FORCE SENSORS

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SEP
Science Enhancement Programme

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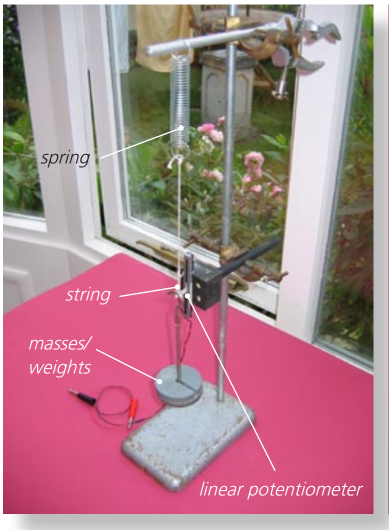
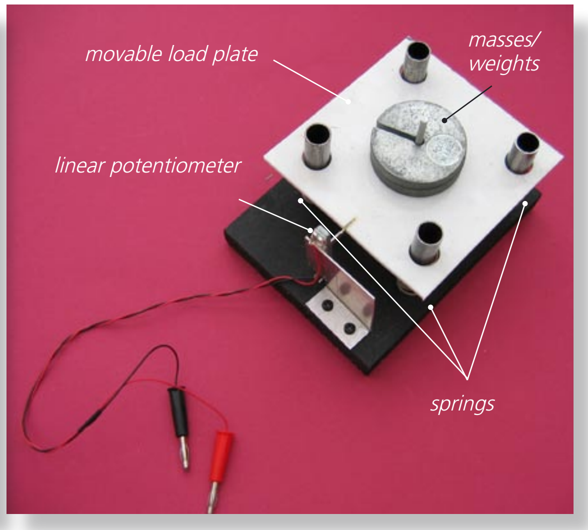
FORCE SENSORS

INTRODUCTION

Most students will at some point have made a **newtonmeter** (spring balance) from a spring, or by winding a spring from some fairly stiff wire. It would be worthwhile to remind them of this and show them a newtonmeter. If you had enough time you might quickly show that, *up to the Hooke's Law limit*, the stretch or compression of many springs is directly proportional to the load/weight on it. This is a useful characteristic to show as it introduces an ideal circumstance where doubling the load produces double the stretch or compression, and tripling the load produces triple the stretch or compression. Having a linear relationship between the load and the stretch or compression produced makes **calibration** a simple task.

Only two force sensors have been provided for students to experiment with – the **piezoresistive** and the **conductive foam sensors**. Two others were considered, each dependent on springs and a linear potentiometer. These are shown below.

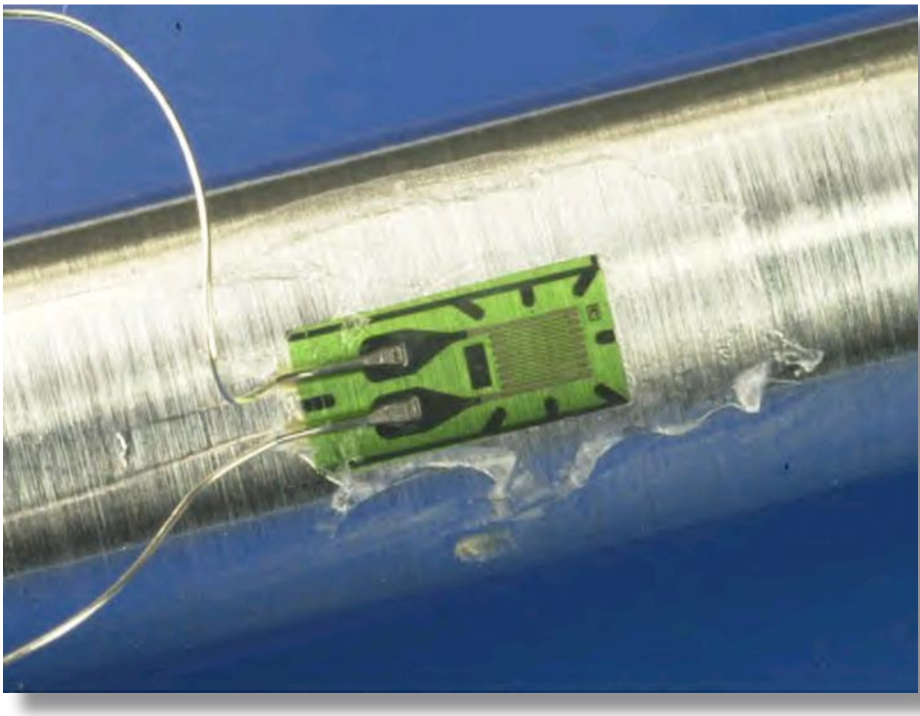




Two sensors based on the movement of a linear potentiometer

Whilst you might have expected these to work, there were difficulties in making the load plate of the sensor in the left hand image move down evenly and in overcoming the friction on the linear potentiometer in both. Whilst these problems could be overcome with far more expensive devices, it was not thought worthwhile doing so in this context. However, if your students suggest such devices, it would be sound advice to praise such suggestions but then outline the sorts of problems that are then found in their development and construction.

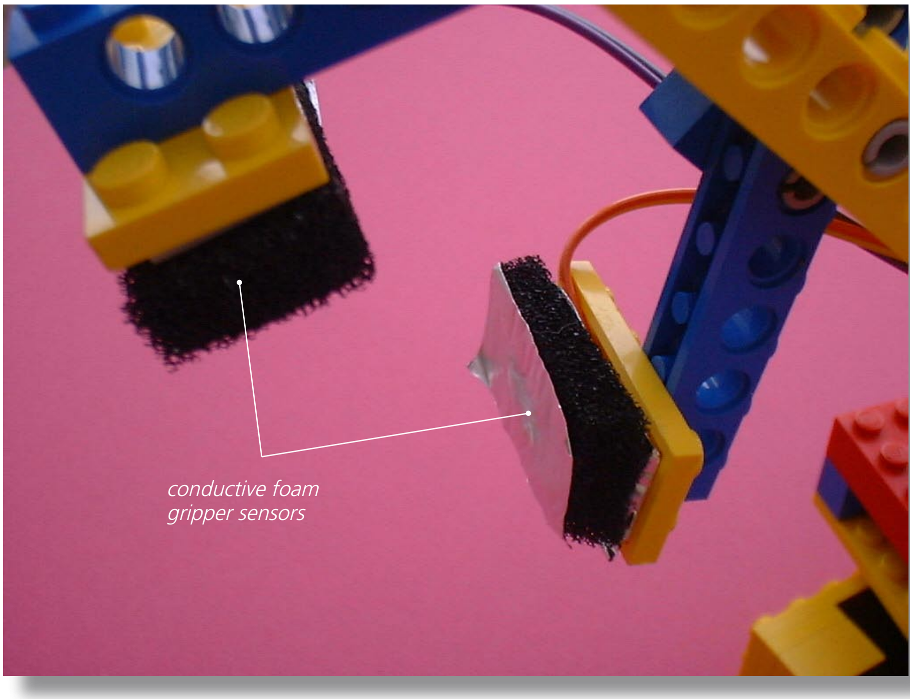
Another force sensor in common use is the **strain gauge**. As this is incorporated into a Wheatstone Bridge network and requires the addition of a temperature compensated instrumentation amplifier, it was felt best to leave this to later years. Modern strain gauges are usually made of foils of an alloy of copper and nickel bonded to a supporting structure as shown in below. As the material to which it is attached comes under strain, so the metal foil gets stretched, changing its resistance. Typical resistance changes are from around 120Ω to 600Ω.



Metal foil strain gauge (courtesy of DoITPOMS, University of Cambridge©)

The **piezoelectric force sensor** is really a strain gauge, too, and depends for its working on the **piezoresistive effect** discovered by Lord Kelvin in 1856. This is where the resistance of a material – indeed most materials – is changed slightly by small mechanical stresses being exerted on them. At first it was seen only in metals but the much greater effect in semiconductors was noted in 1954 and is generally used in force and pressure sensors of this type today. In relatively simple terms (too complex for most pre-16 students) the stress produces a deformation of the energy bands of the substance which then affects the mobility of the electrons and holes, so changing the material's resistivity. The sensor used (Honeywell FSG15N1A) is made up of silicon resistors arranged in a Wheatstone Bridge network. A force on the steel plunger/button causes these resistors to change in value and affect the voltage across the Wheatstone Bridge. The output voltage varies linearly with the force applied to the steel plunger but it does not usually give a zero output with no load. Connection of this force sensor is to a 9V battery (alkaline type essential) and a series diode is included to protect it against reverse connection to the battery. There are two versions available, with the one recommended operating up to loads of 1500g. A common use of such a sensor is in measuring engine oil pressure and in robotic grippers.

Two useful websites related to these activities are:
National Instruments – Measuring Strain with Strain Gauges
http://zone.ni.com/devzone/conceptd.nsf/webmain/C83E9B93DE714DB0862568 6600704DB1?OpenDocument
PCB Piezotronics
http://www.pcb.com/techsupport/tech_force.php
http://www.pcb.com/techsupport/tech-gen.php



Conductive foam gripper/bumper sensor

The **conductive foam sensor** is based on the material used for packaging integrated circuits. It is most commonly found in both robotic gripper and bumper sensors, but as discrete level switches rather than sensing changes over a range as is necessary here. There are two ways of explaining its operation. The simplest is to view its compression as a means of shortening the foam sensor: the shorter a wire is, the less its resistance, so the shorter the foam the smaller its resistance. A better explanation is to promote the idea of increasing contact across the 'bubbles/holes' within the foam as it is compressed: this increased contact provides more current routes (or short circuits) and so lessens the resistance.

THE ACTIVITIES

In the first part of the activity using the piezoresistive force sensor, students load the sensor with masses from 0g to 500g (weights 0N to 4.90N), noting the respective output voltages on a multimeter or millivoltmeter and then plotting a graph of voltage output against weight. They could do this either manually or by using a spreadsheet or computerised data handling program, such as djb microtech's *Simple Data Handling*. Uncertainties of results could be incorporated if required. It should give a straight line graph, but not quite through the origin.

