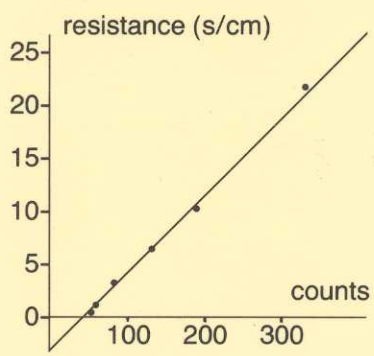
J. Operating Summary

Function checks: Check that silica gel in container is blue, that battery level is above bat. min. with RH range set to 0.

Calibration: A perforated polypropylene plate backed with damp paper is used to simulate a leaf.

1 Switch to RH range nearest ambient RH, and to CYCLE.
2 Take a 30 × 60mm piece of absorbent paper and wet all over with distilled water. *Very thoroughly blot off excess water.* Place damp paper on flat side of calibration plate so that all holes are covered. Over this stick a piece of 50mm wide waterproof tape ensuring that the edges are sealed. Don't warm the plate or sensor by excessive handling.
3 Insert the plate into the sensor, engaging position 1.
4 Adjust PUMP RATE so that pump-down time is approx. 2 secs.
5 Record the count when it stablises. Also the cup temperature and cup — leaf temp. difference, (try to keep this below 0.5°C).
6 Take readings from the other 5 positions, adjusting the PUMP RATE each time.
7 Remove the calibration plate—the pad should remain damp for several hours.
8 Plot a calibration graph of diffusive resistance vs count using the known resistance of each group of holes.

Typical Calibration Graph



Group of holes	1	2	3	4	5	6
Resistance (s/cm)	22.5	10.9	6.5	2.9	1.3	0.4

9 The count varies with temperature by about 4%/°C, so another calibration graph will be needed if the temp. changes much, or when switching between RH ranges. Check with the calibration plate whenever uncertain.

Leaf measurement: Clamp the cup onto the dry leaf surface, ensuring that viens or wrinkles do not spoil the foam seal. Switch to CYCLE and note the count when stabilised and also the cup and cup — leaf temperatures. Use the appropriate calibration graph to calculate leaf stomatal resistance. Develop a brisk technique for leaf measurements.

After use: Wipe any moisture from the sensor head: a steady meter reading on RH indicates that it is dry. Avoid RH>80% during storage—it is recommended that during *short* breaks the instrument should be left on CYCLE. Never expose the sensor to smoke, salt spray or organic solvents. Recharge battery and silica gel as necessary.

Ed's copy

ΔT

DELTA-T DEVICES
128 Low Road, Burwell, Cambridge CB5 0EJ, England
Telephone: Newmarket (STD code 0638) 741584

Automatic Porometer Mk3

Operating Manual

Check that your porometer includes:
1 Sensor head with cable, plug and airpipe
2 Calibration plate
3 Absorbent paper and tape for calibration plate
4 Spare silica gel container
5 Carrying case
and if ordered:
6 120 mA battery charger.

Contents

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B. System Details

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3) Temperature differences
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5) Choice of RH range

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3) Measurements on leaves
4) Leaf response
5) Difficulties

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J. Operating Summary

Record the Serial Number of your instrument here (see back panel)

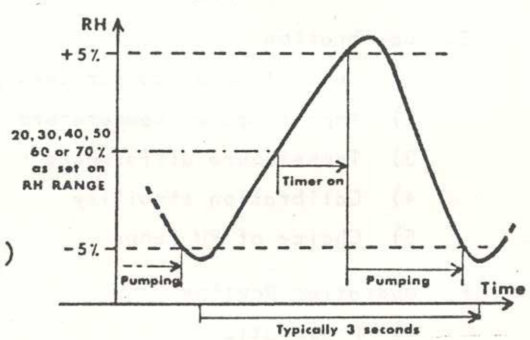
SERIAL NO: AP3 -

A. GENERAL DESCRIPTION

A narrow cup containing a relative humidity sensor is clamped to the leaf surface. Water vapour emitted by the transpiring leaf surface causes the relative humidity (RH) within the cup to rise, and the instrument automatically times the RH rise over a fixed interval. The leaf stomatal resistance can then be found by comparing this transit time with similar times obtained using a calibration plate which incorporates a set of known diffusion resistances.

