LC*i* ***T*** Accessible Photosynthesis System

INSTRUCTION MANUAL

L.MAN-LCi T
Issue 3; Novenber 2022 Software issue 1.10 onwards
Copyright © 2022 ADC BioScientific Ltd.

Contact details:

ADC BioScientific Limited
Global House
Geddings Road
Hoddesdon
Hertfordshire
EN11 0NT
UK

Telephone: +44 (0)1992 464527

E-mail: sales@adc.co.uk

Website: http://www.adc.co.uk

For details of your nearest ADC approved agent, refer to our website.

© ADC BioScientific, 2022

All rights reserved. No part of this printed document or enclosed pdf file (if applicable) may be reproduced or transmitted in any form or by any means without prior written permission of the copyright holder.

The product described in this manual is subject to continuous development and, while every effort is taken to ensure that the information contained herein is correct, ADC BioScientific Ltd cannot accept any liability for errors or omissions or their consequences.

Contents

SECTION 1. INTRODUCTION

This manual covers the operation and maintenance of the LCi T Accessible Photosynthesis System.

1.1 Equipment list

The LCi T Analyser is supplied in a convenient carrying case containing the following items:

Air probe, used to supply stable ambient air to LCi T in the field.

Recess for drying agent for the case interior.

Power lead, battery charger, USB cable & RS232 cable. Carrying strap.

SD card.

Leaf thermistor M.PLC-011*.

Spare gasket set*.

Leaf Chamber

LCi T "handle" (PLC) and cable cord

Plastic bottle to hold spare soda lime.

Tool box containing: a 'pot adjustor' calibration tool, ground spike for the air probe, a stylus for calibrating the touch screen, a 'CO_2 exhaust tool', a 'jaw adjustment tool' and SD card.

LCi T Console

LED light unit (store the light unit here when not in use). Either White or RGB, specified at order.

NOTE the cord must be stored in exactly this way.
Tuck the cord into the recess in the foam all the way around the edge, to prevent damage.

Also with the carrying case is a **spares kit**, which includes all required chemicals, CO_2 cartridges and a selection of spare parts (all listed in Appendix 11). Lastly, the LCi T User Manual and Quick Start Guide.

Please note: The supplied carrying case is for 'By Hand' transportation only. If the instrument is being shipped by courier (e.g. back to ADC for servicing), please use suitable packaging to protect both the case and instrument. A good example would be a cardboard box filled with polystyrene chips or board.

*If the LCi T system is part of an SRS1000 T soil respiration system, it is not supplied with a leaf thermistor or spare leaf chamber gasket set, but does include the chamber jaw spring in case a leaf chamber is ordered at a later date.

1.2 Description

The LCi T is specifically designed for portability and field use, and provides internal battery power suitable for up to 10 hours of continuous operation. Its purpose is to measure the environment of a leaf contained in the jaws of the chamber, and to calculate the photosynthetic activity of the leaf or, when used with a Soil chamber, to measure the gas exchange associated with soil biomass respiration.

The Leaf chamber contains a printed circuit board comprising conditioning and pre-amplifier circuitry for Chamber temperature, leaf temperature and PAR (Photosynthetically Active Radiation) sensors. Two laser-trimmed humidity sensors provide the reference and analysis humidity signals and an Infrared Optical bench is used for CO_2 analysis.

The main console supplies air with a relatively stable CO_2 concentration at a controlled flow-rate to the leaf chamber (or soil pot). The CO_2 and H_2O concentrations are measured, and the air is directed over both surfaces of the leaf (or allowed to flow around the soil pot). The discharged air leaving the chamber is analysed, its (generally decreased) CO_2 content and (increased) H_2O content are then determined.

From the known airflow rate and differences in gas concentration, the assimilation and transpiration rates are calculated and updated every second, with a complete analysis cycle taking about 20 seconds depending on the flow-rate used. A small fan in the chamber ensures thorough mixing of the air around the leaf.

The system also measures leaf (or soil) temperature, chamber air temperature, PAR (Photosynthetically Active Radiation), and atmospheric pressure. The PAR at the leaf and the radiant energy balance of the leaf are calculated, (see Appendix 4).

Measured and calculated data are displayed on the large Liquid Crystal Display (LCD) on the front panel of the console. The display has three pages, which can be scrolled through using the “page/power” button. The data, (listed in the Log? and screen columns in Appendix 1) can either be logged on a SD card or sent directly to a “dumb” terminal via the RS232 serial link connector.

The SD card, which is located in a socket at the front of the unit, can be removed by pressing it in to release it. The stored log (file) can be viewed on the LCD display, dragged to a PC over the USB, or loaded directly into a spreadsheet on a PC equipped with a SD card reader.

The measurements are carried out in an ‘Open System’ configuration in which fresh gas (air) is passed through the PLC (Plant Leaf Chamber) on a continuous basis. Measurements are carried out on the state of the incoming gas (the ‘reference’ levels) and after passing the leaf/soil specimen (the ‘analysis’ levels); the gas is then vented away. This arrangement tolerates some outward gas leakage and ad/absorption by the materials used in the gas path.

By comparison, in a ‘Closed System’, a gas sample is continuously circulated and measured over a period of time to establish rates of change in the parameters measured. This is therefore less tolerant to leakage and material ad/absorption.

1.3 Calculated Values

A complete list of Units and Symbols used, either for display, or for the purpose of calculations, are given in Appendix 1.

A number of internal calculations are performed repetitively using the measured parameters and various correction factors. These produce intermediate results and values for various photosynthetic parameters derived from established formulae. Derivations for these and the soil respiration calculations are given in Appendix 3.

The calculated values are displayed on the screen to serve their main purpose of providing a check on the validity of the measured data. This is useful for reference just before a record is taken, and as a means of checking that the leaf is photosynthetically stable (or equilibrium is reached in the Soil pot).

For a typical leaf, CO_2 flux will be between -10 and +100 μmol m^{-2} s^{-1} and H_2O flux will be between 0 and 15 mmol m^{-2} s^{-1} (displayed values).

The LCi T performs checks on magnitudes of readings, particularly of certain settings which have pre-set limits (minimum airflow rate, for example). There is, however, a wide tolerance on 'allowable' settings for which the user is responsible (leaf area, for example) and which can significantly affect the validity of the photosynthesis measurements.

Further information on photosynthesis and its measurement can be found in:

- "Photosynthesis" by Hall and Rao, Pub. Cambridge University Press
- "Plant Physiological Ecology field methods and instrumentation" by Pearcy, Ehleringer, Mooney and Rundel, Pub. Chapman and Hall
- "Techniques in Bioproductivity and Photosynthesis" by Hall, Long and Scurlock, Pub. Pergamon Press.

Further information on soil respiration and its measurement can be found in:

- Knoepp, Jennifer D.; Vose, James M. 2002. Quantitative comparison of in situ soil CO2 flux measurement methods. Res. Pap. SRS-28.Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 11p.

SECTION 2. GETTING STARTED

Before fitting or changing a chamber, please read section 2.9 for guidance.

Note that this section assumes that a "conventional" leaf chamber is being used. If a Small leaf chamber is used, please read in conjunction with section 4. If using a Soil pot, please read in conjunction with section 5.

2.1 Initial Preparation

The LCi T is delivered with the internal battery fully charged and connected and the Soda Lime column filled with fresh self-indicating Soda Lime. This should be a pure, white colour.

Connect the Plant Leaf Chamber's (PLC) umbilical cable 15-pin plug to the LCi T console connector and the three colour-coded pipes to their respective colour–coded entries.

The LCi T requires an input of ambient air, with stable CO_2 &/or H_2O concentrations. The air supply should be taken from a region where the CO_2 levels are reasonably stable, preferably some 3-4 meters above ground level. Air drawn directly from occupied rooms, adjacent to vehicle traffic or a heavily populated canopy can result in unstable "reference C" and "delta C" data. The supplied air probe and tubing can be used when outdoors. Extend the probe fully and secure in the ground using the ground spike provided. Attach the tubing, with the metal filter close to the probe end). Position the probe around 1m away from your sample area.

Alternatively, you may construct your own buffer volume (this can be portable, attaching to a belt or back pack) using a plastic or glass container with a screw top lid*.

Drill two holes into the lid and glue in place 2 x  air entries, provided in the spares kit.
One entry carries "air in" (connected to a length of PVC tubing, supplied, which can be hung out of a window) and the other carries "air out" (connected to a tube which is connected to the LCi T console "air in" entry). The "air in" entry on the container should also have a length of PVC tubing connected to it, which hangs down inside the container and extends to the bottom of the container. This piece of tubing ensures that the air is drawn out of the container from the top, so that air is fully "volumised".

2.2 Checking the Chemical Column

The removable column furthest from the connectors (see figure 2.2) holds soda lime, which is used to strip carbon dioxide. The other column is used as a water trap and filter. On delivery the soda lime column is filled with an indicating Soda Lime.

To maintain the performance on the LCi T, always replenish the soda lime when it is exhausted. This is shown by a colour change of white to violet (see section 6.1).

Disconnect the column by pulling it outwards at the top and bottom then lift off the top cap. Fill the column to just below the top with the chemical. Tap the column a few times against a solid surface to compact the chemical and top up as required. Replace the top cap. Ensure that all 'O rings' are lightly greased with the supplied silicone grease and that both ends are located tightly to prevent gas leaks then refit the column to the console.

It is possible to use the LCi T on its side so that the columns are horizontal. Ordinarily in the horizontal position, chemical in the column would not be effective, as it would settle so as to leave a continuous horizontal air gap. To avoid this problem, the soft plastic cap (OP2-134) in the spares kit may be fitted half way along the column. The hole in the cap forces the air to pass through the main bulk of chemical. The cap also allows the economy of a half-used chemical column to be easily half emptied.

2.3 Electrical Connections

Power Socket

This is provided for an external 12V supply or the battery charger connection, and is current limited. Reverse current flow is not prevented, which allows you to power external equipment from the LCi T battery provided that the power requirements are modest.

This socket also provides two analogue output channels of 0-5V, being voltage sources intended for connection to a high input impedance (1MΩ) recorder channel. They are protected against an accidental short circuit to ground.
The connections are: channel one = pin 4 channel two = pin 1 0V ground = pin 5

See "An o/p" column in Appendix 1 for available parameters.

The power socket mates with a standard 5 pin 240° DIN audio plug connector. This is provided in the spares kit, pre-wired as follows:

braid	= signal ground (0V)
blue lead	= analogue 1 signal
red lead	= analogue 2 signal
red 4mm shielded plug	= +12V.DC
black 4mm shielded plug	= 0V

USB Connector

The USB Mini B connector mates with a standard USB A to USB Mini B connector often used with digital cameras. When connected to a PC, the LCi T looks like a drive and data files may be "dragged and dropped".

RS232C Connector

The RS232C connector mates with a standard 9 pin 'D' type null-modem serial link cable socket (female). A suitable cable is included in the spares kit. It provides RS232C signals and handshake lines to suit standard printers, VDU's, PC's etc. The user can set the baud rate and handshake protocols. The socket connectivity is PC standard.

2.4 Switching On

The LCi T is delivered ready for use with the internal battery fully charged and connected and the Soda-lime and Drier columns filled.

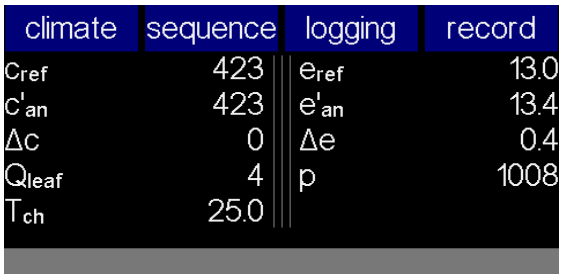
The LCi T can be switched ON by pressing the front panel switch key at the top right-hand side of the display (shown in the text as ).

Wait for five minutes to allow the CO_2 measurements to stabilise.

The LCi T will display an 'analyser is warming up' message during this time, and will beep when ready. If you wish to bypass the warm up timer, press the left button just after the LCi T has been switched on and is displaying the software version and serial number. Note that if warm-up is bypassed the LCi T will need to complete at least one full analysis cycle before normal readings are displayed.

Some default factory settings may need editing; for example time & date, serial link.

A few seconds after switch-on, the screen displays a set of parameters and values. Pressing ⏻ will cycle between the three main pages. Appendix 10 shows all the pages and how they are related. The 'function' headings along the top correspond to keys on the keypad above. The instrument may be switched off by holding down ⏻ for at least 3 seconds. If the screen is very light or dark, the contrast can be adjusted (see section 2.5).



Close the Leaf Chamber. Check that the chamber fan is rotating (usually it can be heard) and check that the chamber gaskets are sealing. (It may take a few minutes for new gaskets to be compressed sufficiently by the spring. In the case of Conifer chambers, ensure that the clip is latched).

2.5 Display

The Display unit is a colour, touchscreen, Liquid Crystal Display type with an adjustable contrast control and adjustable timed dimming function. If the user prefers a different contrast level, adjustment is available using potentiometer RV92 (Located in the right hand corner of the PCA-289 'digital' board).

2.6 Operation

Prior to taking measurements on a leaf, the chamber sensors can be checked as follows. With the chamber closed, after a few seconds the CO_2ref & CO_2anl readings on the LCi T display should stabilise to give similar CO_2 levels.
The H_2O levels should also be checked for similarity and that PAR (Q) and chamber temperatures (Tch) readings are in accordance with ambient conditions.
If these checks are satisfactory, leaf measurements can be made.

Once the leaf is enclosed in the chamber, the system may take up to 2 minutes to stabilise. During this period CO_2 & H_2O values will gradually stabilise. Generally a good indication is when the value for **Ci** (sub-stomatal CO_2) has stabilised.

After readings are stable, a 'record' may be taken (see section 10).

2.7 Error, Warning & Status Messages

Status messages indicate the functional state of the LCi T, and are generally associated with tasks that are occupying the processor, and during which time other normal functions are suspended. Since these messages usually relate to the function or facility involved, they should not be disturbed. For example, do not disable the printer whilst the 'printing record' status message is on the screen.

Warning messages indicate that it is not possible to comply with a user request. The text of the message always describes why compliance is not possible, offering the user the opportunity to correct the situation.

Warning messages usually appear with an OK function label, which, if operated, will allow the user to continue.

Troubleshooting:

If the LCD remains blank after switching on the LCi T, check that the battery is fitted and/or charged.
To restart the LCi T, hold down ⏻ for 15 – 20 seconds.

Expected parameter values:
A number of parameters are displayed on the screen; including values for CO_2 & H_2O. With the jaws shut and no leaf in the chamber, 'CO_2anl' should equal ambient 'CO_2ref', and 'H_2Oanl' should equal ambient 'H_2Oref'.'PAR' should also reflect ambient conditions. 'T_{ch}' (chamber temperature) will initially equal ambient temperature but will gradually rise 3°C to 4°C above ambient due to the local heating effect of the infrared source and electronics.

2.8 Low Battery Voltage

The internal battery voltage is monitored to detect if the battery is close to being totally discharged. This occurs at 10.8 volts, whereupon a **'Battery Low'** warning message is overwritten on the screen.
At this point, there are typically about 5 minutes left in the battery. This should be sufficiently long to either connect a charger or complete a current record. **If the warning message is ignored the LCi T will switch itself off when the battery voltage has fallen to 10.5 volts.**
The battery power is shown as a bar graph at the bottom of screen page 3, and numerically on the diagnostics page. The battery should be recharged (see section 6.3) after any significant period of use or if it is less than 12V.

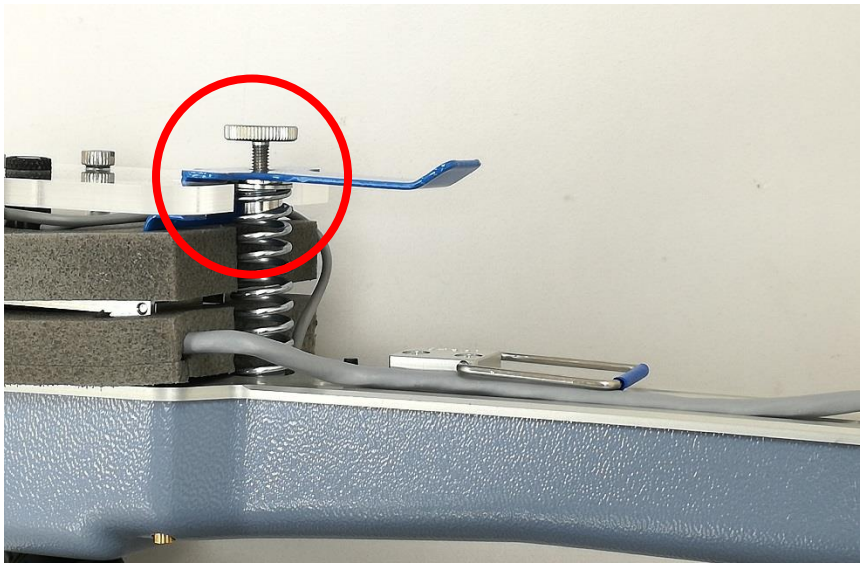
2.9 Fitting/changing a chamber

For Plant Leaf Chambers: Remove the top jaw by pressing against the spring to 'unhook' one hinge pin. Then twist the jaw to disengage the pin and pull the jaw away from the other hinge. If the leaf spider thermistor is present, either it should be removed (see section 3.5), or care should be taken not to damage it while the top jaw is being removed.

Note that only the Broad, Narrow and Conifer leaf chambers have separate upper and lower jaws whilst the Small leaf chamber and the Soil pot feature an "interface block". All references to "jaw" in this section also apply to the "interface block" where applicable.

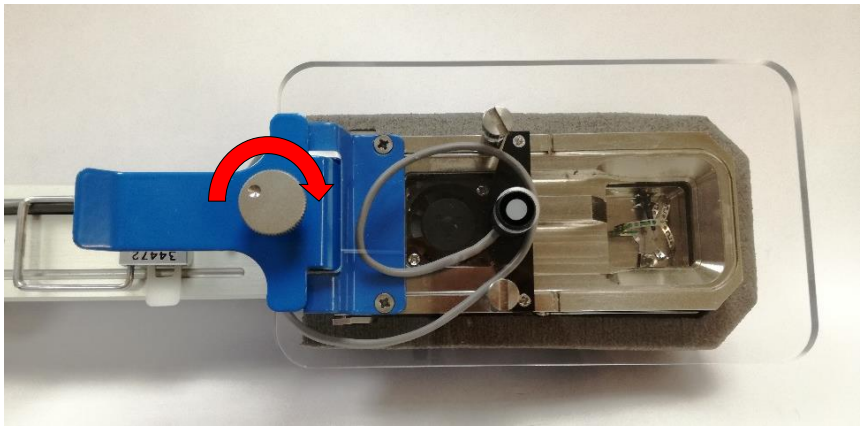
Chamber window "gaskets" (foam) make a seal around the leaf
If the chamber has been left with the jaws closed for a few hours or more, the gaskets will need to reform. This is achieved by leaving the "jaws" open for at least half an hour before use. If the gaskets are badly flattened, we recommend leaving the jaws open overnight, ideally in a warm environment. If the gaskets do not reform, they are easily replaced; being self-adhesive (see Appendix 13 for part numbers).

This thumbscrew varies the spring compression which holds the chamber jaws closed.

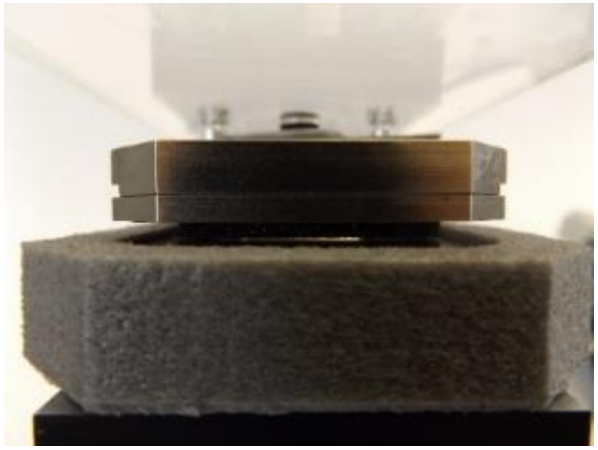


How to use:
Turn the spring adjustor clockwise to apply more force to the spring, ensuring that the gasket seal is airtight around the leaf.

When to use: Only turn the thumb screw when required, and do not overtighten. If the jaw clamping pressure is too high, there is a risk of damage to the leaf.



Do not leave the thumbscrew engaged for long periods of time otherwise the compressed gaskets may not recover. It is suggested that the screw be slackened off every 10 minutes to see if it is still needed.



Only use when:
You can see a gap between the two “gaskets” (shown opposite, where light is coming through). Any gap will cause a leak in the system and incorrect results.

Or
You are working with a leaf which has thick veins or ribs, or is an undulating shape.
Or
The A and ΔC values are lower than expected. Applying more pressure to the gaskets with ½ turn of the tool may increase A values to the expected range.

Important note: Do not leave the thumb screw engaged unless it is needed.

Leaf Chamber Description

The jaw is fitted to the handle using three captive screws. The three screws carry the analysis stirrer fan signal, the built-in leaf thermistor (where applicable) and the ground return.

Note: Only the Broad and Narrow leaf chamber jaws feature the built-in leaf thermistor. The Conifer, Small and the Soil chambers do not feature a built-in thermistor and the screw is grounded. With any chamber type, care should be taken as described below:

Fitting a chamber (see photographs on the following two pages)

Before fitting the chamber, check to see that the five "O" rings are all in place (two gas stems and three sensor housings) and that the three captive spacers are free to move (by 1mm) and not engaged on the screw threads. A set of 'O' rings are provided in the spares kit.

When fitting a chamber, press down on the jaw itself and turn the three captive screws evenly **using the fingers or an ADC jaw screw adjustment tool ONLY.**

Do NOT use a screwdriver or a coin as overtightening the screws may destroy the electrical connections through to the circuit board inside.

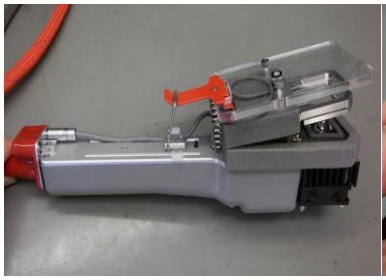
Do NOT push down on the screws as this may dislodge the mounting bushes from the handle baseplate, causing loss of the electrical connections. To ensure that the jaw forms a gas-tight seal, it is only necessary to push down on the jaw itself.

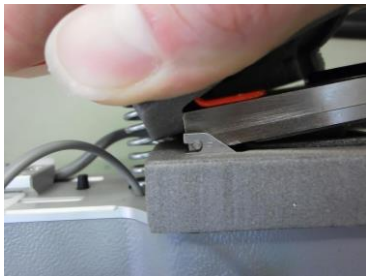
Removing a chamber

When removing a chamber, fingers or the jaw screw adjustment tool should be sufficient to unscrew the three captive screws but again it should be stressed that no downwards pressure should be applied to the screw heads.

Check to ensure that the small "O" rings on the two gas stems in the handle baseplate remain in place and are not carried away in the jaw.