Mass /g	Weight /N	Voltage output /mV
0	0	7.6
100	0.98	27.3
200	1.96	47.0
300	2.94	66.9
400	3.82	81.6
500	4.90	104.2
Unknown		72.0

Table of results with the piezoresistive force sensor connected to a millivoltmeter

This calibration graph then allows the students to determine an unknown weight.

The same technique can be used with ***PicoScope*** running on ***DrDAQ***, though (due to a differing impedance) the results are slightly different:

Mass /g	Weight /N	Voltage output /mV
0	0	14
100	0.98	34
200	1.96	50
300	2.94	71
400	3.82	90
500	4.90	107
Unknown		77

Table of results with the piezoresistive force sensor connected to DrDAQ

Using *PicoScope* with *DrDAQ*, students could calibrate this system to automatically display the weight directly on the computer screen. This is not difficult to do, nor does it take long. Here it is useful to emphasise how the data input allows a **matching and interpolation process** to take place in a similar manner to that done in interpolating with the aid of a best-fit line graph. As this is a linear relationship, only two pairs of points are really necessary. If the students have not already met a calibration **curve** rather than a **straight line**, then discussion could focus on the need for an **array of paired plots covering the whole range** in order to get reasonable interpolation. It is always useful to point out the dangers of extrapolation, too.

The conductive foam sensor is not ideal for use in a weighing machine, but the activity can show how it might be incorporated, and it also introduces problems of **stability of reading**, the need for a **time lapse before taking a reading**, and the **inability to return quickly to an earlier state when the load is reduced.** The stability problem can be overcome to some extent by suggesting that the students wait a minute before considering the value to record and, even then, to record 'average' or 'most often seen' values.

The simplest use of this sensor entails just measuring resistance on a multimeter. However, very few, if any, weighing machines would use resistance as the measured quantity: as you might expect, voltage is most commonly used.

Mass /g	Weight /N	Resistance /MΩ
0	0	0.18
100	0.98	0.12
200	1.96	0.10
300	2.94	0.09
400	3.82	0.08
500	4.90	0.07
Unknown		0.09

Table of results when the conductive foam sensor is linked to a multimeter

Once voltage measurement is brought into the process, the use of a **potential divider** becomes prime. For the least able students it may be wise to just tell them the resistor value to select on the universal potential divider. For the more able they could tackle this selection problem practically, measuring the voltage outputs for each potential divider resistor when the load is zero and when it is at the maximum (500g). The resistor which produces the largest variation in voltage output would then be chosen. For the most able, and as good practice at using the expressions I = V/R and V = IR, the process of seeing how the value of the potential divider resistor affects the change of voltage output could be tackled – see the 'The potential divider' materials on the CD.

Mass /g	Weight /N	Voltage output /V
0	0	2.18
100	0.98	2.89
200	1.96	3.19
300	2.94	3.34
400	3.82	3.56
500	4.90	3.77
Unknown		3.48

Table of results when the conductive foam sensor is connected to a multimeter

As with the piezoresistance force sensor, data can also be collected using *PicoScope* on *DrDAQ*, following this up by calibrating it to display the values of loads directly in newtons. The voltage outputs on *DrDAQ* differ a little from those with the multimeter due to their different impedances.

***Note**: The displayed resolution of the weight will not actually be correct. Although this can be dealt with in setting up PicoScope it would be better to leave it as it is and discuss this issue with students.*

Mass /g	Weight /N	Voltage output /mV
0	0	1500
100	0.98	2120
200	1.96	2400
300	2.94	2660
400	3.82	2780
500	4.90	2840
Unknown		2690

Table of results when the conductive foam sensor is connected to DrDAQ

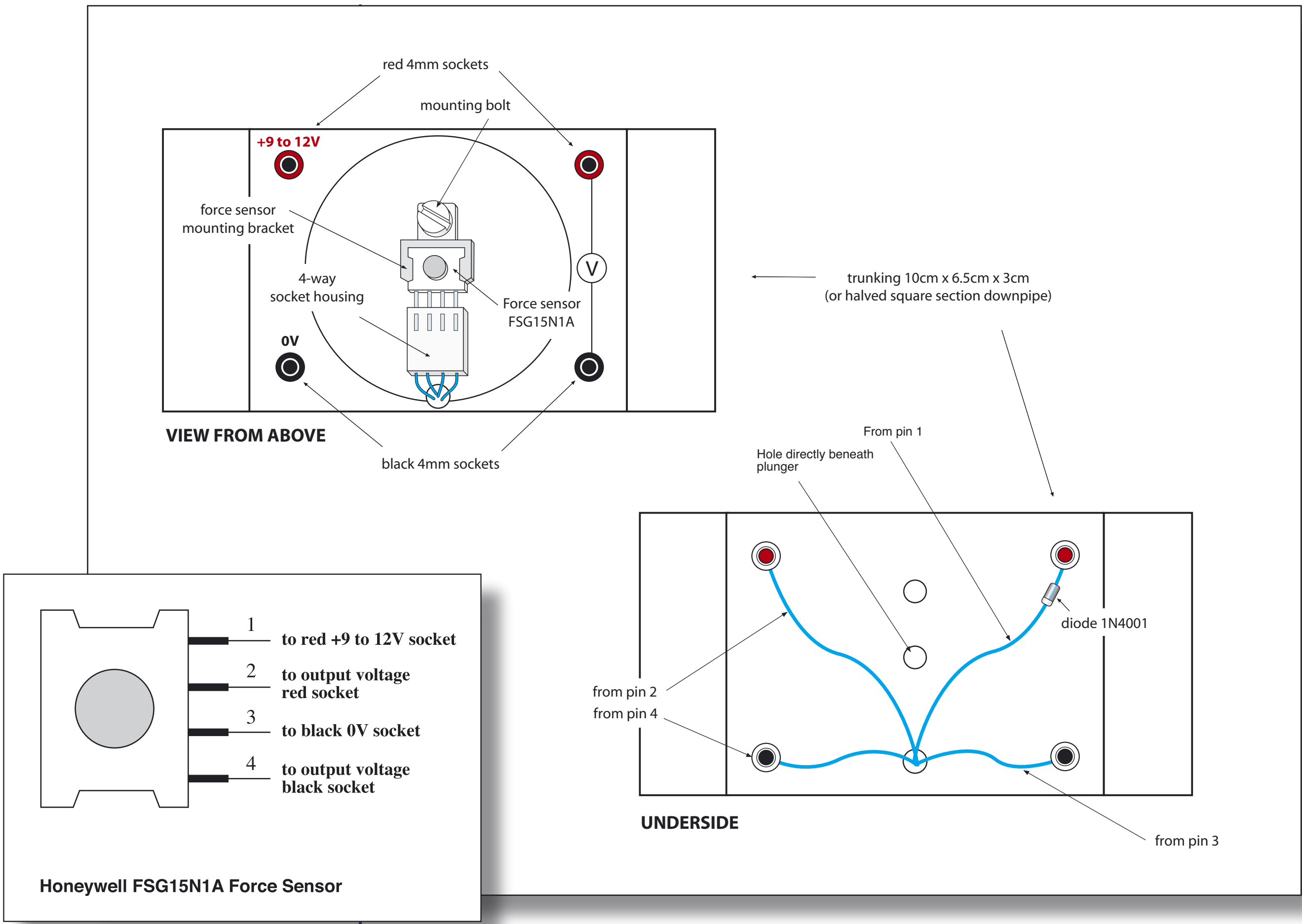
FORCE SENSORS: TECHNICAL NOTES

USING A PIEZORESISTIVE FORCE SENSOR AS A WEIGHING MACHINE

(I) USING A MULTIMETER/MILLIVOLTMETER

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:
multimeter
connecting leads
100g mass hanger and 4x 100g masses
9V alkaline battery PP3
PP3 type battery snap
Force sensor unit – see construction diagram
4mm plug red
4mm plug black)
2 x 4mm sockets red
2 x 4mm sockets black
plastic trunking
1m heat shrink sleeving 1.5mm i.d.
spray can of matt black paint
piezoresistive force sensor FSG15N1A (Farnell 721-6671)
piezoresistive force sensor mounting bracket (Farnell 721-6683 pk5)
nut, bolt and washer
diode 1N4001
socket housing 4-way
crimp terminals
mortar mix for making unknown masses
plastic cups



Force sensor construction

Connections to force sensor

Note: *on constructing the force sensor unit there is a small hole just beneath the sensor's button through the trunking. The diode is connected in series with the input from the battery and serves to protect against reverse connection of the battery.*

Ensure that the connections to the force sensor are as shown in the diagram. Pins 1 to 4 then slot into the 4-way socket housing.

Unknown weights are made from mortar mix in plastic cups. Make their masses in between 300 and 400g. When dry, paint them black.

(II) USING PICOSCOPE ON DrDAQ

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

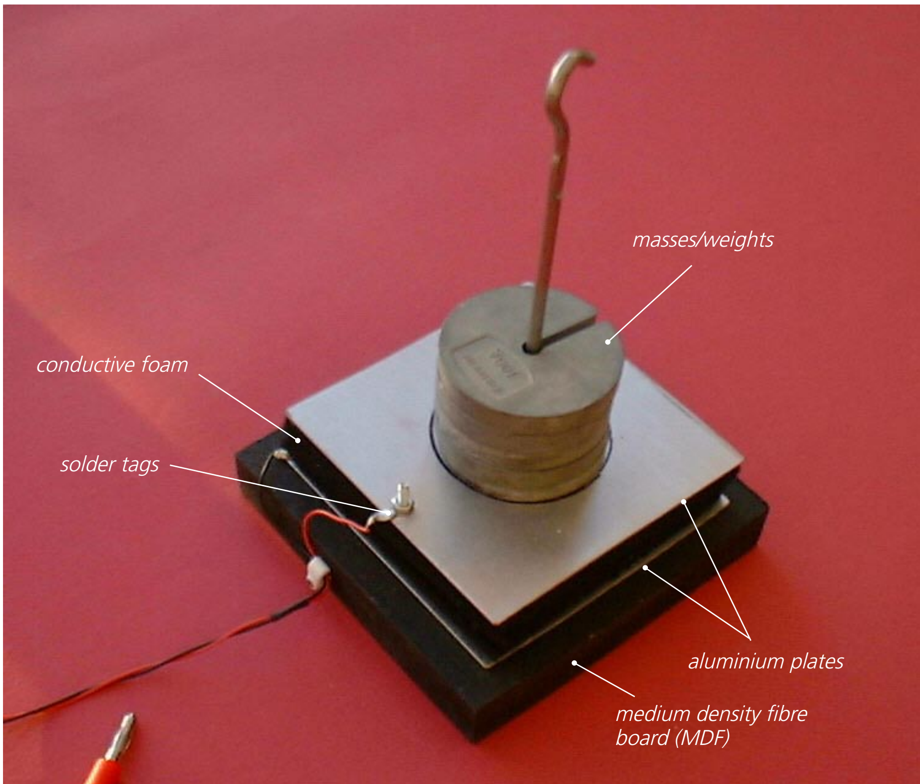
Equipment (additional):

computer
DrDAQ and associated connecting cable (Pico Technology)
PicoScope software (Pico Technology)
Software for plotting graphs and dealing with uncertainties and best-fit lines, such as djb microtech's ***Simple Data Handling***, may be of use here instead of a spreadsheet.