In practice the transit times are found to depend upon the RH history within the cup. For this reason it is necessary to repeat the readings via a consistent cycle of humidification and dessication until the conditions within the cup have stabilised - usually this only takes 3 or 4 cycles. The cycle is achieved by means of a pump which blows dry air into the cup after each timing measurement and takes the RH back down below the timing interval starting point (see fig. 1)

Fig. 1
- a typical automatic cycle

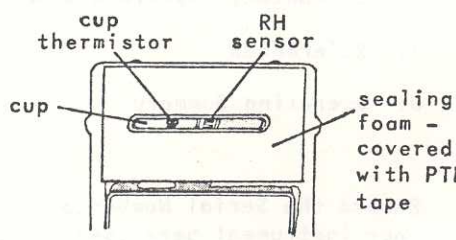


B. SYSTEM DETAILS

RH Measurement

RH in the cup is measured with a thin film sensor. This sensor has an electrical capacity which changes linearly with RH, and features low hysteresis (<1%), low temperature coefficient and high stability of calibration. A high frequency signal is used to measure changes in sensor capacity. The position of the RH sensor in the cup is shown in fig. 2.

Fig. 2 - cup with RH sensor



Timing

A 200 Hz. counter is incorporated which switches on at the preset RH level and times a 5% rise within the cup. The time is displayed on the right hand liquid crystal display (LCD). As each new timing is completed the display is automatically updated.

Dry Air Supply

Dry air is then blown into the cup by a small electric diaphragm pump connected to a silica gel drying agent. When the RH in the cup has been reduced to 5% below the set level, the pump switches off.

Temperature Measurement

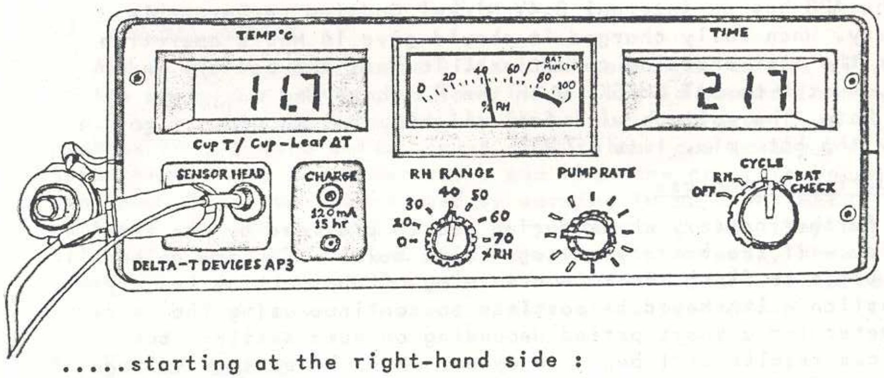
Leaf and cup temperatures are measured by two thermistors. During pumping the cup temperature is displayed on the left-hand LCD. During the remainder of each cycle, the difference between leaf and cup temperatures is displayed.

Sensor Head

The sensor head is moulded from polypropylene and has polished reflectors in order to reduce solar heating. A sliding window is provided so that leaf alignment can be checked. A $\frac{1}{4}$" Whitworth tapped hole (photographic tripod thread) enables the sensor head to be mounted on a flexible stand (ref. 1).

C. INTRODUCTION TO THE CONTROLS

Fig. 3 - the front panel.



.....starting at the right-hand side :

Main Switch

On RH, cup RH is displayed on the meter and the pump is inhibited. This position is used for measuring the ambient RH level.

CYCLE is the operating position - the meter displays RH and the pump is triggered at the appropriate point in the cycle (see fig. 1).

