FLOW SENSORS

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SEP
Science Enhancement Programme

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FLOW RATE SENSORS

INTRODUCTION

Measuring and controlling rates of flow is a very common requirement in industry, and so a wide range of sensors has been developed to enable the measurement of such rates without interrupting the flow. Some situations that are worthy of mention are measuring water flow into houses, coolant flow in power stations (nuclear included), aviation fuel flow on aircraft and when refuelling, petrol and diesel fuel flow when filling up one's car at a filling station, chocolate flow when covering biscuits or in the enrobing process of coating chocolates, and oil and gas flow from oil and gas fields to distribution centres and on to consumers.

Types of flow rate sensor

The list of sensors which follows is by no means exhaustive and new methods are being developed all the time.

In the activities described, students will be using two simple techniques, both based on **electromagnetic induction**: these are described in **section 1**, below.

It is also useful for you to know a little about a number of **other flow sensors** such as **float-position, hinged vane, Venturi, Pitot, thermal, electromagnetic, vortex-shedding, vee-notch , sharp-edge orifice** and **ultrasonic**: these are described in **section 2**.

SECTION 1: FLOW RATE SENSORS USED IN THE ACTIVITIES

(I) THE DYNAMO/GENERATOR PROPELLER METER

Most students will have heard of a dynamo even if they have not previously seen one – use on a bicycle is quite rare nowadays – so they should know that it is a device which generates electricity. This property is easily demonstrated by using the **SEP Energy transfer kit** and connecting up any of the output devices to the dynamo, then turning the handle. Alternatively, you could connect a solar motor to a digital multimeter set on either its millivolt of milliamp range and getting the propeller to spin by blowing on it.

If you wished to go further in explaining what is going on inside the dynamo or solar motor then it would be useful to obtain a cheap model motor and take it to pieces to show its armature, magnet and brushes. If you have any kits with which to construct such a motor/generator, then that may be a useful extra activity through which you can explain that movement of a coil in a magnetic field generates electricity.

In the first two activities, students position the dynamo/generator so that its propeller is in the (steady) flow from a water tap and record the average voltage or current for five or so different flow rates. They measure the flow rates by collecting a litre of water in a measured time, so they should be able to see how the flow rate varies with the e.m.f or current, and whether or not there is direct proportionality between the flow rate and these electrical quantities. This is effectively the process of **calibrating** the flow meter and this process should be drawn attention to as something which has to be done with all sensors to make them into useful devices in measuring instruments.

The data collected could either be plotted manually onto graph paper or made into a graph with the aid of a spreadsheet or data handling program such as Simple Data Handling from djb microtech ltd. Uncertainties of results could be incorporated if required: I found the e.m.f.s to vary ±2mV and the collection times could only be judged to the nearest second. The use of pond fountain pumps would produce more consistent flow rates than from a tap.

Typical results:

Mean e.m.f /mV	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	
114	29	30	29	29	0.034
126	27	26	27	27	0.037
137	24	23	23	23	0.043
150	20	20	21	20	0.050
165	19	18	19	19	0.053

Propeller dynamo/generator with multimeter

Mean current /mA	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	
17	30	31	31	31	0.032
26	22	22	21	22	0.045
30	19	19	20	19	0.053
34	18	17	18	18	0.056
41	15	16	15	15	0.067

Propeller dynamo/generator with multimeter

Mean e.m.f. /mV	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	
76	17	16	17	17	0.059
90	14	14	13	14	0.071
102	12	11	12	12	0.083
124	10	10	9	10	0.10
132	9	9	9	9	0.11

Propeller dynamo/generator with Picoscope on DrDAQ

(II)THE TURBINE WITH MAGNETIC PICKUP

This is again a flow meter working on the basis of electromagnetic induction with a series of magnets changing the magnetic field in the coil that makes up part of the magnetic pickup. As each magnet passes the pickup an e.m.f. is induced across it and the frequency of production of these e.m.f.s is related to the rate of rotation of the turbine and the rate of flow of the liquid.

As a larger scale explanatory introduction to how this system works, you could wind a coil of a few tens of turns round a soft-iron rod and connect it to a sensitive galvanometer or millivoltmeter, then show that close movement of a magnet past the end of the soft-iron rod results in a voltage being developed.

Connection of this device to a multimeter with a frequency range on it (Model CM1604 from J P R Electronics Ltd. is very inexpensive), or to Pico Technology's *DrDAQ* running *Picoscope* on its digital frequency meter range, allows a set of results of frequency to be collected for a variety of flow rates, and a graph plotted to see how these quantities relate to each other. Again, this is really calibrating the device. You could of course use an oscilloscope to measure frequency, but its use does overcomplicate this measurement.

Typical results:

Mean frequency /Hz	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	
25	32	32	31	32	0.031
30	26	25	26	26	0.038
36	21	21	20	21	0.048
42	19	19	20	19	0.053
46	17	17	16	17	0.059

Turbine with multimeter

Mean frequency /Hz	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	
19	38	38	39	38	0.026
29	27	26	27	27	0.037
34	22	22	22	22	0.045
38	20	19	20	20	0.050
43	17	18	18	18	0.056

Turbine with Picoscope on DrDAQ

The data collected could either be plotted manually onto graph paper or made into a graph with the aid of a spreadsheet or data handling program such as Simple Data Handling from djb microtech ltd. Uncertainties of results could be incorporated if required: I found the frequencies to vary by ±1Hz and the collection times could again only be judged to the nearest second. The use of pond pumps should produce more consistent flow rates than those from a tap.

Additional comments

Using *Picoscope* with *DrDAQ*, students could calibrate the system to automatically display the flow rate directly on the computer screen. This is not difficult to do, nor does it take long. It would be 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. The dangers of extrapolation should also be pointed out.

Note: *The displayed resolution of the flow rate 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.*

In commercial systems a **Schmitt trigger** (electronic circuit device) would be connected to the output of sensors being used to produce a frequency measurement. This device 'sharpens' a relatively slow change of e.m.f. into one with a fast rise and fall time – it squares off the waveform being generated – and so makes the detection and counting of such pulses more reliable.

The RS Components' flow transducer (RS 257-149) is a turbine flow meter but operates with its turbine blades interrupting an infrared beam, much in the same way that a dynamics trolley timing card cuts the light beam of a timing gate. The frequency of interruption gives a measure of the flow through the system.

SECTION 2: OTHER TYPES OF FLOW RATE SENSOR

The float-position sensor is one in which a free-floating indicator rises in a transparent tube to a position dependent on the rate of flow of the fluid passing through it. They are direct reading and have flow rate markings on the tube.

Paddle wheel (rotating magnet) and Float position sensor (courtesy of Cole-Parmer UK)

Hinged vane flow meters go back as far as World War 1 (WW1) aircraft where they were used as air speed indicators. They are simply a vane or plate which can swivel by an amount again dependent on the rate of flow of the fluid passing/pushing by. Whilst the WW1 version would just have had an air speed marked on a scale alongside, modern ones would be connected to potentiometers or optical shaft-encoders (see section on use of a rotary potentiometer as a sensor) to give a voltage or digital state output.

The **Venturi meter** and **Pitot-static tube** both look at pressure differences to give a measure of flow rate:

- The **Venturi meter** consists of a tube with a section containing two differing bores, the pressure difference being measured between those two sections.
- The **Pitot tube** has two sensing apertures. One aperture directly faces the flow and the other is parallel to it. The device is inserted into the fluid stream and measures the pressure difference between the two apertures.

Thermal sensors are used in the oil and gas industry where, in one technique, the flow rate is related to temperature differences produced by intermediate heating of the fluid in the pipeline. In another, the **hot-wire anemometer**, flow past a heated filament produces cooling and a change of its resistance. The voltage required to bring its resistance back to the original value is measured and relates to the rate of flow past it.

The electromagnetic flow meter relies on the generation of an e.m.f. across a conducting fluid placed in a magnetic field. It is usually quite an expensive meter as it needs powerful magnets. Its great advantage is that it has no moving parts. The e.m.f. generated is directly proportional to the flow rate.