USING A CONDUCTIVE FOAM SENSOR TO MAKE A WEIGHING MACHINE

(I) USING A MULTIMETER ON A RESISTANCE RANGE

Equipment:
multimeter
100g mass hanger and 4x 100g masses
conductive foam sensor unit – see image below
light duty equipment wire black
light duty equipment wire red
4mm plug red
4mm plug black
aluminium sheet
conductive foam low density (Maplin FA83E)
solder tags
nut, bolt and washer
4 small brass wood screws
mortar mix for making unknown masses
plastic cups
small cable grip
spray can of matt black paint
MDF board



Construction of conductive foam sensor

Cut out two 10cm x 10cm squares of aluminium sheet, three 10cm x 10cm squares of conductive foam, and one 12cm x 12cm square of MDF. Spray the MDF with matt black paint.

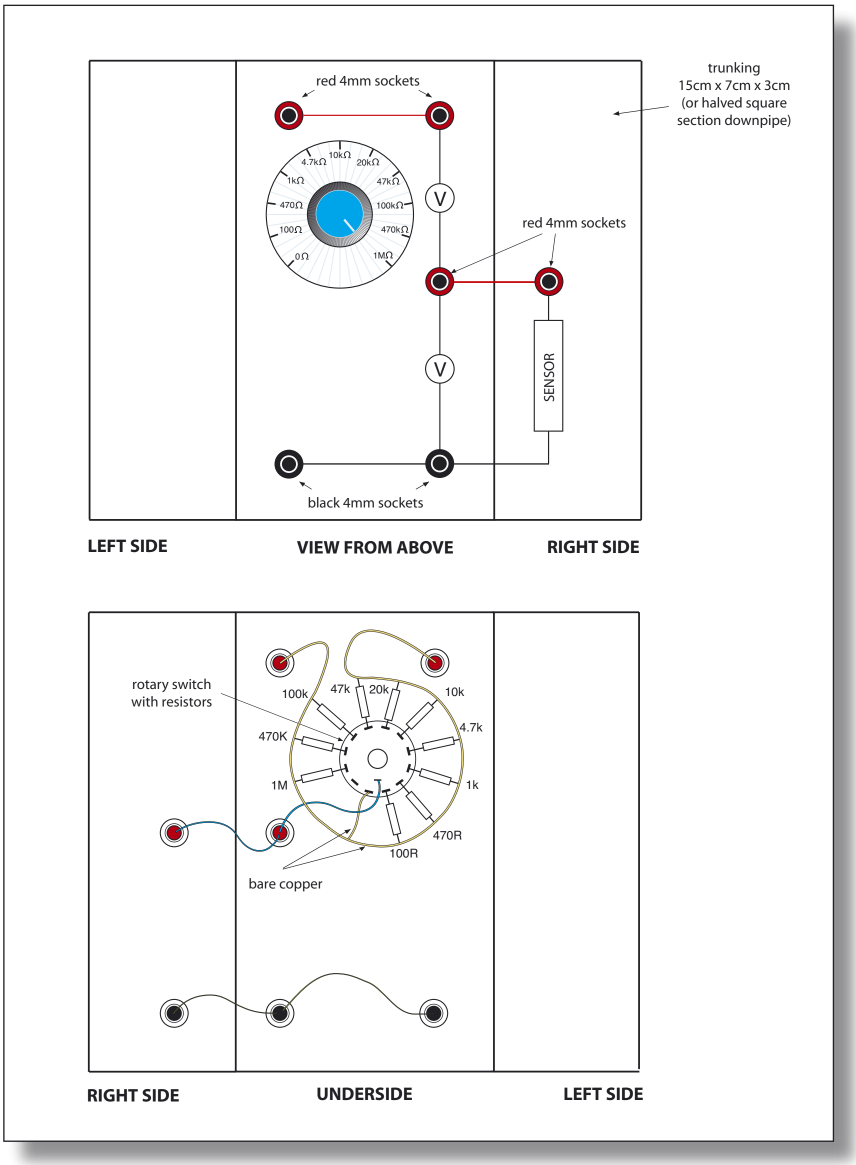
Drill holes at the corners of one of the aluminium plates and screw it centrally onto the MDF board with a solder tag attached to one of the four screws holding it down. Place the three pieces of conductive foam onto this plate. Take the other aluminium plate, drill a hole on one side to take a solder tag held in place by a nut and bolt. Solder red connecting wire to the top aluminium plate's solder tag and a black connecting wire to the base aluminium plate's solder tag. Twist the wires lightly together and slide a couple of short lengths of heat shrink sleeving over them to keep them together. Terminate the black wire with a black 4mm plug and the red wire with a red 4mm plug. Anchor the wires onto the MDF board using a small cable clip.

Draw a circle with a permanent marker pen centrally on the top aluminium plate to indicate where to place the masses.

(II) USING A POTENTIAL DIVIDER NETWORK

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
L C cap – blue
resistor M100R - 0.6W *
resistor G470R - 0.25W
resistor G1K - 0.25W
resistor G4K7 - 0.25W
resistor G10K - 0.25W
resistor G20K - 0.25W
resistor G47K - 0.25W
resistor G100K - 0.25W
resistor G470K - 0.25W
resistor G1M -0.25W
copper wire 18swg tinned
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.

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



Construction of universal potential divider unit

(III) USING A POTENTIAL DIVIDER NETWORK WITH DrDAQ

Note: *The activity notes and technical notes are for DrDAQ and associated software, 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 students on their use with DrDAQ and PicoScope.*

Apparatus requirements (additional):

computer
*DrDAQ** and associated connecting cable (Pico Technology)
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.

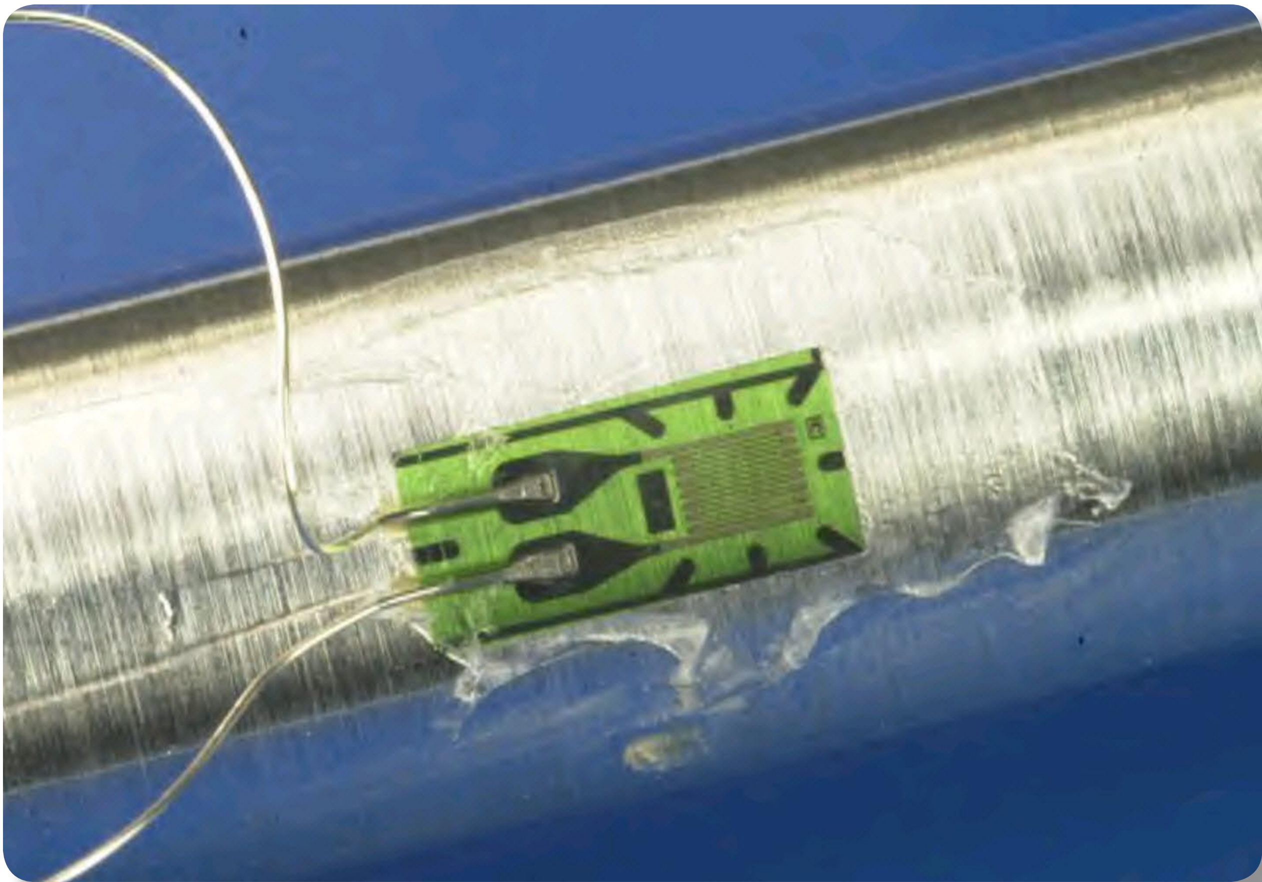
About Force Sensors

A newtonmeter

Whenever you weigh something, as long as it is not on a balance which compares masses, you are measuring a force. It is very likely that you have used a newtonmeter already, or you may have made one from a spring or by winding some wire to form a spring.

