For use at home or in the laboratory

An easy-to-build digital pH meter

From fish tanks to swimming pools to gardening, our new pH meter has many applications around the home. This unit features a large 3½-digit liquid crystal display and resolution to .01pH units, making it suitable for use in the laboratory as well.

by JEFF SKEEN

There are a number of uses for a pH meter outside the laboratory. Chief among these would be helping to keep algae at bay in the family swimming pool. Unfortunately for the pool owner, algae grows best in the warm summer months when the pool is in peak use. To prevent this growth and combat other "nasties", a chlorine-based chemical such as sodium hypochlorite is added to the pool water.

To allow the chlorine to function most effectively, and hence prevent waste, the pH of the swimming pool should be maintained between 7.2 and 7.6. If the pH is allowed to stray too far from these limits algae will begin to stain the pool tiles despite the addition of chlorine. During periods of heavy use, the pool pH should be checked every second day and the appropriate chemicals added to keep it within bounds.

A pool with a pH below 7 (ie acidic) will consume large amounts of chlorine. In addition, excess acidity causes eye irritations, skin rashes, and corrosion of metal pipes and fittings.

Two hobbies in which the pH of the environment also plays an important role are gardening and pisciculture (got you there).

Plants will generally flourish in soils with a pH somewhere in the range 6 to 8, although some familiar plants prefer soils outside this range. Camellias and azaleas cannot tolerate alkalinity and do best in soils of pH 4 to 5. On the other hand, tomatoes and potatoes like acidic soils of pH 6 to 7.

To analyse soil pH, "spear point" pH probes are available which measure the soil directly. In this project, however, analysis is carried out by mixing 10 grams of soil with 100 millilitres of water and measuring the pH of the resulting solution.

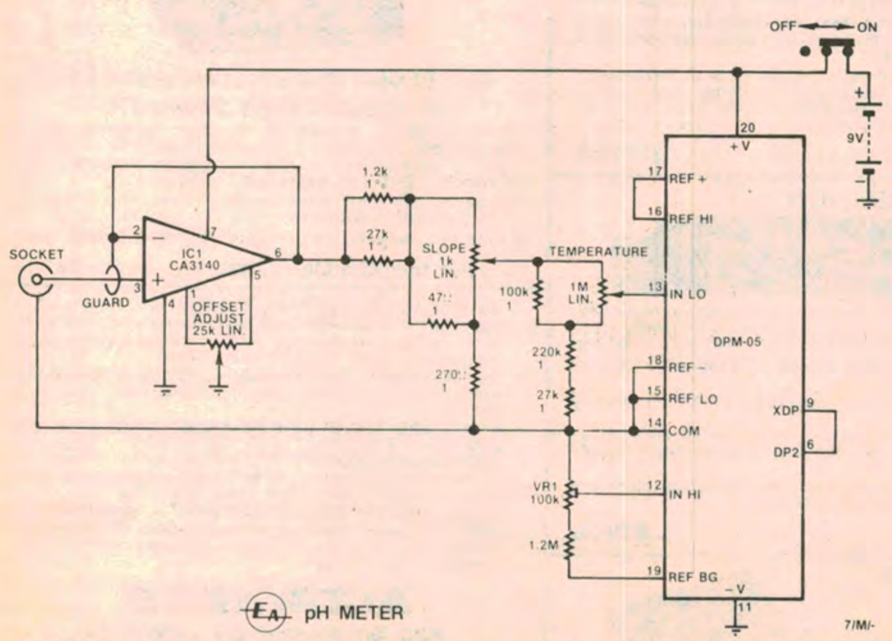
When keeping fish as a hobby (yes, pisciculture), the pH of the fish tank water has an obvious bearing on the health of the fish. A pH of around 6.5 to 7.5 is suitable for most freshwater fish but for best results (and the happiest fish!), the water should be maintained at the preferred pH for the fish species. For goldfish this is slightly alkaline, a pH of just over 7.5 being about optimum.

When raising either marine or rare tropical fish, where a lot of time, effort and money is involved, a pH meter is a logical accessory to have.

The pH meter to be described here is a general purpose instrument equivalent to commercial units costing hundreds of dollars more. It is simple to construct, easy to calibrate, and is built around a DPM-05 3½-digit liquid crystal display module to keep the parts count to a minimum.