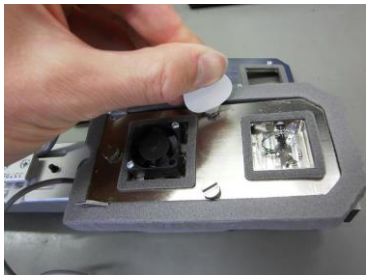
Removing and fitting jaws



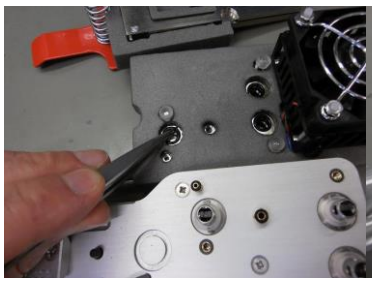


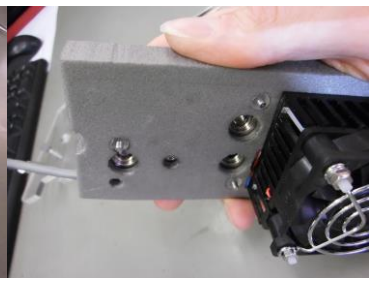
The photographs demonstrate a set of **Broad** jaws, upper and lower, collectively known as the Plant Leaf Chamber.

1. Remove the radiation shield, pull out the PAR sensor then remove the upper jaw as shown.



2. Use the correct tool (LCi-220) to undo the screws, remove the cable from under the cable clip (LCM-166) and lift the chamber jaws from the handle. Take care that all 5, small 'O rings' remain in place on the lower jaw.

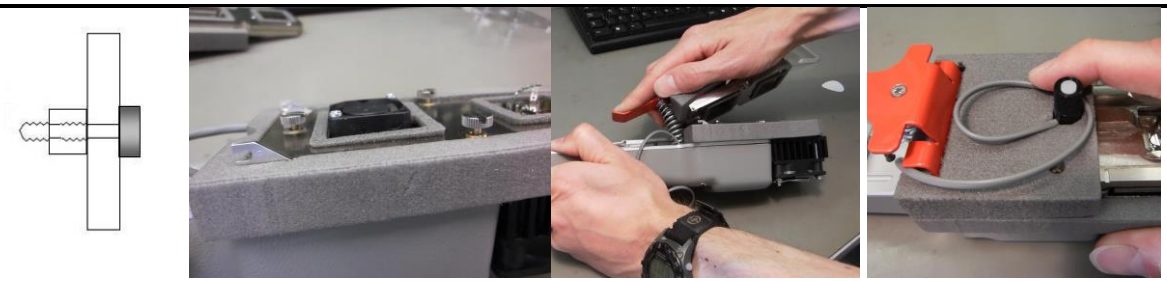




3. Remove the lower jaw and retrieve any O rings that have come off with the jaw, using a pair of blunt tweezers. Take care not to damage the O rings.

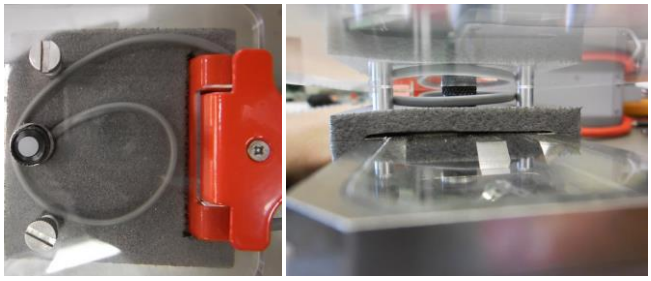
A jaw may now be fitted to the handle:

4. Make sure the jaw screws each have a threaded nylon spacer, and that each spacer is fully threaded onto the screws as far as they will go. The jaw screw spacers are half threaded and must go onto the screws as shown in the first photograph below.



5. Push the lower jaw onto the handle, tighten each screw in turn by hand then with the jaw screw tool (LCi-220) until the tool just starts to bend. **Please do NOT overtighten.**

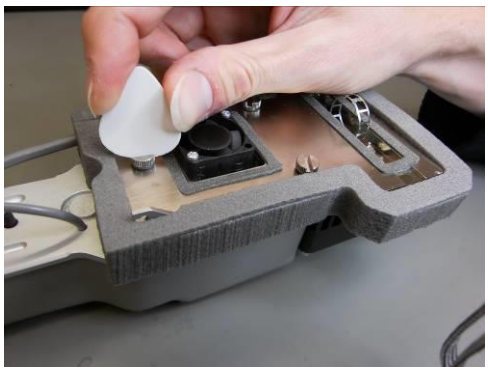
6. Attach the jaw spring to the upper jaw and fit as shown above (third photograph).
Mount the PAR sensor as shown in the final photograph above, with the cable laid as shown.



7. Fit the radiation shield as shown above, taking care not to trap the PAR cable.

Always inspect the gaskets on a closed jaw for any gaps, before use. Gaps may be reduced by temporary use of an elastic band around the jaw, or by squeezing and releasing the jaw by hand to compress the foam gaskets.

The Jaw Screw Adjustment Tool (LCi-220):



Tighten the screw until the tool just starts to bend and then stop.

Careful use of the tool will ensure the screws are tight enough for the O rings to make a good seal, but not tight enough to break a delicate wire just underneath the screw head.

If the chamber has been left with the jaws closed for a few hours or more, the gaskets will need to reform. This is achieved by leaving the "jaws" open for at least half an hour before use. If the gaskets are badly flattened, we recommend leaving the jaws open overnight, ideally in a warm environment. If the gaskets do not reform, they are easily replaced; being self-adhesive (see Appendix 13 for part numbers). Chamber jaws should be latched open when not in use.

Always inspect the gaskets on a closed jaw for any gaps, before use. Gaps may be reduced by temporary use of an elastic band around the jaw, or by squeezing and releasing the jaw by hand to compress the foam gaskets

SECTION 3. THE PLANT LEAF CHAMBER

3.1 General Description

There are four styles of leaf chamber: Small, Broad, Narrow and Conifer (refer to section 4 for a description of Small leaf chambers). The Broad, Narrow and Conifer leaf chambers consist of a top jaw, which may be fitted with a radiation shield or light unit, and a lower jaw. Broad and Narrow leaf chambers feature a built-in leaf thermistor commonly known as a "Spider" and "Snail" respectively because of their appearance (see 3.5).

The Broad chamber has a square ($6.25cm^2$) aperture sealed around the edge, and can be used for any flat leaf, whether the leaf fills the aperture or not.

The Narrow chamber has a rectangular ($5.8cm^2$) aperture sealed around the edge, and can be used for long flat leaves, i.e. grasses etc.

The Conifer chamber is cylindrical in design with sealed edges and can be used for non-flat plant material e.g. conifer needles, small fruits etc.

The chamber handle contains a jack socket for a detachable leaf temperature sensor, a 'record' button for instantaneous measurement, and an electronics board. The 'umbilical cable' links the electrical signals and gas lines between the chamber and the LCi T console. Repeated flexing can break the cable. **When storing and using the chamber, avoid tight bends to the umbilical cable, as these can damage internal cables. Please only bend the umbilical cable loosely.**

To fit a light unit instead of the radiation shield (which is fitted as standard to Broad, Narrow and Conifer leaf chambers), remove the two slotted and knurled screws. The spacers underneath are held captive with threads. The method of mounting the light unit depends on the type of leaf chamber, see also section 3.7.

If the chamber is used without the radiation shield, the transmission loss (T_{rw}) will be for the window only and therefore lower than the default values, which are for window and shield combined. This also applies if the white or colour (RGB) light unit is fitted (see section 8 for configuration values).

Removing and fitting leaf chambers:

1) To access or change any parts of the chamber, loosen the radiation shield mounting screws a few turns (it is not necessary to remove them completely).
2) Lift off the radiation shield and pull the PAR sensor off its mounting plate.
3) While holding the jaw fully open against the spring, twist it slightly so that the hinge pin slides out on the slotted side.
4) To change a chamber or access the temperature and humidity sensors, the three fixing screws and lower jaw can now be unscrewed about 6 turns. It is not necessary to completely remove them, as they remain captive in the jaw.
5) When replacing the jaws, the slots in the knurled screws are intended to assist with removal rather than tightening: Finger tight is sufficient and over-tightening should be avoided as damage may be caused.
7) Now perform a 'flow check', found in the calibration menu. See section 4.5 for instructions.

3.2 Operation

To minimise noise on the measurements, the chamber should be held as steadily as possible during the measurement. The underside of the chamber has a thread for a ¼" Whitworth screw to attach to a standard tripod.

Prior to taking measurements on a leaf, the chamber sensors can be checked as follows: With the chamber closed, after a few seconds the CO_2 ref & CO_2 anl readings on the LCi T display should stabilise to give similar CO_2 concentrations.

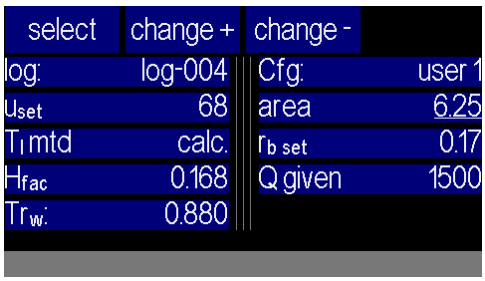
The H_2O concentrations should also be checked for similarity. Check also that the PAR and chamber temperatures (Tch) readings match ambient conditions.

If these checks are satisfactory, leaf measurements can be made.

Once the leaf is enclosed in the chamber, it may take up to 2 minutes to re-adjust to its new microclimate. During this period CO_2 & H_2O values will gradually stabilise. Generally a **good indication of stability is when the value for Ci (sub-stomatal CO_2) has stabilised**. After readings are stable, a 'record' may be taken (see section 12.2).

3.3 Leaf Chamber Constants

The design of the leaf chamber affects various parameters, which are constants for a particular design or type.



'r_b' The value for 'rb' is influenced by the efficiency of gas mixing within the chamber, ab/ad-sorption of CO_2/H_2O of the materials used, and 'dead' volume (see Section 8.1 for typical values).

'H_{factor}' **(**Previously defined as 'Trans' in LCA2 & 3 references) Hfactor is affected by the material used for the shield (if fitted) and the chamber window. Wavelengths in the visible and infrared regions have different transmission factors. The position of the PAR sensor (inside or outside the chamber), and the type of light source (see Appendix 4) all influence this parameter.

'Tr_w' On the chambers, the measurement of PAR is via a sensor mounted on the shield above the window. The value for PAR at the leaf (Q_{leaf}) is therefore less than that measured (Q) by factor 'Tr_w' – the transmission factor of PAR introduced by the arrangement of the chamber shield and/or window. See Section 8 for typical values.

$T_l$mth Toggle between 'calc and 'meas'.

These constants may be changed with configure set up select.

When the appropriate parameter is underlined, it can be modified with the change + and change – keys, or by pressing a parameter (in blue) on the touch screen.

3.4 Leaf Thermistor

The leaf temperature may be either measured or calculated. The parameter used to switch between the two options is *Tl mtd* in the configure setup menu. For example, if the Broad chamber area (6.25cm^2) is completely filled by a leaf, or contains a leaf of a a known area, it is best to select 'calculated' leaf temperature. If the area is uncertain, e.g. conifers, the temperature will need to be measured, by a leaf temperature thermistor assembly attached to a jack plug (supplied). To use the thermistor: connect the plug to the socket on the chamber handle, and rest the thermistor on the leaf with the wires trapped between the jaws (together with the leaf). To hold the thermistor in position, it is sometimes easier to insert it into a small cut made in the leaf with a scalpel, or by taping the wires to the edge of the chamber.

3.5 Leaf Thermistor "Spider"

(Broad and Narrow style heads only)

Broad and Narrow chambers offer an additional integral microchip thermistor mounted in the leaf chamber. This integral thermistor is disabled if the external thermistor is plugged in. The integral thermistor has a springy 'spider' mounting that touches the underside of the leaf. It is held in place in the lower jaw with two pins.
To fit: Remove the top jaw, connect the horizontal pin of the spider by pushing on the back of the connector socket. When it is fully connected, align the vertical connector with its mating pin, and push it together by pressing on the back of the connector socket. To remove the spider, use a pair of thin nose pliers with serrated jaws, or a strong pair of tweezers with serrated jaws. Hold the end of the vertical socket and pull it off gently, ensuring that there is no sudden snatch when it finally disengages. Then hold the horizontal socket between the two plates and pull the connector off about 1mm. With a cocktail stick or similar, hold the free side of the spider above the edge of the jaw, whilst pushing apart the connector with another stick.

3.6 Light Units

Light units are available in colour (with red, green and blue LEDs), or in white (with white LEDs only). Both types are available for the Broad and Narrow leaf chambers. Only white light is available for the Conifer leaf chamber.

Fitting:
With the radiation shield removed, a light unit slides (Broad, Narrow) or clips (Conifer) onto the top jaw with the lead towards the cable end of the chamber. The cable is long in order to connect to the plug in the LCi T console (with a 3 pole jack plug). The conifer light unit also has a reflector which clips to the lower jaw. The light unit cable can be tidied together with the main handle-to-console cord using the cable sheath kit supplied.

Removing:
The Broad or Narrow light unit is removed by first disconnecting the plug, then lifting the spring-loaded metal tab on top, above the cable. With the tab lifted, the light unit can be pushed off the jaw. The Conifer white light unit includes a 'hood' to prevent outside light from entering the chamber through the lower jaw and uses plastic clips to keep it in position. The hood can be fitted/removed by applying a moderate pressure.

Key points when using a light unit:
Trw is the transmission factor of PAR into the leaf chamber at the exposed leaf surface. i.e. it is the factor which Q is multiplied by to obtain Qleaf.
Trw is dependent upon the materials used in the construction of the Leaf Chamber window and, where applicable, the radiation shield. A radiation shield is supplied with Broad, Narrow and Conifer leaf chambers (not Small chambers) but is removed in order to fit a light unit. When a light unit is fitted, Trw should be increased by **0.05** to compensate.

To change Trw: Enter the "configure" menu from Main Menu 3 and touch **Trw**. Now that the radiation shield is removed, the window transmission factor should be changed to **0.92** for Broad or Narrow, or 0.91 for Conifer light units. Use the number keypad then 'tick' to confirm changes.

Using a light unit in direct sunlight: The join between a light unit and the upper jaw of the leaf chamber is not totally light-proof. We recommend shielding the light unit from direct sunlight when in use, especially when the light unit is running at low light levels.

White light unit output:
The white light unit has a colour temperature of 4250º, and a CRI (Colour Rendering Index) of 80 minimum. The Broad and Narrow white light units can produce 2500µmol m^{-2} s^{-1}. The conifer light unit can produce up to 1500µmol m^{-2} s^{-1}. Please note that the achieved, maximum outputs are reduced by Trw, to give Q at the leaf plane!

Colour, RGB light unit output:
The colour, RGB light unit contains Red LEDs at 660nm, Green at 525nm and Blue at 455nm wavelength (all +/-10nm). The output of the LED array is monitored with a light sensor, which adjusts the power so that the light output for all each of the three colours is constant at any set value. Broad and Narrow colour light units can produce a maximum QTotal of 2400µmol m^{-2} s^{-1} of light when all three colours are at full power. The maximum available QTotal output for red, green and blue LEDs is 800µmol m^{-2} s^{-1}, when all three colours are equally proportioned at a ratio of 33:33:33 %*.

*The exact maximum values, as stated on the technical specification, for available Q when using an RGB light unit, **are not achieved at the leaf plane level** due to Trw factor (see section 3.7) between the light unit output and chamber window and, to a lesser degree, due to rounding in the software.

The software will round values to the nearest whole number. For example, in equal percentages R, G and B can only be allocated 33:33:34, one is rounded up to 34 rather than each being exactly '33.333'. In which case, the total RGB output (QTotal) becomes 2344 µmol m^{-2} s^{-1}. This translates to a Qleaf value of [2344 x Trw], 2133 µmol m^{-2} s^{-1} with a Broad or Narrow light unit in use.

Always set the correct Trw value before taking measurements, setting a timed log or sequence file, so that the recorded Qleaf values are correct.

Columns taken from LCi T 'timed log' data file:

8	9	10	11	12	13	
Qleaf	Q mode	Qwhite	Qred	Qgrn	Qblu	QTotal
2155	climate	n/a	773	796	773	2342
2208	climate	n/a	800	800	800	2400
1949	climate	n/a	708	702	708	2118
Qleaf = Total x Trw of 0.92						

8. **Qleaf,** PAR at the leaf plane (µmol m^{-2} s^{-1}) will be corrected for Trw factor (0.92 for Broad or Narrow, 0.91 for Conifer chamber) if set by user in the "configure" menu, prior to setting data logging.

Using "PAR" or "%RGB" editing modes (applies to colour light unit only):
The software will set appropriate limits automatically, detecting which type of lamp is connected. The software also allows the user to configure the system for a different jaw type than the light unit that is fitted. A mismatch will not cause any error messages, but an automatic limit will be placed on the light level 'Q' that can be user-set. For example, if the chamber type has been set to Conifer but a Broad lamp is fitted, the software will allow levels up to 2500µmol m^{-2} s^{-1} to be set.

In the current software, when a user selects the %RGB mode of editing, the requested ratio, for example 33:33:33, is achieved and the correct QTotal is also achieved, e.g. 800µmol m^{-2} s^{-1} for Red, Green and Blue. *These values are NOT the leaf plane level values (see "**Trw factor changes Q at the leaf plane!"** below).

If the user switches from %RGB to 'PAR' mode (by using the upper right hand toggle key), or vice versa, whilst editing a sequence file or controlling using climate Q, there may be a difference in achieved values. This is due to the software rounding to the nearest whole number when transforming % values into absolute Q values.

Editing PAR or %RGB in a PAR Sequence File (applies to RGB light unit only):

For this reason, we strongly recommend only using only ONE mode whilst editing a PAR sequence file for an RGB light unit. Choose between mode option 1 or 2:

Mode option 1: Use the PAR menu to set **Qred, Q grn, Qblu** in µmol m^{-2} s^{-1} values, before editing the total PAR if required. Only edit the total PAR through the sequence. Individual **Qred, Q grn, Qblu** values will automatically calculate to equal Qtotal. All values recorded in a sequence data file will be displayed as actual µmol m^{-2} s^{-1} values, (not as %).

Mode option 2: Set the %RGB and only edit %RGB through the sequence. QTotal will be automatically calculated according to your set %RGB values and total. All values recorded in a sequence data file will be displayed as actual µmol m^{-2} s^{-1} values, (not as %).

TIP:
Set 1) Q%Red then 2) Q%Green then 3) Q%Blue **in this order** to allow the automatic recalculation of the other two colours, whilst keeping your set values as entered.

Using PAR or %RGB in Q climate (applies to RGB light unit only):

You have the option to use either PAR editing mode or %RGB editing mode in order to control an RGB light unit.

There can often be a rounding error (<5 µmol m^{-2} s^{-1}) when using the %RGB mode, due to the software rounding to the nearest whole number. The QTotal value will also be affected by this rounding.

Trw factor changes Q at the leaf plane!

- **When Trw is set to 0.92**, Qred maximum will be 736, Qgreen maximum will be 736, and Qblue maximum will be 736, when the user enters 800 µmol m^{-2} s^{-1}. QTotal available maximum will be 2208, when the user sets QTotal to 2400 µmol m^{-2} s^{-1}. QTotal is not recorded in the data file, for an RGB light unit. (For a white light unit, Qwhite is equal to QTotal and only PAR mode is available).

- **When Trw is set to 0.91, for conifer white light unit**, Qwhite is equal to QTotal. The achieved (and recorded) Qleaf will be 2275 µmol m^{-2} s^{-1}, when the user sets Qwhite to 2500 µmol m^{-2} s^{-1} in PAR mode.

Light Unit	**Displayed output range** µmol m^{-2} s^{-1}	**Achievable output range, corrected by Trw** (window only, no shield)
Broad or Narrow White	0 to 2500	0 to 2300
Broad or Narrow Colour, **Qtot**	0 to 2400	0 to 2208
Red, Green or Blue, **Q%rgb**	0 to 800	0 to 736
Conifer White	0 to 1500	0 to 1365

3.7 Q options

The Q options menu has 4 keys (hold Q, release Q given Q and climate Q) that determine the PAR (Q_{leaf}) reading.

The hold Q, release Q feature is not needed with the light unit supplied with the system, which has an integral light sensor. It is useful for users who wish to use their own light source, whose dimensions are such that a PAR sensor and a leaf cannot both be simultaneously illuminated. In that case, this feature can be used as follows: The PAR sensor is removed from its usual position and placed in the chamber with the sensor facing the light source.

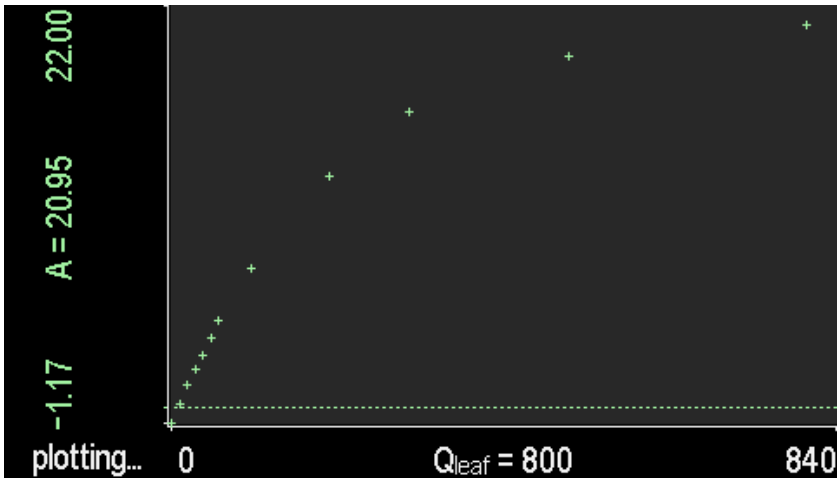
The option hold Q holds the resultant PAR reading (Qleaf). This value does not have the window transmission factor applied to it. The PAR sensor can then be removed from the chamber, and replaced by the leaf. All subsequent calculations are based on the frozen value, which can be used for many leaves. Normal operation is restored with the release Q button.

The option given Q allows a given value of PAR (Q) outside the chamber to be used. The "given" value is entered from the configure set up menu by selecting */Q set/* then inputting the required value. The default value is 1500µmol m^{-2} s^{-1}. Any value between 0 and 3000 may be entered. Once given Q is pressed, the given value will conform to whatever configuration is being used at the time.

Note: The corresponding window transmission factor is applied to it, so it will generally be less than the value entered. Press release Q to return to measured values. If hold Q is pressed whilst "*given Q*" is being used, the current value for Q will be held even when changing to an alternative configuration set-up.

Note: When release Q is pressed, the value for Q will return to *measured* (not *given*).

The climate Q option selects the Q value currently entered into the climate menu. When selected, climate Q brings up the message: "using Q from climate control". It is important to check the Q mode when running a **light response curve (see example LCi T graph recorded during a light sequence, below)** on a leaf, as the selected Q value will operate the light unit when the LCi T is switched on, and once a PAR/Q sequence (see Section 11) has completed.