Vortex-shedding flow meters rely on the production of vortices by an obstruction placed in the flow. The number of vortices produced each second can be related to the flow rate of the fluid passing the obstruction. Various techniques are used for sensing the vortices: **thermal** (vortices would cool a heated filament or thermistor), **mechanical** (in detecting the voltage generated by the tiny movement of a piezoelectric bimorph sensor as each vortex passes), and **pressure variation** (as the vortices pass).

The Vee-notch is used in open trough situations and is simply a V-shaped aperture made at the end of a trough (plastic guttering) through which the liquid flows. The height of the liquid above the bottom of the V, together with the angle of the V, relate to the flow rate.

The Sharp-edged orifice is similar to the Vee-notch in that the orifice, a circular hole, is made at the end of a trough through which the liquid flows. This time the flow rate relates to the height of the liquid above the centre of the orifice, together with the diameter of the orifice.

Ultrasonic flow meters use the Doppler effect, the frequency of the transmitted ultrasound being affected on reflection from particles within the flow and the received frequency being used to calculate the particle/fluid speed and so the flow rate.

Further reading

Details of how to construct and use many of these flow meters are provided in the Supported Learning in Physics publication, Physics of Flow by Chris Butlin and Michael Brimicombe. (Published by Heinemann Educational Publishers). Two other publications on which the above was based are available free from the Institute of Physics: Investigations of Liquid Flow and Laboratory Gas Meter Science Activities for A level, both by Chris Butlin. The latter provides a sub-set of activities from the long out-of-print Science Activities for A-level – Some Ideas for Using the Laboratory Gas Meter in Advanced School Science, edited by Robin Millar and published by British Gas Education.

For a definitive guide to flow meters, reference should be made to Flowmeters: a basic guide and source-book for a user by A T J Hayward and published by Macmillan Press. It is likely to be a library reference volume.

FLOW RATE SENSORS: TECHNICAL NOTES

DEMONSTRATION OF DYNAMO/MOTOR ACTION

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:
SEP Energy transfer kit (MUTR)
or
2x Low inertia miniature solar motor
or
Motor construction kit –MUTR self-assembly motor (MUTR), or Westminster type or similar
Millivoltmeter – large scale or arrange for projected image with a FlexCam or webcam.

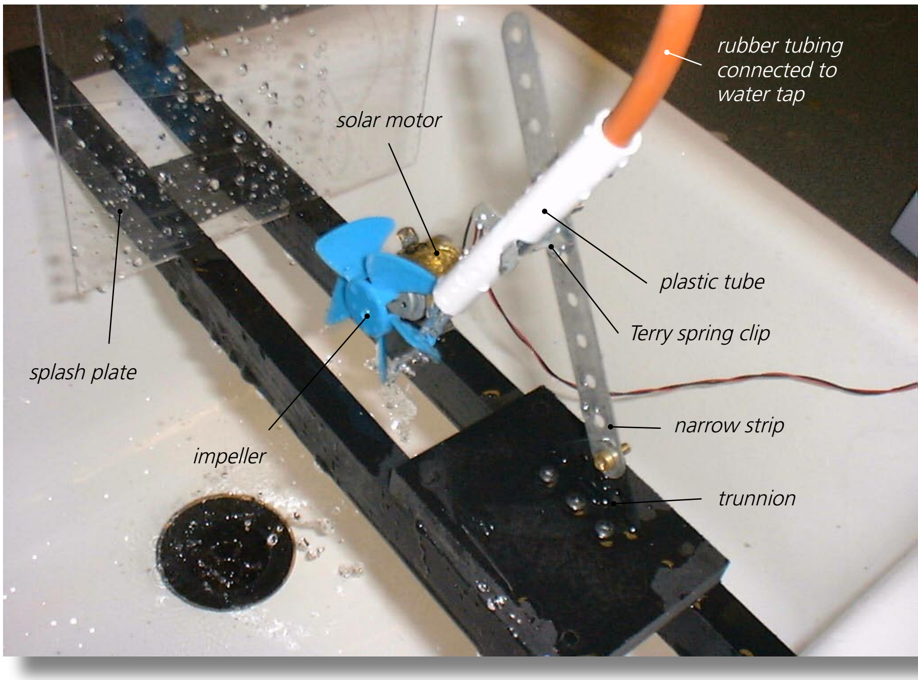
Either make up the dynamo/generator from the construction kit in order to show its structure or dissemble one of the solar motors. Put 4mm red and black plugs onto the solar motor's red and black leads.

USING A PROPELLER DYNAMO/GENERATOR TO MEASURE LIQUID FLOW RATES

***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.*

Equipment:

Low inertia miniature solar motor
Miniature impeller – 5 blades
Wood approximately 2.5cm x 1.5cm cross-section made into mounting frames to fit across laboratory sinks (see photo)
MDF 8.5cm x 8cm
Clear polystyrene sheet 15cm x 30cm for splash plate
Plastic tubing 10cm long, external diameter 12mm, internal 9mm
Rubber tubing to connect to tap, external diameter 8mm, internal 5mm
Terry spring clip and screw to fit solar motor
Terry spring clip to fit plastic tube
Nuts and bolts
Trunnion - Meccano part 126
11 hole narrow strip - Meccano part 235f
65mm square section downpipe or 22mm width Trunking
Panel pins
Glue
Velcro
Black paint
Connecting wire – red and black
1 x 4mm plug – red
1 x 4mm plug - black
1 x 4mm socket – red
1 x 4mm socket – black
1 x 4mm socket – yellow
1 x 4mm socket – blue
Digital multimeter
Dr DAQ with PicoScope software (PicoTechnology)
Access to spreadsheet or data handling/graph plotting software



Propeller dynamo/generator system in close-up

Make up the mounting frame so that it will fit across a laboratory sink and paint it black. Mount the solar motor with its turbine blades fitted into the Terry spring clip so that the turbine blades run centrally between the frame's main beams. Bolt the trunnion and narrow metal strip together, fitting the Terry spring clip onto the metal strip five holes from its top end. Bolt the trunnion onto the piece of MDF so that, when the plastic tube to direct the flow is fitted, it makes the water impinge on the turbine blades making them turn. Now fit the plastic tube in place. The whole system needs to be adjustable so that the water flow can be directed to best effect.

Solder two leads, one red and one black, onto the solar motor and terminate with red and black 4mm plugs respectively. The leads should be connected so that, when connected to the multimeter on its d.c. voltage range with the black one in COM and the red one in V, a positive voltage is recorded when the turbine blades are rotating in the required direction.

If you are using *DrDAQ,* it is most usefully secured to a piece of plastic downpipe cut in half, or trunking, with Velcro and 4mm sockets mounted on it to connect to the Ground (0V) – black socket, Digital Output (DO) – yellow socket, Resistance (R) – Blue socket and Voltage (+V) – red socket. This makes it easy to connect other equipment to it with 4mm plug leads.

Plug *DrDAQ* into the appropriate port on each computer to be used. *DrDAQ* connects direct via a cable to a parallel port, but a USB adaptor is available to connect it to a USB port.

The instructions may need some additional comment if the computers are being used on a network.

It is advisable to fit a splash plate to contain the water spray as the experiments can be a little messy.

