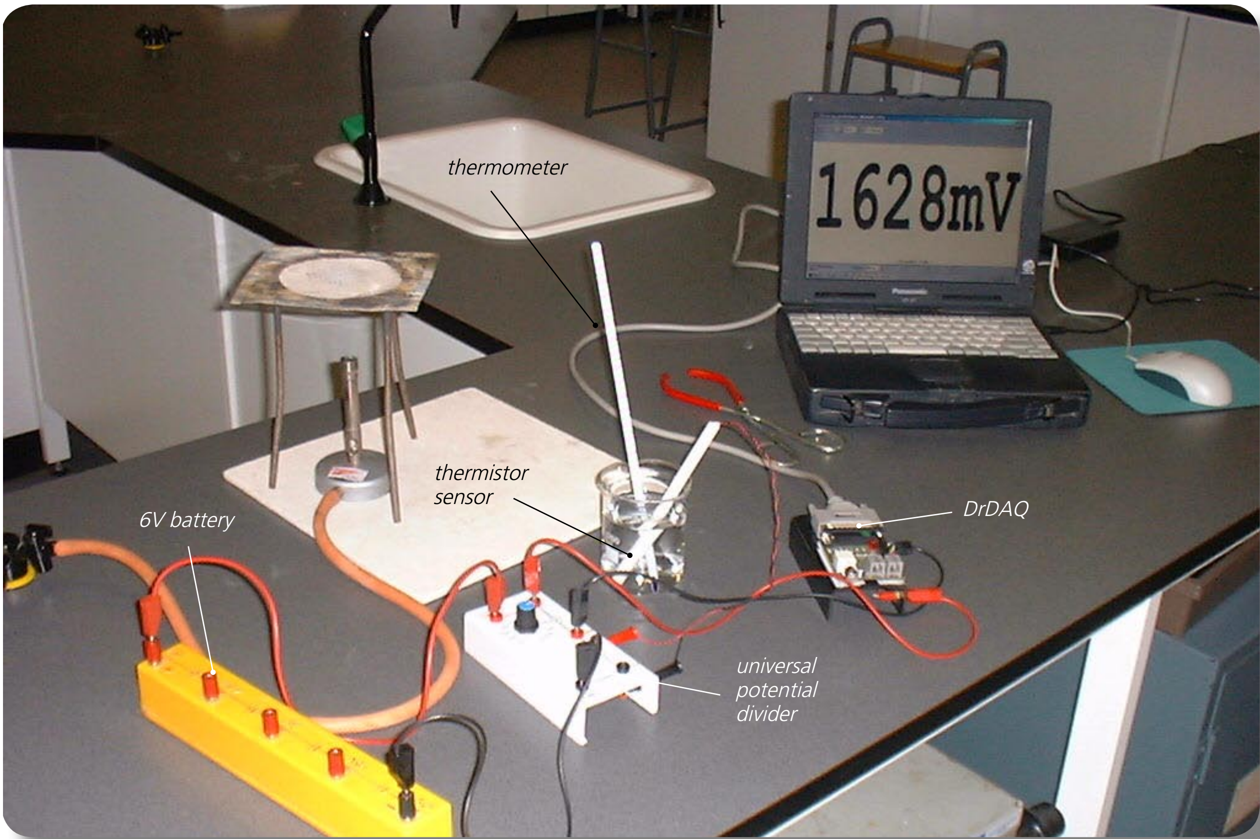
How close was your estimate of the water's temperature?

Why wouldn't a prediction of an unknown temperature be so reliable if the voltage output obtained for it was way beyond those used to produce the calibration 'curve'?

Activity (iii): Using a potential divider network and PicoScope on DrDAQ

This equipment allows you to have the digital meter reading directly as a thermometer, giving a temperature in degrees Celsius. (This is not possible with an ordinary multimeter or millivoltmeter).