Power is supplied by a single 9V battery, freeing the user from the requirement to have a power point handy. A "low battery" indicator is provided in the display to warn the user when the battery needs replacing. Sensing of solution pH is done with a standard glass pH probe which produces an output voltage proportional to the pH.

Other features of the meter include: compact size, direct readout of the solution pH, a measurement range from pH 0 to 14, and resolution to .01 pH units. To maintain the accuracy of the meter under varying conditions, three front panel calibration controls are provided:



A CA3140 op amp (IC1), a resistive divider network, and a 3½-digit LCD module make up the circuit. IC1 provides the required high input impedance.

This view shows the completed unit measuring the pH 6.88 buffer solution provided with the probe. Note the front-panel calibration instructions.

Temperature, Slope, and Offset. More about these later.

The pH probe

The device which makes this pH Meter possible is the pH probe. We are using an "Ionode" probe, manufactured in Queensland and stocked by Sydney-based company Starcross Scientific Pty Ltd. At the time of writing the cost of the probe is $45 plus sales tax.

In essence the probe is simply a wet cell, the output voltage of which is proportional to the pH of the solution. Corrections need to be applied to this voltage to take into account the effects of age, temperature and a less than ideal probe characteristic.

The glass bulb on the end of the probe is porous to hydrogen ions but blocks the passage of larger ions which would contaminate the silver/silver chloride half-cell inside the bulb. Although porous, the glass bulb (or membrane) still presents a significant impedance to the free flow of the hydrogen ions. As the flow of these ions determines the probe output current, the glass bulb determines the electrical impedance of the probe.

The major problem to overcome when designing a pH meter is the extremely high internal impedance of the probe. This impedance is of the order of 200 to 500MΩ depending upon the type of glass used for the membrane. To prevent the circuit from loading the probe (and reducing its output), the measuring circuit needs to have an input impedance at least 10 times greater than the internal impedance of the probe.

SPECIFICATIONS

MEASUREMENT RANGE	pH 0 to pH 14
RESOLUTION	0.01 pH units
ACCURACY	within 0.5% (dependent upon care taken in calibration)
TEMPERATURE RANGE	0°C to 100°C
POWER SUPPLY	Single 9V battery
CURRENT DRAIN	2.4mA

PARTS LIST

1 printed circuit board, code 82ph12, 67 x 36mm
1 ABS plastic case, 152 x 80 x 47mm
1 Scotchcal label, 148 x 78mm
1 panel-mounting BNC socket
1 SPST slide switch
1 DPM-05 LCD module
3 knobs
1 14cm length of RG58 coaxial cable
1 9V battery (type 216)
1 9V battery clip
1 Ionode pH probe (G101NFE) plus pH 4.00 and 6.88 calibration buffers (supplied with probe)
4 rubber feet
1 1MΩ linear potentiometer
1 100kΩ large vertical trimpot
1 25kΩ linear potentiometer
1 1kΩ linear potentiometer

SEMICONDUCTORS
1 CA3140T operational amplifier (metal can version)

RESISTORS (¼W, 1% unless stated)
1 x 1.2MΩ 5%, 1 x 220kΩ, 1 x 100kΩ, 2 x 27kΩ, 1 x 1.2kΩ, 1 x 270Ω, 1 x 47Ω

MISCELLANEOUS
Rainbow cable, scrap aluminium, machine screws and nuts, solder etc.

How it works

To achieve the required input impedance, we used a CA3140 FET-input operational amplifier (op amp) which has an input impedance of one tera-ohm (1 x 10^{12}Ω). This is assured by connecting the CA3140 as a unity gain voltage follower. The limiting factor for the input impedance then becomes the resistance of the printed circuit board (PCB) material.

Leakage currents from other tracks can flow across the PCB, swamping the input current from the probe and causing incorrect readings. To prevent this a guard ring of copper track at the same potential as the input is placed around the input to the CA3140. Because the ring and the input are at the same potential, no leakage current will flow across the PCB.

As the CA3140 is connected as a

voltage follower, a convenient place to connect the guard ring to the circuit is at the output of the CA3140.

The 25kΩ potentiometer connected between pins 1 and 5 initially cancels out any small DC offset voltage produced at the output of the CA3140. Later on, this potentiometer is also used to cancel out any offset in the probe output.

Following the CA3140 is a resistive divider network designed to reduce the probe output voltage to a level suitable for measurement by the DPM-05 LCD panel meter. Included in this network are two additional potentiometers – the Slope and Temperature controls.