BAT CHECK - the battery voltage is displayed on the meter but other functions remain the same as for CYCLE.

Pump Rate

This control allows the flow rate of dry air into the cup to be adjusted. Turning the knob clockwise increases the flow.

RH Range

The RH level at which the cycle operates can be selected to centre around 20,....,60 or 70 % RH. a further position, 0, is provided which is used to check the pump/silica gel effectiveness.

D. HANDLING NOTES

1) Storage

Avoid RH >80% in the cup, as indicated by the red bar on the meter. The RH sensor is reversibly affected by high humidities, and may take several hours to recover. Store the sensor head in its foam compartment with a partially exhausted (pink) silica gel capsule. For longer storage periods, the sensor head should be disconnected and stored in an airtight bag containing a silica gel capsule. Also close off the silica gel container with its captive rubber bung.

2) Battery

Checking

The AP3 has an internal 8.4V Nickel Cadmium rechargeable battery. When fully charged it should give 16 hours operation under the most exacting conditions. To test the battery under load, switch to BAT CHECK, 0 on the RH Range and maximum Pump Rate. The voltage will fall slightly but should not go below the bat. min. line (7 V).

Exhaustion during use

A further battery check during use is provided by the time display - if the battery voltage falls below 7.7 V, the colons will begin to flash. This is a warning of approaching battery exhaustion - it should be possible to continue using the porometer for a short period depending on pump setting, but spurious results will begin to appear when the battery voltage falls below 7 V.

Recharging

A constant current of 120 mA for 15 hours is required to recharge an exhausted battery. A 2.5 mm jack plug socket on the front panel is provided for recharging the battery, and a red LED confirms that charging is taking place (see fig. 3). It is possible to use the porometer during charging even with an exhausted battery.

Note; the battery chargers supplied with Mk2 porometers are suitable for use with the Mk3.

WARNING : The battery can be damaged by both over exhaustion and over charging. DO NOT charge for more than 24 hours at the 120 mA rate. DO NOT run the battery completely flat e.g. by leaving the instrument on and unattended for long periods.

Protection

A 20 mm 1A fuse (with spare) on the main circuit board protects against battery misconnection and a 20mm 200mA fuse (with spare) protects against charger misconnection.

Should it be necessary to replace either the battery or a fuse, proceed as follows:

- Disconnect the sensor head and charger if connected,
- Remove the instrument from its carrying case,
- Undo the three large screws on the side of the case,
- Prise off the two shells by levering them out with your thumbs

It is now possible to replace the fuses. To remove the battery:

- Remove the battery connectors
- Push the battery upwards
- At all times protect the battery terminals from short-circuit.

3) Dry Air Supply

Air is drawn through the silica gel container on the side of the porometer, through a foam filter and is pumped into the cup. The silica gel crystals change colour from deep blue to pink as they absorb water.vapour. The colour can easily be seen through the container walls and when the crystals become pink they should be regenerated by warming in an open (metal) container at 120 - 150°C. It is very important that they be allowed to cool to ambient temperatures before reuse. When fresh, the capacity of the crystals should be adequate for at least a full days use. A spare container is provided.

4) Care of Sensor

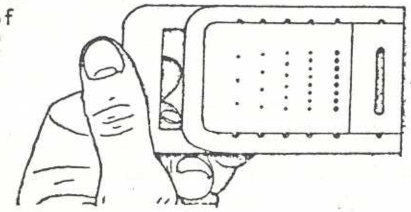
The RH sensor itself is delicate, so avoid any shock to the sensor head. It is also very vulnerable to corrosion,- particularly from acid-laden soot particles, cigarette smoke and organic solvents. It can be cleaned by gentle blowing and/or wiping with a soft brush or, if necessary, by wiping with distilled water (which will necessitate a long drying period).

E. CALIBRATION

1) General Guidance for the Operator

The moulded polypropylene calibration plate provides 6 diffusion resistances of known value. A calibration graph of these resistances is plotted against their corresponding counts (see fig. 6).