SECTION 4. SMALL LEAF CHAMBER

4.1 General description

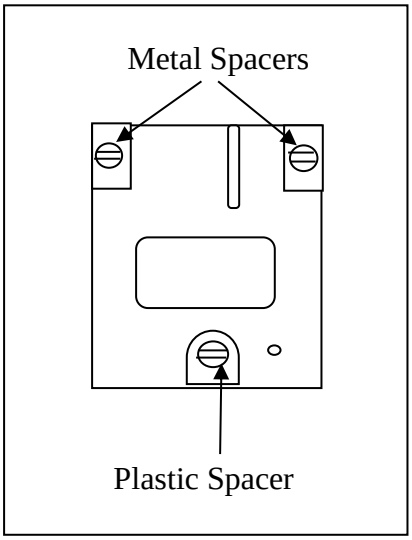
This chamber is designed specifically to access small leaves that grow close to the ground. Due to the very small size, the chamber does not have light or temperature climate controls or a radiation shield. The head consists of an “interface block” that attaches to the handle using three captive screws and spacers (see following paragraph and figure for LCi T configuration) and a leaf chamber that is carried at the end of a flexible neck or “snake”. The flexible neck allows the leaf chamber to be positioned where needed. The “snake” can then be locked into position by means of a lever on the interface block.

The chamber jaw has an offset spring that holds the jaw closed. When the jaw is opened manually the spring passes through the fulcrum point and holds the jaw open. When not in use the jaw should be left in the open position to prevent the gaskets from becoming compressed.

4.2 Configuring the Chamber for use with an LCi T

The three fixing screws that secure the interface block to the chamber handle are each fitted with a spacer that is required for the longer sensor bodies on an LCi T analyser. They ensure correct spacing to suit the handle sensors and correct electrical connection or insulation as appropriate. When using the chamber on an LCi T these spacers must be fitted directly under the head of the captive screws as shown in the figure below.

The interface block has a spacer fitted onto each of the fixing screws on the upper side of the interface.



4.3 Leaf size/position:

There is no restriction on the position of the leaf in the Small leaf chamber (active window diameter 16.5mm) because it has an air supply path in both the top and base.

4.4 Leaf Temperature reading

Note that since there is no integral leaf thermistor in either of this chamber, the measured leaf thermistor reading ($Tl_{(m)}$) will be invalid and read ↑o/r↑ (over range) unless the thermistor probe (Part No. PLC-011) is plugged into the jack socket. The message "Tleaf probe error" will appear on the Status line. Alternatively the calculated rather than measured leaf temperature reading method ($Tl_{(C)}$) can be selected.

4.5 Flowrate and stability

The exposed leaf area in the Small leaf chamber is 2.14cm^2. In order to obtain a reasonable ΔCO_2 it is necessary to reduce the airflow (by selecting /config/Uset/) to a low value e.g. the minimum value of 68. With such low values of ΔCO_2, it is necessary to ensure good stability of the CO_2 concentration in the supply air. This can be obtained by taking the air supply from a place away from human breath, by ensuring that the air probe is used or drawing air via a large container e.g. a 25 litre container as used for carrying water.
It is advisable to perform a flow check calibration when changing from the Broad, Narrow, and Conifer leaf chambers or Soil pot to a Small leaf chamber.

4.6 Use of the flexible neck or "Snake"

The handle should be supported on a small tripod or laid on the ground next to the plant. The "snake" can then be positioned with the leaf to be tested inserted in the chamber and finally locked in place by moving the locking lever down into its slot.
When not in use the "snake" should be left in the relaxed position, (locking lever up) in order to prevent stress of the tensioning wire.

SECTION 5. THE SOIL POT

5.1 General Description

The ADC Soil pot is a chamber incorporating an enclosed volume used for the measurement of gas exchange associated with soil biomass respiration. It is designed specifically for use with the LCi T (and LCpro T).

The Soil pot consists of an acrylic pot containing an air stirrer fan and pressure equalisation vent. A separate temperature probe is supplied that may be inserted in the soil adjacent to that under analysis. In addition a stainless steel "ground spike" to support the soil pot and a "Collar insertion pad" is supplied for pushing the collar into firm soils.

5.2 Operation

"SOIL POT" should be selected as the chamber type in the configuration menu (see 3.1). Since the analysis flow has quite a different characteristic than the leaf chambers, it is important to carry out a flow check when the chamber is changed to and from the Soil pot. (When making such a change the software reminds the user of this and asks whether a flow check should be performed). It is important that the relevant chamber is attached when the flow check takes place.

The Soil pot accepts "reference" air and passes "analysis" air to the IRGA cell in the same manner as conventional chambers. The flow of air into the soil pot is controlled by the "Uset" function in the configuration menu of the LCi T. An excess of air is provided to the Soil pot over that extracted for measurement, and a pressure relief vent ensures that the Soil pot is not pressurised as this would interfere with the gas exchange at the soil/air interface.

The temperature and humidity of the air within the Soil pot are monitored in the normal fashion by the chamber sensors Tch, Ean, Eref.
The soil temperature is measured with the soil temperature probe supplied, which is plugged into the handle's jack socket. This probe uses the same type of thermistor as the leaf temperature probe and has a small non-linear response, which is compensated for by the software in the analyser. The temperature range of both sensors is : -5°C to +50°C.

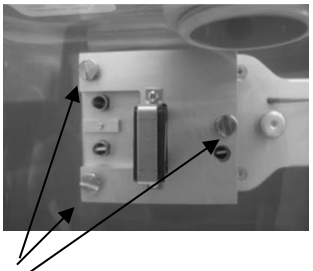
A "Leaf Chamber Jaws OPEN" message will be present until the Soil pot has been attached correctly. A "Tleaf probe error" will be seen on the status line if the leaf temperature method is set to "measured" until either the probe supplied or the standard Leaf Thermistor probe (ADC Part No. M.PLC-011) is connected. It is advisable to use a temperature probe and configure the leaf temperature method to "measured" (Tlm).

Since the air above soil can be near dew point, the warning "analyser condensation risk" is more likely to occur than with leaf chambers. The risk of condensation can be removed if the instrument is at ambient temperature or above. Ensure that the instrument is left on without making a measurement for an hour or so if it has been taken from a colder environment.

5.3 Preparing the Soil pot for use

5.3.1 Removing the existing leaf chamber

Remove the Shield from the current leaf chamber upper jaw, unplug the PAR sensor then unhinge the upper jaw from the handle. Using a suitable coin (if required), unscrew the three captive screws from the handle and detach the lower jaw from the handle, unplugging the Peltier cable if necessary. Safely store the upper and lower jaws, shield and spring.
Note: When swapping between leaf chambers and the Soil pot, be careful not to lose the 'O' rings, particularly the two small ones. If these two remain in the chamber jaw, poke them out and fit them to the ends of their pipes before fitting the Soil pot. Tweezers are useful for this.



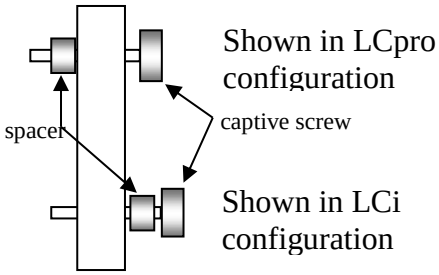
5.3.2 Attaching the soil pot to the handle

The soil pot is attached to the handle in the same manner as a leaf chamber, using the three captive screws, see photo.

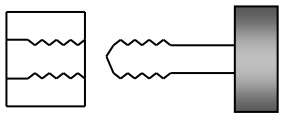
Important Note:

When fitting a Soil pot to the LCi T, the spacers on the three screws (see figure right) should all be metal and fitted directly under the heads of the captive screws, on the inside of the Soil hood (see figure below).
An extra metal spacer is provided in the spares kit for this purpose.

The LCi T sensors are shorter than the LCpro T, requiring a different arrangement of screws and spacers to be fitted. If you also have access to an LCpro T from ADC, the configuration for the LCpro T is with the spacers fitted on the outside of the hood and the fan drive screw's spacer (lower screw of the 3) is plastic to avoid a short circuit to the handle baseplate.



The spacers are not threaded all the way through and should be fitted onto the screws threaded end first to avoid the spacer binding, see figure right.



The PAR sensor should be fitted in the top of the vent spacer as shown.

5.3.3 Inserting the "Collar"

Collars are intended to be installed in fixed locations a long time before measurements are made so that disturbances to the soil can settle. The installation of multiple collars allow measurements to be quickly made at repeatable locations without needing to wait for the soil conditions to settle each time. The "collar" (if used) should be inserted into the soil as far as is necessary to eliminate diffusion through the soil. If for example the soil is loose, the collar should be inserted quite deeply.

This minimises gas transference through the soil and also to provide more support to the Soil pot. Firmer soil may be difficult to penetrate and the "Collar insertion pad" should be used (see image above).

Using the Insertion pad minimises the possibility of damage to the seal on the top rim of collar. The pad should not be left on top of the collar before a measurement, as the soil should be allowed to 'breathe' naturally.

Note: Depending on the soil condition the user may feel the collar is not required and may insert the soil pot directly. This may allow measurements to be taken sooner than would otherwise be the case (see section 5.5).

5.3.4 Locating the hood on the collar

Once the "Collar" has been inserted the soil pot (coupled to the handle), can be installed. The soil pot should be placed above the collar and pushed down until the hood forms a good seal over the collar.

5.3.5 Attaching the "ground spike" and PAR sensor

A metal spike is provided to support the handle, when angled towards the rear of the handle (see photo). It does not need to be fitted at all times, but will help take the strain off the multi way cable, or help support the handle if the Soil pot is being used on a gradient. A 'foot' is supplied that may be fitted to the ground spike for use in soft media – such as sand. It is not recommended that this is used to insert the spike with any great force.

5.3.6 Flow check calibration

A flow check calibration will now need to be performed. This is important as the fan in the Soil pot has different characteristics compared with the leaf chambers which can affect the analysis gas settling time, especially at very low flow rates. If the settling time is too short then inaccurate readings may be obtained.

The suggested flow rate is 200 µmol s^{-1}. Ensure that the displayed NCER reading is stable before doing this flow check. The flow check need only be done once even if the instrument is switched off, unless the jaw type is changed and used in another configuration. If the flow rate or jaw type is changed then redo the flow check calibration.

Flow check calibration is performed to allow the analyser a long enough time for gas readings to become constant during the reference and analysis parts of the measurement cycle and should preferably done at the same flow as the user intends to operate the soil

hood. If the user wishes to keep the cycle time as short as possible or the soil is very active, then the calibration should be performed at higher flow rates such as 250 – 300 µmol s^{-1}.

5.4 Soil respiration measurements

The Soil pot is now ready to begin soil respiration measurement, please read "*5.5 other considerations*" before continuing. After measurements have been recorded the log file may be downloaded into a computer and calculations performed to determine the amount of soil respiration taking place (see Appendix 3).

Note: at a flow rate of 200 µmol s^{-1} it will take 15-20 minutes for the gas in the Soil pot to reach equilibrium and for the LCi T to obtain an accurate reading.

5.5 Other considerations

It is recommended that the collar be left in place for at least a few hours for a minor soil disturbance and at least a day for a major one before results are taken in earnest.

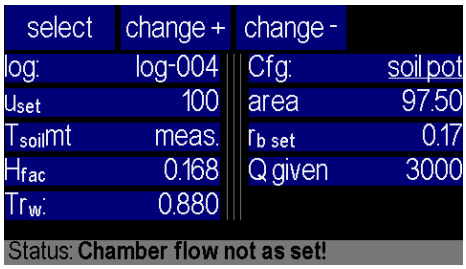
Additional collars may be purchased to enable several test sites to be defined and the collars left in place.

Flow check calibration is performed to allow the LCi T a long enough time for gas readings to become constant during the reference and analysis parts of the cycle and should preferably be done at the same flow as the user intends to operate the Soil pot.

When a Soil pot is fitted, neither the temperature nor the light control should be activated either in a sequence or in climate control, as neither will be functional.

5.6 Soil pot constants

The only Soil pot constant relevant for respiration calculations is area, other leaf chamber associated constants are not displayed once the Soil pot is selected. The area has been pre-set to 97.5 cm^2 which assumes the Collar is used. Chamber type be changed with configure, Cfg (also called ChCfg).



5.7 Soil pot Dimensions

5.7.1 Using the Soil pot without a collar

The surface area of the enclosed soil is nominally **132.5cm²**
The volume of the soil pot (without soil intrusion) is approximately **839cm³**

5.7.2 Using the Soil pot with a collar:

The surface area of the enclosed soil is nominally **97.5cm²**
The volume of the soil pot with the collar (without soil intrusion) is approximately **803cm³**

5.8 Using other, non-standard chambers

When using the following ADC 'non-standard' chambers: canopy, whole plant, fruit and versatile chamber (when using to measure plant gas exchange), you must select and edit the configuration of the LCi T to the appropriate chamber and plant sample in use.

There are a total of 4 configuration options provided for 'USER' settings, which may be completely adjusted to suit specific requirements for a type of sample or non-standard chamber. These are labelled:

USER 1 flow rate: 68 µmol m^{-2} s^{-1}
USER 2 flow rate: 341 µmol m^{-2} s^{-1}
USER 3 flow rate: 200 µmol m^{-2} s^{-1}
USER 4 flow rate: 200 µmol m^{-2} s^{-1}

The total leaf area must be user-defined and entered manually into the USER configuration, for each specific plant or sample. Total leaf area will then be used in plant gas exchange calculations.

Without changing the default 'area' within any USER configuration, data will be calculated incorrectly, not accounting for leaf area.

Note: When configured to "SOIL POT", measured parameters will be calculated in 'respiration' mode so that CO_2 values are given based on the area of the chamber rather than leaf area. These values would normally be converted to NCER.

Using the Soil pot, versatile or sealed chambers for whole plant gas exchange:

If the above chambers are used in "SOIL POT" configuration, it will be necessary to adjust 'respiration' mode data to photosynthesis data. The parameters required for adjusting NCER to plant gas exchange or A values, are:

- Reversed NCER, re-labelled accordingly. NCER values should be reversed from + to – delta C values or *vice versa*).
- Differential CO_2 (ΔC column in a data file)
- Flow rate (already provided in column 'U' of a data file, units µmol m^{-2} s^{-1})
- Active leaf area of the sample, entered manually. Use this data to calculate the flow per unit leaf area, in ml min^{-1}.

SECTION 6. ROUTINE MAINTENANCE

6.1 Chemicals

The performance of the LCi T is dependent on the satisfactory condition of the soda lime, which is in the column furthest from the connectors. The life expectancy of the soda lime before it becomes exhausted depends on use and ambient conditions; but is approximately 200 hours at normal CO_2 (air) levels. The soda lime supplied is an indicating type, which turns from white when fresh, to violet when exhausted. Some water content is necessary to assist the chemical reaction, which is to convert CO_2 to calcium carbonate + H_2O. Re-conversion back to soda lime is not practicable, the colour may revert back when stored in an airtight container, it will not work for long if used.

Alternative Chemicals

Soda lime is commonly available, but is unlikely to be an indicating type – this will lead to erroneous CO_2 measurements if the soda lime is used (unknowingly) in an exhausted state. Occasional calibration of CO_2 and/or H_2O 'span' levels may be necessary. Unless a serious problem (with a part) exists, the need for re-calibration is not usually obvious, and may only become apparent if LCi T values are in disagreement with another similar instrument, or known gas concentrations. In this case however, note also that if the 'zero' chemical is exhausted, a false zero calibration will occur resulting in lower values!

6.2 Dust Filters

Although 'clean' chemicals are supplied, in practice fine dust particles can be given off, which eventually may cause a malfunction of the mass flow sensors and/or the optical bench. This will also be the case if dust or pollen is drawn in from the air supply.

The filters used are designed to prevent this, but will gradually restrict the airflow in the process.

If difficulty is experienced in obtaining the maximum (PLC) flow of 340 μmol sec^{-1},(ie. indicated flow 'u' very much less than 340 μmol sec^{-1} and pump "racing") this can be taken as a sign that filters should be changed.

The most likely filter to become blocked is the external plastic bodied one (M.630-980), if fitted. Otherwise, check the 3cm diameter disc filter with a Luer connector, located under the top bezel. In dusty atmospheres, with continuous operation, and no other external filtering, this can become blocked in less than a week. If in doubt, compare its colour with the spare filter in the Spares Kit. The other filters are not transparent so cannot be checked visually.

The next filter to check is the external metal bodied one (M.631-180), if fitted. It contains a 25μm gauze filter element that can be cleaned with a small brush. Replace it with the largest part of the body on the inlet side as this will ensure that trapped dirt is on the outside of the mesh and can be easily removed.

6.3 Battery description

The LCi T has an internal, sealed, re-chargeable lead-acid battery, which, when fully charged, operates the system for up to 10 hours, with no light unit running. With a light unit continuously running at high output, the battery life is reduced to less than 3 hours. Battery power is shown on a bar graph, and also as a numerical voltage 'V_{batt} in the */config/diagnose/* page. The battery and the supply fuse are located in the base of the console, and are accessed by rotating the two spring fasteners on the bottom panel and opening it. The battery can then be lifted out, and removed, after disconnecting the two spade terminals.

Spares are available through ADC, or as advised by local agents.
When the battery in the LCi T is near to a discharged state, a **warning** – **low battery voltage** message is flashed on the display. In this event, terminate the work as soon as possible, switch the LCi T off and, either recharge, or replace the battery. If a suitable external DC power source is on hand, connect it to the LCi T as soon as the message appears. In this case, work can continue undisturbed.

If you plan to store the instrument, fully charge the battery first. Giving it an 8-hour top up charge at least once every 6 months will maximise its life. It is not necessary to remove the battery, but if you do, and leave it out for a few weeks, you may find that the rechargeable clock battery has become discharged and so you will need to reset the clock.

6.4 Battery Charging

The battery can be re-charged *in situ* via the five-pin power socket on the side, using the charger lead supplied or it can be removed (see section 6.5) and charged directly. The LCi T can also operate from an external 12-volt supply of at least 0.3A capability (using the charger lead), without the internal battery fitted. Be aware that there is no diode to prevent power flow back out of the battery (although there is a fuse), so disconnect the charger from the LCi T when the charger is disconnected from the mains.

The main battery will give several years' service, **providing** the following precautions are taken:

Never over-charge the battery as this can damage it. An indication that a battery is being overcharged is a noticeable rise in temperature. When the instrument is being used in the field on a daily basis, an overnight charge will be sufficient; do not leave the battery on continuous charge for more than a day.

Never store the battery in a discharged condition – this will shorten its life.

Never charge the battery using a constant current supply, commonly used to charge Ni-cad batteries – this can over-charge it. A constant voltage supply only should be used, i.e. one in which the charge current (which must be monitored) is set by adjusting the supply voltage**,** or an ADC battery charger.

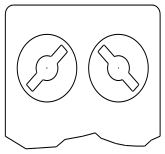
In the field, the battery can be charged to some extent by connecting it with the power cable supplied to a vehicle battery. It will be more fully charged if the vehicle engine is running. For field operations, spare, fully charged batteries will extend operating time.

6.5 Battery Replacement

Battery replacement can be done at any time but, before doing so, switch the LCi T OFF via the power off function. The configuration used at the time will then be preserved. Batteries cannot be expected to last beyond 5 years, which is the same time as the recommended service interval. Symptoms of a faulty battery are a short running time even after it has been left on charge for 8 hours, or a very small charging current, even if it appears to be discharged.

In order to swap to a fully charged battery without switching off, it is necessary to first connect an external supply to the 5 pin power socket. The supply could be from a battery charger (supplied), or from another 12V battery using the crocodile clips.

The battery and the supply fuse are located in the base of the console, and are accessed by rotating the two spring fasteners on the bottom panel and opening it. The battery can then be lifted out and removed, after disconnecting the two spade terminals.



With the instrument upside down, undo the two fasteners on the base plate of the LCi T by rotating them a quarter turn; the base plate can then be removed to expose the battery. Disconnect the battery by holding the spade terminals and not the wires. Turn the instrument the right way up to withdraw the battery. Reconnect a replacement, ensuring that the LCi T RED lead terminal is connected to + and the black terminal to –. When removing or refitting the battery, ensure that the metal tabs on the battery do not touch the chassis. Fit the battery into the LCi T and refit the base plate by locating its 'tongue' into the chassis then rotating the two fasteners to the positions shown in the figure above and pressing firmly until they are heard to click.

6.6 Battery Fuse

The battery fuse is a 20mm glass type located in a bayonet type holder next to the two fasteners under the base plate. This 800mA time delay glass fuse is connected in series with the battery 'positive'.

Under normal conditions, the fuse should not fail. If it does, it could be due to an internal fault, by a high voltage applied externally, by an external supply reversal or by the battery over-charging which can cause its terminal voltage to increase. Providing the cause of fuse failure/s is removed, and the fuse is replaced (a spare is provided), the LCi T will have been protected from permanent damage.

SECTION 7. SET-UP AND CALIBRATION

It is strongly recommended to return your LCi T to an ADC approved calibration centre for a full service and recalibration every 4 to 5 years.

7.1 Serial Link Port Set-up

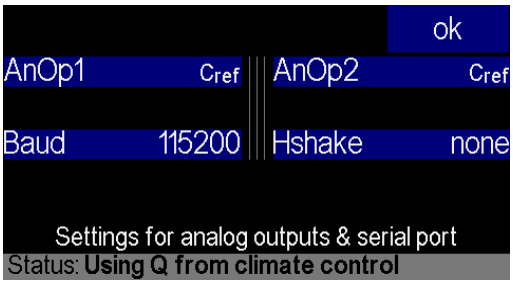
/output/serial/ gives a menu to select *baud rate* and *handshake protocol.*
Set the required baud rate by highlighting it with the */select/* key then use the /+/ and /-/ keys to cycle through the options of 300, 1200, 2400, 4800, 9600, 19200, 38400, 75800, 115200 and 230400 baud.
Highlight the handshake to cycle through the options of "none", "CTS", "xon-xoff" and "use CTS for record". If you select "CTS for record", you will not be able to send recorded data over the serial port. If you try to do so you will get a message 'Serial port set for record trigger'.

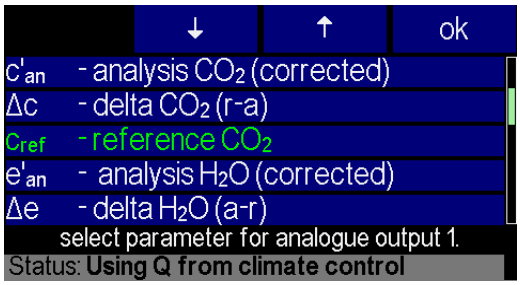
7.2 Analogue Output Port Set-up

/output/ gives a display of a list of parameters, one of which can be selected for the chart recorder output. The menu gives the usual cursor controls over a number of parameters, which can be selected with the /+/ and /-/ keys. The selected parameter will not be output until the page key is pressed.

7.2.1 Output Parameters & Scaling

Pressing output displays the parameters list, from which two can be selected for the two chart recorder outputs by pressing AnOp1 or AnOp2.





The An o/p column in Appendix 1 lists the parameters available for the analogue outputs. The following three columns list the unit of measurement, the range and derivation. An explanation of the derivation codes follows the table in Appendix 1.
The port output is scaled at 0.0V = zero or offset and +5.0V = full scale readings. Further information such as Units per Volt is shown in Appendix 2.

7.3 Time & Date Set-up

Pressing configure more time/date displays the Time and Date menu. Press select to step through hours; minutes; seconds; day; month; year. Pressing change + or change - increments or decrements the chosen parameter (except for seconds which resets to zero). The clock is in a 24-hour format.

While in use, all of the current settings are retained indefinitely by a non-volatile electrically alterable RAM. A small rechargeable battery supplies the clock. If the LCi T supply is removed (e.g. its battery is discharged), this battery will become discharged, typically after 7 weeks. It will be automatically re-charged when LCi T power is re-applied, but it will be necessary for the user to set the date and time (See section 7.3).