DEMONSTRATION OF EFFECT OF CHANGE OF MAGNETIC FIELD NEAR A COIL

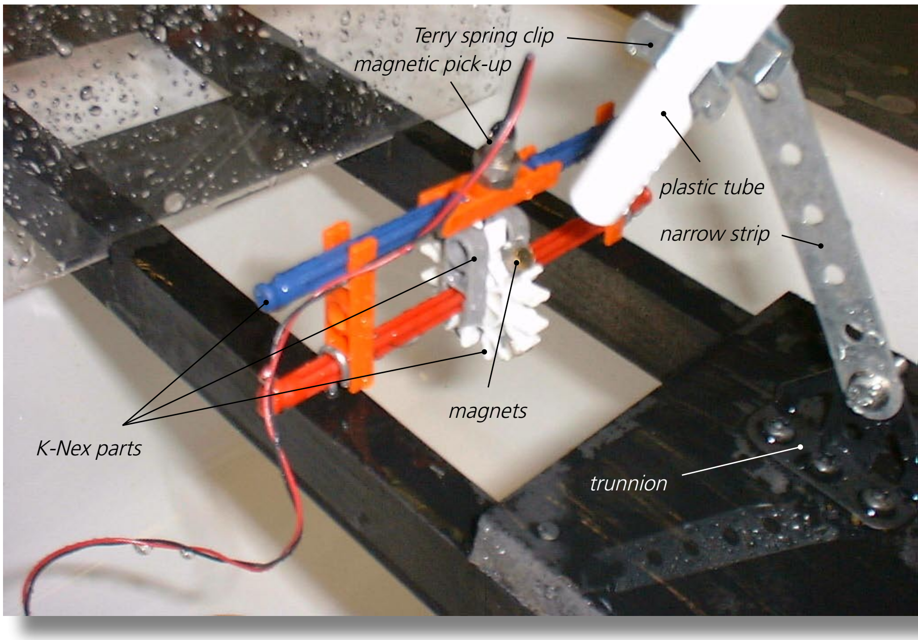
Equipment:
soft iron rod
solid core single connecting wire
strong magnet
galvanometer – large scale or arrange for projected image with a FlexCam or webcam and computer with digital projector.

Wind a few tens of turns of the wire around and along the soft iron rod and connect the ends of the wire to the galvanometer. When the magnet is moved past the end of the soft iron rod the galvanometer needle should deflect.

USING A TURBINE METER WITH MAGNETIC PICKUP TO MEASURE LIQUID FLOW RATES

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.*

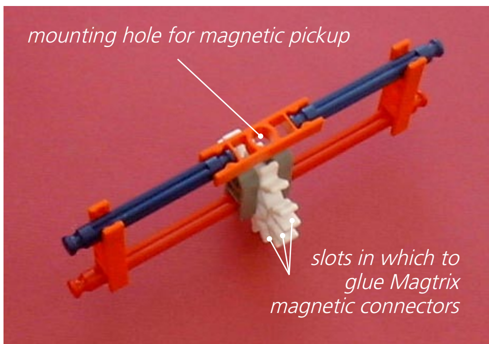
Equipment:
Wood approximately 2.5cm x 1.5cm cross-section made into mounting frames to fit across laboratory sinks (see close–up photo of turbine)
Clear polystyrene sheet 20cm x 30cm for splash plate
MDF 11.5cm x 8cm
Plastic tubing 10cm long, external diameter 12mm, internal 9mm
Rubber tubing to connect to tap, external diameter 8mm, internal 5mm
Terry spring clip and screw to fit solar motor and
Terry spring clip to fit plastic tube
Nuts and bolts
Trunnion - Meccano part 126
11 hole narrow strip - Meccano part 235f
65mm square section downpipe or 22mm width trunking
Panel pins
Nuts and bolts
Velcro
Glue
K'Nex component assembly – see photos
2 screw eyes to fit K'Nex axle)
Magtrix magnetic connectors (Maplin N51AK)
Magnetic pickup (RS 304-166 RS Components)
1 x 4mm plug – red
1 x 4mm plug - black
1 x 4mm socket – red
1 x 4mm socket – black
1 x 4mm socket – yellow
1 x 4mm socket – blue
Autoranging multimeter with frequency range – for example, Model CM1604 (JPR Electronics 375-490) or similar from electronics suppliers
DrDAQ with *PicoScope* software (PicoTechnology)
Access to spreadsheet or data handling/graph plotting software



Turbine with magnetic pick-up close-up

Make up the mounting frame so that it will fit across a laboratory sink and paint it black. Bolt the trunnion and narrow metal strip together, fitting the Terry spring clip onto the metal strip five holes from its top end. Bolt the trunnion onto the piece of MDF so that, when the plastic tube to direct the flow is fitted, it makes the water impinge on the turbine blades making them turn. Now fit the plastic tube in place. The whole system needs to be adjustable so that the water flow can be directed to best effect.

Select four of the Magtrix Magnetic Connectors of the same polarity on their non-wire ends and cut off their wire connections. Glue these mini-magnets into the K'Nex turbine wheel so that they are spaced at 90° intervals. You will need a strong glue and will have to keep repositioning the magnets as the glue sets – these magnets are very strong! Screw the two screw-eyes onto the main beams so that the K'Nex axle will fit through them across the beams, fit the turbine wheel onto the axle and pinch the screw-eyes tight to grip this axle. Assemble the rest of the structure with K'Nex fitting the magnetic pickup in position just a few millimetres above where the magnets will pass as the turbine wheel spins.



K'Nex parts and assembly

Solder red and black 4mm plugs onto the magnetic pickup's two leads, the red one onto the red lead and the black one onto the black lead.

If you are using *DrDAQ*, it is most usefully secured to a piece of plastic downpipe cut in half, or trunking, with Velcro and 4mm sockets mounted on it to connect to the Ground (0V) – black socket, Digital Output (DO) – yellow socket, Resistance (R) – Blue socket and Voltage (+V) – red socket. This makes it easy to connect other equipment to it with 4mm plug leads.

Plug *DrDAQ* into the appropriate port on each computer to be used. *DrDAQ* connects direct via a cable to a parallel port, but a USB adaptor is available to connect it to a USB port.

The instructions may need some additional comment if the computers are being used on a network.

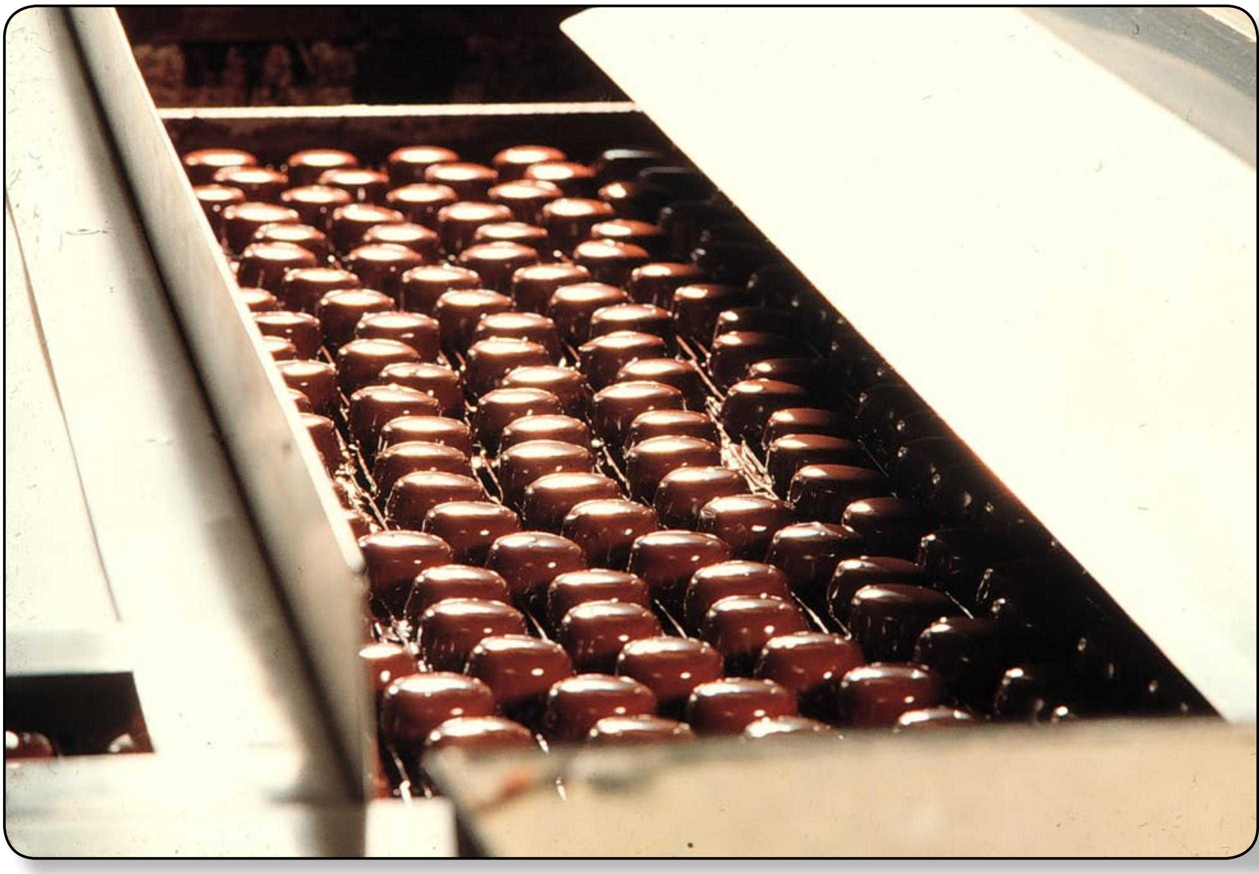
About flow rate sensors

There are many industrial and domestic situations in which we need to measure the flow rates of fluids (that is, liquids or gases).