These change the division ratio of the resistive network to compensate for variations in the probe output due to temperature and age.

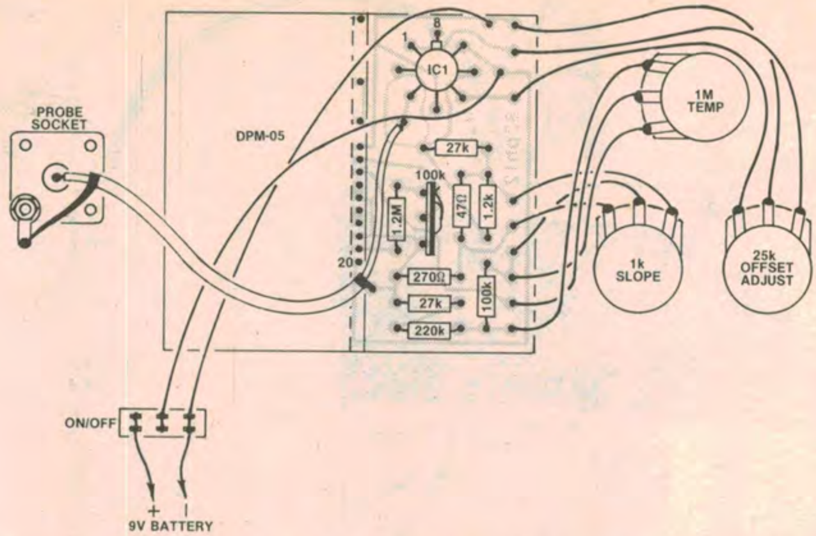
In order to provide accurate front panel scales, the tolerance of these potentiometers must be greatly improved on their 20% values. This is achieved by connecting low-value close-tolerance resistors across the potentiometers, thus reducing their tolerance variation from 20% to around 2%.

The operation of the DPM-05 LCD module is virtually identical to the DPM-200 used previously, so we will not go into details of the module operation here. For a description of the DPM-200 module, see the February, 1982 issue. The module is connected as a 199.9mV full-scale reading voltmeter with one important difference to previous circuits – the input is fed to the IN LO rather than the IN HI input.

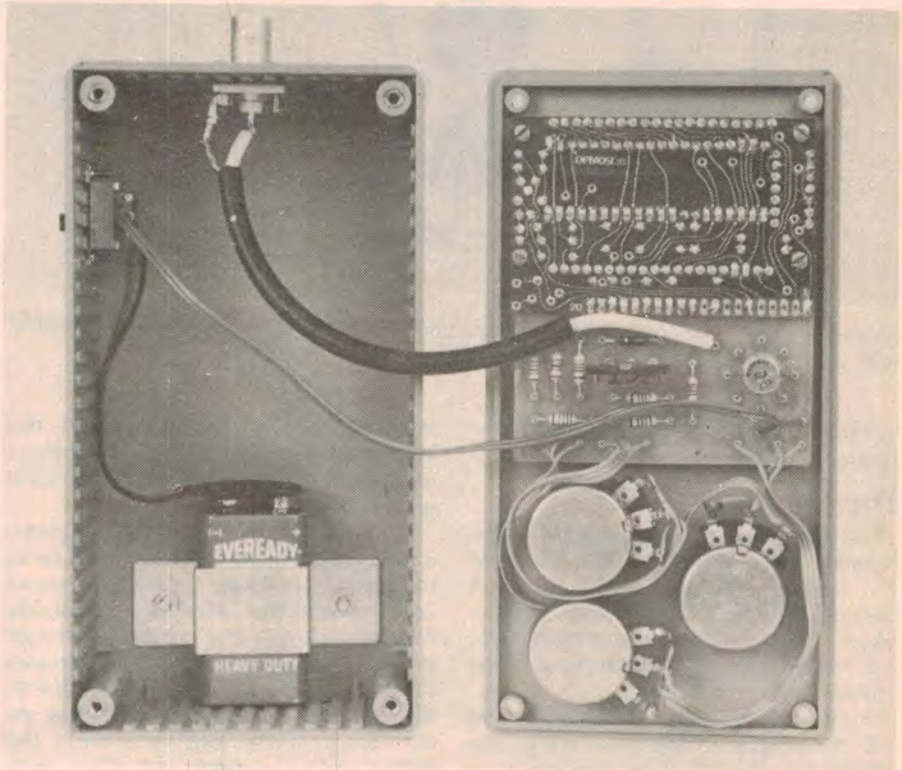
In this configuration, the module subtracts the voltage at the IN LO input from that at the IN HI input and displays the result. Another way of saying this is that the module inverts the polarity of the IN LO input and adds it to the IN HI input. Thus the display reading increases when the probe output is negative and decreases when the probe output is positive.