7.4 Calibration

Press */calibrate/* to access the calibration menu. The various options can be chosen with */select/* and the /+/ and /-/ keys used to set the value where applicable. Press */do cal/* to start the calibration.

It is strongly recommended to return your LCi T to an ADC approved calibration centre for a full service and recalibration every 4 to 5 years.

7.4.1 Flow check

Note: The displayed values for u and u_{set} are related to the Air Supply Unit (ASU) which provides flow to the leaf chamber. Although proportional to the ASU flow to some extent, the values displayed during a Flow Check calibration are the estimated flow through the analysis cell and the time allowed before the gas is stable and a reading taken. Typical values for broad, narrow and conifer chambers are shown in the table below.
Analysis times for Soil chambers and Small chambers may be longer due to the larger chamber volume and lower advised ASU flow respectively.

It is strongly recommended to perform a flow check calibration if you change between chamber types or make a change to the chamber air supply flow larger than 30%. The flow check calibration checks that the cycle times are long enough for the gas in the analysis IRGA cell to become stable before the absorption is measured. The flow check adjusts the cycle times for both reference and analysis, therefore the chamber jaws must be fully closed before the check is started.

Changing the flow by greater than 30% without performing a flow check may result in insufficient settling time which may cause measurement errors.

Typical flow values and normal variation from typical values that can be expected

ASU set flow (µ mol s^{-1})	Settling time (seconds)		Estimated flow (µ mol s^{-1})	
	Reference	Analysis	Reference	Analysis
200	4.45	3.86	83	97
300	4.32	3.36	85	110
Variation	5%	10% - 25%	5%	10% - 20%

7.4.2 CO_2 Zero

The CO_2 zero setting is automatically maintained by a software adjustment during each zero cycle. The adjustment effectively changes the gain in order that the signal level, when zero gas is flowing, is constant. For this to be performed correctly, the soda lime column must be kept fresh. If this is not the case, there will be an apparent reduction in measured (span) values and a warning message 'cref low, check absorber' when the soda lime is exhausted. This effect may therefore appear to indicate that a 'span' calibration is necessary, when in fact it will not be. Prior to reaching this conclusion, ensure that the chemical has been checked.

The degree of software zero adjustment being applied can be checked with configure diagnose . The C(z) reading should lie between 45,000 and 60,000 counts (with the optimum being 52500). If this is not the case, the warning message "cref low, check absorber" will be displayed and a hardware adjustment can be made.

The CO_2 Zero adjustment potentiometer is located inside the jack socket where the leaf thermistor can be connected, see figure. The potentiometer is adjusted using the thin end of the long (13 cm) trim tool supplied in the spares kit. This tool is the correct length and diameter to fit in the jack socket, and correctly engage in the slot of the pot without misalignment and damage. Insert the tool in the jack socket and gently press, (you will feel resistance as it passes the rear contact set). Turn the tool whilst gently pressing until it engages the slotted adjustment screw of the pot. Zero adjustment can now be performed.

In the calibration menu, select CO2zero. Adjust the pot to reduce the displayed count to within 200 counts of zero, turning it clockwise if the displayed value shows a down arrow. A value within 10% of the range will be functional, and will cause 'OK' to be displayed and the displayed value to be in green. Press OK or press the power key to exit. If the adjustment is very wrong, or if there is another fault, other messages will be displayed; "CO_2 low energy", or "CO_2 signal over-range".

The chemical in the column MUST be in a good condition at all times for correct zero operation. **If the check indicates maladjustment, check the state of the chemical before any potentiometer adjustment.**

7.4.3 CO_2 signal phase correction

It is not normally necessary to set the CO_2 signal phase correction unless a new infrared source or detector has been fitted or a large adjustment has been made to the CO_2 zero.

The set phase operation is fully automatic but can be escaped from without effecting a change by pressing any button.

During the set phase operation, the instrument performs a series of checks in 1° steps between 65 ° and 100 ° to find the phase correction that gives the best CO_2 signal energy.

During the scan the current angle being checked and the best angle found so far are displayed. When the best angle remains the same, the scan has probably already found the ideal angle. It is worth keeping an eye on the best angle and noting its value. Typically, the phase correction angle is between 70 and 80 °.

When the scan is completed, it will show the best angle found and ask whether you wish to save the new setting.

7.4.5 CO_2 Span Calibration

The CO_2 span calibration setting may be recalibrated by one of two methods, the first method is somewhat crude and not recommended unless an instrument has lost its stored calibration setting, the second method is to be preferred.

Note before using either method

Using a stable air supply either from a small volume or from the extended air probe (or the bottled gas if using method 2)
Set the flowrate to 341µmol/sec, perform a phasecheck *config>diagnose>sysinfo>auto phase*, followed by a CO_2 zero calibration (in the calibration menu – you will need a potentiometer adjustment tool to insert into the handle jack socket and rotate until the screen displays “ok” when in CO_2 zero calibration mode).
Lastly perform a CO_2 flowcheck, from the calibration menu (the jaws must be correctly fitted with all 5 o rings making a good seal from the jaws to the handle. Make sure the jaw gaskets have no gap around them, a small gap can be fixed with an elastic band around the jaws).

Method 1. The ambient method.

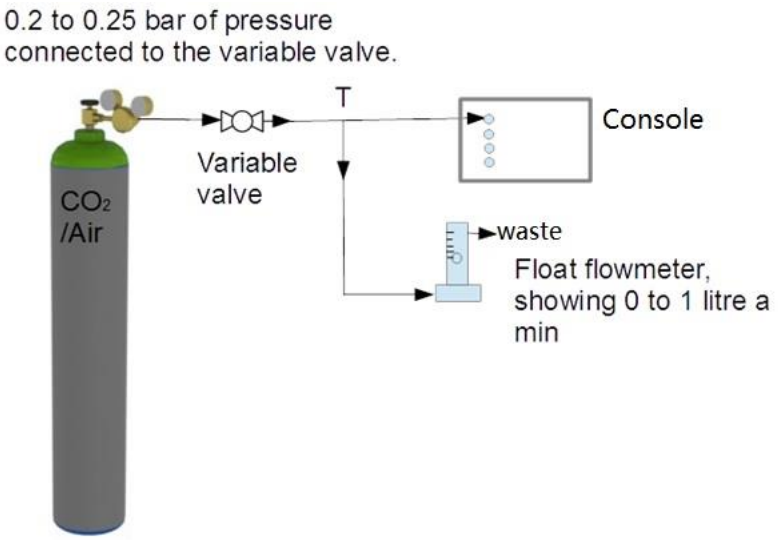
This can only be done in an open area, several Km away from and ideally not downwind of any major sources of CO_2 such as cars, buildings etc. It should be done in an open area not for example in a forest environment. A good location would be on a coast with light wind or an onshore breeze. Connect the console air in port to a buffer volume or the air probe (extended and held upright by use of the groundspike) using 3 or 4mm bore PVC tubing. Next enter the calibration menu and perform a CO_2 span calibration, having first adjusted the span gas ppm level in the calibration menu to 400 ppm (in 2017) this being a typical global average. After calibration exit the calibration menu and monitor Cref for a couple of minutes, redo the calibration if Cref deviates more than 10ppm away from the span gas value.

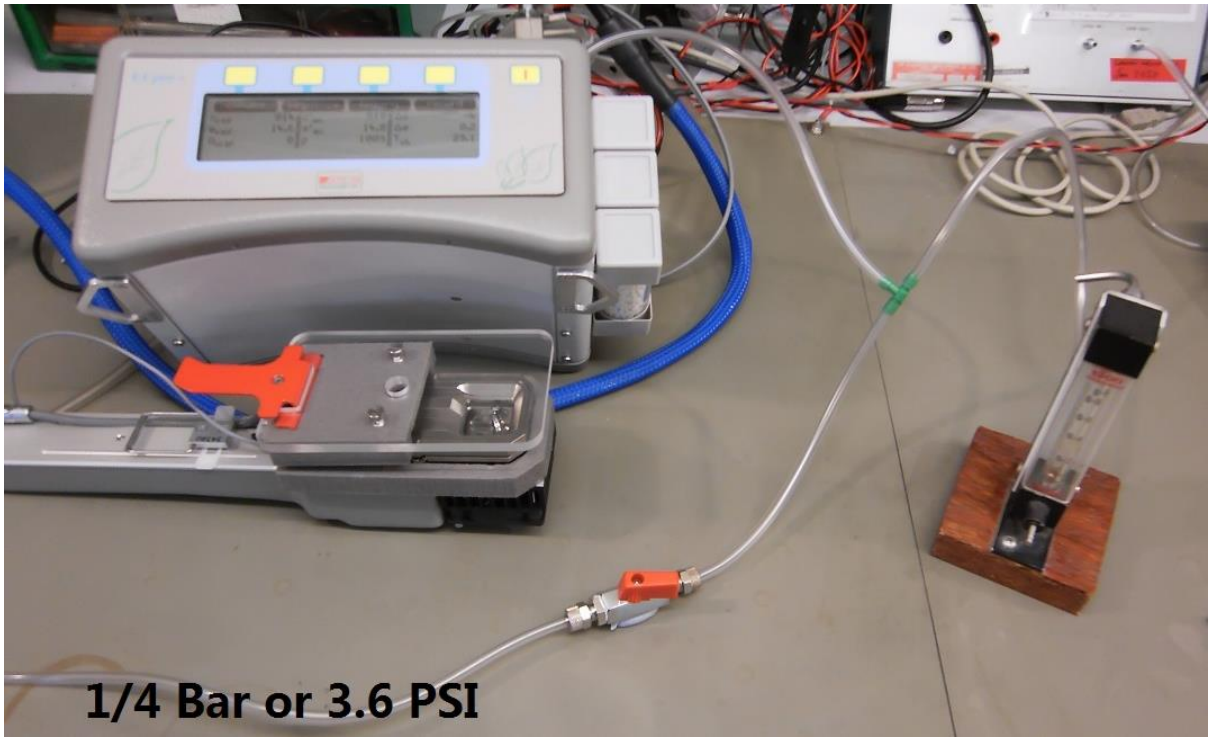
Method 2. The bottled gas method.

To do this you will need a pressurized bottle/cylinder of gas made from a mixture of CO_2 and Nitrogen. The PPM value of the CO_2 must be known to a good level of certainty e.g 1% accuracy. The span gas should be 40-99% of the maximum range of the instrument.

Equipment:
You will also need a two stage pressure regulator fitted to the gas bottle/cylinder to reduce the pressure to approximately ¼ bar or 3.6 PSI, a ball or needle valve, some 3 or 4mm bore PVC tubing, a T piece and a float flowmeter with a range of or close to 100ml to 1000 ml or more per minute. The flowmeter must allow enough reverse flow for the console to run at maximum flow rate – most float flowmeters do but some ball type flowmeters do not, this should be tested as follows:
Set the console flowrate to 341µmol/sec, use a piece of PVC tubing, 3 or 4 mm bore to connect the inlet of the flowmeter to the air in port of the console. If the console pump becomes very noisy then disconnect the flowmeter quickly – it will not be suitable. A small increase in pump noise is acceptable.

Setting up the Equipment:
Connect the output of the two stage regulator to the ball/needle valve, then connect the remaining entry of the valve to one air entry of the T piece. Connect one of the remaining air entries of the T piece to the air in port of the console. Connect the last air entry of the T piece to the flowmeter air in entry. The diagram and photograph below show this setup:





Method:

Turn on the LCi T and set the flow to 341µmol/sec.

Turn off the variable valve (ball or needle).

Next use the two stage pressure regulator to set the pressure to or slightly under 0.25BAR or 3.6 PSI. Very slowly open the variable valve until the flow meter reads about 200 ml/min – this reading will fluctuate over the instruments CO_2 cycle.

Adjust the control valve so that the flowmeter never drops below 100 ml/min, watch this for a minute to make sure and continue to monitor this while performing the calibration. The excess flow ensures that the system always has a surplus of span gas and never dilutes this by sucking in non-span gas.

After the system has finished its warm up cycle – this will clear from the status line of the display and the console will make a beep noise to indicate this, perform the steps laid out in "notes before using either method".

After 5 minutes enter the calibration menu and adjust the CO_2 Span value to the value of the gas being used, then perform the CO_2 span.

After calibration exit the calibration menu and watch the Cref reading for a couple of minutes, repeat the span calibration if Cref deviates more than 0.5% +4ppm away from the span gas value.

7.4.4 H_2O Calibration

Please skip this section if you are setting up a new LCi T

Recalibration and Small Δ e offsets.

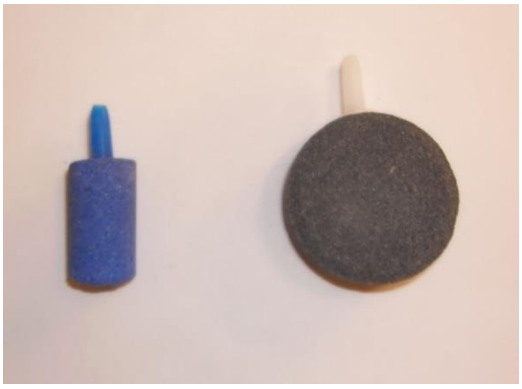
RH recalibration is NOT normally required, unless a sensor has become faulty and been replaced. As long as a system is returned every 4-5 years for service by ADC (which includes RH calibration and a linearity test), then recalibration should not be necessary.
A small Δ**e** error due to component drift does not have a significant effect on the final calculated value of transpiration rate (**E**).
A small Δ**e** error may however be eliminated by first making sure the air supply is stable i.e. via a volume; second, by making sure the jaws are correctly fitted with no gaps in the gaskets, no loose screws, no missing 'o' rings, and finally if a delta e is still present, then a H_2O span may be done in the calibration menu using the measured value of **e'ref** as the span level. This should only be done after both **e'ref** and **e'an** have been stable for 20 minutes or more at a flowrate of 200 µmol s^{-1} or higher.

Full H_2O Calibration

This may be done outside of ADC Bioscientific, but the following equipment will be necessary. (If a dew point generator is being used then not all the following may be needed depending on the additional features of the dewpoint generator, e.g whether it has a variable air pump/flowmeter).

1. A **source of dry air or granular drying agent**.
2. A **float flowmeter** (air) of, or close to, the range 0-500ml/min (1000 ml/min if using method 2 of the H_2O zero calibration). The company, Cole-Parmer, supply suitable flowmeters.
3. A **low voltage DC air pump** that can go up to 500 ml/min (1000 ml/min if using method 2 of the H_2O zero calibration) or more with a **variable power supply**. ADC Bioscientific can supply a suitable pump if required, but inexpensive alternatives are easily found online.
4. **Two water bubblers** (see appendix 11 for construction details), one of which must have the means of allowing the water temperature to be accurately measured. Water bubblers can be made using glass jars with air entries mounted through the lids, one entry (air in) will need a length of tube below the water line as shown in the photographs. The ends of these tubes should be attached to "air stones" which are made for aquariums, to ensure small bubbles, which are important. Ideally two types of air stone should be used and the one that makes the smallest bubbles used on the second water bubbler which also contains a thermocouple to measure the water temperature. If making water bubblers from glass jars they must be airtight. ADC Bioscientific can supply plastic air entries to mount through the lid. The lids should be sealed with PTFE tape around the glass threads. Alternatively, a dew point generator can be used.
5. An **empty water bubbler jar** (see appendix 11) to act as a water trap between the flowmeter/pump and the water bubblers – when the pump is powered down, a small amount of water is sucked out of the first bubbler and may reach the flowmeter without this water trap.
6. Some means of measuring the water temperature in the final water bubbler, e.g. a submerged thermocouple/**digital thermometer** probe through a hole in the lid, then sealing the lid hole with glue (hot or resin glue) works well. Digital thermometers must be calibrated and regularly tested to a high standard.
7. Some short lengths of PVC tubing bore diameter 3 to 4mm, one length of 4mm x 60cm.

8. A **room thermometer** of good accuracy **or a second thermocouple** if using a digital thermometer.
9. If a linearity test (optional) is to be done, a good quality RH meter will also be required. Preferably one that has been tested using saturated salts as a calibration medium, an internet search will explain this.



Two types of "air stones" commonly used in aquariums. The larger more expensive one on the right produced smaller bubbles. It is preferred if the second water bubbler makes smaller bubbles than the first one.

Method:

Select the calibration menu to be used for the H_2O zero and Span calibration.

H_2O zero calibration

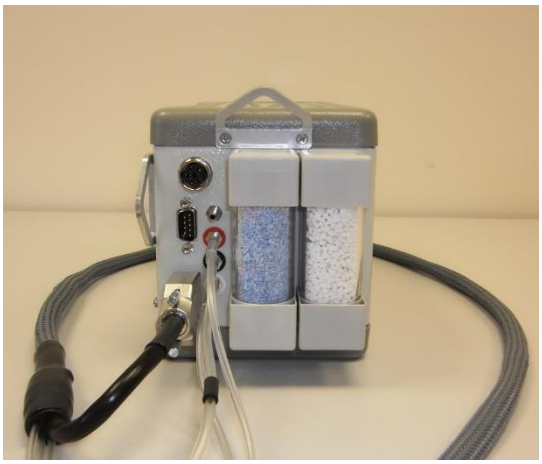
First make sure the console has the correct time and date. This can be seen and edited by going to ***config>time/date***.

Method 1

This method requires a granular drying agent such as Silica Gel, it is slightly less accurate than method 2 but easier to do.

1. Ensure the LCi T is switched off.
2. Remove the normally inert chemical column of the LCi T (containing 4 pieces of removable foam), remove the pieces of foam and replace with a granular drying agent such as Silica Gel.
3. Refit the chemical column, switch on the LCi T and run at a flowrate of 341 µmol s^{-1} for 20 minutes.
4. Reduce the flowrate to 200 µmol s^{-1} for 20 minutes
5. Perform a H_2O zero from the calibration menu.
6. Once the calibration has completed, monitor the **e'ref** and **e'an** values, they should be within 0.1mb of 0.0 mb over a period of 5 minutes, if not then repeat the zero calibration.

The images below show the chemical columns fitted as normal (left) and fitted for a H_2O zero calibration (right) with a drying agent, in this case blue Drierite.

Method 2 (recommended)

1. Switch on the LCi T and allow it to warm up.
2. Supply dry air into the black ringed handle tube at a rate of 800-1000ml/min (this normally connects to the console as one of the three colour coded tubes). Pure nitrogen may be used for this purpose. The air must be completely dry. The black ringed handle tube goes directly to the closed jaws which is where the two RH sensors are located.
3. Allow 20 minutes at this flowrate of 800-1000ml/min
4. Reduce the flowrate to about 300 ml/min, allow this to run for 20 minutes,
5. Enter the calibration menu and calibrate by selecting the H_2O zero option.
6. Once calibration is complete, monitor the **e'ref** and **e'an** values, they should be within 0.1mb of 0.0 mb over a period of 5 minutes. If not, then repeat the zero calibration.

H_2O Span Calibration

Warning 1:
The temperature of the water in the second bubbler should be <u>equal to or less than</u> ambient temperature, otherwise water will drop out of the air in the tubing *en route* to the black ringed handle pipe. If water does get into the black ringed handle pipe then disconnect the pipe from the water bubblers, remove the jaws and blow compressed air down the small brass entry sticking out of the handle (make sure it is the smaller one of the two), water will be expelled (out) at the console end of the black ringed handle pipe. This risk is eliminated if you perform the calibration in a room which is slowly increasing in temperature during the day, provided the water has been exposed to a lower temperature overnight in the same room. This way the water temperature will slightly lag behind the temperature of the room.

Warning 2:
When using the water bubblers, **the Tch value on the console screen should be ≥ 1 °C above ambient temperature before connecting the black ringed handle pipe to the two water bubblers**. If this is not the case then running the system for 20 minutes is normally enough for Tch to become ≥1 °C above ambient temperature. Make sure the black ringed handle pipe is connected to the console during the warm up period.

Dew Point Generators

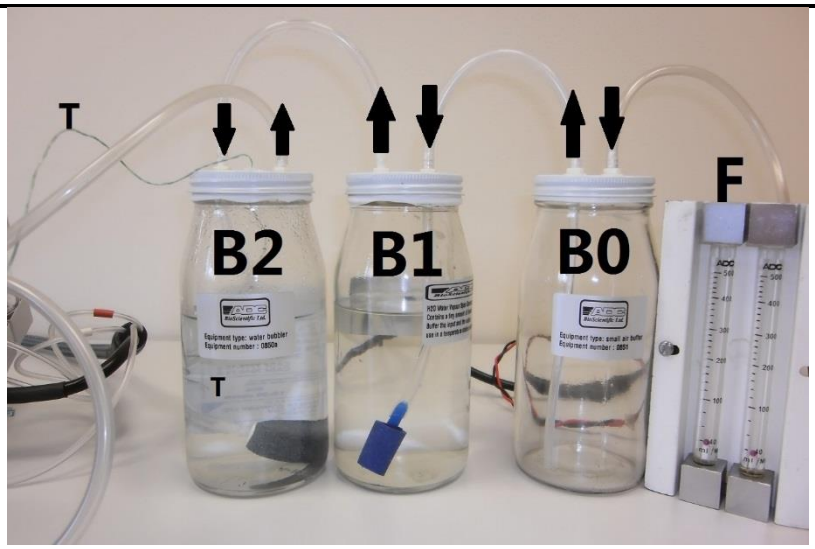
If using a dew point generator instead of the water bubbler method described, set the dew point temperature 5 °C below the ambient temperature in which the calibration is being done. Refer to the table in appendix 5 to get a mb value for the H_2O span air.
Setting a dew point temperature below that of ambient reduces the risk of condensation.

IMPORTANT NOTE:

Before connecting everything together it is a good idea to raise the temperature of the first water bubbler slightly above the second or final water bubbler. This ensures the air is over saturated when leaving the first bubbler but reduced to the calculated saturation value, accurately determined by water temperature, when leaving the second bubbler. This increase in water temperature is easily realised by adding approximately a tablespoon (25ml added to about 250ml of room temperature water) of boiling hot water to the first bubbler and mixing it up before replacing the lid. The water in the first bubbler should be 5-10 °C warmer than in the second bubbler.

Connect:
1. The “air out” entry of the pump to the “air in” port of the flowmeter, leaving the “air in” entry of the pump free to suck in room air.
2. The “air out” port of the flowmeter (F) to the buffer jar (B0) “short” port (the one without the internal tube fitted),
3. The other port of the buffer jar to the first bubbler (B1) “air in” port (the one with the tube that connects to the air stone),
4. The “air out” of the first bubbler to the “air in” port (the one with the tube that connects to the “air stone”) of the second bubbler (B2), this second bubbler should have some means of measuring its water temperature e.g a submerged thermocouple probe.
5. The “air out” port of the second bubbler to the black ringed handle pipe (P), using a piece of 4mm bore PVC tubing about 60cm long. Form a loop in the 4mm section secured with a cable tie as shown in the second photograph below, this way if water vapour condensates in this piece of connecting pipe it can be seen and quickly disconnected.

The first image, below, shows the buffer jar and the two water bubblers connected in series. The arrows indicate the direction of air flow. The second image, below, shows complete setup including the loop in the section of pipe which connects to the black ringed handle pipe.