Examples of situations in which such measurements may be needed include:

- for billing consumers for gas or water consumption,
- for ensuring the correct delivery and billing for filling up with petrol at a filling station,
- for ensuring adequate cooling by liquid sodium in a fast-breeder nuclear power station, or
- for making sure that enough chocolate is being exuded to adequately cover chocolates or biscuits.

The range of uses and needs is enormous, as are the means of measuring and monitoring such flow rates.



Enrobing chocolates (courtesy of Nestlé)

Scientists and engineers talk about two kinds of flow rates: **volumetric**, in which the volume of fluid passing through each second is measured, and **mass**, in which the mass of fluid passing through each second is measured.

About flow rate sensors

The simplest method of measuring a flow rate is to interrupt the flow and collect and measure the amount of fluid (mass or volume) collected in say ten seconds. So if, for example, 5 litres (5 kilograms) of water was collected in 10 seconds, then the flow rate would be

$$5 \div 10 = 0.5 \text{ litres/second or kilograms/second.}$$

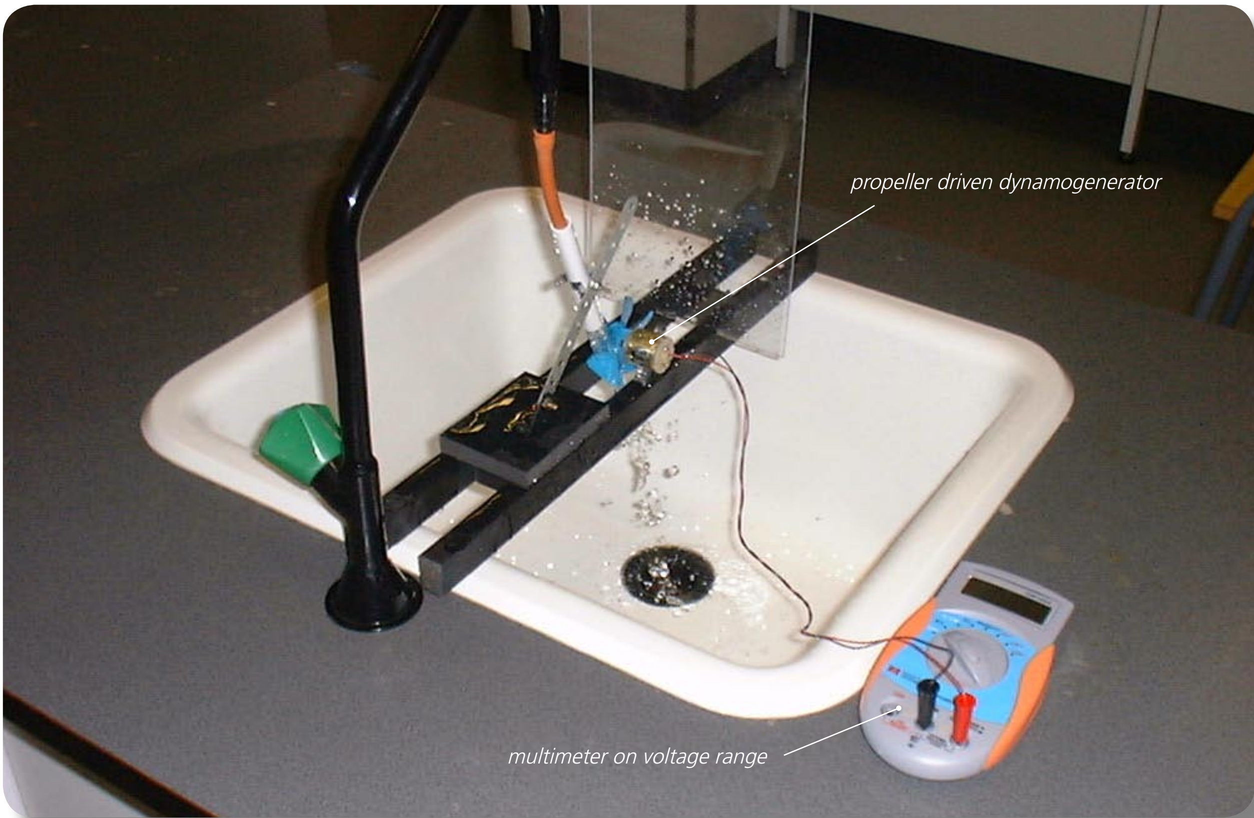
However, interrupting the flow completely is not usually a sensible thing to do and so various sensors have been developed to allow on-going measurement. The activities describe two of the simplest: a **dynamo/generator propeller meter** and a **turbine meter linked to a magnetic pick-up**.

With the dynamo/generator propeller meter, the rotation of the **armature coil within a magnetic field** created by magnets inside the device produces an **electromotive force** (e.m.f.). This e.m.f. is then measured directly as a voltage or indirectly through the current it produces, and we can use these values (voltage or current) to compare flow rates.

With the turbine meter, the **rotation of a series of magnets past a magnetic pickup** produces a change of magnetic field in the pickup's coil, resulting in an e.m.f. across it. The frequency of this e.m.f. depends on the speed of rotation of the turbine and the rate of flow of liquid past it, so we can use frequency measurements to compare flow rates.

Activity (i) - Mean emf method with a multimeter

Procedure



Propeller dynamo/generator linked to a multimeter

Calibration

- **Arrange the dynamo/generator with its propeller in the flow of liquid (such as water from a steadily flowing tap). Connect its leads to a digital multimeter set on a millivolt range.**
- Record the **mean e.m.f.** (voltage) displayed for the first selected flow rate. You may well need to take this as the displayed value that appears most often, as it might well vary slightly with time.
- **Without switching off the tap**, remove the rubber tubing from the plastic pipe, direct the flow into a measuring beaker and record how long it takes to collect one litre of water.
- Repeat this timing twice more, recording the value each time. Calculate an average time, and then an average flow rate. (If you collected 1.0 litre of water in 12.8 seconds, then the flow rate would be 1.0 ÷ 12.8 = 0.078 litres/second, for example). Do this for five different flow rates.
- Now plot a graph of mean e.m.f.s (Y-axis) against their respective average flow rates (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 flow meter

You will now have **calibrated** the flow meter, producing a graph or calibration 'curve' which you will be able to use to obtain values of flow rates just from the e.m.f. (voltage) measurements obtained.

- Turn on the tap until an e.m.f. (voltage) measurement is obtained which is within the range of values obtained previously, but not equal to any of them.
- Using your calibration 'curve' note down what you think the flow rate must be.
- Check this by measuring again how long it takes to collect a litre of water.

Activity (i) - Mean emf method with a multimeter

Results

Mean e.m.f /mV	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	

Questions

Does your graph show the mean e.m.f. to be
(a) **linearly related** to the flow rate and
(b) **directly proportional** to the flow rate? Explain.