The reason for the inversion of the input signal polarity is evident from Fig. 1. This shows the probe output for solutions of varying pH. When pH is 7, the probe output is zero. For low pH (acid) the probe output is positive and for high pH, above 7, the probe output is negative. Therefore, the probe output signal needs to be inverted and offset (subtracted from a reference voltage) to enable it to be used in a conventional voltmeter circuit.

Trimpot VR1 in series with the 1.2MΩ resistor is adjusted during the calibration procedure to give exactly 70.0mV at the IN HI input. Because the module works in 10ths of a millivolt, this would normally be displayed as 700 but the permanent wiring in of DP2 changes this to read 7.00.



This wiring diagram and the photograph below show how the PCB is wired to the DPM-05 LCD module. Make sure that you mount the CA3140 the right way round.



When the circuit is correctly calibrated, the input to the IN LO pin of the DPM-05 module will be 10.0mV for every pH unit that the solution differs from neutral (pH 7). As already noted, this voltage is positive for pH below 7 and negative for pH above 7; eg, for a pH 10 solution the input to the IN LO input will be (7 – 10) x 10.0mV = –30.0mV.

The difference between the two inputs is measured and displayed by the module as follows: 70.0 – (–30.0) = 100.0mV. Since DP2 is wired in, this appears on the display as 10.00 which is the pH of the solution we are measuring.

Construction

The circuit is built on a small printed circuit board (PCB) coded 82ph12 and measuring 67 x 36mm. Begin construction by mounting the components on the PCB according to the parts overlay diagram, taking care with the orientation of the CA3140 integrated circuit.

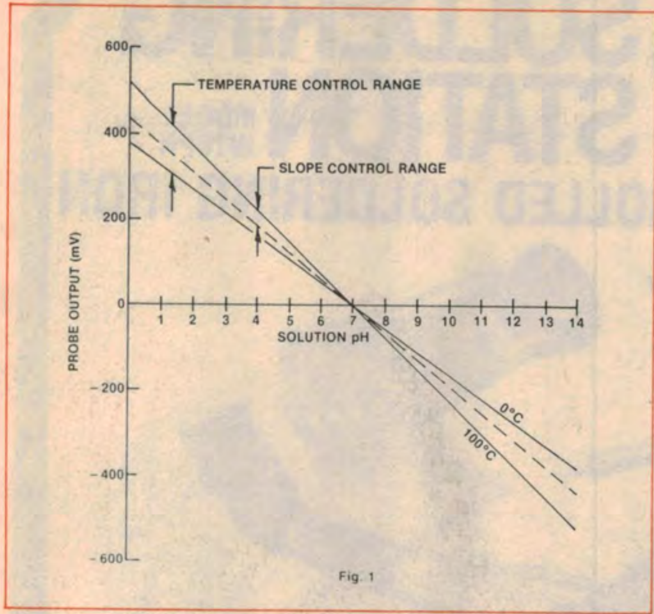
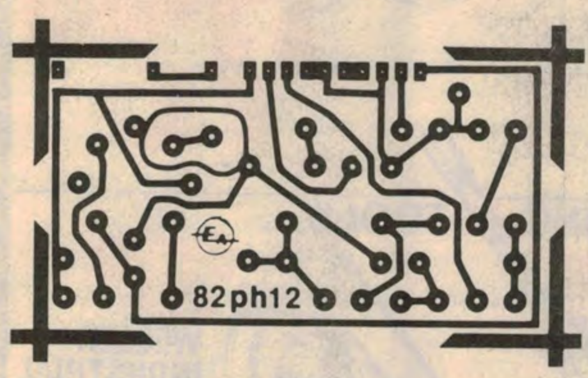
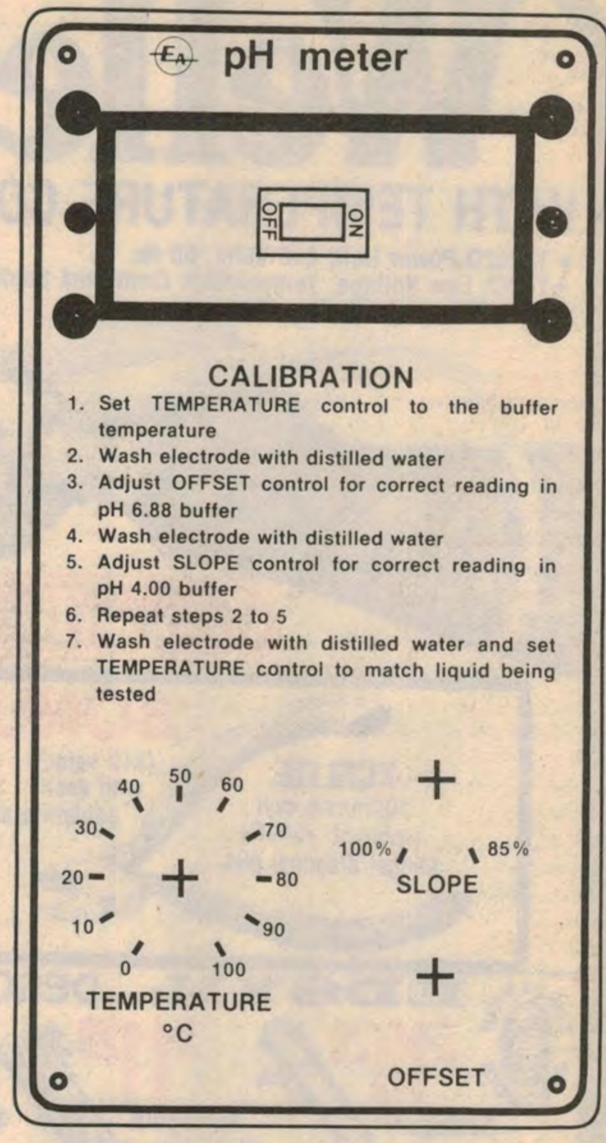