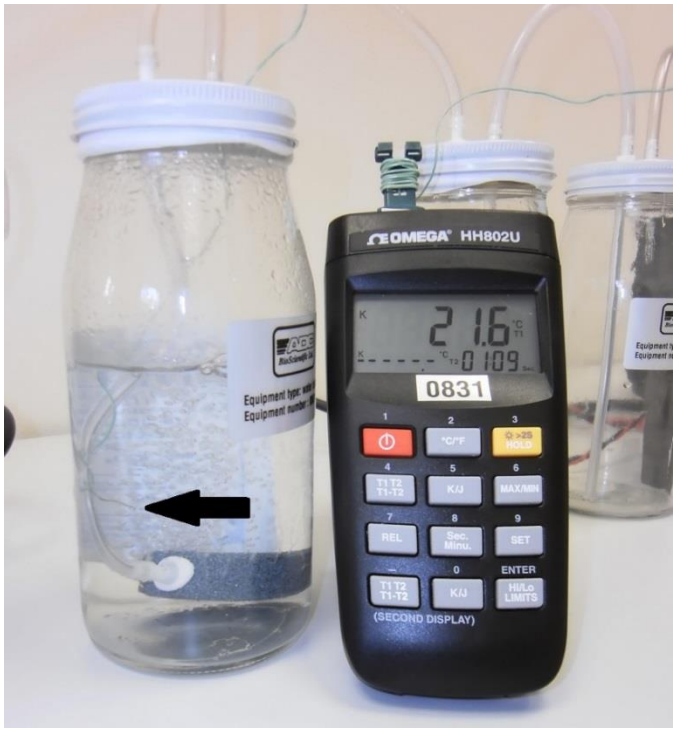


T = Thermocouple probe for measuring water temperature.
B0 = Buffer jar.
B1 = Water bubbler 1.
B2 = Water bubbler 2.
F = Float flowmeter.

The photo below shows the complete setup for H_2O span calibration. Note that the loop formed in the connecting pipe is attached to the black ringed handle pipe with the connection made above the lowest part of the loop. Watch this loop during calibration and disconnect the handle pipe quickly if water forms in the loop. If this occurs then blow out the water with compressed air and try again having first reduced the temperature (by a few °C) in the second water bubbler.

Before powering up the pump (shown above connected to a variable power supply), check that the water temperature is slightly cooler than ambient conditions, power up the pump at a flowrate of 500ml/min. Carefully watch the pipework coming out of the bubbler system and make sure no condensation is visible. Stop at once if it is present! **As a precaution you can disconnect the black ringed handle pipe and start the pump and see if condensation occurs before reconnecting the black ringed handle pipe.**

The photo below shows the water temperature being measured using a submerged thermocouple (indicated by the black arrow and not touching the glass!) in the second bubbler.



IMPORTANT NOTE:

The thermocouple shown above in the second bubbler should not be in contact with the side of the jar.

IMPORTANT NOTE!
Make sure the thermocouple lead is sealed around the hole in the lid where it enters the second water bubbler as shown opposite. Glue from a hot glue gun is good for a few weeks or months but may need to be replaced over time. Two part slow setting resin based glues are best for long term use e.g araldite 2011.
Make sure the thermocouple is not touching the side of the jar.

Run the pump at a flowrate of 500ml/min for 10-15 minutes, reduce the flowrate to 250-300ml/min and continue to run the pump for another 10-15 minutes.
With the pump still running you are now ready to perform a H_2O span calibration from the calibration menu. First you must calculate the H_2O saturated vapour pressure (SVP) in mb value which is determined by the water temperature and the fact that the water bubblers give an output of 100% RH.
Using the same formula as the LCP/I which is based on the Arden Buck 1981 formula for saturated vapour pressure, the table in **Appendix 8** can be used to quickly give this value in mb.

Read the table (in **Appendix 8**) down first then across, for example 20.5 °C would be the row labelled 20 and the column labelled 0.5 which gives a SVP value of 24.2mb.
Enter the value obtained from the table as the span level in the calibration menu, perform the span calibration. Afterwards, monitor the **e'ref** and **e'an** values. They should be within 0.1mb of the span value over a period of 1-2 minutes. If not, leave the system alone for 10 minutes with the pump still running at 250-300ml/min then repeat the span calibration using a new SVP value from the table, if the water temperature has changed.

Switching off

When the pump is switched off the glass jars will be lightly pressurised which will normally result in water flowing backwards up the pipes. To prevent this, simply **remove both pipes from the first water bubbler as soon as the pump is switched off**, as shown opposite.

Empty the water away and allow the jars to dry out before placing them into storage.

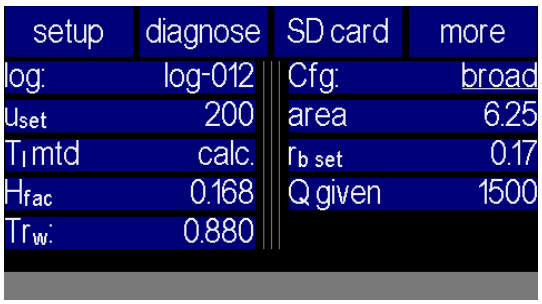
Linearity Test (optional)

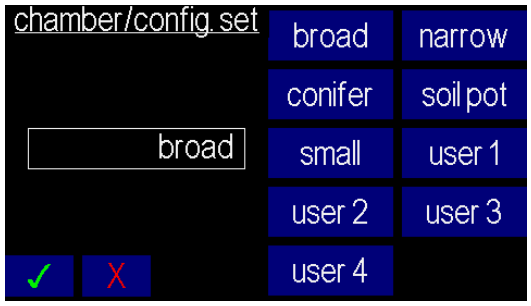
This can be done as a basic check but is not necessary. You will need a good RH sensor and a thermometer next to the console and close to the "air in" entry on the console.
Connect the black ringed handle pipe to the black coloured air port on the console.
Position the LCi system in a quiet corner and leave it to run on full flowrate (341µmol sec^{-1}) for 30 min. Note the e'ref value, when it is stable over a period of 10 minutes then the linearity check may be done.
Obtain a value of SVP using the table, based on the air temperature. Multiply this by the RH value/100, this calculated value is the water vapour **partial** pressure (PVP) of the air being sucked into the LCi.
Compare this to the **e'ref/e'an** values on display, typically they will be within 2 mb of each other.
The test is limited by the accuracy of the thermometer and the RH sensor next to the LCP/I console, commercial RH meters are very rarely accurate and fast responding.

SECTION 8. MEASUREMENT CONFIGURATION

8.1 The "Configure" Menu

Use configure to get to menu set up diagnose SD card more The various options can be chosen with set up or by touching on them directly.
The type of chamber you are using can be selected from: Broad, Narrow, Conifer, Soil pot, Small, User 1, User 2, User 3 and User 4.





The chamber parameters, Uset, area, T_l method, rb, Hfac, Qgiven and Trw are stored separately for each type, and the LCi T is factory set with suitable default values. You can change the parameters to suit your chamber and the leaf being measured, see section 3.1. Note that when Soil pot is selected, some of these parameters are not used or displayed.

When the LCi T is switched on, it will select the last used configuration.
The table below defines the default values:

	U set	Area	Tl mtd	rb	Hfac	Trw	
Units	µ mol s^{-1}	cm^2	n/a	m^2 s mol^{-1}	n/a	n/a	
Range	68 to 341	0 to 100 *2	n/a	0.1 to 1.00	0.1 to 1.000	0.25 to 1.000	
Steps *1	1	0.01 *2	n/a	0.01	0.001	0.01	
Chamber						with shield	without shield
Broad	200	6.25	Meas.	0.17	0.168	0.870	0.920
Narrow	200	5.80	Meas.	0.30	0.168	0.870	0.920
Conifer	200	100.00	Calc.	0.35	0.177	0.860	0.910
Soil Pot	200	97.5*2	Meas. *3	n/a	n/a	n/a	0.965
"Soil Pot" for Versatile Chamber	200	97.5 *2	Meas. *3	n/a	n/a	n/a	Manually change to 0.96
Small	68	2.16	Calc.	0.25	0.168	n/a	0.930
User 1	68	6.25	Meas.	0.17	0.168	0.870	
User 2	341	5.80	Meas.	0.30	0.168	0.870	
User 3	200	100.00	Meas.	0.35	0.177	1.000	
User 4	200	6.25	Calc.	0.17	0.168	0.880	

*1 The steps are greater when the /+/ or /-/ keys are held down.
*2 The Soil pot range is 0 to 400cm^2 in 0.5cm^2 steps, assuming use with a soil collar.

*[3]The Tl method cannot be changed from measured.

Refer to the table on the previous page for the default values.

/*Uset*/ is used to set flow rates through the Leaf Chamber/Soil pot.

/*area*/ is used to input the effective leaf area exposed to PAR or the area enclosed in the Soil pot.
The area exposed depends upon the type of Leaf Chamber in use, and how much of the leaf is within the window area. When using Conifer Chambers, the 'area' may have to be established by experiment.
See section 5.7 for the Soil pot.
Note; within some experiments, some 'constants' may vary from one specimen to another (e.g. area), and must be re-entered.

/T_l *mtd*/ is used to determine how the leaf temperature is obtained and toggles between /*calc* / and /*meas*/. The Soil pot is set to /*meas.*/ and cannot be changed.

/calc/; selects the value as calculated by the LCi T from the energy balance equation./*meas/*; uses the temperature measured by whichever leaf temperature thermistor is connected.

/rb/ is used to input the value of 'boundary layer resistance to water vapour', which is a function of the leaf chamber type.

For Conifer chambers, rb will be about 0.35, but is dependent on plant morphology and should be determined by experiment.
For all other chambers, refer to the table on the previous page for default values.
r_b is not applicable to the Soil pot.

/H_{fac}/ is used to enter the absorption factor of the broad band radiant energy onto the leaf chamber by the exposed leaf surface. This factor is dependent upon the materials used in the construction of the shield and/or window of the Leaf Chamber. Appendix 4 gives the derivation of H_{fac}.
H_{fac} is not applicable to the Soil pot

/*Qgiven*/ is a value of Q entered by the user, to be (optionally) used in the calculations, see section 3.9. The default value is 1500 µ mol m^2 s^{-1} for all leaf chambers and is not applicable to the Soil pot.

/T_{rw}/ is the transmission factor of PAR into the leaf chamber at the exposed leaf surface. i.e. it is the factor which *Q* is multiplied by to obtain Q_{leaf}. It is dependent upon the materials used in the construction of the Leaf Chamber window and, where applicable, the radiation shield. A radiation shield is supplied with Broad, Narrow and Conifer leaf chambers but may, at the users' discretion, be removed. In this case T_{rw} should be increased by 0.05 to compensate.
Note that Small leaf chambers do not have a radiation shield and therefore the default value should not be changed.
Note that holding down the change + or change – key causes the parameter's steps to be increased tenfold.

8.1 GPS

The LCi T is fitted with a GPS unit to automatically record the exact position of each sampling location.

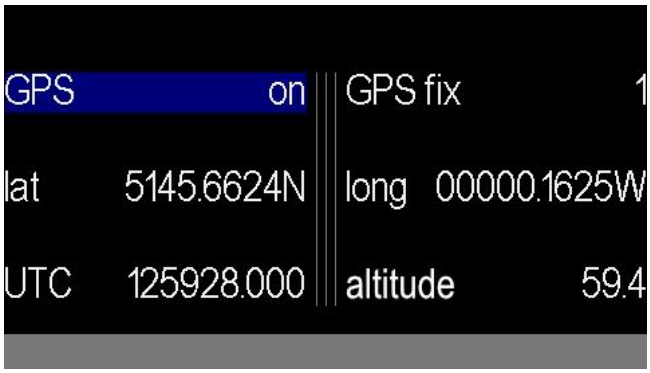
The GPS data screen is accessed through configure and more.

For all measurements taken outside: latitude, longitude, UTC (Coordinated Universal Time) and altitude are displayed on this screen within 30 seconds of obtaining a clear signal.

All GPS parameters are automatically saved with each data record, and integrated into the data files for viewing on spreadsheet software.

GPS Fix: The stability of the GPS reading. This value ranges from 0 to 2, with 0 being the lowest and 2 being the highest stability.

The blue key at the top left of the screen can be switched between ‘GPS on’ and ‘GPS off’. The status displayed is the current, live status (the screen below shows that GPS data is live).



SECTION 9. GRAPHICAL DISPLAY

The LCi T has the facility to display parameters in graph form.
The graphing function is particularly useful to see if an experiment has settled and/or proceeding as expected.

Two types of graph are available that plot either one to four parameters against time (Y-T) or against another parameter, (X-Y plot). X-Y graphs have each data set shown as a cross, the most recent of which is shown "flashing".

For all modes, the graphs are scaled automatically to make best use of the display resolution.

Either type of graph is capable of displaying up to 200 data sets. After this, the earliest sets will be replaced by the most recent set. In the case of the Y-T type, this has the effect of appearing to scroll the graph from right to left as each new data set is added.

The graph options are:

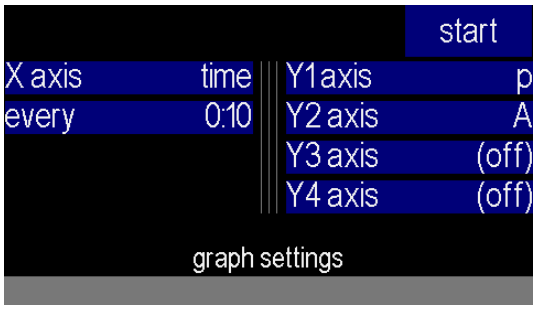
Y-T plot

1. One to four parameters against time
2. One to four parameters against record number

X-Y plot.

3. One to four parameters against another parameter (triggered by time)
4. One to four parameters against another parameter (triggered by record number)

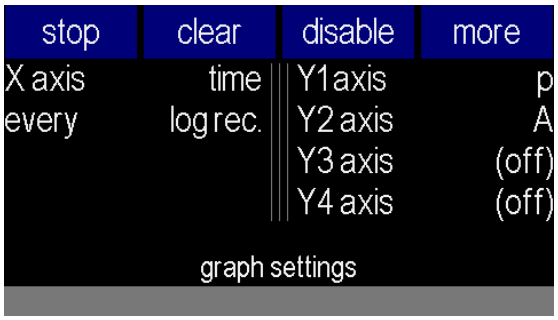
9.2 Operation



Graphs are set up by pressing graph from the output, calibrate, graph, record menu.
The available parameters for display are extensive, and shown in Appendix 1.
The Xaxis button allows the X axis value to be set to any of the parameters available for display.
The every button determines when a plot is taken. It allows the *plot every* value to be between 2 to 30 seconds or log record.
The Yaxis buttons are used to determine the parameter for the Y axis.

To set a parameter against time for example use X axis to set to 'time' then press every and select the desired time between 2 to 30 seconds. Select the Y axis parameter by pressing Y1axis and selecting from the list. To graph other parameters use Y2axis .. Y4axis. Press start when ready.
When 'every is set to 30 seconds (0:30), one graph screen fills up over 3 hours, giving 3 hours of data points. If set to 0:02, one screen fills up in 12 minutes.

To stop the graph, press the page button and select the page shown by pressing graph :

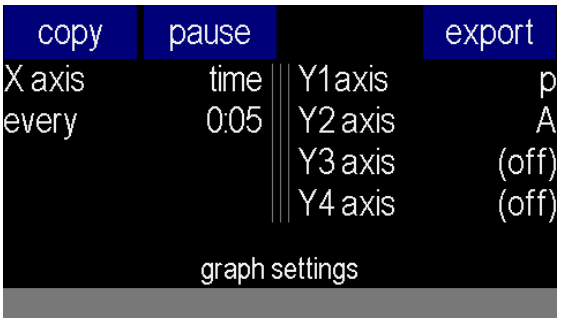


The stop button stops the graph being updated but does not erase it, in case it is required for later viewing.

The clear button erases the graph data but allows it to be restarted with the current parameters.

The disable button erases the graph and removes it from the top level screens.

The more button loads the page shown which has copy pause export keys. Alternatively these buttons can be activated from the graph page by a downward swipe.



The copy button stored the graph as a bitmap on the SD card.

The export button saves the graphical data as a comma delimited (.csv) file on the SD card.

The pause button temporarily halts the graph and the button label changes to resume. This is to allow the user to make adjustments which might cause large disturbances to the data and are not to be recorded, for example, changing the jaws. The graph will restart when resume is pressed.

SECTION 10. RECORDING A LOG

10.1 The nature of a record

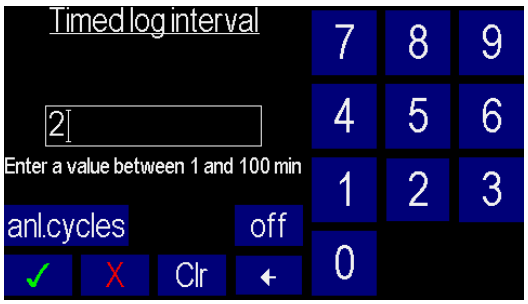
The data record is associated with a log file, in which a single record is stored for every 'record' action. A single SD card can store a maximum number of 61 accessible log files. Additional records will be saved to the card, but the oldest will not be available to the filing system.
The 'record' is a single recording of all the parameters listed in the Log (column 1 of Appendix 1). The number of records that can be accumulated depends on the size of the SD card and the amount of data already on it. A warning message is displayed when the SD card is full.

10.2 Taking a record

A record can be taken by any one of four methods.

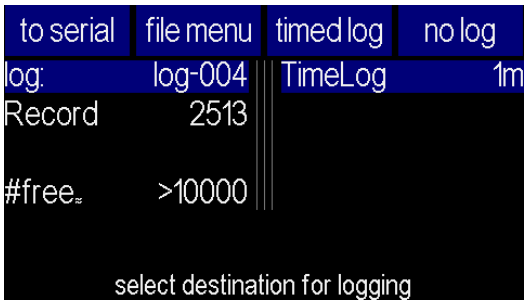
1. By pressing any of the record buttons displayed on the three top-level menus.
2. By pressing the 'record' pushbutton switch on the handle of the PLC.
3. By sending "r" or "R" over the serial port from a dumb terminal.
4. By closing a remote switch connected between pins 7 (12V) and 8 (CTS) on the 9 pin RS232 connector. To enable the last option, it is necessary to set up the serial port (see Section 7.2)

The log can be sent serially via the RS232 connector or to the SD card. The choice should be made using the menu page shown. A log file has to be selected, and Time Log should have a value displayed for logging to happen automatically.



After a record is successfully taken, the LCi T will beep. If a log file has not been set, a message appears "log file not set, would you like to set a log file now?"

When a record is 'taken', it is appended sequentially in the current log 'filename' on the SD card. The 'record number', which starts at '1', is automatically incremented.



The number of records in the .csv file is stored as the first entry. Parameter values are stored as signed integers, or in exponential form; the associated units of measurement are NOT stored.

Timed log
If records are to be taken at regular intervals, the timed log function can be used. It allows log intervals of 1 minute to 100 minutes in minute increments to be chosen or the intervals can be synchronised with the gas cycle in which case the increment will vary dependant on the ASU flow. To select intervals synchronised with the gas cycle press anl.cycles.

Selection of intervals synchronised to the gas cycles is preferred as it allows the maximum meaningful update rate and optimises noise performance. The fastest is about 19 seconds, using the highest air flow.
The timed log will continue until it is switched off by selecting no log in which case the top menu will display log: off, or by selecting "off" as the timed log interval.
The timed log function can be used simultaneously with the sequence function to give more records for each step of the sequence.

10.3 Deleting a record

If you have taken an unwanted record, it can be marked as 'deleted' on the log file, but it still has a unique record number attached to it. To do this, hold the record button down continuously until the message "hold record key to delete last record" appears. Continue to hold the button pressed until "last record deleted" appears. If you release the button before the second message, no action is taken, and the message "record not stored" appears.

In regard to taking or deleting a record, the record pushbutton on the chamber handle works in the same way as the one on the front panel.

To prevent data loss accidentally, avoid continuously holding down the record button on the handle.

10.4 Sending a serial record

Rather than storing a record, it can be sent directly to the serial port using logging to serial as shown in section 12.2. In this case, the record is not appended to a log file. Sending a record successfully requires the serial link (Section 7.2), to be set-up so that it matches the protocol settings of the receiving device, see section 12.6. If a record is sent when the serial port has its CTS line enabled to initiate a record, an error message will be displayed.

A record can also be requested via the serial port: a "P" or "p" sent to the port will cause the LCi T to transmit a single record.

The serial data is sent in csv (comma-separated-value) format, without labels or headers, in the following sequence:
record number, date, time, e ref, delta e, c ref, delta c, Q leaf, chamber temp (t_{ch}) ,leaf temperature (t_l) , ASU flow (u), ambient pressure (p), ci, E, gs, A, area, rb, tl_{mthd}, Q_{mode}.
Appendix 1 gives further details of the parameters recorded and their units of measurement.

10.5 Deleting a serial record

A serial record can also be marked as deleted. If you are recording to the serial port, and follow the method for deleting in section 12.3 above, the ‘record number’ for the deleted record is transmitted a second time, with the message, ‘record deleted’. As for recording to a file, the ’record number’ will continue to be incremented as if you had not deleted the record.

10.6 Receiving a serial record

This applies to Windows 95, 98, ME, NT & XP. For non-Windows systems, you will need to use a terminal emulator.
For Windows 7, 8 and 10, Hyperterminal is no longer included as standard, but Hilgraeve do allow a trial download or a purchased download for a modest fee.

1. Select Hyperterminal from the start menu: “START”, “PROGRAMS”, “ACCESSORIES”, and “HYPERTERMINAL”

2. Select (double click on) the Hypertm.exe icon.

3. Name your new connection e.g. LCpro, and choose an icon if desired. Click on “OK”. This will save all your settings so that it is easy to repeat the transfer.

4. Ignore the telephone number and click on the “connect using” option window. Select the COM port number that you intend using on your PC. The other options on this window will then be automatically deselected. Click on “OK”. A window will then appear asking you to set the COM port settings.

Select :	bits per second	115200 (or as set on the LCi T)
	data bits	8
	parity	none
	stop bits	1
	flow control	xon-xoff

5. Click on “OK”
   Ensure that the settings match those on your LCi T before transmitting data (see section 7.2)

6. As a check, each time you press a “p” on the PC you will receive one data record.

7. Click on the “transfer” button and select “capture text”.

8. Enter a filename and click on “start”

9. The PC should then be ready to receive data from the LCi T, which can be sent by pressing logging to serial on the LCi T.

10. To stop data transfer, click on “call”, “disconnect”.

Tip: if you give your file a csv extension you will be able to import it directly into most spreadsheet programs.

SECTION 11. PAR (Q) SEQUENCE FILES

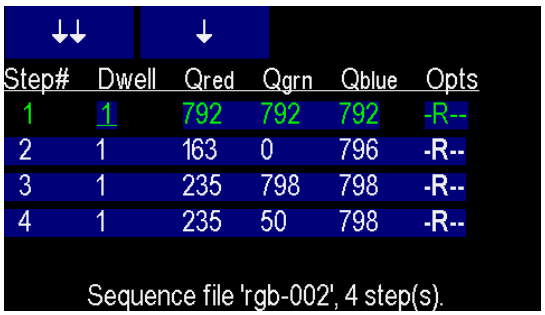
Description

A 'PAR sequence file' is a series of steps through which irradiance from a light unit can be increased, decreased held at a defined value or held at 'ambient'. Sequences allow a complex experiment to be performed automatically by selecting and running a file. A file can be used repeatedly, saved and edited on the LCi T or on a PC.
Sequence files are typically used to generate Q/Ci plots to analyse the photosynthetic response rates to step changes in PAR (Q).