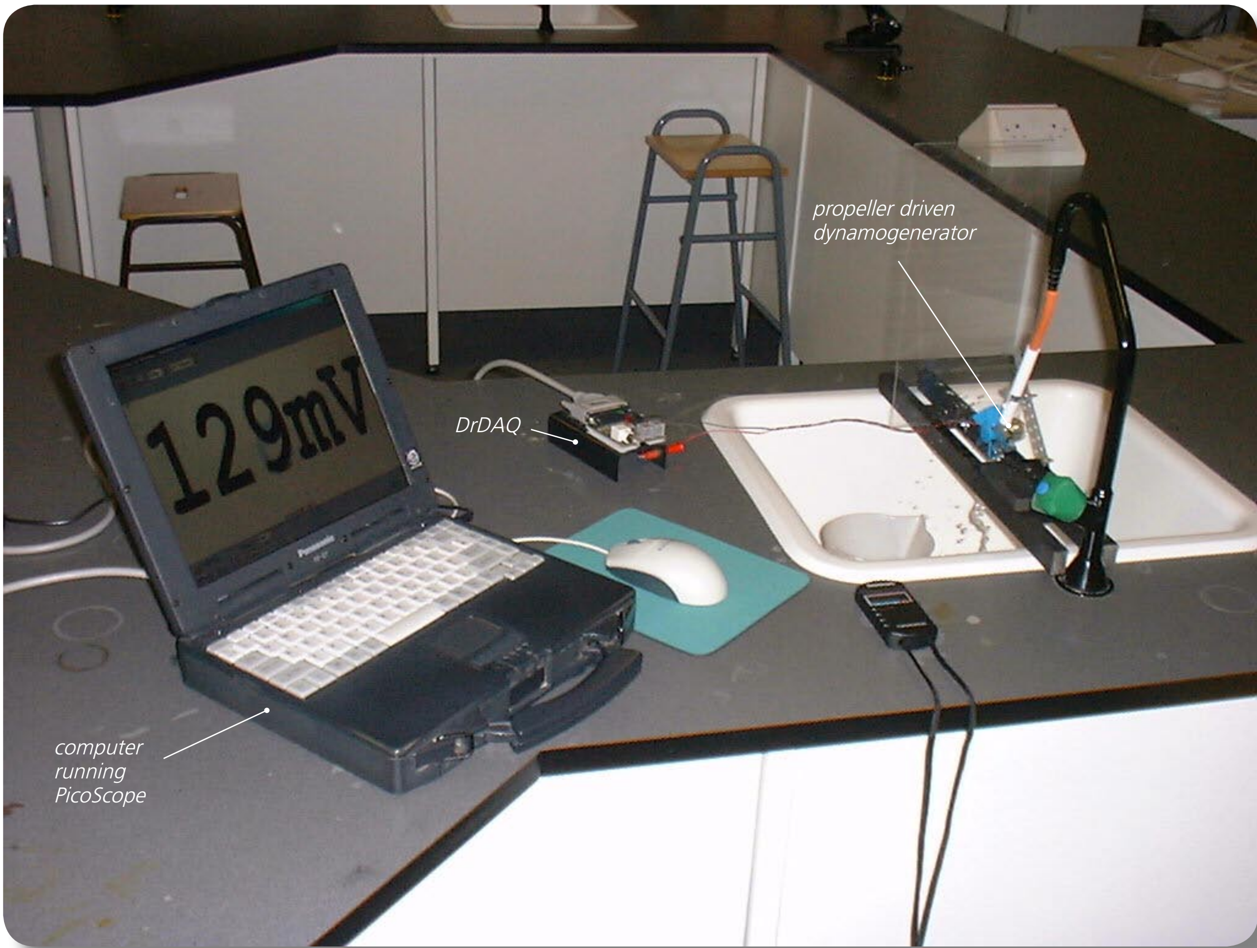
How close were the prediction for the flow rate and the actual flow rate?

Why wouldn't a prediction for a flow rate be likely to be reliable if the e.m.f. (voltage) measured was way beyond those used to produce the calibration 'curve'?

Activity (ii) - Mean emf method with PicoScope on DrDAQ

This activity allows you to have the digital meter so that it reads directly as a flow rate meter. (This is not possible with an ordinary multimeter or millivoltmeter)

Procedure



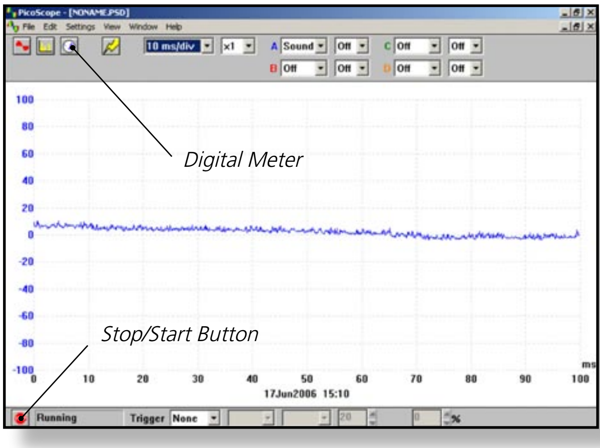
Propeller dynamo/generator method using PicoScope on DrDAQ

Calibration

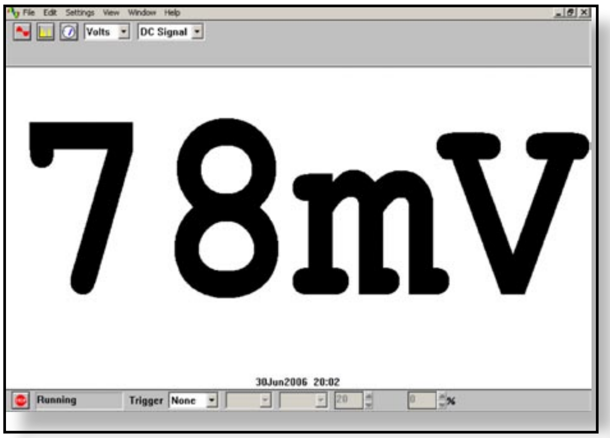
Note: If you are connected via a network you may need to obtain additional instructions.

- **Before** the computer is switched on check that DrDAQ has been plugged into the computer.
- Connect the magnetic pickup's **red** lead to the **V** socket on DrDAQ and its **black** lead to the **GND** socket.

Activity (ii) - Mean emf method with PicoScope on DrDAQ



DrDAQ opening screen



Digital Voltmeter display

- 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.

- 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.
- **Arrange the propeller in the flow of liquid** (such as water from a steadily flowing tap) and you should get a display like that shown.
- Record the mean e.m.f. (voltage) displayed for the first selected flow rate. You may need to take this as the displayed value that appears most often as it might well vary slightly with time.
- **Without switching off the tap**, remove the rubber tubing from the plastic pipe, direct the flow into a measuring beaker and record how long it takes to collect one litre of water.
- Repeat this timing twice more, recording the value each time. Calculate an average time, and then an average flow rate. (If you collected 1.0 litres of water in 12.8 seconds, then the flow rate would be 1.0 ÷ 12.8 = 0.078 litres/second, for example). Do this for five different flow rates.
- Now plot a graph of mean e.m.f. (voltage) on the Y-axis against the respective average flow rate on the 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) - Mean emf method with PicoScope on DrDAQ

Using the calibrated flow meter with a calibration 'curve'

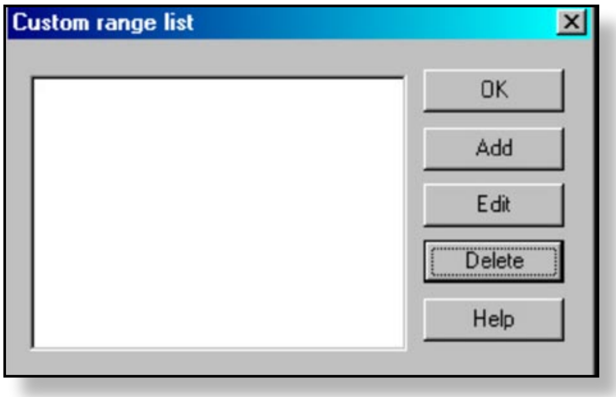
You will now have **calibrated** the flow meter, producing a graph or calibration 'curve' which you will be able to use to obtain values of flow rates just from the e.m.f. (voltage) measurements obtained.