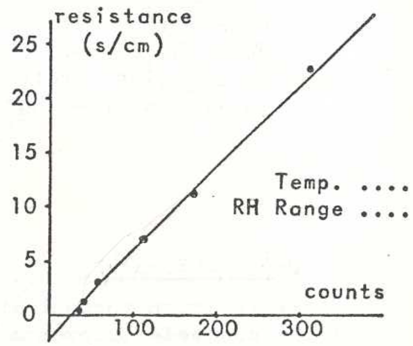
Fig. 5
- the calibration plate



The appropriate graph can be used to convert the counts obtained from leaf measurements into diffusion resistance (or conductance) values.

Other graphs with different slopes need to be plotted when the temperature changes (see fig. 7), and each graph needs to be checked during use in case of any instability of calibration. The calibration should be checked under the same conditions as leaf measurements, and the most recent of any differing graphs used to ensure that leaf measurements are correctly interpreted.

Fig. 6
- Typical Calibration Graph



At 20°C. the calibration plate diffusion resistances are:

Group of holes	1	2	3	4	5	6
Resistance (s/cm)	22.5	10.9	6.5	2.9	1.3	0.4

Table 1.

These values are obtained by applying the following formulae for diffusion resistances:

positions 1 to 5, $r = \frac{A\,(L + \pi d/8)}{n.D(\pi d^2/4)}$ position 6, $r = \frac{L}{D}$

where
- r = resistance s/cm
- A = cup area cm^2 (= 0.559 cm^2)
- n = number of holes
- L = plate thickness cm
- d = hole diameter cm
- D = diffusion coefficient cm^2/sec (= 0.242 @ 20°C)

For temperatures other than 20°C, a small correction can be applied as shown below:

Temperature °C.	0	10	20	30	40	50
Multiply plate resis. by	1.12	1.06	1.0	0.94	0.88	0.81

Table 2.

The low resistance point (position 6) is useful when leaf resistances in the range 0 - 2 s/cm are encountered because, although in theory the graph should be a straight line passing through - 2.5 s/cm (which corresponds to the diffusion resistance of the cup itself), <u>in practice</u> the graph is a gentle curve with a negative intercept in the range -1 to -2.5 s/cm (see fig. 6).

2) Importance of Temperature Readings

Temperature changes affect the count by about 4 % per°C, or more at low temperatures. When the temperature changes appreciably (e.g. by about 4°C) a calibration graph appropriate to the new temperature must be plotted. If such a graph is already plotted, it can be checked by using one or more of the resistance values on the calibration plate. To improve accuracy, diffusion resistances can be interpolated for temperatures between those of the calibration graphs.

3) Temperature Differences

If the leaf temperature is higher than the cup temperature, extra water vapour will be driven into the cup with a corresponding decrease in the count. The effect is slightly greater at low temperatures, and is accentuated while any temperature is increasing.

At 50 % RH the count is increased by 12% per°C temperature difference (cup - leaf). Table 3 shows the relationship between RH range and coefficient of temperature difference (ref. 2).

RH range %RH	20	30	40	50	60	70
Coefficient of temp. diff. %/°C	7.5	8.5	10	12	15	20

Table 3.

The temperature difference is displayed directly on the temperature display, except during pumping (see 'System Details', section B) and it is obviously important to keep the difference to a minimum.

4) Calibration Stability

The RH sensor has a small hysteresis (<1 %) and temperature coefficient (.05 %/ C) and a stable calibration, unless it is actually corroded. Its calibration may be reversibly changed (5 %) by exposure to RH >80%, especially with prolonged exposures.

In practice the count obtained for a given diffusion resistance may show small variations from day to day. For this reason it is advised that calibration <u>checks</u> should be carried out frequently, especially when the operating temperature or RH has changed, and new graphs drawn up when necessary.

If the cup is exposed to an RH outside its cycling range (see fig. 1), the count will appear to drift and will take time to settle down again to a consistent value. The time taken may be a cycle or two for short exposures or several minutes when the exposure is long.