Pressing sequence enters the sequence menu page. From here, a new sequence file can be written using edit, or an existing file loaded from the SD card, using file load seq.
A sequence file can be saved using save seq., or deleted using load seq. delete.

Sequence files can also be created on the computer before being loaded into LCi T (see Appendix 5).

If the file is new or to be edited, press edit. The select modify ↓ keys are then displayed. The ↓ and ↑ keys move up and down the list of steps, and select moves left to right.



The select button moves the cursor to select the dwell time, Q (white or RGB) or the options (Opts). If dwell is selected, the modify key changes the menu keys to ambient change+ change- as prev. The change keys increment or decrement the time in 1 minute steps up to 100, whilst as prev is used to set the dwell time to that in the previous step.

When the desired time has been chosen, pressing the page key will cause the menu to change back to the select modify ↓ ↑. The default setting for the Q parameters is ambient, which means that the control is turned off.

If opts (options) is selected for modification, the possibilities are:

ignore — where the step does nothing. This is a way of turning off a step, (since there is no delete function) and being able to easily turn it back on. 'I' is inserted in the 'opts' column.

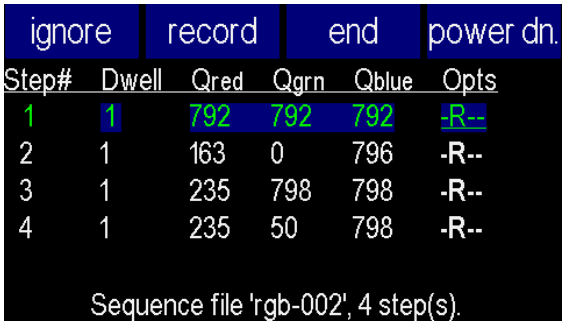
record — which causes a record to be made at the end of the dwell time, prior to the next step starting. 'R' is inserted in the 'opts' column.

end — which stops the climate sequence running, even if it is not the last entry. (This is a way of changing the length of a sequence). 'E' is inserted in the 'opts' column.

power dn — which turns off the analyser completely at the end of the step, and is useful for lengthy unattended experiments. 'P' is inserted in the 'opts' column.

Each of these four keys toggles on/off. Once the climate sequence is programmed, it can be saved using file, using 'file', 'save' and editing/selecting the seven digit default name (seq-nnn) using the numerical keypad.

The sequence can be initiated with start, which changes the menu to run ↓ and ↑
The last two keys allow the sequence to start from a point that is not the start of the file.
run starts the sequence, which can be left running in the background by pressing the page/power key once. When the sequence has finished, this message appears: "Control sequence stopped. End of sequence file reached at step # ".
(If more than one record per step is required then the timed log function can be run simultaneously, see section 12.2).



Example File

The SD card is supplied with an example sequence file named "demo". The file consists of lines of information called "steps". Each line has a sequential step number, a dwell time for which the step is active, the values of PAR if a white light unit is selected, or of Qred, Qgrn, Qblue if a colour light unit is selected, and an option to ignore, log, power off or finish.

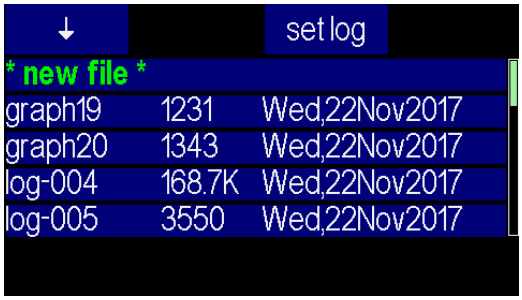
SECTION 12. DATA FILES & USING THE SD CARD

Never remove a card while you are recording or transferring files.

The SD card supplied has a minimum capacity of 8GB. All files are allocated in 512B blocks. Log files vary in length depending on the recorded data. An empty 1GB card will hold a single log file of around 8000 to 16000 records. The tightest restriction is on the number of files (around 60) rather than the number of records within each file.

12.1 Selecting a File

When you first switch on, no file is selected. To set a file, install the SD card, press logging file menu then either use the arrow buttons to select an existing file or leave the arrow cursor pointing to *new file*. Press the set log button.



If you select an existing file, records will be added to it otherwise if *new file* is chosen the LCi T will choose a default file name with a value one higher than that currently on the card. You can change the name if you wish by using the > + - and del buttons. If your file names are numeric, the numeric part should not have leading zeroes suppressed if you wish the filing system to display them in correct order, for example log-100 will be displayed before log-2, but after log-002.

12.2 Reviewing Log Files

Press the logging file menu buttons then select a file as described above. Press options review .The data may be reviewed sequentially using next and previous or switched between first and last record using 1st/last. Holding down next or previous for one second will increase the steps to ten at a time (or return to single steps if pressed again for one second). Depending on the length of the file and the position of the record to be reviewed, it may be preferable to select the first record then step through using next.

12.3 SD Card Data Format

SD cards are preformatted in a DOS format and the LCi T stores data on the SD card using this format. Files may be read with a PC which has a suitable card reader. Since SD cards are suitably preformatted a format function is not required on the LCi T. In the unlikely event that the format of a card has been corrupted then it can be formatted on a PC.

12.4 Delete (Erase) Existing Files

Press file menu, select a file as described above then press options delete. You will then be asked to confirm Yes or No. If you wish to abort the deletion press No otherwise press Yes. 'File erased' will then be displayed. Press yes to acknowledge the confirmation message.
If you currently have the selected file in use as a logging destination, you will not be allowed to delete it. If you still wish to delete the file deselect it by pressing page then no log then starting the process again.

12.5 Copying Files using the USB

Files may be moved or copied using the USB connection. When a PC is connected over the USB the SD card in the LCi T will look like a mass storage device and will appear as another drive on the PC.

Note: When the LCi T is connected using the USB no file operations can be carried out from the LCi T front panel. To do so may corrupt the file system.

12.6 Storing Cards

In common with all computer storage media, SD cards must not be exposed to extremes of temperature, dampness or dirty environments.

The construction of the cards protects them from normal environments and handling but are best kept in their plastic case or a suitable anti-static container when not in use.

12.7 Using Alternative Card Types

SD Cards are available from different manufacturers and with various capacities and all those compatible with the SD card format should work in the LCi T. However only those supplied by ADC BioScientific have been tested and guaranteed to work. If using SD cards supplied from elsewhere it is suggested that cards from well known recognised manufacturers such as **Sandisk, Kingston** or **Transend**, are used.

SECTION 13. HOW THE ANALYSER WORKS

13.1 Infrared Gas Analysis

The LCi T uses the principal of Non Dispersive Infrared (NDIR) for the CO_2 measurement. This relies on the fact that CO_2 absorbs energy in the infrared region in a proportion related to the concentration of the gas. The gas sample to be measured is passed through a tube (or cell). A source of infrared is directed down the cell which is gold plated to maximise the intensity of the source. A solid state detector at the receiving end of the cell measures the amplitude of the infrared signal, which will be reduced if CO_2 is present in the gas sample. A thin film filter (TFF), with a pass band of 4.24μm, is fitted in front of the detector to narrow the bandwidth being measured to one which includes a strong absorption band for CO_2.

The reference (TO the chamber) and analysis (FROM the chamber) gases are alternated with 'zero' gas during a measurement cycle which typically lasts 16-20 seconds. The 'zero' gas is generated by passing the air through soda lime, which removes all of the CO_2. The cycle time allows for the cell to re-fill, and is automatically adjusted to suit the current flow rate, if requested by the user. This arrangement provides measurement of the CO_2 content in both the reference and the analysis gases, while eliminating much of the drift due to temperature change etc.

The infrared source is pulsed at 8Hz to give an alternating waveform. The waveform varies in amplitude with the energy absorbed by the gas, being a minimum when full-scale concentration is present and a maximum when 'zero' or non-absorbing gas is present. The waveform is rectified, with the resultant DC voltage at the zero condition providing a reference for the subsequent measurement cycle. Any change in the zero reference condition is applied ratiometrically to the measurement. This system provides very stable gain settings, which are independent of the IR source condition (unless this has deteriorated appreciably) and, are only slightly affected by deterioration of the optical elements.

13.2 Gas Correction

Measurement of a gas concentration using its IR absorption properties provides a comparative measurement against a standard gas of known concentration. However, once the system is calibrated, secondary effects relating to the state of that gas being measured can subsequently affect the accuracy of measurement. This is also true of the stability of the optical system.

The absorption properties are affected by changes in temperature and atmospheric pressure. Variations due to changes in temperature are minimised with a thermal jacket around the cell assembly. Ambient pressure is monitored by a sensor in the main unit and used to compute a correction to the measured values.

The presence of water vapour in the CO_2 measurement introduces 'interferent', 'density', and 'pressure broadening' effects which are dealt with as follows.

H_2O partly shares the CO_2 IR absorption band. Its presence, therefore, appears as a proportionate level of CO_2. The effect, however, is relatively small and is eliminated by computing a reduction of the signal as a function of H_2O. H_2O in the gas displaces CO_2 and therefore reduces the density of CO_2. At known temperature and pressure the effect is predictable from physical laws, and is computed out.

H_2O also has the more significant effect of broadening the CO_2 IR response band and therefore of increasing the signal for a given concentration of CO_2. As part of the design, in which the optical filters can also influence the results, the appropriate compensation has been established experimentally, and a computed correction is applied based on this.

All the values used or displayed for CO_2 and H_2O are after full correction i.e. there are no 'raw' values used.

13.3 Other measurements

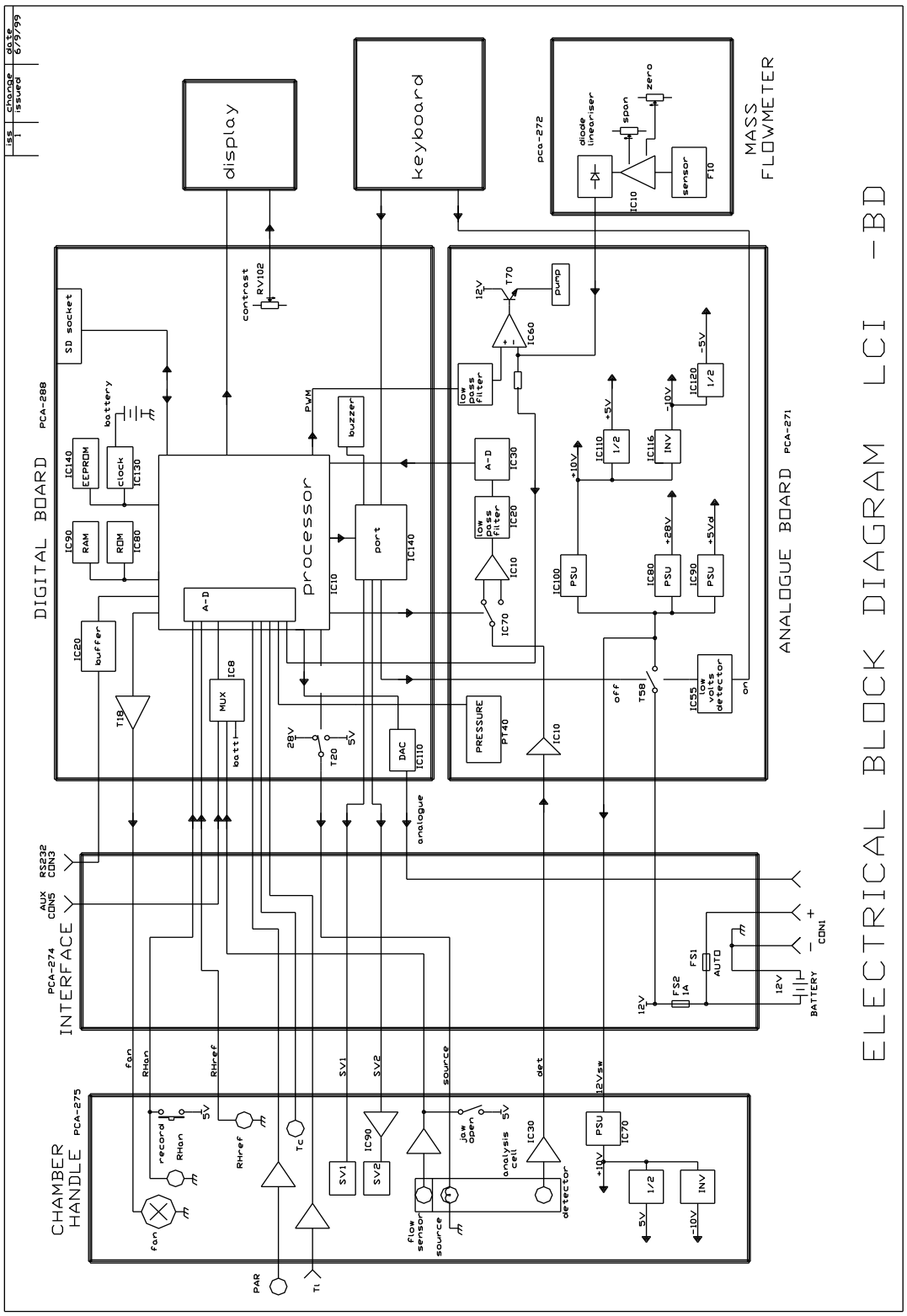
PAR (Q) is measured with a silicon-based sensor.

Chamber temperature (Tch) is measured with an accurate thermistor sensor mounted in the leaf chamber.

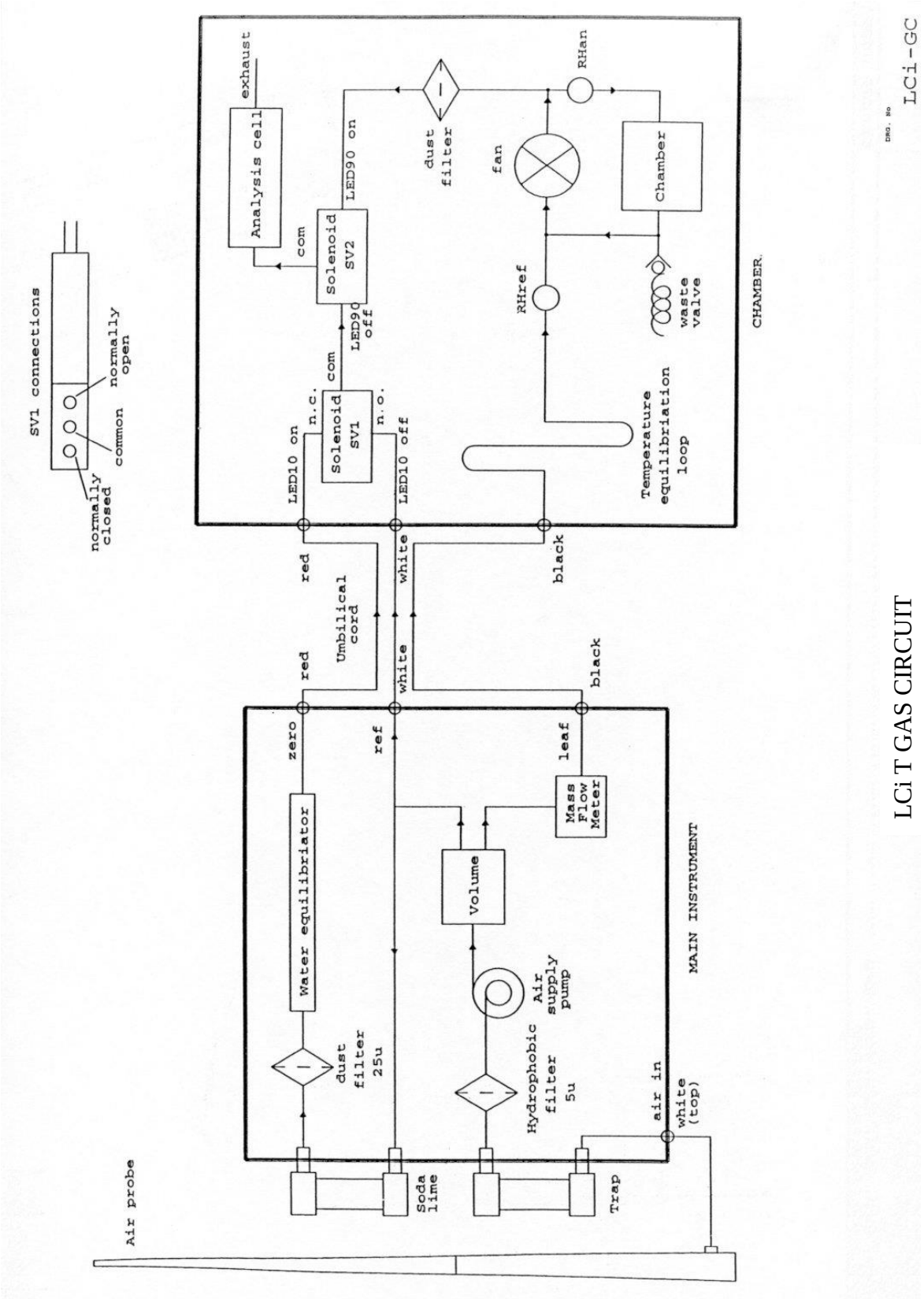
Leaf temperature (Tl) is measured by a miniature thermistor sensor. The thermistor can be positioned against the surface of the leaf. You can select an internally calculated value derived from the energy balance equation or the value measured with the thermistor.

Gas flow rate (U) to the chamber is measured by an accurate air mass flow sensor and controlled to either a default or user-selected level (Uset).

13.4 Electrical Block Diagram



13.5 LCi T Gas Circuit Block Diagram



13.6 The gas circuit Description

Fresh air is drawn in via the trap and hydrophobic filter by the internal pump. The trap and filter remove dust particles and help prevent water being sucked in (limited protection against water). The filter contains a porous PTFE membrane, which prevents the flow of water using the effect of surface tension. If the water contains impurities, which substantially reduce the surface tension, e.g. detergent, the water may be sucked in. Following the pump is the internal volume, the purpose of which is to average out fluctuations of CO_2 and H_2O concentrations that occur naturally in the background. This greatly reduces noise on differential measurements. The air probe, if connected, will also help in this regard, having a volume of 460cc.

The air then splits 3 ways:

1. Through the soda lime column to remove CO_2 and then through a dust filter to remove any soda lime dust. Soda lime contains water and in addition, generates more as a by-product of the conversion process. This causes the air leaving the column to be very damp and, if the analyser has been taken from a hot place to a cold place, condensation will form inside the 'zero' tube to the chamber. To minimise this effect, the air passes through an equilibrator pipe that matches the water vapour concentration inside the tube to that of the outside.

2. Directly to the analysis cell as 'reference' air when SV1 and SV2 are open.

3. Through the mass flowmeter as air supply to the leaf in the chamber. The mass flowmeter acts with the pump in a closed loop feedback system to keep the air supply constant despite changes in pump loading due to the various states of SV1 and SV2.

The air supply to the chamber first passes through a temperature equilibration loop that brings it to the chamber temperature. The air is stirred around the chamber with a fan, which also blows air through the analysis cell when SV2 is open. The analysis cell being in the handle gives a faster response than would be the case with a long length of pipe leading to a cell in the main instrument. Excess air is allowed to escape via a waste valve in the top half of the chamber. This air would otherwise pressurise the leaf if the jaws were tightly shut.

SECTION 14. MAINTENANCE

Note: When the LCi T is first switched on, the display shows the 'Instrument Serial Number' and 'Software version'. Always quote these in correspondence about the instrument

14.1 Tools

There are no special tools needed to dismantle the LCi T and replace parts, except for a PLCC extractor, which is needed to replace the microprocessor. The use of a small sized thermostatically controlled soldering iron is recommended to replace electronic components, as is an anti-static wrist strap, especially when working on the digital board. All screws are metric except the hexagonal pillars on the 'D' type connectors. All screw heads are 'Pozidrive' (crosshead) types. A sphygmomanometer without the cuff is useful for testing for leaks or, alternatively, a water manometer connected with pipe and a tee to a 100ml disposable syringe can be used. A small paintbrush is good for general cleaning, and cotton wool buds and acetone or alcohol are good for cleaning the cell.

All pipes are push-on although some have been fitted using 'Hellerman' oil, which allows pipes to push on easily, but sticks them in place when dry. If a pipe will not pull off easily, do not continue to tug as the pipe tends to become thinner and grip even tighter, instead use a pair of thin nosed pliers with one jaw either side of the connector to push on the end of the pipe. This particularly applies to barbed plastic fitting, which might otherwise be damaged. Note that if you remove a pipe from a barbed plastic fitting by cutting along the length of the pipe with a sharp knife, you will probably damage the barb and introduce a small leak.

14.2 Accessing the Inside of the Main Instrument

With the LCi T switched off, unscrew the 4 screws securing the strap clips, then the 5 securing screws around the top bezel of the LCi T after which the display panel can be lifted up and to one side. (Care should be taken to protect the clear membrane over the display as it can be easily damaged). The digital board (PCA-288) is attached to the display panel and, unless you are taking static precautions, you should avoid touching the electronics. Do not pull on the electrical cables.

To gain further access to the analogue board (PCA-271) and the piping, remove the three M3 screws either side of the curved plate, the two near to the middle, and the two M2 screws in the lower bezel. With care the curved plate can be lifted up and out. There is usually no advantage in dismantling the LCi T further.

When replacing a set of screws, it is best to have all of them inserted a few turns before tightening any of them fully.

14.3 Air Flow (Mass Flowmeter)

The mass flowmeter is in a closed feedback loop with the pump, and will drive it faster or slower until the set flow is achieved. If the pump has stopped or is going as fast as possible, the mass flowmeter may be faulty.

The air mass flowmeter is very stable. If its calibration changes, the cause is almost certainly contamination inside it. If this happens, a subsequent re-calibration cannot be considered reliable and a replacement of the flowmeter and its interface board (PCA-272) is recommended. It might be possible to blow out the contamination. The board is supplied pre-calibrated and, as such, replacement is a simple matter of removing the pipes [See Section 12.1 if you experience difficulty], and pulling the flowmeter and its board off the mounting pillars. Fitting the new board is a reversal of the removal procedure, but ensure that the 5-way electrical connector is properly engaged before pushing the board onto its pillars. Support the flowmeter with one hand while pushing the pipes back on with the other.

14.4 Filters

Filters must be replaced if there is evidence that the pump is being over-loaded, as indicated by an inability to achieve maximum airflow for example. Otherwise replacement should be based on an assessment of previous use in dust-laden conditions, or visual inspection.

There is a hydrophobic filter and a particulate filter inside the main analyser and filters at each end of the columns. The filters in the main unit can be accessed by removal of the top (and side for maximum convenience) described in section 12.2 above. Individual filters can be disconnected from their piping in each part of the gas circuit, and a new one inserted. If during these operations piping is damaged, or a good seal cannot be achieved with existing piping, then the section of pipe should be replaced with a new piece. If a section of pipe is seen to contain any debris, it is easier and safer to replace the pipe.

Please note that the hydrophobic filter will capture droplets of water but can become saturated if the inlet pipe is flooded (dropped in water, for example), allowing water to be sucked into the LCi T.

If there is a risk of water being sucked into the LCi T, please use the 50mm diameter hydrophobic filter (630-976) supplied in the Spares Kit. This filter should be fitted with a short length of tubing 706-100 (also provided, please cut and use as needed) at either end, allowing the filter to be connected to the incoming air-line.