- Turn on the tap until an e.m.f. (voltage) measurement is obtained which is within the range of values obtained previously, but not equal to any of them.
- Using your calibration 'curve', note down what you think the flow rate must be.
- Check this by again measuring how long it takes to collect a litre of water.

Calibrating the computer to automatically display flow rates

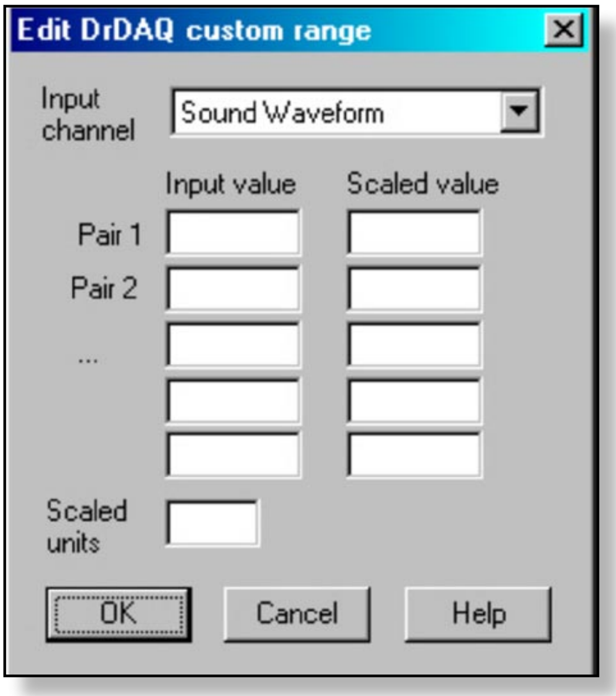
It would be unusual to find an instrument which had not been calibrated for direct use. With a computer-based device it is often possible to calibrate it so that it automatically displays the quantity you wish to measure directly on the screen. In this case you would want to get the computer to 'convert'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

Activity (ii) - Mean emf method with PicoScope on DrDAQ



Custom range list

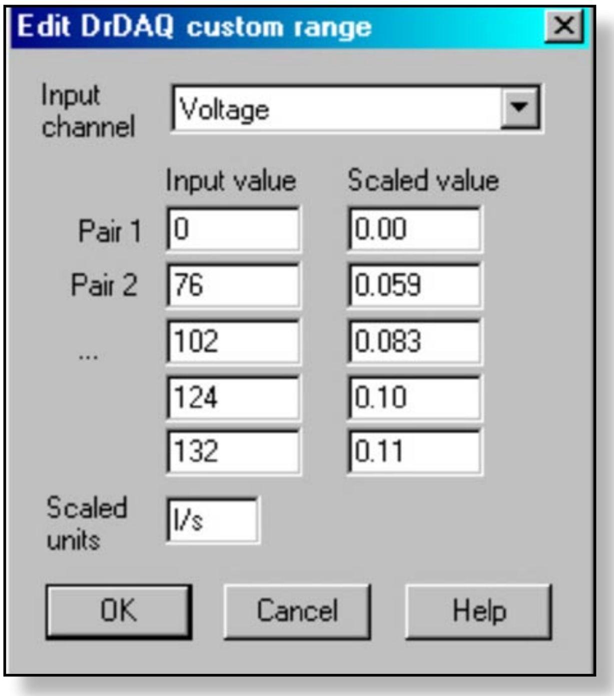
- Click the **STOP** button. Now click on **Settings** in the Menu bar and then on **Custom ranges** in the drop-down menu to display the Custom range list.
- Click on **Add** to display the Edit *DrDAQ* custom range box.



Edit DrDAQ Custom range box

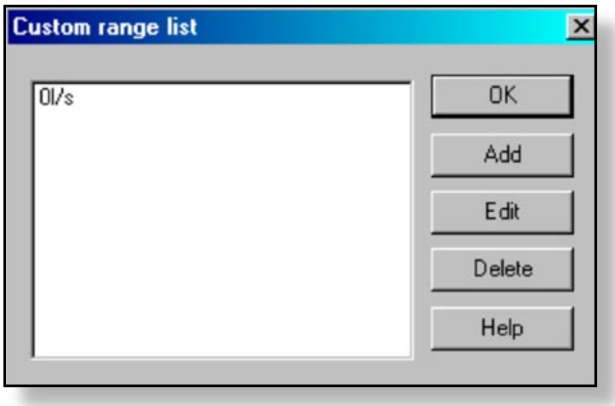
- Select the **Input channel 'Voltage'** by clicking on the down arrow alongside. Now type in your pairs of data into the two columns – **e.m.f.s** into the **Input value** column and the **average flow rates** into the **Scaled value** column – adding in a voltage of 0V for a Flow rate of 0.00 $l\ s^{-1}$.

Activity (ii) - Mean emf method with PicoScope on DrDAQ



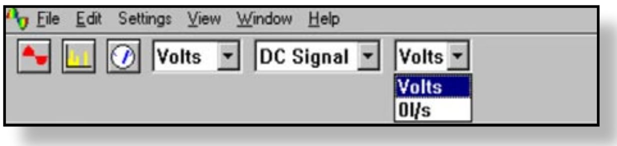
Add values and scaled units

- Type **'l/s'** (for litres per second) into the **Scaled units** box.
- Click the **OK** button. You should now see a '0l/s' range appear in the Custom range list.



Custom range list with new range added

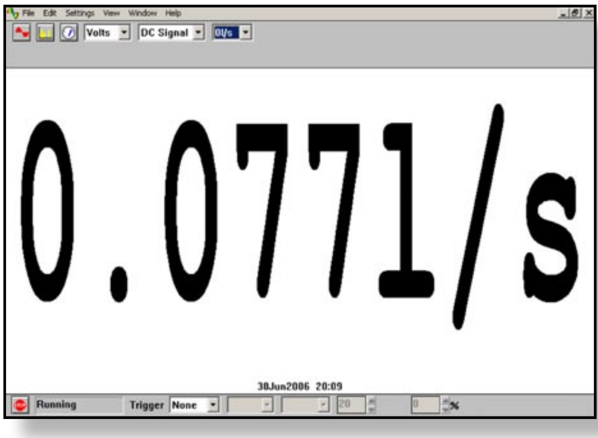
- Highlight this new range and click the **OK** button.



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 as shown.

Activity (ii) - Mean emf method with PicoScope on DrDAQ



Flow rate display in l/s (litres/second)

- Select this new range and then click the **GO** button. With water flowing, you should now see a digital meter reading displayed directly as a flow rate.
- Measure the flow rate using a measuring beaker and stopwatch: compare this value to the displayed value.
- Click the **STOP** button.

- To return the program to its original state, click the down arrow alongside '0l/s' and select 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, then click on 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 (ii) - Mean emf method with PicoScope on DrDAQ

Results

Mean e.m.f /mV	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	

Questions

Does your graph show the mean e.m.f. (voltage) to be
(a) **linearly related** to the flow rate and
(b) **directly proportional** to the flow rate? Explain.