Procedure



Set up of apparatus to measure temperature with a potential divider network, a thermistor and DrDAQ

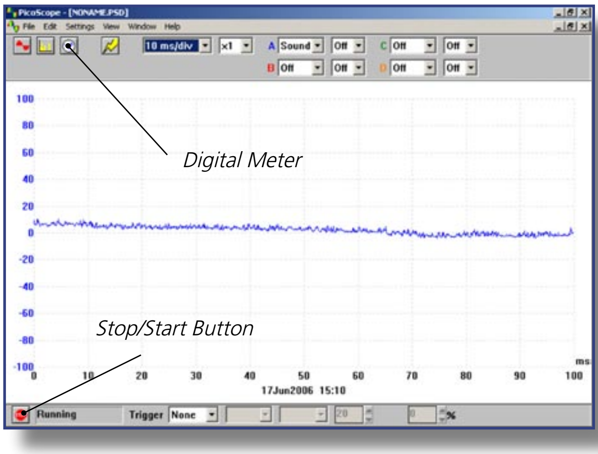
SAFETY NOTE: Safety goggles need to be worn whilst you are conducting these activities. It is also much safer to stand alongside a beaker of water being heated as, if the hot water was knocked over, you would be able to move out of the way more quickly than if seated.

Calibration

Note: If you are connected via a network you may need to obtain additional instructions.

- **Before the computer is switched on** check that *DrDAQ* has been plugged into the computer.
- Set the universal potential divider unit to **47kΩ**.
- Connect the 6V battery so that its +6V socket is connected to the red +6V socket of the potential divider unit and its 0V socket to the black 0V socket of the potential divider unit.
- Connect the **thermistor** so that its black and red sockets are connected to the **black and red sensor sockets** on the side of the potential divider unit. Connect the **upper red output voltage socket** of the potential divider unit to the **V** socket on *DrDAQ* and the **lower red output voltage socket** to the **GND socket** on *DrDAQ*.

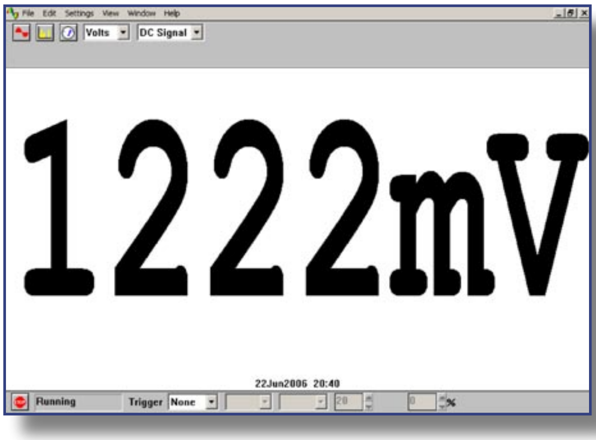
Activity (iii): Using a potential divider network and PicoScope on DrDAQ



DrDAQ opening screen

- Switch on and load the PicoScope software. If necessary, enlarge by clicking the in the top right-hand corner of the screen to provide a full screen display as shown below with the program already running.

Note: If the program appears to have frozen at any time then it can usually be unfrozen by pressing the F10 function key. If this does not succeed then close down the program by pressing the **Ctrl, Alt** and **Delete** keys simultaneously, and then restart the program.



Digital Voltmeter display

- Click the **STOP** button in the bottom left-hand corner of the screen. Close down the Oscilloscope mode by clicking the lower of the two Xs in the top right-hand corner of the screen. Now click on the **Digital Meter icon** in the Toolbar, select **Volts** and **DC Signal** and then click the **GO** button to put PicoScope into **Display Voltmeter** mode. You should now see a small voltage reading on the screen similar to that shown below.

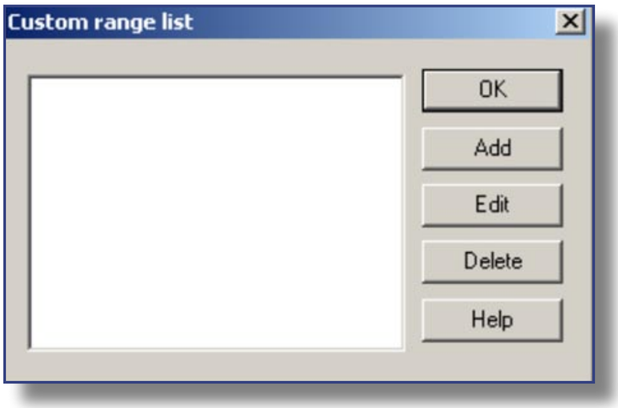
- Set up a bunsen burner, tripod, gauze and heat-proof mat, or other form of appropriate heating.
- Place melting ice into a beaker and insert the thermistor temperature sensor together with a thermometer, gently giving the melting ice a stir. After a minute or so give the melting ice another gentle stir and note its temperature and the voltage output in your table.
- Remove the thermistor temperature sensor and thermometer and empty out the ice. Two-thirds fill the beaker with water from the tap. Put the thermistor temperature sensor and thermometer back into the beaker, give the water a stir and leave for about a minute. Stir the water again, and note its temperature and the voltage output in your table.
- Remove the thermistor temperature sensor from the beaker. Place the beaker, together with the thermometer, on the tripod and heat gently for a few minutes until the water has reached a temperature of around 40°C.
- Remove the beaker with the beaker tongs and place it on the heat-proof mat. Put the thermistor temperature sensor into the heated water and stir gently. Leave it for a minute or so, stir gently again and record the temperature and the voltage output in your table.
- Repeat this process to obtain another three sets of readings of temperature and voltage output, the last near or at the boiling point of water. Turn off the Bunsen burner if it is no longer needed.
- Now plot a graph of voltage output (Y-axis) against temperature (X-axis), and incorporate a best-fit line. You could do this manually or by entering your results into a graphing package or a spreadsheet.