Appendix 11. Spares and Accessories gives details of the necessary piping, excluding the pipe in the umbilical cord connecting the chamber, repair of which is beyond normal maintenance.

In the chamber, there is a permanent mesh filter under the stirrer, which is best cleaned of large debris with a small paintbrush. The fan cannot be removed to assist cleaning and so the paintbrush must be small enough to pass between the blades of the fan. If there is fine dust on this filter, there is a risk that it will be pushed through the filter with the brush. It is best to remove the handle cover, remove the pipe connecting the SV2 to the back of the

stirrer, and use a piece of pipe from the spares kit to blow backwards through the mesh filter while you disturb the dust with the brush.

There is another permanently fitted mesh filter in the corner of the stirrer cavity in the upper jaw, leading to the waste valve. The same general comment applies with regard to dust, but you will not be able to blow backwards through the filter because the waste valve is one way and is delicate.

14.5 Pump

The pump is fixed to the analogue board by screws under the board, which are accessed by removing the curved panel. Do not lose the two spacers that are in the grommets. The most common pump problem is insufficient flow and is caused by contamination under the flap valves. The valves can be accessed by removing the four self-tapping screws that retain the head. Note the orientation of the parts. Some pumps have parts that will fit two ways round but only one way is correct! Wipe the flaps, even if they look clean, with a smooth cloth. Reassemble, but only tighten the screws enough to make the pump leak tight. After much use (a few years), the motor bearings will become slack and noisy, and the pump will need replacing.

14.6 Chemical Column filters

Maintenance on the chemical column is limited to checking the general condition of the 'O' rings. Air seals should be maintained around all of the 'O' rings. The use of silicon grease provided will greatly assist this and help to keep the 'O' rings in good condition. Occasionally the columns themselves should be cleaned in soapy water and left to dry before replacement.

14.7 Dismantling the Chamber

The radiation shield is removed by loosening (but not fully removing), the two captive screws. The shield can then be slid out from the retaining slots on the jaw-opening lever.

The PAR sensor is permanently connected electrically and must be moved aside by pulling it out of its mounting plate if you wish to remove or exchange the jaws.

The top jaw can be removed by pressing against the spring so that one hinge pin is no longer hooked in place. The jaw can then be twisted to disengage the pin then pulled away from the other hinge. The top jaw contains the chamber window, a magnet, (which operates the jaw-open detector reed switch when the chamber is closed), and the waste valve.

The waste valve is a thin transparent diaphragm held against the valve seat by a spring, but dismantling the jaw to access this is not recommended.

The window is made from Polycarbonate, and, with the exception of the Conifer window, which is curved, is hard faced both sides.

The bottom jaw can be removed by unscrewing the three knurled captive screws. If they are too stiff to loosen by hand, you can use a coin, but the slot should not be used for tightening. It is not necessary to unscrew the screws so far that they become detached, they just need to be loose.
With the bottom jaw removed, check that the fine mesh filter under the fan does not have dirt in it. If it does, use a small paintbrush between the blades of the fan, or blow clean air into the pipe.
The bottom jaw is constructed of two pieces of aluminium, screwed together with air tight gasket compound. There are wires between the plates connecting from the fixing screws to the fan and jaw-open reed switch sensor. It is not practical to dismantle it to this extent. If you have problems with the fan or sensor, return the jaw to ADC Bioscientific or your local Service Centre.

Removal of the bottom jaw exposes the analysis and reference humidity sensors and the chamber temperature sensor (which looks like a black bead). Take care not to lose any of the 5 ‘O’ rings. The humidity sensors can be withdrawn by unplugging them after the M1.6 slotted countersink screws have been removed.

Note that the software stores separate span and zero constants for each of the sensors, so be sure to put them back in their original locations if you wish to avoid re-calibration. If it is possible that the sensors have become swapped when you reassemble it, and you have no calibration facility, choose the locations that make the sensors most closely agree when there is no leaf in the chamber. The sensors are interchangeable to within 5%RH without re-calibration.

The temperature sensor has wires and a socket on the back and it can only be removed by taking off the handle lid and disconnecting it (see below and Appendix 6. Chamber Exploded diagram). The socket will pass through the sensor hole with care The plug is not polarised and so a note should be taken of its orientation (the white wire should be nearest the end of the board). If you are unsure, no damage will result from an incorrect orientation, but the temperature reading will be obviously in error. The sensors are interchangeable to better than 0.1°C without re-calibration.

Before refitting a chamber lightly grease the 5 'O' rings with the silicone grease supplied before re-assembly, and be sure that the rings around the two humidity sensors and the temperature sensor are pushed completely down to the flange before re-assembly.

The position and function of the connectors and the potentiometers on the printed circuit board are shown on a label inside the cover.

Before proceeding further, note that the metal plate is at ground potential. A Mylar film insulator is fitted between the circuit board and the metal back plate. However, if the circuit board is allowed to come into contact with the back plate while the instrument is switched on and connected to the chamber, it is possible the fuse will be blown or damage caused to components on the circuit board.

The status of the solenoid valves is indicated by the light emitting diodes LED10 and LED90 (see gas circuit diagram). The solenoid valves are both replaceable items and cannot be dismantled.

Solenoid valve SV1 is used to select Zero or Reference gas and is activated when LED 10 is lit. It can be tested as follows. Connect a Sphygmomanometer to the Red and White sleeved pipes in turn and applying a very low pressure. When LED10 is lit the pressure will be lost from the red pipe and when both LED10 and LED90 are not lit pressure will be lost from the white pipe. If pressure is not lost from either pipe then it is likely that solenoid valve SV2 is not operating and is stuck at the Zero/Reference end. If pressure gradually drops then the valve is leaking and should be replaced.

Solenoid valve SV2 of a latching type; that is, it stays in its last position without power. When LED90 is lit the valve is opened at the Analysis gas end. To leak test it, it is necessary to remove the chamber to gain access to the Analysis gas stem. Connect the sphygmomanometer to the gas stem and apply a very low pressure. The pressure should be maintained whilst LED90 is out and lost rapidly when LED90 is lit. If the pressure falls gradually there is either a leak or a blockage in the pipe between the valve and the cell.

If SV2 leaks, it is probably dirt on the seal, which might be possible to dislodge as follows. Ensure that the valve is switched so that the leaky direction is open. Strip back 4mm of the insulation from some 7/0.1 tinned copper wire and, while turning it, push it into the valve entry that leaks. The wires will spread sideways and dislodge the dirt from under the seat. Remove the wire, and blow clean air into the leaky port, to blow the dirt out. When replacing the valves, refer to the piping diagram.

If the detector signal falls so far that CO_2 zero cannot be manually corrected with the potentiometer or it is known that dirty water has entered the analyser, it is possible that the analysis cell will need cleaning, or that the source or detector is faulty. The procedure for checking and replacing the source and detector is shown below.

To clean the cell, first remove the handle cover as shown below. It is best to first remove the cell by unplugging the infrared source and detector leads from the circuit board, removing the single M3 screw under the lower jaw and the M3 screws that retain the jaw-open clip then pull the cell off the pipe that connects it to SV2.

Remove the large insulation around the detector. Pull back the insulation around the cell sufficiently to remove the two M2 screws that retain the detector housing. Remove the

infrared source and its two M2 screws, and the flow sensor housing and its two screws. You can now look through the cell, which should appear uniformly shiny. If it appears dull or patchy, it may be possible to clean it.

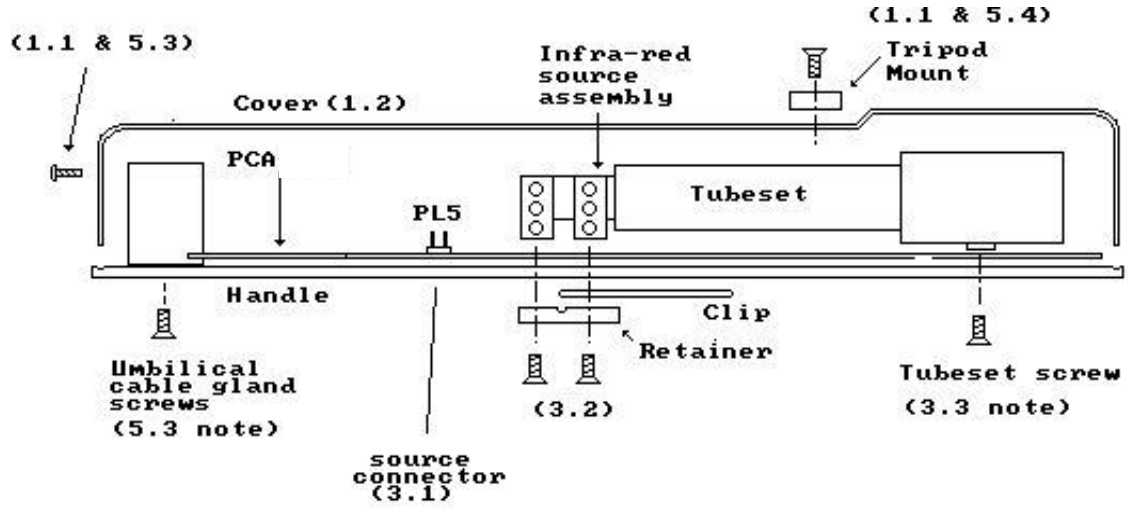
The cell is gold plated internally and can be cleaned with care with cotton wool wrapped around a thin stick. For persistent dirt, alcohol or acetone can be used. If the cell has had liquid in it for a few days, it is possible that there is corrosion under the plating, in which case, it will need to be re-plated or replaced by ADC.

14.8 Removing the Handle Cover

Unscrew the two retaining screws from the tripod boss.
Note the orientation of the boss.

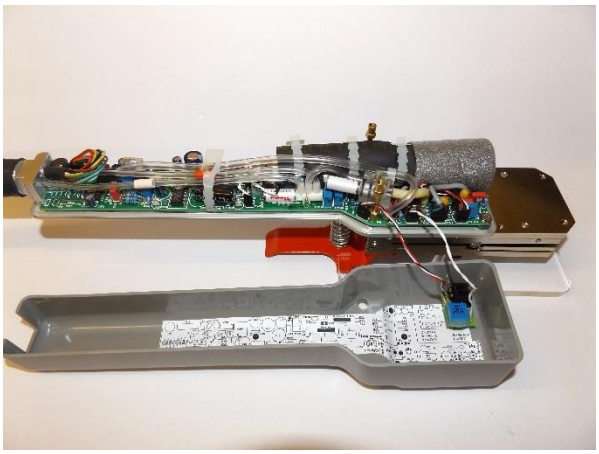
There are two screws holding the cable gland in place. Remove them both

If you wish to completely remove the handle cover, take a note of the orientation of the connectors (there is a diagram inside the handle cover) and unplug the two sockets of the Tleaf thermistor and the CO_2 zero potentiometer wires from the PCB.



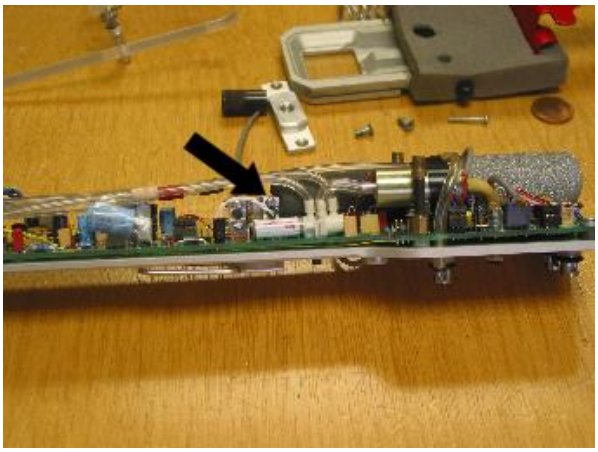
Later models have the CO_2 zero potentiometer mounted in the handle cover instead of on the board so that an additional twisted pair of wires runs from the jack-socket assembly to RV9 on the board

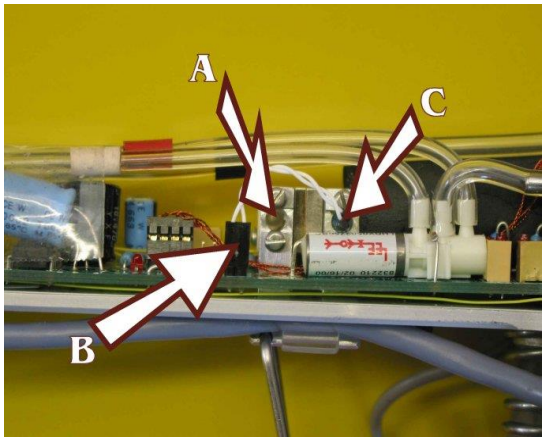
On the diagram/label in the handle:
R indicates red
B indicates black
W indicates white
X indicates no connection (polarising pin)



14.9 Checking the Source

First remove the jaws and then the handle cover, (see previously). It is not necessary to completely remove the cover.
The source is indicated by the black arrow in the above picture**.** It is a small light bulb, which has been pre-aged to minimise drift. It has a thin envelope to minimise infrared loss, and a low-mass, fast response filament.

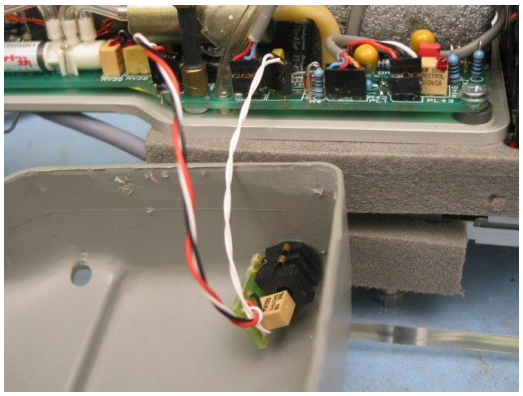




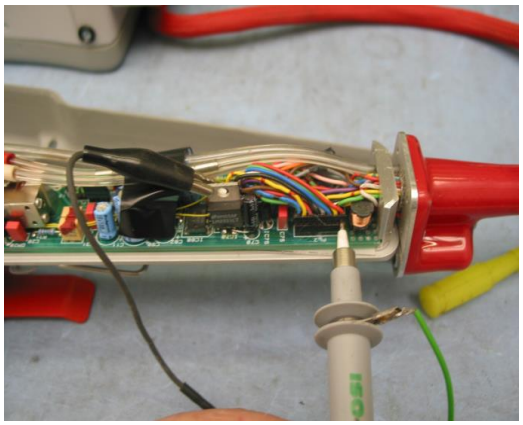
Look for flashing coming from the small window (A). This is best done in a dark area.
If the source has a white body then light can be seen through the body.
If there is no sign of flashing then unplug the source connector (B) and check resistance to see if the source bulb is open circuit.
If there is no flashing and the source is open circuit then the source (C) will need to be replaced. It will also need to be replaced if it is blackened or in any way dark.

The resistance of a good source is about 125 ohms. If there is flashing then carry out the next test.

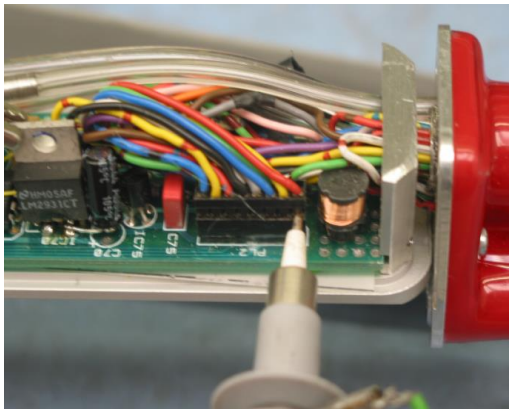
14.10 Checking the Detector



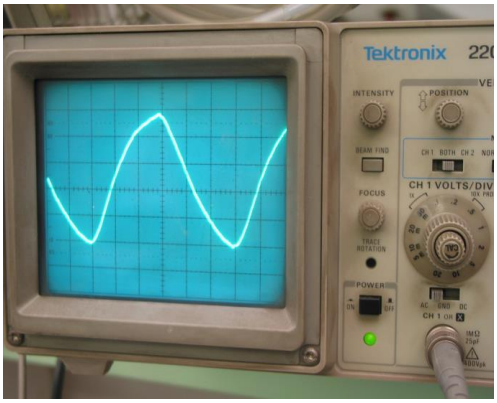
Before checking the detector, check the source is OK. Remove the jaws and handle cover, without disconnecting it electrically.
Check that the wires are not broken and that the connector is securely fitted to the PCB pins.



Place the earth clip of an oscilloscope probe on the metal body of the regulator as shown.



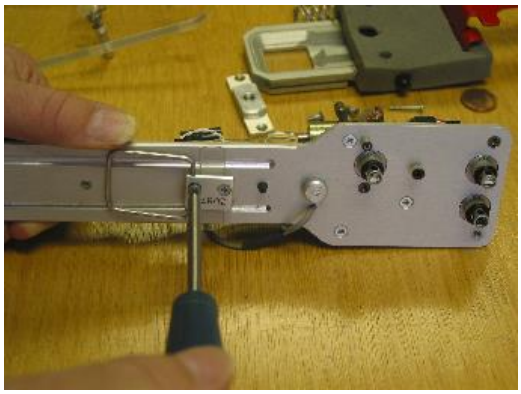
With a narrow oscilloscope probe measure the signal on the red wire of the connector. This can be done through the small hole in the side of the connector.



The detector signal should be an approximate sine wave between 3.5 and 2 volts peak to peak, depending on (amongst other things), the setting of the CO_2 zero pot. If you do not have an oscilloscope measure the voltage with an AC Voltmeter. If there is no detector signal, then the detector is probably faulty and will need to be replaced.

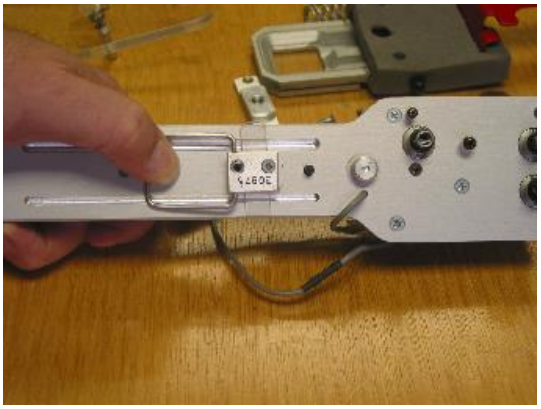
The detector can be removed with the cell in place. It is a static sensitive device and so static precautions should be observed as for changing the EPROM. Unplug its connector, and remove the large piece of insulation around the detector housing. Unscrew the knurled nut by turning it counter-clockwise, but do not turn the circuit board. The circuit board, the socket, and the detector may now be withdrawn. Do not touch the window on the detector. Any fingerprints need to be removed with alcohol and cotton wool. If the detector is unplugged, note its orientation with respect to the circuit board. Also note that there is a thin film filter (TFF) assembly remaining in the end of the tubeset. It is a loose fit, and may fall out. Replacement is a reversal of the removal procedure. Tighten the knurled nut with your fingers only, do not use pliers, and do not turn the circuit board.
If you do have a detector signal then reassemble the handle cover, replace the cable clamp securing screws and fit the camera tripod boss and its securing screws.
Leave the LCi T to warm up for 10 minutes and reset the CO_2 zero as indicated in the manual.

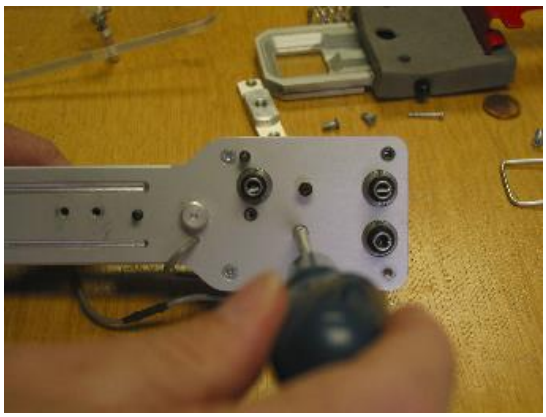
14.11 Replacing the Source



Unscrew and remove the two screws from the lever catch body.

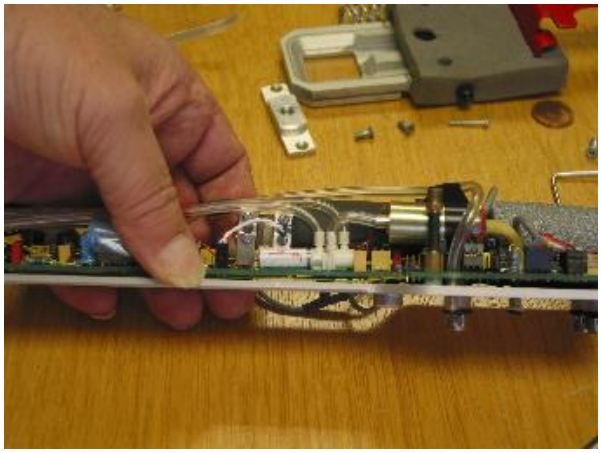
Note that the retaining screws are off-set and not central. Remember this when reassembling the handle.

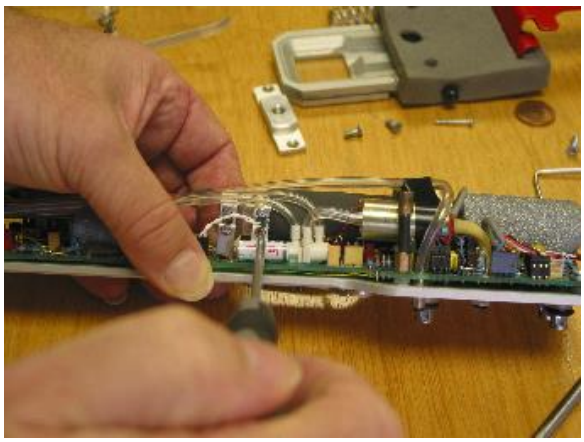




Unscrew the retaining screw TWO TURNS. Do not remove this screw completely because it locates the analyser cell at the detector end and prevents its pipe connection and detector wires being strained.

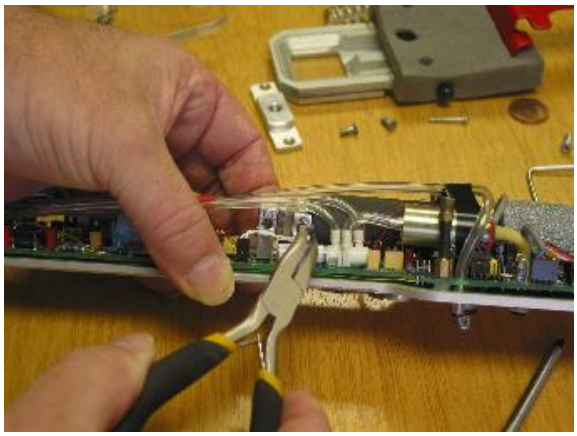
This will give you just enough slack to lift the source end of the analysis cell, giving you access to the lower source retaining screw. If there is not enough movement to get a screwdriver on to the sources lower screw then go back to the previous instruction and unscrew the retaining screw another half a turn and try again.