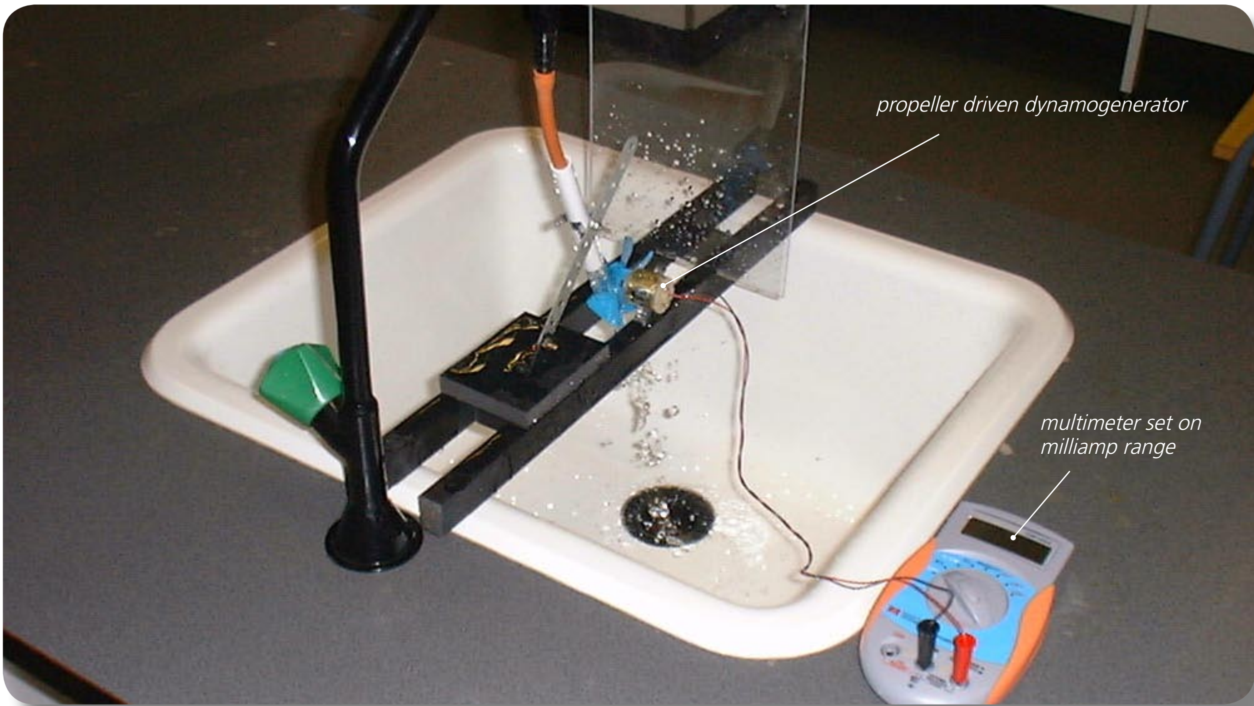
How close were the prediction for the flow rate and the actual flow rate?

Why wouldn't a prediction for a flow rate be likely to be reliable if the e.m.f. (voltage) measured was way beyond those used to produce the calibration 'curve'?

How well does this value match with a measured value obtained by timing how long it takes to collect one litre of water at this same flow rate?

Activity (iii) - Mean current method with multimeter

Procedure



Propeller dynamo/generator linked to a multimeter

- **Arrange the dynamo/generator with its propeller in the flow of liquid (such as water from a steadily flowing tap)**.
- Connect its leads to a **digital multimeter** set on a **milliamp** range.
- Record the mean current displayed for the first selected flow rate. You may well need to take this as the displayed value that appears most often as it might well vary slightly with time.
- **Without switching off the tap**, remove the rubber tubing from the plastic pipe, direct the flow into a measuring beaker and record how long it takes to collect one litre of water.
- Repeat this timing twice more, recording the value each time. Calculate an average time, and then an average flow rate. (If you collected 1.0 litres of water in 12.8 seconds, then the flow rate would be 1.0 ÷ 12.8 = 0.078 litres/second, for example). Do this for five different flow rates.
- Now plot a graph of mean current (Y-axis) against the respective average flow rate (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 flow meter

You will now have **calibrated** the flow meter, producing a graph or calibration 'curve' which you will be able to use to obtain values of flow rates just from the current measurements obtained.

- Turn on the tap until a current measurement is obtained which is within the range of values obtained previously, but not equal to any of them.
- Using your calibration 'curve' note down what you think the flow rate must be.
- Check this by again measuring how long it takes to collect a litre of water.

Activity (iii) - Mean current method with multimeter

Results

Mean current /mA	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	

Questions

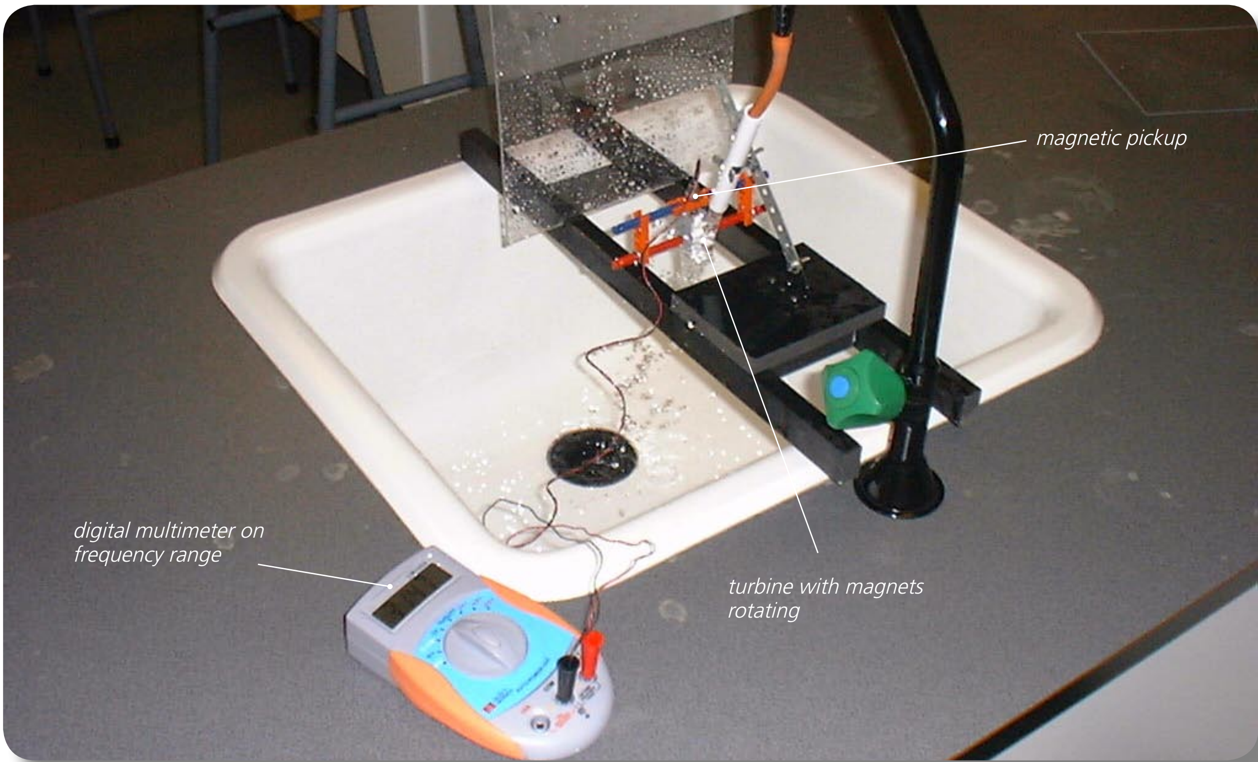
Does your graph show the mean current to be
(a) **linearly related** to the flow rate and
(b) **directly proportional** to the flow rate? Explain.

How close were the prediction for the flow rate and the actual flow rate?

Why wouldn't a prediction for a flow rate be likely to be reliable if the e.m.f. (voltage) measured was way beyond those used to produce the calibration 'curve'?

Activity (i) - Mean frequency method using a multimeter or frequency meter

Procedure



Turbine with magnetic pickup linked to a multimeter

Calibration:

- Arrange the **turbine** in the flow of liquid, most conveniently water from a steadily flowing tap. Connect the **leads from the magnetic pickup** to a **digital multimeter set on its frequency range**, or to a **frequency meter.**
- Record the mean frequency displayed for the first selected flow rate in your results table. You may well need to take this as the displayed value that appears most often as it might well vary slightly with time.
- Without switching off the tap, remove the rubber tubing from the plastic pipe, direct the flow into a measuring beaker and record how long it takes to collect one litre of water.
- Repeat this timing twice more, recording the value each time, calculating an average time, and then an **average flow rate**. If you collected 1.0 litres of water in 12.8 seconds, then the flow rate would be 1.0 ÷ 12.8 = 0.078 litres/second. Do this for five different flow rates.
- Now plot a graph of mean frequencies (Y-axis) against their respective average flow rates (X-axis) and incorporate a best-fit line.