5) Choice of RH Range

Six operating ranges are provided at 20, 30, 40, 50, 60 and 70% RH. We recommend use of the RH range nearest to ambient RH - this will minimise problems due to surface effects, inadvertent leakage of air round the cup and also disturbance to the leaf's environment. However it may occasionally be advantageous to switch to a lower RH range (giving faster cycling) or to a higher RH range (giving greater resolution).

Frequent switching between RH ranges is not recommended since the count takes a few minutes to stabilise after any change in the cup RH conditions.

F. OPERATING ROUTINE

1) Preparation

Remove the captive rubber bung from the silica gel container.

Briefly check the following instrument functions - switch to

1. BAT CHECK - check that the battery voltage under load ('O' on RH range and Pump Rate maximum) does not fall below bat. min.(7V).
2. CYCLE - check that the silica gel is blue and is easily capable of drying the cup RH down on the selected RH range.

Switch to 'RH' and keeping the head held open, wave it gently. The meter will read ambient RH. Set the RH Range as close as possible to this value, switch to CYCLE and leave the instrument for a few minutes while cup conditions equilibrate.

2) Calibration

Take care not to warm the cup or plate by excessive handling or exposure to thermal radiation.

Preparing the Plate

Wet the paper pad all over with distilled water, which should be at ambient temperature. It is extremely important that the pad is not too wet - thoroughly blot it off at least three times with absorbent tissue. Place the damp pad on the flat side of the plate so that all the holes are covered. Over this stick a piece of the adhesive tape provided, taking care to seal the edges in order to minimise evaporation from the pad, which would cool it undesirably. The damp pad can be left on the calibration plate all day, ready for instant use - a resealable plastic pouch is provided for keeping the plate in the carrying case pocket.

Plate Contamination

Avoid touching the upper plate surface or in any way contaminating the plate. Should the plate get dirty or greasy, remove the pad and wipe the plate with a high purity solvent, ensuring that this has totally evaporated before bringing it anywhere near the RH sensor.

Pump Rate

Make sure that the main switch is at CYCLE and, holding the plate by its handle, insert it into the sensor head so that the alignment pips on the side of the head engage with the two recesses of position 1 on the plate.

When the pump is triggered, adjust the PUMP RATE until the pump-down time is approximately 2 seconds. Pump-down times that are either much longer or shorter than this will give longer counts so it is important to be consistent.

Temperature Readings

After the pump rate has been correctly adjusted, record successive counts. When the count has stabilised, also record the cup temperature and 'cup-leaf' temperature difference. Best accuracy is only obtained with isothermal conditions in the cup, so aim to keep the cup-leaf temp. difference less than 0.5°C by minimising any heating of the plate or cup and by allowing time for equilibration when necessary. Use Table 3 to apply corrections if larger temp. differences are unavoidable.

Drifting

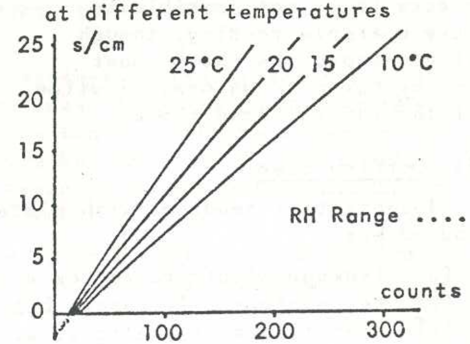
At the beginning of each session of use, the count will take a minute or two to stabilise, especially if the storage RH has been outside the operating RH range (see Calibration Stability). Further drifts of the count can be minimised by only opening the cup for brief periods, by not changing the RH range unnecessarily and by leaving the instrument on CYCLE during breaks from readings, even without a leaf.

Proceed similarly to take counts from the other five positions on the plate. Plot a graph of the given plate resistances (Table 2) versus the corresponding counts.

Subsequent counts from leaf measurements can now be converted into diffusion resistances - provided they relate to the same temperature and RH range.