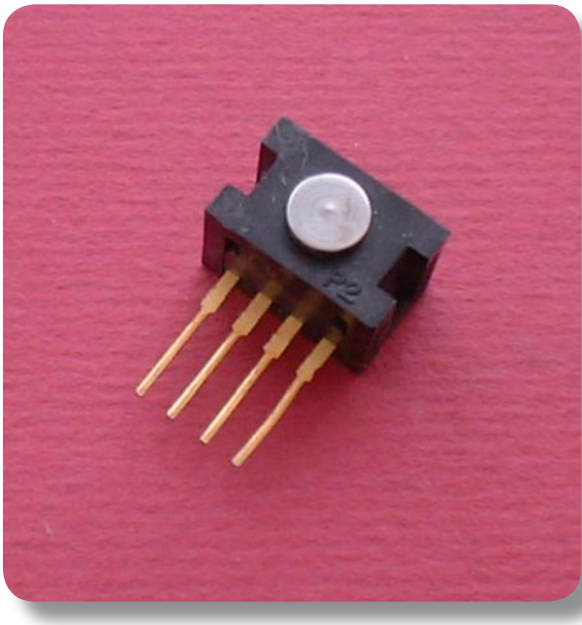
Cars go through Euro-NCAP (European New Car Assessment Programme) tests to see how safe they are for the occupants and, more recently, for pedestrians they might collide with. In these tests specially designed crash dummies are used to record the accelerations and forces involved in crashes. Inside them are a series of accelerometers and force sensors.

Whilst a spring is useful to measure some forces, most force measuring devices today will need an electrical output in the form of a voltage. This voltage is then used to calculate the value of the force. One of the most common devices to do this is the **metal foil strain gauge**, made from very thin metal 'wires' which change in length as a force is exerted upon them: this changes their resistance.



Metal foil strain gauge (courtesy of DoITPOMS, University of Cambridge©)

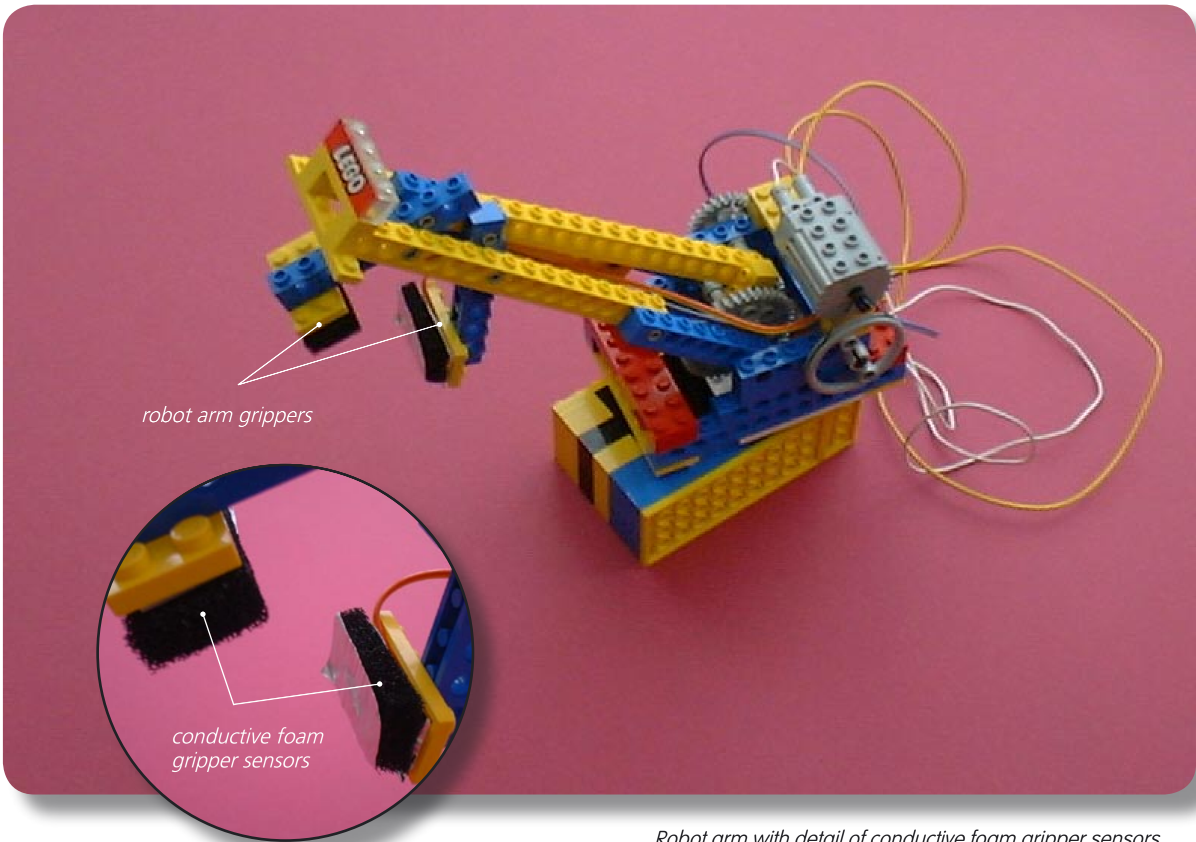
About Force Sensors



Piezoresistive strain gauge

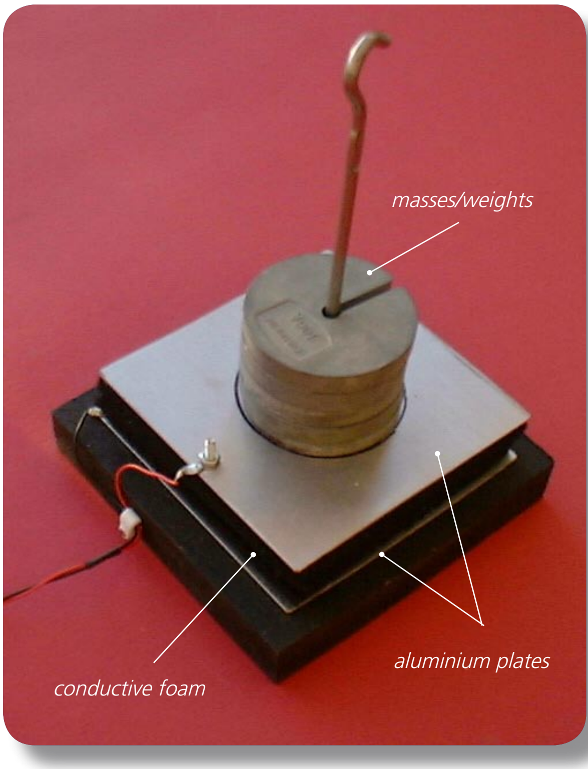
Another type of strain gauge relies on the **piezoresistive effect** first discovered by Lord Kelvin in 1856. Here the force exerted on tiny silicon resistors causes their resistance to change slightly. This resistance change then produces a change in voltage in what is known as a Wheatstone Bridge network, and it this voltage that gives a measure of the force.

Two of the force sensor activities use a piezoresistive strain gauge, while the other three use a form of squashable spring made from a slightly conductive foam which also changes in resistance as a force is exerted upon it. This type of sensor is often used by hobbyists in grippers on robot arms, as shown below.



Robot arm with detail of conductive foam gripper sensors

Using the conductive foam sensor to make a weighing machine



Conductive foam sensor

Conductive foam sensor

The slightly conductive foam that you will be using is most commonly used to package integrated circuits (i.c.) as partial protection against electrostatic hazards. It is also used in robotics to make touch and bump sensors. Your task is to see how such a material could be used to make a force sensor.

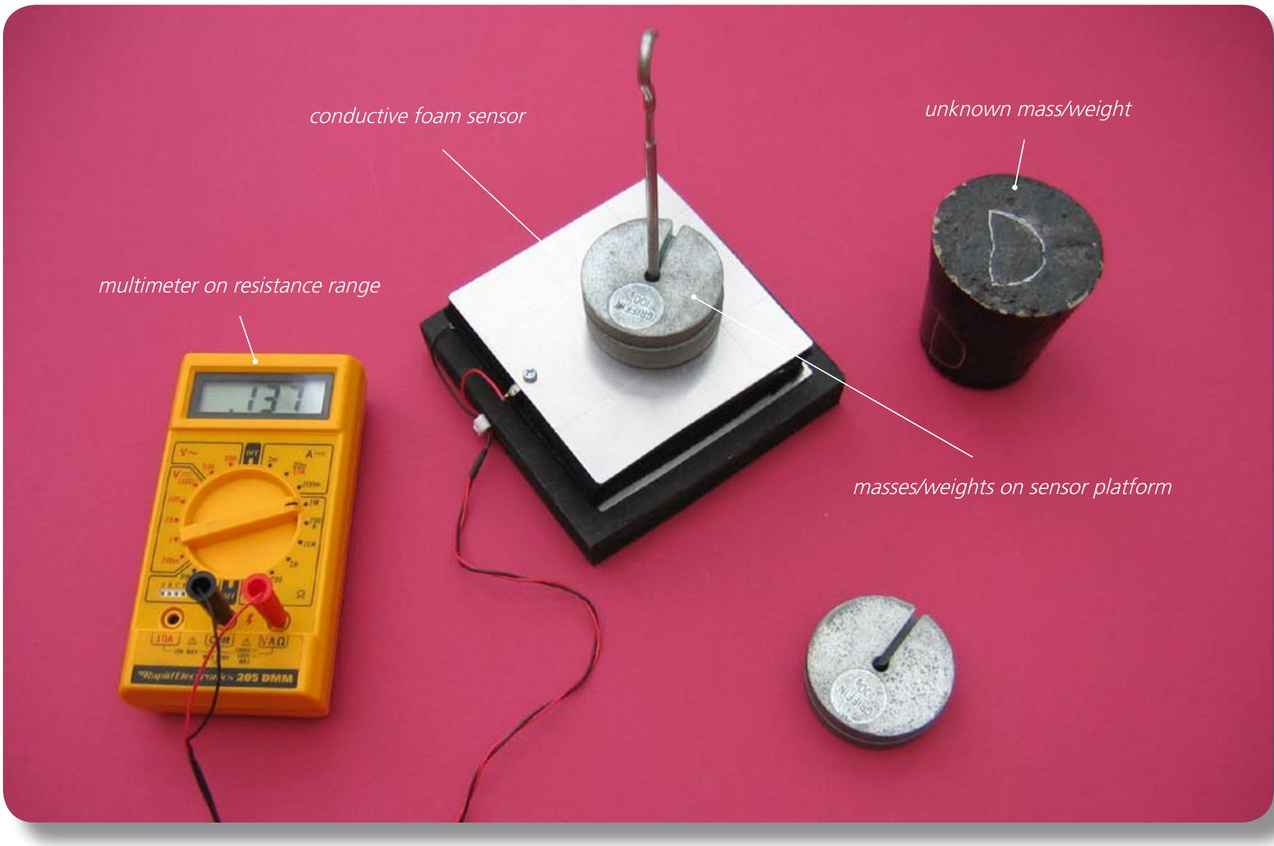
As the foam gets compressed under the weight of the object resting on it, its resistance gets lower. We could explain this in two ways:

(i) if it is acting like a piece of resistance wire then it is now shorter and so will have less resistance or,

(ii) as it compresses the foam's hole walls make better electrical contact with each other with some 'shorting' across the hole walls, and so the overall resistance is less.