Fig. 1 above shows how the probe output varies with changes in solution pH and temperature. The adjacent PCB and front panel artworks are shown actual size.





This done, the PCB and DPM-05 edge pads are aligned by overlapping the boards and wire links inserted through the corresponding holes (see wiring diagram). Clamp the two boards firmly together and then solder the links to their respective pads on both sides of the assembly. Note that the component side of the PCB faces in the opposite direction to the component side of the DPM-05.

An ABS plastic case measuring 80 x 47 x 152mm (W x D x H) is used to house the project, and is fitted with a Scotchcal label for a professional finish. Cut out and save the on/off switch markings inside the display rectangle, then trim the label to size and carefully affix it to the lid of the case. The label can now be used as a template to drill the necessary holes and make the display cutout.

The display cutout can be made by first drilling a series of holes around the inside perimeter and then filing the rectangle to shape. Proceed carefully with this step and always file inwards, otherwise the file may tear the Scotchcal away from the plastic panel. Note the six clearance holes for the display bezel at the corners and sides of the display cutout.

Next, mount the BNC input socket and the on/off switch as shown in the photographs, and mount the three potentiometers on the front panel. The wiring can now be completed according to the wiring diagram. Note that a short length of RG58 coaxial cable is used to connect the BNC input socket to the PCB. We do not recommend the use of shielded cable.

We estimate that the current cost of parts for this project is about

$115

This includes sales tax.

Power for the prototype is supplied from a small 9V battery, and this is held in position using a "U"-shaped clamp made from a piece of scrap aluminium. We mounted the clamp on the bottom of the case, beneath the three front panel pots, using machine screws and nuts.

With the wiring completed, glue the display bezel to the front panel using epoxy adhesive and mount the DPM-05 module using the self-tapping screws supplied. Finally, connect the battery clip to the battery, affix the four rubber feet, and you are ready for the calibration procedure.

Calibration

To initially calibrate the pH Meter, we use the DPM-05 as a voltmeter to measure offset voltages within the circuit. To do this, place a short circuit

What is pH?

Some readers may not be familiar with the pH scale although most will know that it measures the acidity or alkalinity of a solution. Let's take a look and see how the pH scale works.