Activity (iii): Using a potential divider network and PicoScope on DrDAQ

Using the calibrated thermistor temperature sensor:
You will now have calibrated the thermistor temperature sensor, producing a graph or calibration 'curve' which you will be able to use to help you find the value of an unknown temperature.

- Place the thermistor temperature sensor into a beaker of water of unknown temperature (do not insert a thermometer) and record the voltage output. Using your calibration 'curve' note down what you think its temperature must be.
- Now measure the unknown temperature using the thermometer.

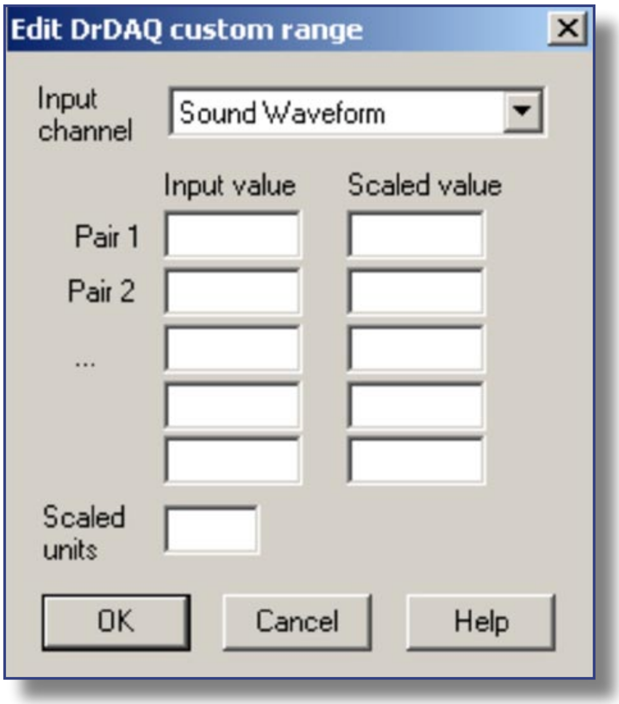
In everyday life, it would be unusual to find an instrument which had not been calibrated for direct use. With a computer-based device it is often possible to calibrate it so that it automatically displays the quantity you wish to measure directly on the screen. In this case you would want to get the computer to 'convert' the voltage input to give a temperature display on the screen. With PicoScope this is easily done by setting up a **Custom Range.**



Custom range list

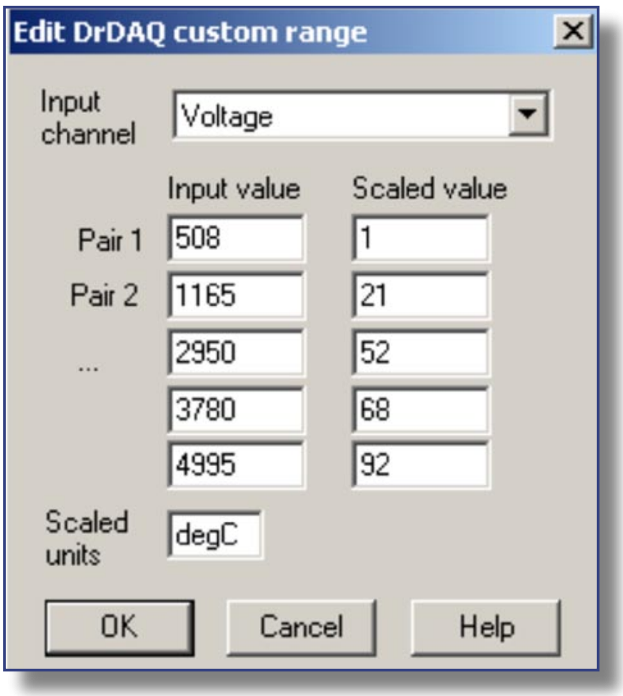
- Click the **STOP** button. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list.