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

Procedure



Conductive foam sensor connected to a multimeter on a resistance range

Calibration

- Connect the leads from the conductive foam sensor to a **multimeter** set on a **megohm (MΩ)** range.
- Record the **resistance output** from the sensor for each of the weights from 0N to 4.90N (masses 0g to 500g) placed centrally on it. The values may not be very stable so you will need to record 'average' values or those that are displayed 'most often'.
- Now plot a graph of resistance output (Y-axis) against the weight (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 conductive foam force sensor

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

- Place the **unknown weight** on the sensor platform and record the resistance output. Using your calibration 'curve' note down in the second column of the table alongside 'Unknown' what you think its weight must be.
- Ask your teacher what the weight of your unknown mass actually is, or go and weigh it.

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

Results

Mass /g	Weight /N	Resistance output /MΩ
0	0	
100	0.98	
200	1.96	
300	2.94	
400	3.82	
500	4.90	
Unknown		

Questions

Does your graph show the resistance output to be

(a) **linearly related** to the weight placed on the sensor button

and

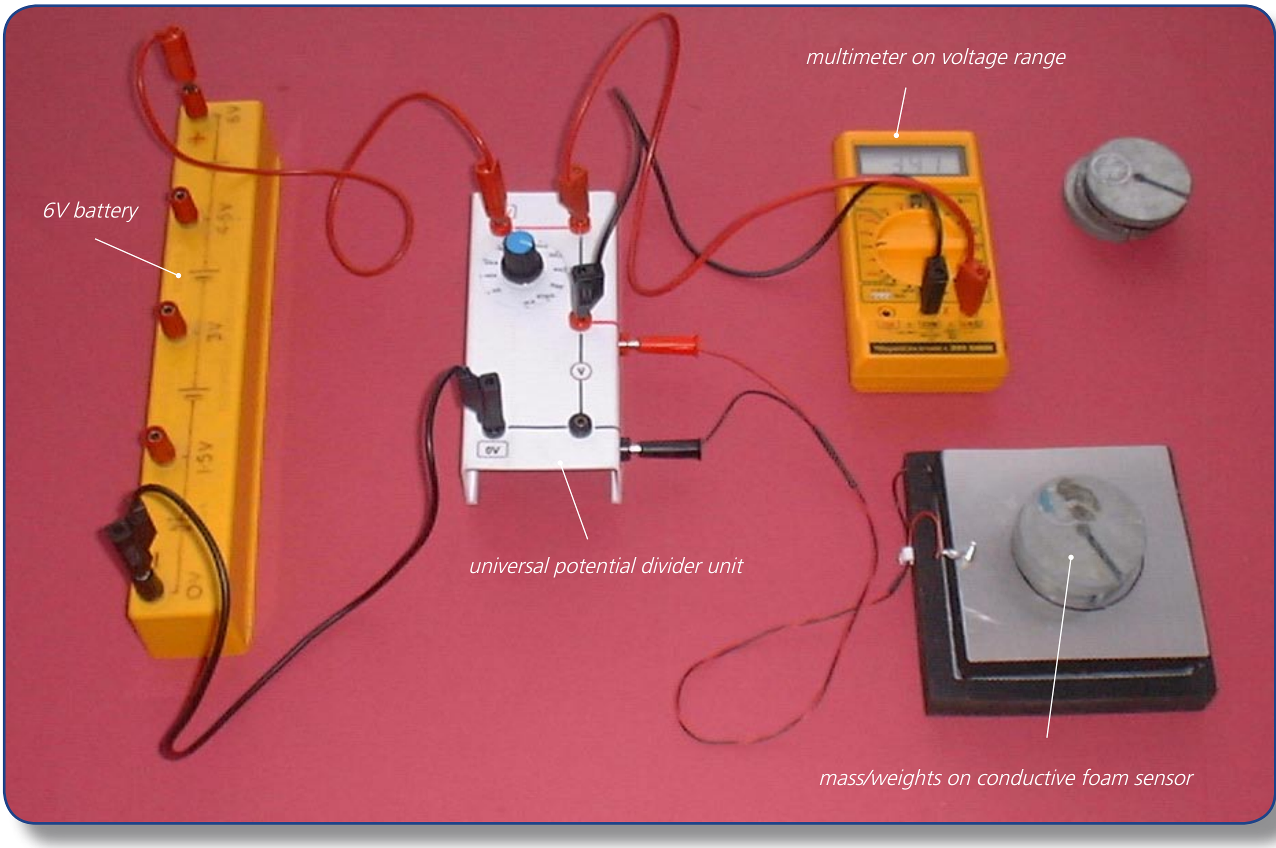
(b) **directly proportional** to the weight placed on the sensor button? Explain.

How close was your estimate of the unknown weight?

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

Activity (ii): Using a potential divider network

Procedure



Conductive foam sensor set up for use in a potential divider network

- First, **rotate the switch** on the **universal potential divider** to select the **100kΩ** resistor.
- Plug the leads from the **conductive foam sensor** into the **sockets on the edge of the universal potential divider unit.**
- Connect a **multimeter** set on its **20V** range (or a 5 or 10V voltmeter) across the **upper pair of voltage output sockets**, and a **6V battery** across the **0V and +6V sockets.**
- Record the voltage output from the force sensor for each of the weights from 0N to 4.90N (masses 0g to 500g) placed on the sensor platform. The values may not be very stable so you will need to record 'average' values or those that are displayed 'most often'.
- Now plot a graph of voltage output (Y-axis) against the weight (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 conductive foam force sensor

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

- Place the unknown weight on the force sensor platform and record the Voltage output. Using your calibration 'curve' note down in the second column of the table alongside 'Unknown' what you think its weight must be.
- Ask your teacher what the weight of your unknown mass actually is, or go and weigh it.

Activity (ii): Using a potential divider network

Results

Mass /g	Weight /N	Voltage output /V
0	0	
100	0.98	
200	1.96	
300	2.94	
400	3.82	
500	4.90	
Unknown		

Questions

Does your graph show the voltage output to be
(a) **linearly related** to the weight placed on the sensor platform
and
(b) **directly proportional** to the weight placed on the sensor platform? Explain.

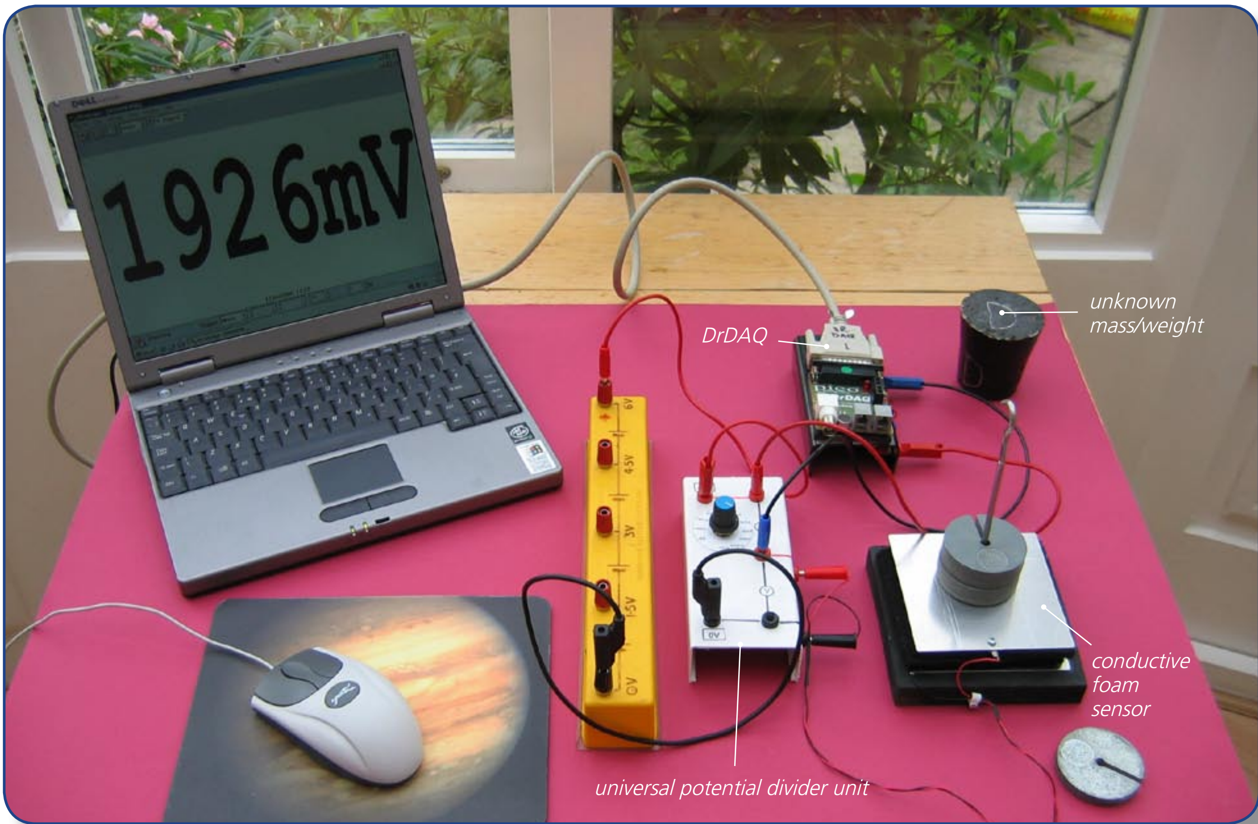
How close was your estimate of the unknown weight?