Using the calibrated flow meter:

You will now have **calibrated** the flow meter, producing a graph or calibration 'curve' which you will be able to use to obtain values of flow rates just from the frequency measurements obtained.

- Turn on the tap until a frequency measurement is obtained which is within the range of values obtained previously, but not equal to any of them.
- Using your calibration 'curve', note down what you think the flow rate must be. Check this by again measuring how long it takes to collect a litre of water.

Activity (i) - Mean frequency method using a multimeter or frequency meter

Results

Mean frequency /Hz	Time to collect 1 litre of water /s				Average flow rate /l s-1
	1st trial	2nd trial	3rd trial	Average	

Questions

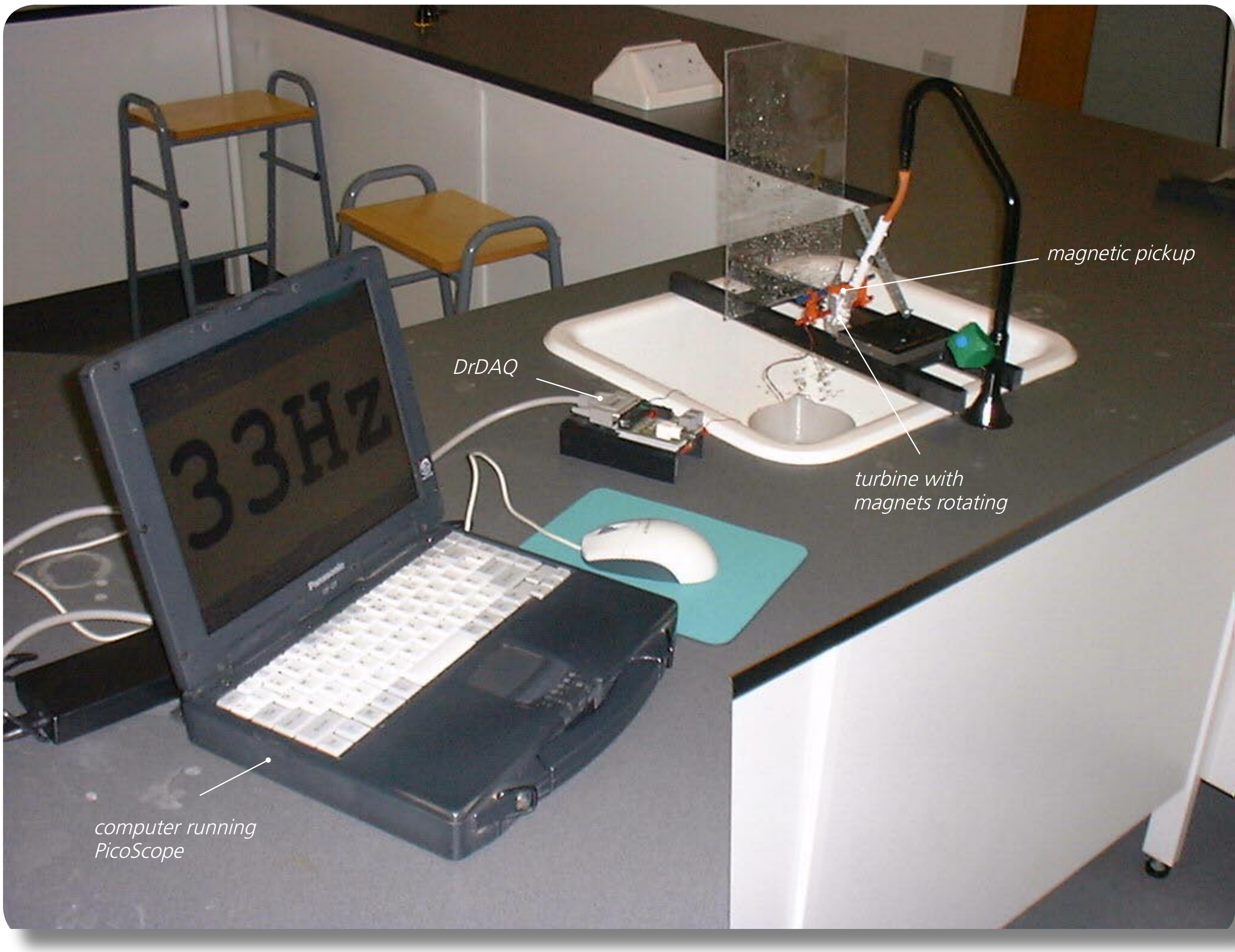
Does your graph show the mean frequency to be
(a) **linearly related to** the flow rate
and
(b) **directly proportional to** the flow rate? Explain.

How close were the prediction for the flow rate and the actual flow rate?

Why wouldn't a prediction for a flow rate be likely to be reliable if the frequency measured was way beyond those used to produce the calibration 'curve'?

Activity (ii): Mean frequency method using PicoScope on DrDAQ

Procedure



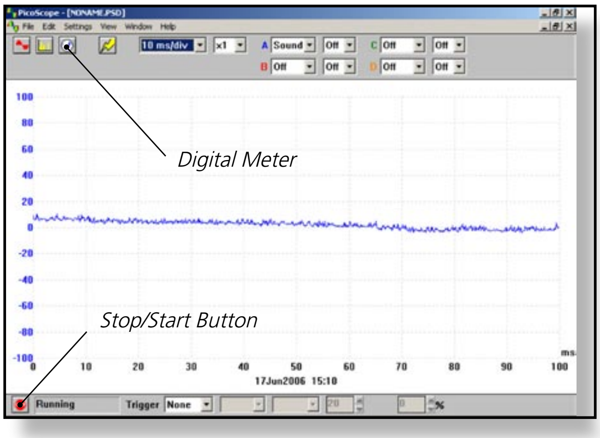
Turbine meter set up with DrDAQ

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 magnetic pickup's red lead to the V socket on *DrDAQ* and its black lead to the GND socket.

Activity (ii): Mean frequency method using 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 Frequency Meter 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 ico**n in the Toolbar, select **Volts** and **Frequency** and then click the **GO** button to put PicoScope into **Frequency Meter** mode. Arrange the turbine in the flow of liquid, most conveniently water from a steadily flowing tap, and you should get a display like that shown.
- Record the mean frequency displayed on the screen for the first selected flow rate. You may well need to take this as the displayed value that appears most often as it might well vary slightly with time.
- **Without switching off the tap,** remove the rubber tubing from the plastic pipe, direct the flow into a measuring beaker and record how long it takes to collect one litre of water.
- Repeat this timing twice more, recording the value each time, calculating an average time, and then an average flow rate. If you collected 1.0 litres of water in 12.8 seconds, then the flow rate would be $1.0 \div 12.8 = 0.078$ litres/second.
- Do this for five different flow rates.

Now plot a graph of mean frequencies (Y-axis) against their respective average flow rates (X-axis) and incorporate a best-fit line.

Activity (ii): Mean frequency method using PicoScope on DrDAQ

Using the calibrated flow meter with a calibration 'curve':
You will now have calibrated the flow meter, producing a graph or calibration 'curve' which you will be able to use to obtain values of flow rates just from the frequency measurements obtained.

- Turn on the tap until a frequency measurement is obtained which is within the range of values obtained previously, but not equal to any of them.
- Using your calibration 'curve', note down what you think the flow rate must be.
- Check this by again measuring how long it takes to collect a litre of water.

- **To finish with the program** first click on the **STOP** button. Now click **File** on the Menu bar and **Exit** in its drop-down menu.

Activity (ii): Mean frequency method using a multimeter or frequency meter

Results

Mean frequency /Hz	Time to collect 1 litre of water /s				Average flow rate /l s^{-1}
	1st trial	2nd trial	3rd trial	Average	

Questions

Does your graph show the mean frequency to be
(a) **linearly related to** the flow rate
and
(b) **directly proportional to** the flow rate? Explain.

How close were the prediction for the flow rate and the actual flow rate?

Why wouldn't a prediction for a flow rate be likely to be reliable if the frequency measured was way beyond those used to produce the calibration 'curve'?