Fig. 7

- example of calibration graphs at different temperatures



WARNING - Never leave a plate or leaf in the head unless the instrument is switched to CYCLE, since the cup RH will rise above 80% (red band on meter), causing a shift in sensor calibration (see 'Storage').

3) Measurements on Leaves

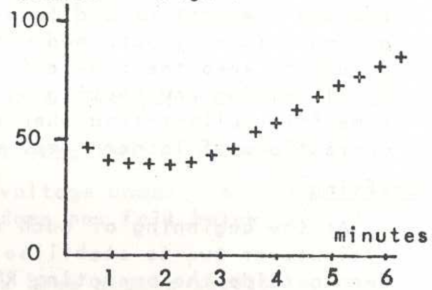
Clamp the cup onto the leaf suface and proceed generally as described above for calibration, aiming to achieve consistent readings as quickly as possible, and noting the count, cup temperature and temperature difference. All traces of dew or other surface moisture must of course be absent. Try to avoid prominent leaf veins or wrinkles that might spoil the cup's seal.

The sliding window at the back of the cup can be opened in order to check leaf alignment, but should be closed during normal use as it might otherwise lead to undesirable radiative heating effects.

4) Leaf Response

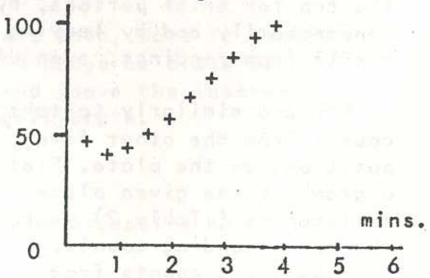
A typical record of count against time is shown in fig. 8. The increasing count is due to stomatal closure under the low light conditions within the cup. The graph illustrates the need to take readings quickly - preferably within 2 minutes even for leaves with high diffusion resistances.

Fig. 8



Occasionally a count versus time record such as fig. 9 will be obtained. In this case it is assumed that the leaf stomata have reacted very fast to the presence of the cup. In such a case it is not possible to take a stable reading, though if necessary the third count can be taken as an approximation of the initial conditions.

Fig. 9



5) Difficulties

Inconsistent readings with plates or leaves are most commonly caused by:

(a) leakage of air round the edge of the cup
(b) temperature differences between the leaf and cup
(c) leaf incorrectly aligned with the cup
(d) damp paper dried out, or oozing water
(e) dirt or grease on the calibration plate
(f) sensor exposed to >80% RH
(g) pump rate not consistently set.

G. TECHNICAL INFORMATION

Socket Connections

Head : 5 pin DIN 240
1. Leaf thermistor
2. Cup thermistor
3. Earth
4. Head calibration resistor
5. RH sensor drive
screen: earthed

N.B. do not alter the individually selected head calibration resistor in this DIN plug.

Battery : 8.4V, 1.2Ah Nickel-Cadmium, recharge 15 hrs. at 120mA

Fuses : Battery - 1A, 20mm on main circuit board, spare adjacent
Charger - 200mA, 20mm " " " " "

RH Sensor : Thin film capacitative type, Vaisala

Temperature Measurement : thermistors Fenwal type UUA 32J2

Cup temperature : 0.0 - 40.0°C, ± 0.5°C max.
40.0 - 50.0°C, ± 1.0°C max

Cup - Leaf temp. : -5.0 to +5.0°C, ±1 digit

Charger : constant current, output 100 - 120 mA required

Electronic Circuit Description (see fig. 10)