Why wouldn't a prediction of an unknown weight 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 with *DrDAQ*

This activity allows you to have the digital meter so that it reads directly as a weighing machine, giving a weight in newtons. (This is not possible with an ordinary multimeter or voltmeter).

Procedure



Conductive foam force sensor set up with a potential divider to use with PicoScope on DrDAQ

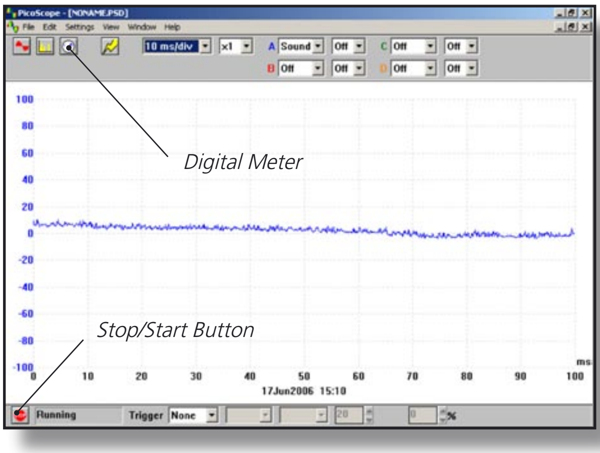
Calibration

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.

- Now rotate the switch on the **universal potential divider** to select the **100kΩ** resistor.
- Plug the leads from the **conductive foam sensor** into the **sockets on the edge of the universal potential divider unit** and connect a **6V battery** across the **0V and +6V sockets.**
- Connect a **red lead** from the **upper (red) voltage output socket** on the universal potential divider unit to the **V** socket on *DrDAQ* and a **black lead** from the **middle (red) socket** on the potential divider unit to the **GND** socket on *DrDAQ*.

Activity (iii): Using a potential divider network with *DrDAQ*

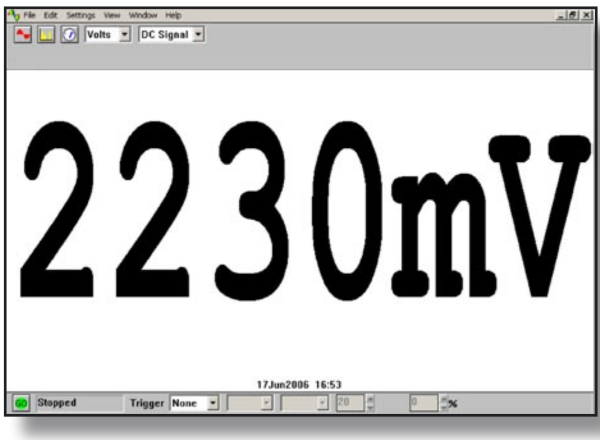


DrDAQ opening screen

- 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.

- 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.



Digital Voltmeter display

- 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.
- Place one 100g mass on the conductive foam force sensor to check that it is functioning and you should get a display like that shown, though not necessarily of that value.
- Record the voltage output from the force sensor for each of the weights from 0N (nothing placed on the force sensor) to 4.90N (masses up to 500g) placed on the sensor button. The values may not be very stable so you will need to record 'average' values or those that are displayed 'most often'.
- Now plot a graph of voltage output (Y-axis) against the weight (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.

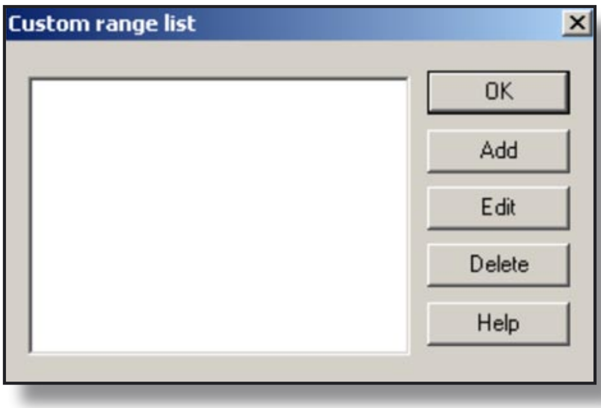
Activity (iii): Using a potential divider network with *DrDAQ*

Using the calibrated force sensor

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

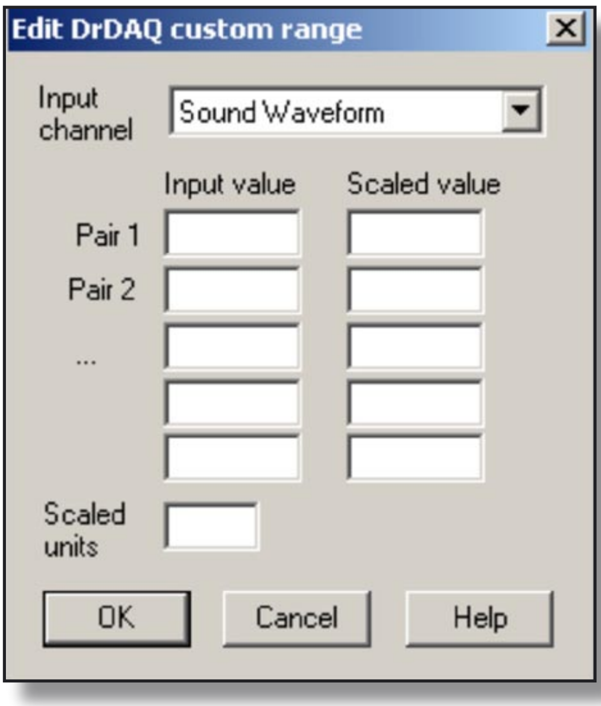
- Place the unknown weight on the force sensor platform and record the voltage output. Using your calibration 'curve' note down in the second column of the table alongside 'Unknown' what you think its weight must be.
- Ask your teacher what the weight of your unknown mass actually is, or go and weigh it.

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 weight display on the screen. With ***PicoScope*** this is easily done by setting up a **Custom Range.**



Custom range list

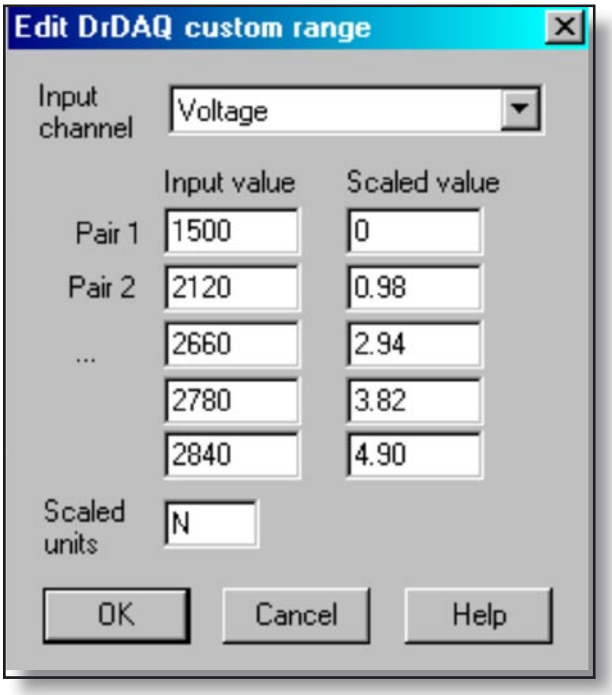
- Click the **STOP** button. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the **Custom range** list.



Edit DrDAQ Custom range box

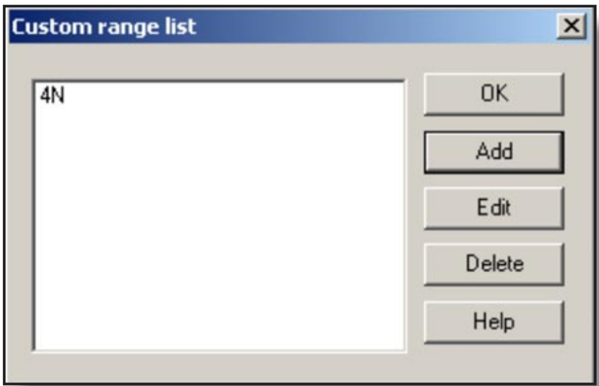
- Click on Add to display the Edit DrDAQ custom range box

Activity (iii): Using a potential divider network with *DrDAQ*



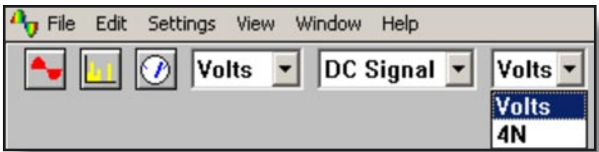
Add values and scaled units

- Select the **Input channel 'Voltage'** by clicking on the down arrow alongside. Now type in your pairs of data into the two columns – **output voltages** into the **Input value column** and the **weights** into the **Scaled value column**. Ensure that you input a zero weight (0N) and the Output voltage that this produced.



Custom range list with new range added

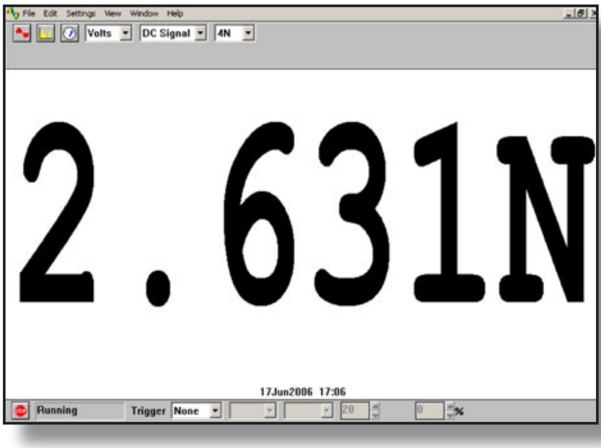
- Type **'N'** (for newtons) into the **Scaled units box**.
- Click the **OK** button. You should now see a '4N' range appear in the Custom range list.
- Highlight this new range and click **OK**.