Activity (iii): Using a potential divider network and PicoScope on DrDAQ



Edit DrDAQ Custom range box

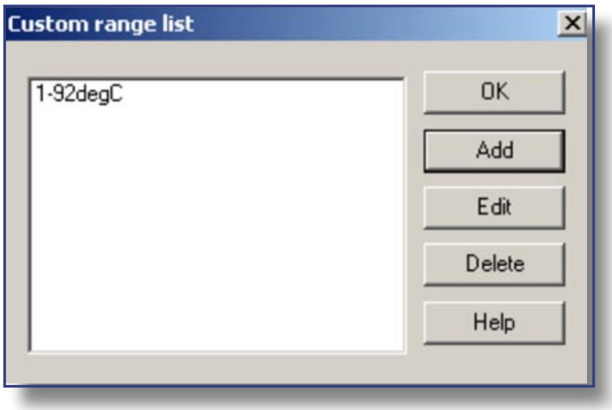
- Click on **Add** to display the **Edit *DrDAQ* custom range box** as shown.
- Select the Input channel **'Voltage'** by clicking on the down arrow alongside.



Add values and scaled units

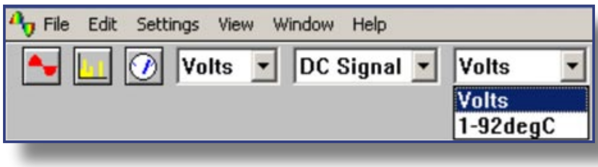
- Now type in your pairs of data into the two columns – output voltages into the **Input value column** and the temperatures into the **Scaled value column**. Ensure that you input the lowest output voltage and its matching temperature as Pair 1. Make the last pair the highest output voltage obtained and its corresponding temperature. Type **'degC'** into the **Scaled units box**. It should appear something like that shown.

Activity (iii): Using a potential divider network and PicoScope on DrDAQ



Custom range list with new range added

- Click the **OK** button. You should now see a '1-92degC' (or to whatever your highest temperature was) range appear in the Custom range list.
- Highlight this new range and click the **OK** button.



New range to select

- Click on the down-arrow next to the right-hand 'Volts': you should see an extra box for this new range.

Unknown temperature displayed in degrees Celsius

- Select this new range, place the temperature sensor into a beaker of water of unknown temperature (do not use a thermometer) and then click the GO button. You should now see a digital meter reading displayed directly as a temperature (not necessarily the value shown here).
- Compare the displayed temperature to the temperature obtained with a thermometer.
- Click the **STOP** button. Turn off the Bunsen burner if it is no longer needed.

To return the program to its original state, first click the down arrow alongside '1-92degC' and reset on 'Volts'. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list. Highlight the newly added range and click the **Delete** button to remove it. Now click the **OK** button.

To finish with the program click **File** on the Menu bar and **Exit** in its drop-down menu to leave the program.

Note: When you keyed your data into the 'Input value' and 'Scaled value' columns you were giving the computer information from which it could estimate other values that occur in between – it **interpolates**. It is doing the same job that you do with a graph and best-fit line. If the relationship between the data is a linear one, then only two pairs of data items are needed, but otherwise a spread of data pairs across the range is needed.

Activity (iii): Using a potential divider network and PicoScope on DrDAQ

Results

Temperature /°C	Voltage output from potential divider into DrDAQ /mV

Table of data

Questions

Does your graph show the voltage output to be
(a) **linearly related to** the temperature
and
(b) **directly proportional to** the temperature? Explain.

How close was your estimate of the water's temperature?

Why wouldn't a prediction of an unknown temperature be so reliable if the voltage output obtained for it was way beyond those used to produce the calibration 'curve'?

What value is displayed for the temperature when you use a calibrated sensor?

How well does this value match with the actual value?