The pH scale or notation was developed by a Danish chemist, S.P.L. Sorensen, in 1909. The notation was accepted for the same reason that scientific notation is: large numbers are reduced to an easily handled form. Whereas scientific notation refers to powers of 10, ie $1,000,000 = 1 \times 10^6$, the pH scale is based on logarithms to a base of 10; eg $\log_{10}(1 \times 10^6) = 6$.

When dealing with fractions, as we do in pH calculations, logarithms work out as negative numbers so we multiply the logarithm by -1 to give a positive answer. This leads us to the equation for pH which is:

$$pH = -\log_{10}[H^+]$$

where $[H^+]$ is the concentration of hydrogen ions in the solution. Hydrogen ions are the active ingredient in acids and their concentration is a measure of the strength of the acid.

Concentrations are measured in a chemical unit called the mole (symbol M). This measure is simply a fixed number (6.023×10^{23}) of the fundamental units (atoms, molecules, ions, etc) that make up a substance. One mole of H^+ ions is therefore 6.023×10^{23} ions.

In a container of pure water, the water molecules break down occasionally in the following manner:

$$H_2O \rightarrow H^+ + OH^-$$

This breakdown happens, on average, to one molecule in 555 million and so the concentration of H^+ ions in pure water is 1×10^{-7}M. The pH of pure water is therefore:

$$-\log_{10}[1 \times 10^{-7}] = 7$$

If an acid is added to the water, the concentration of H^+ ions increases, giving pH values below 7. As an example, assume an acid has increased the H^+ concentration to 1×10^{-3}M.

The pH of this solution is:

$$pH = -\log_{10}[1 \times 10^{-3}] = 3$$

If an alkali is added to the water, the natural concentration of H^+ ions in the water decreases as the alkali neutralises them. Thus, the strength of the alkali can be judged by how few H^+ ions are left in solution.

If we put this H^+ figure into the pH equation we get numbers greater than 7. For example, consider an alkali that has dropped the H^+ ion concentration to 1×10^{-10}M.

The pH is:

$$pH = -\log_{10}[1 \times 10^{-10}] = 10$$

Contrary to what many people believe, it is possible to have acids with a pH below zero and alkalis with a pH above 14. These are very strong chemicals and are not normally found outside the laboratory.

across the probe input and set trimpot VR1 fully anticlockwise (as seen from the wiper side of the trimpot). Now turn the pH Meter on, adjust the offset control for a reading of 0.00 (the positions of the slope and temperature controls do not matter), then set trimpot VR1 for a display reading of 7.00.

The meter will now show a pH of 7.00 for zero probe output.

The rest of the calibration procedure adjusts the meter to match the probe with which it is to be used. This part of the procedure involves measuring standard buffer solutions (supplied with the probe) and is listed on the Scotchcal front panel. Buffer solutions are solutions of known pH which can absorb large amounts of contaminants with little change to their pH. This makes them suitable for use as standards to calibrate the meter.

Before carrying out the front panel calibration, remove any air bubbles from the glass bulb on the end of the probe. This can be done by flicking the probe gently. Now follow the calibration steps and be sure to wash the probe in distilled water when changing from one buffer to the next.

Note that the probe comes with a "wetting cap" on the end which serves the dual purpose of protecting the fragile glass bulb on the end and keeping the salt bridge wet. This cap must be carefully removed before the probe is used and replaced at the end of each measurement session.

A plastic protector cap is also supplied with the probe and this is fitted over the end of the probe to protect it against knocks while taking readings.

Two standard buffer solutions (pH 4 and pH 6.88) are supplied with the Ionode pH probe and are used to calibrate the meter before use.

If pH measurements are being taken regularly, eg every few days, then the meter will not need recalibrating before each use. If used infrequently, however, the calibration procedure on the front panel should be followed before you attempt a measurement.

Using the pH Meter

After the pH Meter has been calibrated, simply place the probe into the solution to be measured. The meter will give a direct readout of the pH without further adjustment.

The main rules to follow when using the probe are:

(1) Keep the glass membrane clean (do not allow fats or oils to dry on the surface);

(2) Keep the salt bridge moist – ie replace the wetting cap after use;

(3) Wash the probe in distilled water between measurements to prevent contamination of samples.

If the glass membrane becomes soiled, it may be chemically cleaned with solvents, detergents or acids as detailed in the instruction leaflet supplied with the probe. Never use an abrasive cleaner as this will damage the glass.