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 as shown.

Activity (iii): Using a potential divider network with *DrDAQ*



Unknown weight displayed in newtons

- Select this new range, place the unknown weight on the force sensor and then click the **GO** button. You should now see a digital meter reading displayed directly as a weight.
- Compare this displayed value for the weight with the actual weight.
- Click the **STOP** button.

- To return the program to its original state first click the down-arrow next to '4N' and return to the 'Volts' range. 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 and then 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.

Activity (iii): Using a potential divider network with *DrDAQ*

Results

Mass /g	Weight /N	Voltage output /V
0	0	
100	0.98	
200	1.96	
300	2.94	
400	3.82	
500	4.90	
Unknown		

Questions

Does your graph show the voltage output to be
(a) **linearly related to** the weight placed on the sensor button
and
(b) **directly proportional** to the weight placed on the sensor button? Explain.

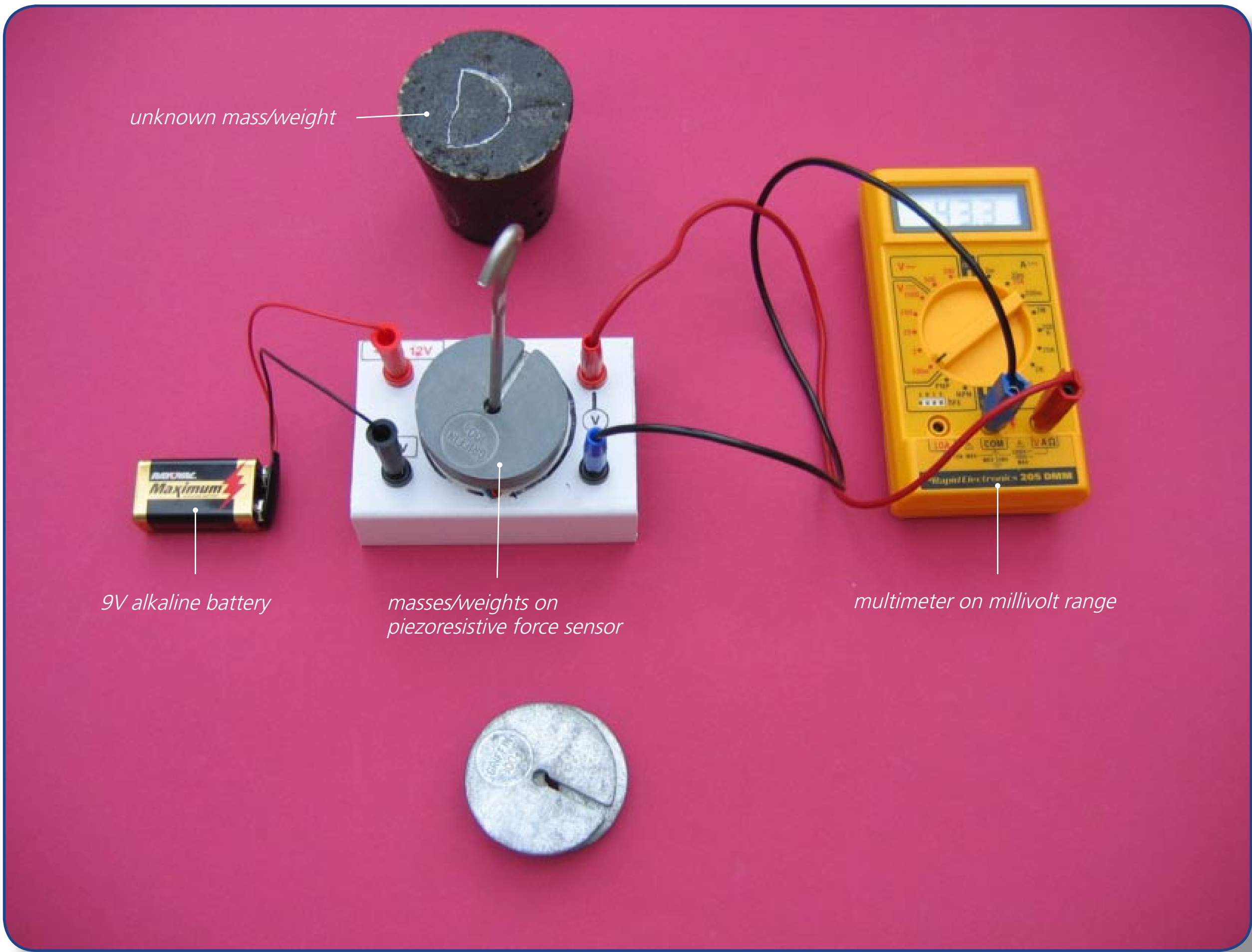
How close was your estimate of the unknown weight?

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

How well did the displayed value of the weight match with the actual value?

Activity (i): Using a multimeter/millivoltmeter

Procedure



Piezoresistive force sensor with output linked to a multimeter/millivoltmeter

Calibration

- Connect the **force sensor** to a **power supply or battery** supplying between **9 and 12 volts**. Connect a **multimeter** on its **millivolt range** (or a millivoltmeter) to its **output** sockets.
- Record the voltage output from the force sensor for each of the weights from 0N to 4.90N (masses 0g to 500g) placed on the sensor button. Leave the sensor platform empty when this has been completed.
- Now plot a graph of voltage output (Y-axis) against the weight (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 force sensor

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

- Place the **unknown weight** on the force sensor button and record the voltage output. Using your calibration 'curve', note down in the second column of the table, alongside 'Unknown', what you think its weight must be.
- Ask your teacher what the weight of your unknown mass actually is, or go and weigh it.

Activity (i): Using the force sensor with a multimeter/millivoltmeter

Results

Mass /g	Weight /N	Voltage output /V
0	0	
100	0.98	
200	1.96	
300	2.94	
400	3.82	
500	4.90	
Unknown		

Questions

Does your graph show the voltage output to be
(a) **linearly related** to the weight placed on the sensor button
and
(b) **directly proportional** to the weight placed on the sensor button? Explain.

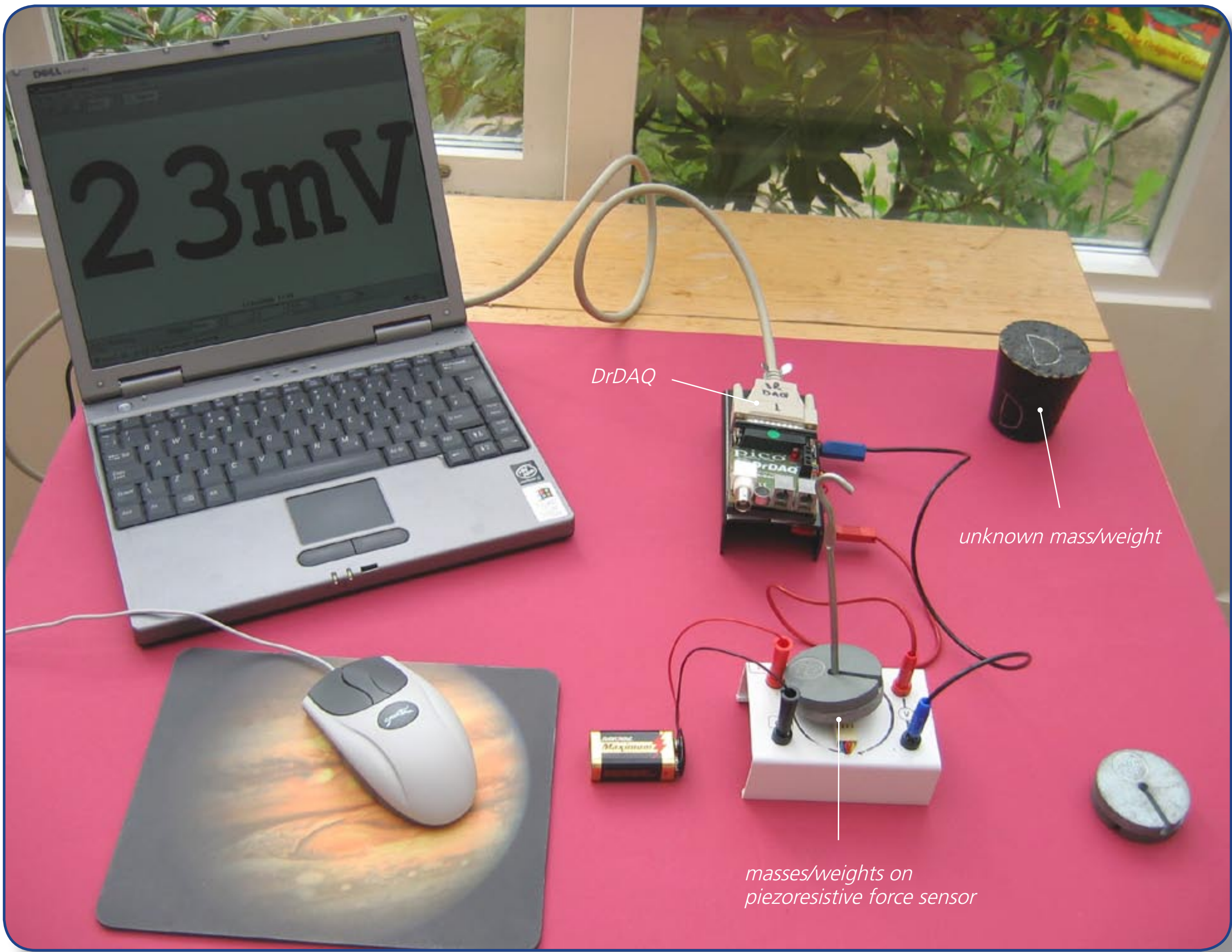
How close was your estimate of the unknown weight?