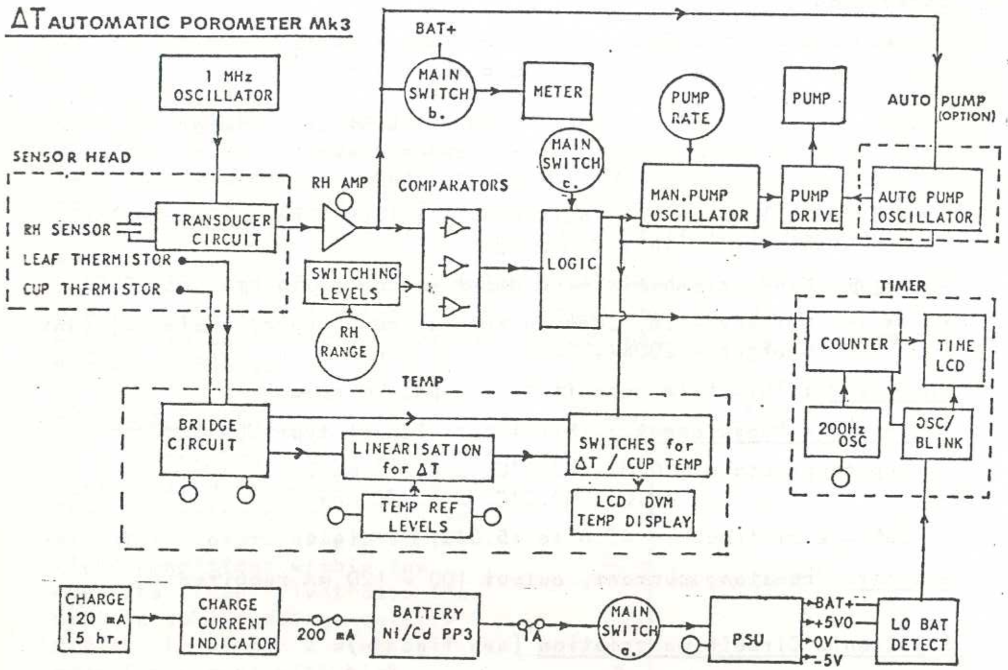
RH measurement : The RH sensor has an electrical capacitance of about 50pF which varies linearly with RH. Its capacitance is measured by a transducer circuit in the sensor head, fed by a 1 MHz oscillator. The resulting mV RH signal is amplified on the main board to an RH voltage, which drives the meter.

Cycling control : This RH voltage is to pump and timer switching levels controlled by the RH range switch. The comparators feed CMOS logic which controls the pump, timer and temperature display.

Temperature measurement : Two thermistors in the sensor head measure the leaf and cup temperatures. They are connected to bridge circuits on the temperature board which are selected by analogue switches depending on whether the pump is on or off. The selected bridge voltage is measured on a Digital Volt Meter module which includes a Liquid Crystal Display.

Power : The battery supplies a precision 5 volt regulator which supplies most of the circuitry. A negative rail generator produces approx. -5 volts for the Temperature board.

Fig. 10



H. GUARANTEE, REPAIRS AND MAINTENANCE

Guarantee

The instrument is guaranteed for 1 year against defects in manufacture or materials used.

The guarantee does not cover damage through misuse or unauthorised tampering.

For the U.K. this means that no charges are made for labour, materials or return carriage for guarantee repairs.

For other countries the guarantee covers free exchange of faulty parts during the guarantee period. Alternatively if the equipment is returned to us for repair we make no charges for labour or materials, but we do charge for U.K. import customs clearance and for carriage to the customer.

Repairs

In case of any damage or malfunction , please contact Delta-T Devices stating as clearly as possible the nature of the trouble. Always quote the instrument serial number in any correspondence. For overseas customers a technical manual is provided giving full circuit diagrams, component lists and test procedures. A comprehensive spare parts list is also available (see price list).

Maintenance

Apart from regenerating the silica gel crystals and recharging the battery, no routine maintenance is required.

I. REFERENCES

1) The ' Palm Tree Clamp' available from C.F.Palmer (London) Ltd. Lane End Road, High Wycombe, Bucks., England.

2) Gaylon S. Campbell (1975) "Measurement of Stomatal Aperture and Diffusive Resistance". Washington State Univ. Bulletin 809.

3) Stiles, Monteith and Bull (1970) "A Diffusive Resistance Porometer for Field Use". Journal Appl. Ecol. 7, pp 617-38.