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

Activity (ii): Using the piezoresistive force sensor with PicoScope on DrDAQ

This activity allows you to have the digital meter so that it reads directly as a weighing machine, giving a weight in newtons. (This is not possible with an ordinary multimeter or millivoltmeter)

Procedure



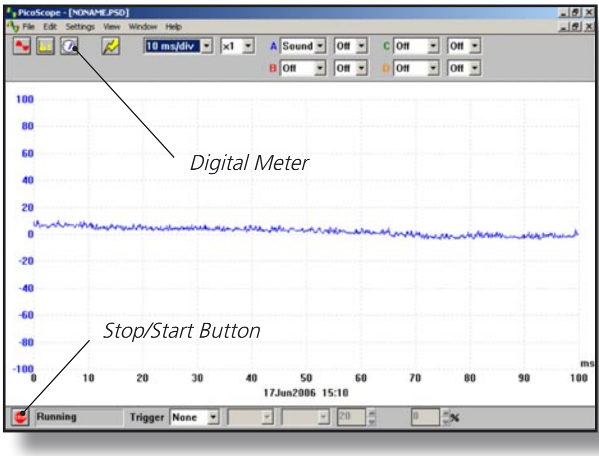
Piezoresistive force sensor set up to use with PicoScope on DrDAQ

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.
- Connect the piezoresistive force sensor's **red lead** to the **V** socket on *DrDAQ* and its **black lead** to the **GND** socket.

Activity (ii): Using the piezoresistive force sensor with PicoScope on DrDAQ

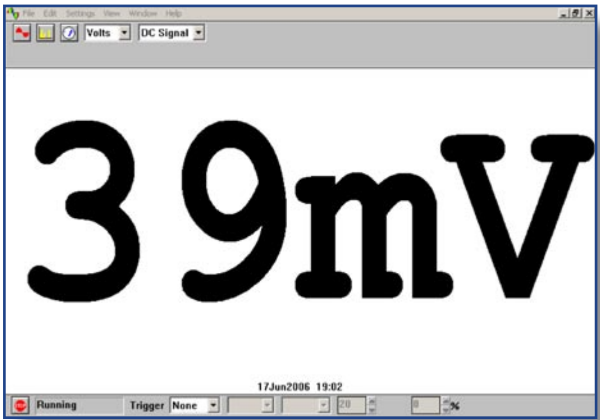


DrDAQ opening screen

- 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.

- 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.



Digital Voltmeter display

- Place just one 100g on the force sensor to check that it is functioning and you should get a display like that shown, though not necessarily of that value.
- Record the voltage output from the force sensor for each of the weights from 0N (nothing placed on the force sensor) to 4.90N (masses up to 500g) placed on the sensor button.
- Now plot a graph of voltage output (Y-axis) against the weight (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.

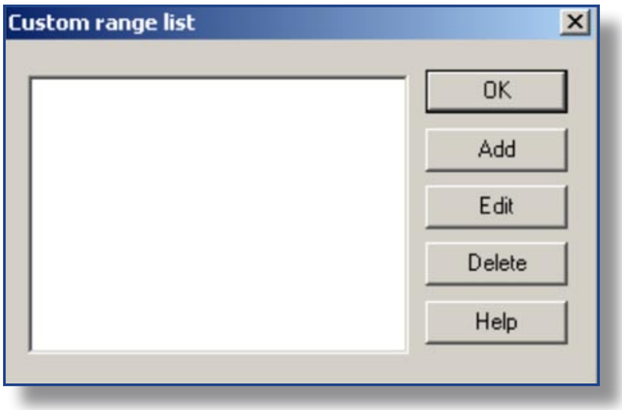
Activity (ii): Using the piezoresistive force sensor with PicoScope on DrDAQ

Using the calibrated force sensor

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

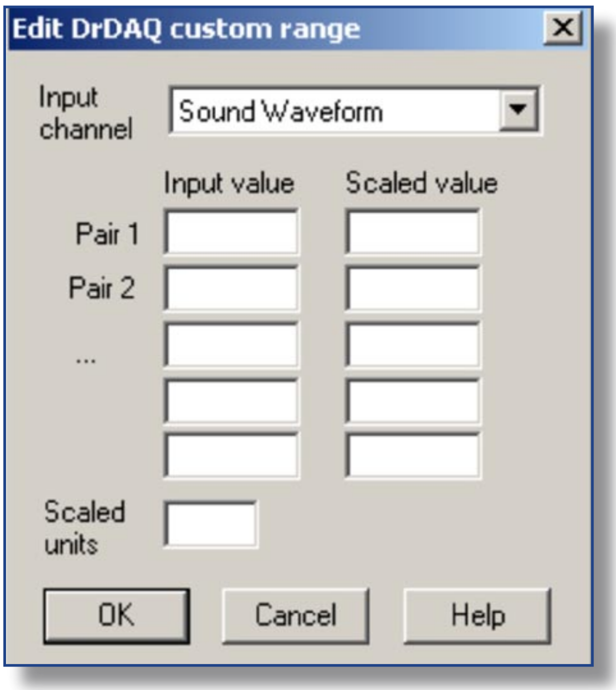
- Place the unknown weight on the force sensor button and record the voltage output. Using your calibration 'curve', note down in the second column of the table alongside 'Unknown' what you think its weight must be.
- Ask your teacher what the weight of your unknown mass actually is, or go and weigh it.

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 weight display on the screen. With *PicoScope* this is easily done by setting up a **Custom Range**.



Custom range list

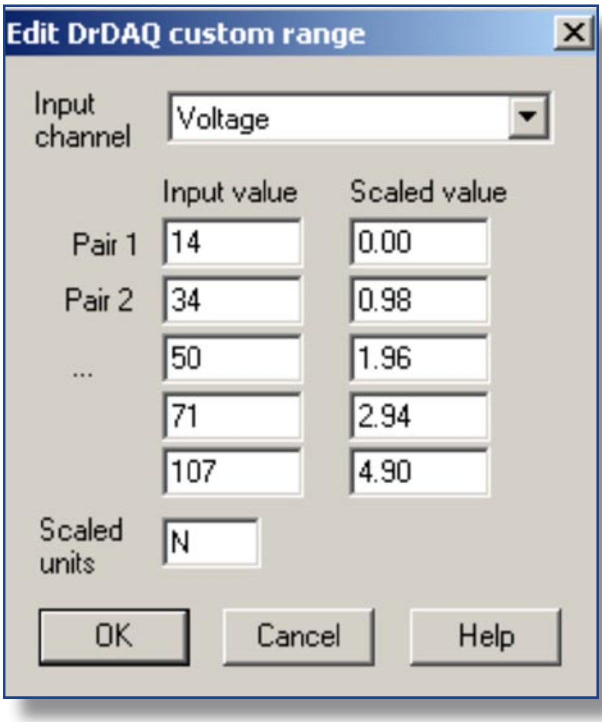
- Click the **STOP** button. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list.



DrDAQ Custom range box

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

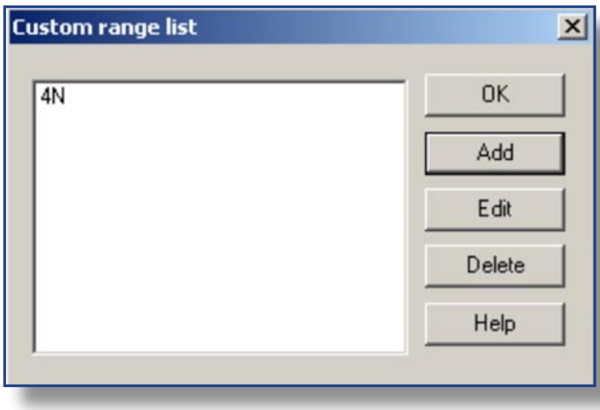
Activity (ii): Using the piezoresistive force sensor with PicoScope on DrDAQ



Add 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 – **output voltages** into the **Input value column** and the **weights** into the **Scaled value column**. Ensure that you input the **lowest weight (0N) and the output voltage that this produced as Pair 1**. Make the **last pair** the **highest weight used (4.90N) and its corresponding output voltage**. Type '**N**' (for newtons) into the **Scaled units box**.

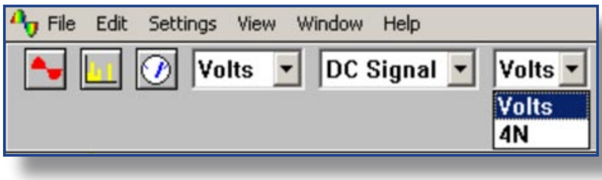
- Click the **OK** button. You should now see a '4N' range appear in the Custom range list.



Custom range list with new range added

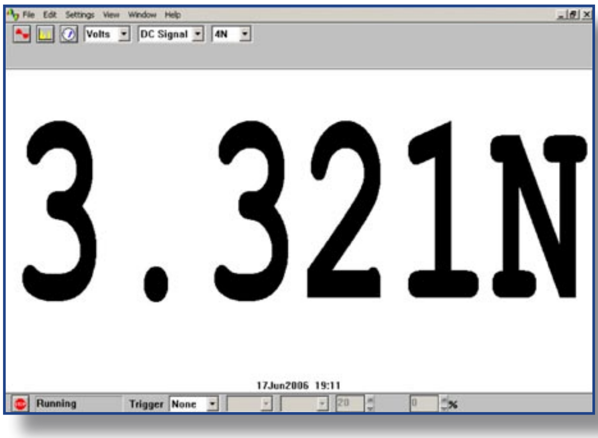
- Highlight this new range and click **OK**.

Activity (ii): Using the piezoresistive force sensor with PicoScope on DrDAQ



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 weight displayed in newtons

- Select this new range, place the unknown weight on the force sensor and then click the **GO** button. You should now see a digital meter reading displayed directly as a weight (not necessarily this value).
- Compare this displayed value for the weight with the actual weight.
- Click the **STOP** button.

- To return the program to its original state first click the down-arrow next to '4N' and return to the 'Volts' range. 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 and then 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 piezoresistive force sensor with PicoScope on DrDAQ

Results

Mass /g	Weight /N	Voltage output /mV
0	0	
100	0.98	
200	1.96	
300	2.94	
400	3.82	
500	4.90	
Unknown		

Questions

Does your graph show the voltage output to be
(a) **linearly related to** the weight placed on the sensor button
and
(b) **directly proportional to** the weight placed on the sensor button? Explain.

How close was your estimate of the unknown weight?

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

How well did the displayed value match with the actual value?