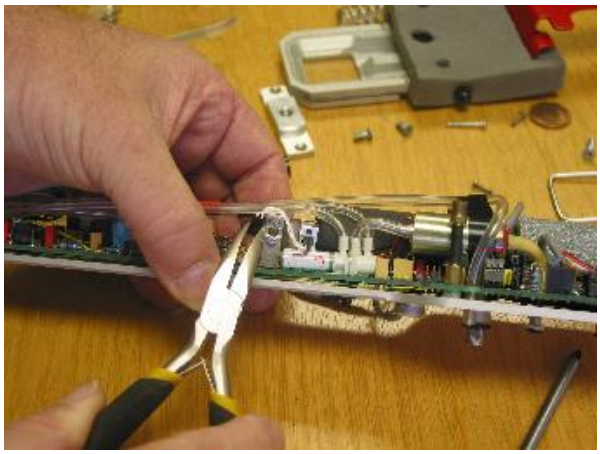




Using a small flat bladed screwdriver, unscrew and remove the upper and lower source retaining screws. These screws are stainless steel – do not replace them with mild steel types.

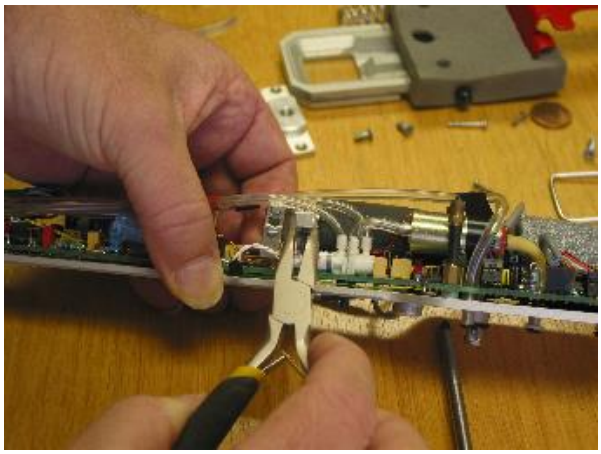
Using tweezers or long nose pliers gently pull out the old source from the analysis cell. Take care not to allow any debris to get inside the analysis cell.

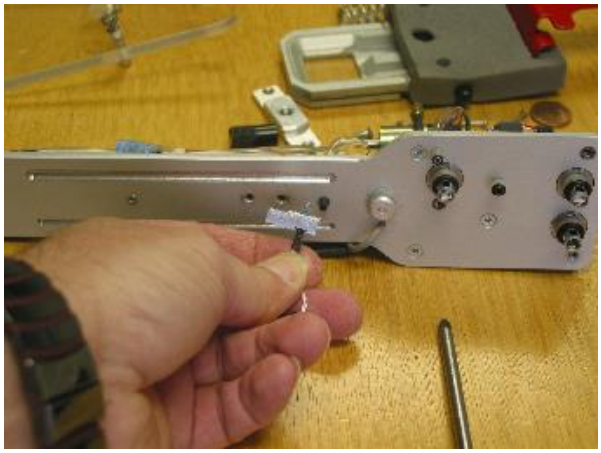




Disconnect the sources electrical connection from the circuit board.

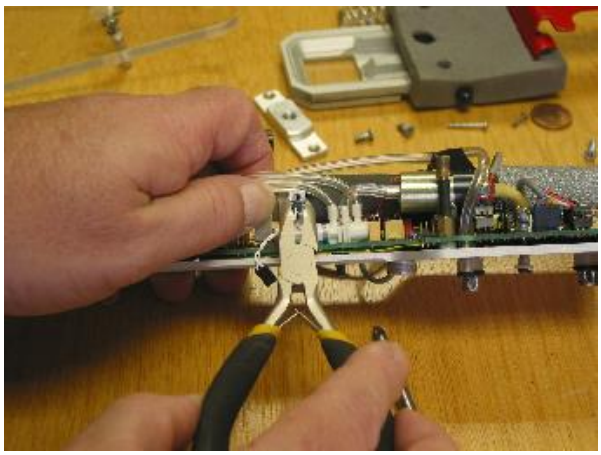
Then remove the old source.



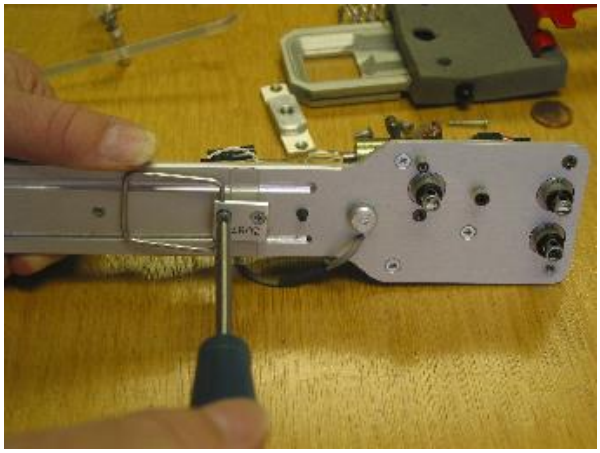


A thermal isolation gasket should have come off with the old source.

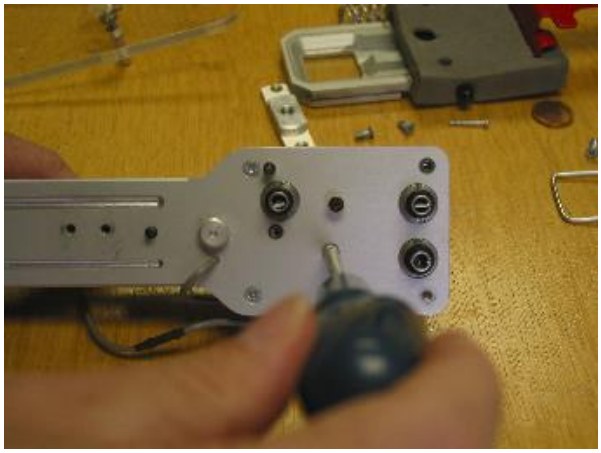
Remove the thermal isolation gasket from the old source and fit it onto the new replacement source.



Fit the new source into the cell and replace the two retaining screws. Connect the electrical connections to the circuit board on connector PL5. The source is not polarized.



Refit the lever catch body, ensuring the correct orientation so that the body sits centrally on the handle.



Tighten the retaining screws but DO NOT OVERTIGHTEN, the threads are into plastic spacers.
Replace the Handle cover and Jaws.

Because the new source will have a different output than the old one the CO_2 Zero will need to be set. Follow the instructions in this manual or in the maintenance guide "Setting the CO_2 zero on the LCi T". If you attempt a zero before the LCi T has warmed up, it will prevent the zero taking place. Either wait for the warming up period, or, switch off, switch back on and press "Opts" while the serial number and software version are still on the screen. This will bypass the warm-up and allow the CO_2 zero to be set faster.

14.12 Fault finding

Fault (warnings in quotes)	Possible cause	Remedy
Analyser will not switch on	Battery discharged Fuse blown	Recharge battery Replace fuse
Analyser will not respond to key presses	Software bug causing it to ignore keypad	Invoke hardware reset by pressing, simultaneously, the left 2 keys and the right key
Pump running fast but not enough flow	Any pipe (red, white or black) is disconnected. The air inlet (top connector) is partially blocked or supply pipe is too thin or long The black pipe is squashed flat inside the chamber handle.	Reconnect Remove blockage or use bigger supply pipe Reposition the pipe.
Pump supplies enough air but is noisy	Pump bearings worn	Replace pump
Difficulty removing or dismantling chemical column	'O' ring seals are dry	Apply a thin wipe of silicone grease to the seals
"CO_2 signal failure"	The detector signal is out of range of the A-D converter. Due to: Source failure Detector failure	Look for source flashing- light escapes through the base. Measure resistance (125Ω) Using oscilloscope look for about 15mVpk-pk triangle wave on pin 1 (blue) of PL1, on PCA-275
"CO_2 low energy"	Soda lime exhausted Gain set too high Dirt in the cell I/R Source nearing end of useful life	Check soda lime Check settings as above Remove and clean cell Inspect source, change if blackened
"C_{ref} low, check absorber" Can and Cref readings very low or zero	Soda lime exhausted or red (zero) pipe blocked, or valve SV1 stuck in NO position	Check soda lime, if OK check pipe, if OK check SV1
Low, or negative CO_2 values	Soda lime exhausted	Check soda lime
C_{an} low or zero	Fan stopped (this happens if jaws are open) SV2 stuck Fan outlet blocked	Check fan, shut jaws. Touch SV2. Check it clicks audibly and tactually when LED90 on PCA-275 changes state. Check outlet filter
"CO_2 signal overrange"	Signal at A-D converter is out of range. Gain is set too high	In calibrate CO2 Zero mode, set approx. 3.3V pk-pk detector signal on PL2 pin 2 (red) on PCA-275 using RV4. Set 4.5V DC on TP20 on PCA-271 using RV9
"span gas reading is too low"	The analyser cannot reduce its span coefficient low enough for the value you have set.	Check that the span gas is not being diluted. Check that the value you have entered matches the cylinder
"span gas reading is too high"	The analyser cannot increase its span coefficient high enough for the value you have set.	Check that the analyser is not being pressurised Check that the value you have entered matches the cylinder
"Current log file cannot be deleted (or renamed)"	You cannot delete a file if it is enabled to receive records	Switch logging off before deleting.
"Chamber flow not as set"	Pipe not connected or kinked in the handle Air supply to analyser partially blocked	Check Check
"T_{leaf} probe error"	The Tleaf reading is outside the A-D converter range.	Check probe is connected, and is not broken (should be 2kΩ at 25°C)

APPENDIX 1. PARAMETER INFORMATION

Symbol	Description	Log	An. o/p	Screen	Units	Type	Range
[c]z	Raw CO_2 zero reading	-	y	Diagnose Hidden	adc counts	-	-
[cab]a	Infra-red absorption due to analysis CO_2	-	-	Diagnose Hidden	%	-	0-40
[cab]r	Infra-red absorption due to reference CO_2	-	-	Diagnose Hidden	%	-	0-40
[w]a	Raw H_2O analysis reading	-	-	Hidden	adc counts	-	-
[w]r	Raw H_2O reference reading	-	-	Hidden	adc counts	-	-
^C	Delta CO_2 (Cref - C'an)	7	Y	1 *	vpm	Ca	+/-2000
^e	Delta H_2O (w'an-Wref), partial p.	5	Y	1	mBar	Ca	+/-75
^w	Delta H_2O (w'an-Wref), as %RH	-	Y	-	%RH	Ca	+/-100
A	Photosynthetic rate	23	-	2	µmol m^{-2} s^{-1}	Ca	0-100
Alt	Altitude from GPS	28	-	GPS	DMM	-	-
Area	projected leaf surface area	24	-	3,Config	cm^2	G	0.1-100
C'an	CO_2 analysis (corrected for dilution)	-	y	1 *	vpm	M,Co	0-2000
C_e	Soil Respiration	20†	-	2	µmol s^{-1}	Ca	
Chcfg	Chamber type / configuration set	30	-	3,Config	-	-	-
Ci	Sub-stomatal CO_2	20	-	2	vpm	Ca	0-2000
Cref	CO_2 reference	6	y	1 *	vpm	M,Co	0-2000
Dt	Date (text)	2	-	Diagnose	-	-	-
E	Transpiration rate	21		2	mmol m^{-2} s^{-1}	Ca	0-1
e'ad	H_2O analysis, dilution corrected	-	y	1	mBar	Ca,Co	0-75
eref	H_2O reference, as partial pressure	4	y	1	mBar	Ca,Co	0-75
GPS Fix	GPS Fix	29	-	GPS	-	-	0-2
Gs	Stomatal conductance of H_2O	22		2	mol m^{-2} s^{-1}	Ca	0-1
Hfac	H factor - energy conversion factor	-	-	3, Config	-	F,G	0.1-1
Lat	Latitude from GPS	26	-	GPS	DMM	-	-
Log	Name of log file	-	-	3, Config,	-	G	-
Long	Longitude from GPS	27	-	GPS	DMM	-	-
Mem.	Free space on memory card	-	-	Log	Kb	-	-
NCER	Net CO_2 Exchange Rate	23†		2	µmol m^{-2} s^{-1}	Ca	0-100
P	atmospheric pressure	19	y	1,Hidden	mBar	M	600-1100
phase	CO_2 rectifier phase shift	-		Hidden	°	-	-
Power	Bar graph showing battery state	-	-	2	-	M	10.5-14.3
Q	P.A.R. at window	-	-	Hidden	µmol m^{-2} s^{-1}	M	0-3000
Qblu	Blue LED light unit output corrected for Trw	13	-	Climate	µmol m^{-2} s^{-1}	M,Co	0-800
Qgrn	Green LED light unit output corrected for Trw	12	-	Climate	µmol m^{-2} s^{-1}	M,Co	0-800
Qleaf	P.A.R. incident on leaf surface	8	y	1	µmol m^{-2} s^{-1}	Ca	0-3000

Qmode	Light measurement method	9	-	-	-	-	-
Qred	Red LED light unit output corrected for Trw	11	-	Climate	µmol m^{-2} s^{-1}	M,Co	0-800
Qw	White LED light unit output corrected for Trw	10	-	Climate	µmol m^{-2} s^{-1}	M,Co	0-2500
Rb	Boundary resistance to H_2O	25	-	3	m^2 s mol^{-1}	G	0.1-9
Rb set	Boundary resistance at full flow	-	-	Config.	m^2 s mol^{-1}	G	0.1-9
Record	Current record number	1	-	2, Log	-	-	-
Rs	Stomatal resistance to H_2O	-			m^2 s mol^{-1}	Ca	0.1-2000
Tch	leaf chamber temperature	14	y	1	°C	M	-5 to +50
Tl mtd	Leaf temperature determination method	16	-	3, Config	-	-	-
Tleaf	Leaf surface temperature	15	y	2	°C	M,G	-5 to +50
tm	Time of day	3		Diagnose	-	-	-
Trw	Chamber window transmission factor	-	-	3, Config	-	F,G	0.25-1
U	ASU mass flow (measured)	17	y	2	µmol s^{-1}	M	68-341
Us	Flow per unit leaf area	-	-	-	µmol m^{-2} s^{-1}	Ca	-
Uset	Desired molar air flowrate	18	-	2,3, Config	µmol s^{-1}	G	68-341
Va(±20%)	Measured analyser flow	-	-	-	µmol s^{-1}	-	-
Vaux	Aux input, scaled as volts	-	-	-	Volts	-	-
Vbatt	Battery voltage	-	-	Diagnose	Volts	-	10.5 -14.3
w'ad	H_2O analysis, dilution corrected	-	y	Diagnose	%RH	Ca,Co	0-100
W_{flux}	Net H_2O Exchange Rate	21†	-	2	mmol m^{-2} s^{-1}	Ca	-
Wref	H_2O reference, as %RH	-	y	Diagnose	%RH	M,Co	0-100

Column key: † Indicates position in log when soil pot is selected

"Screen" column gives the location of displayed parameters.
There are three main screens (1, 2, & 3) and four sub-screens:

diag = diagnostics screen
cfg = configuration set up screen
log = log set up screen
hid = hidden screen for ADC use only

"Log?" column shows the position of a parameter in the log record. If no number is shown the parameter is not logged.

"An o/p" column indicates whether the parameter can be monitored from the analogue output port. See Appendix 2 for scaling details.

"Type" column indicates the method of derivation:

Ca = calculated (generally by a formula given in the appendices)
Co = corrected (by terms defined in the appendices)
F = factors (established by experiment or other means)
G = given (i.e. entered by the user)
K = constants (physical or scientific)
M = measured raw values (by transducers in the LCi T)

APPENDIX 2. ANALOGUE OUTPUT SCALING

Parameter & Symbol		Units	Reading @ 0V	Reading @ 5V	Units/V
Atmospheric pressure	(p)	mBar	600	1100	100
Analysis CO_2	(c'an)	vpm	0	2000	400
Delta CO_2	(Δc)	vpm	-200	+200	80
Reference CO_2	(cref)	vpm	0	2000	400
Analysis H_2O	(e'an)	mBar	0	100	20
Delta H_2O	(Δe)	mBar	-5	+5	2
Reference H_2O	(eref)	mbar	0	100	20
Analysis humidity	(w'an)	%RH	0	100	20
Delta humidity	(Δw)	%RH	-5	+5	2
Reference humidity	(wref)	%RH	0	100	20
Leaf chamber temperature	(Tch)	°C	-5	+50	11
Flow	(u)	μmol s^{-1}	0	342	68.4
Leaf temperature (meas/calc'd)	(Tl)	°C	-5	+50	11
Qleaf (PAR @ leaf surface)	(qleaf)	μmol m^{-2} s^{-1}	0	3000	600
Raw CO_2 zero at TP20 [*1]	([c]z)	Volts	4.05	5	0.19
Raw CO_2 zero Diagnostic [*2]	([c]z)	A-D count	53000	60000	1400

[*1] Volts measured at TP20 during zero parts of gas cycle or CO_2 zero calibration.
[*2] A-D count optimally 56500 for "perfect" CO_2 zero calibration.

APPENDIX 3. CALCULATED PARAMETERS AND CONSTANTS

CO_2 Concentration

The IRGA measures the absorption of infra-red due to the presence of CO_2. This value must be scaled and linearised to get the actual concentration. The processing is done in several steps as shown below for the analysis channel, the reference channel is treated the same, substituting subscript 'r'.

$$[c_{ab}]_a = \frac{z_a - r_a}{z_a}$$

Where	$[c_{ab}]_a$	absorption due (mainly) to CO_2
	z_a	detector signal at zero
	r_a	detector signal at current reading

the calibration set during span adjustment:

$$c_{an} = L_c([c_{ab}]_a s)$$

Where	L_c	linearisation function for CO_2
	$[c_{ab}]_a$	absorption of infra-red due to CO_2
	s	span factor; determined during calibration (span adjustment)

The reading is now compensated for changes in atmospheric pressure. The LCi-SD leaf chamber and IRGA cell are very close to ambient pressure.

$$c_{an}' = c_{an}\ (1 + \frac{(p_{ref} - p)\ a}{p_{ref}})$$

Where	c_{an}'	pressure corrected CO_2 value
	p_{ref}	ambient pressure at last span adjustment, mbar
	p	ambient pressure, mbar
	a	pressure compensation factor (1.4)

The IRGA CO_2 reading is slightly influenced by the presence of water vapour (pressure broadening). The water vapour readings are used to compensate the measured readings:

$$C_{an}'' = C_{an}' + (C_{an}' wm_{an})$$

Where	c_{an}''	reading compensated for the presence of H_2O
	wm_{an}	H_2O concentration, as a molar fraction

Finally, leaf transpiration causes the net volume of air leaving the leaf chamber to be higher than that entering. This volume increase tends to dilute the CO_2 concentration, causing c_{an} and w_{an} to be lower. Dilution compensation removes this effect, so that the Δc Δe value reflects the differences due to absorption by the leaf, not transpiration. This compensation is only applied to the analysis reading.

$$c_{and} = c_{an}'' (\frac{1 - wm_{ref}}{1 - wm_{an}})$$

Where	c_{and}	Final, compensated reading, as displayed
	wm_{ref}	Reference water vapour concentration, as molar fraction
	wm_{an}	Analysis water vapour concentration, as molar fraction

APPENDIX 3 (Continued)

Molar flow of air per m^2 of leaf surface

symbol: u_s (mol m^{-2} s^{-1})

$$u_s = \frac{u}{area}$$

Where ***u*** molar air flow in mol s^{-1}
area projected leaf area in m^2

Difference in CO2 concentration

symbol: ΔC, vpm(≡µmol mol^{-1})

$$\Delta c = c_{ref} - c'_{an}$$

where C_{ref} CO_2 flowing into leaf chamber, µmol mol^{-1}
C'_{an} CO_2 flowing out from leaf chamber, µmol mol^{-1} , dilution corrected

Photosynthetic Rate (Rate of CO_2 exchange in the leaf chamber)

symbol: A (µmol m^{-2} s^{-1})

$$A = u_s \Delta c$$

where u_s mass flow of air per m^2 of leaf area, mol m^{-2} s^{-1}
Δc difference in CO_2 concentration through chamber, dilution corrected, µmol mol $^{-1}$.

Water vapour pressure in and out of leaf chamber

The calculation for reference is show for illustration. Substitute e'_{an} and rh_{an} for the analysis calculation.

symbol e_{ref} into leaf chamber (mbar)
e_{an} out of leaf chamber

$$e_{ref} = \frac{rh_{ref}}{100} e_s$$

where rh_{ref} water vapour concentration as %rh (as measured)
e_s saturated vapour pressure, mbar (see later)

APPENDIX 3 (Continued)

Calculation of molar concentration of water vapour in and out of leaf chamber

The calculation for reference water vapour is shown for illustration.

symbol ***wm_{ref}*** into leaf chamber (ratio)
wm_{an} out of leaf chamber

$$wm_{ref} = \frac{e_{ref}}{p_{amb}}$$

where ***e_{ref}*** water vapour pressure into chamber, mbar
p_{amb} ambient pressure, mbar

Difference in water vapour pressure

Note that Δw and ΔRH are calculated in exactly the same way. The dilution corrected analysis value is used.

symbol **Δe** (mbar)

$$\Delta e = e'_{an} - e_{ref}$$

where ***e_{ref}*** water vapour pressure into leaf chamber, mbar
e'_{an} water vapour pressure out of leaf chamber, mbar, dilution corrected

Transpiration rate

symbol: ***E*** (mol m^{-2} s^{-1})

$$E = \frac{\Delta e u_s}{p}$$

where ***Δe*** differential water vapour concentration, mbar, dilution corrected
u_s mass flow of air into leaf chamber per square metre of leaf area, mol s^{-1} m^{-2}
p atmospheric pressure, mBar

APPENDIX 3 (Continued)

Leaf surface temperature

Where calculated. This value may also be measured or given.

symbol: T_{leaf} (°C)

$$T_{leaf} = T_{ch} + \left(\frac{(Q \, x \, H_{factor}) - \lambda E}{\left(\frac{0.93 \, M_a \, C_p}{r_b} \right) + 4\sigma (T_{ch} + 273.16)^3} \right)$$ [1]

where

	T_{ch}	leaf chamber temperature, °C
	Q	photon flux density incident on leaf chamber window, μmol m^{-2} s^{-1}
	H_{factor}	energy conversion factor J/μmol
	λ	latent heat of vaporisation of water, J mol^{-1}
	E	Transpiration rate, mol m^{-2} s^{-1}
	M_a	molecular weight of air
	C_p	specific heat at constant pressure, J g^{-1} K
	r_b	boundary layer resistance to vapour transfer, m^2 s mol^{-1} (0.93 is conversion factor for above to give boundary layer resistance to heat)
	σ	is Boltzmann's constant, $Wm^{-2}K^{-4}$

Stomatal resistance to water vapour

symbol: r_s (m^2 s mol^{-1})

$$r_s = \frac{(w_{leaf} - wm_{an})}{\left(\frac{\Delta eu_s}{p} \right)} - r_b$$

where w_{leaf} saturated water vapour concentration at leaf temperature, mol mol^{-1}, thus:-

$$w_{leaf} = \frac{e_s}{p}$$

e_s	saturated vapour pressure at leaf surface temp, mBar
p	atmospheric pressure, mBar
Δe	differential water vapour concentration, mbar, dilution corrected
wm_{an}	water vapour concentration out of leaf chamber, mol mol^{-1}
r_b	boundary layer resistance to water vapour, m^2 s mol^{-1}
u_s	mass flow of air per m^2 of leaf area, mol m^{-2} s^{-1}

[1] Energy balance equation for calculating Leaf temperature PARKINSON, K.J. (1983) Porometry in S.E.B. Symposium of Instrumentation for Environmental Physiology, Cambridge University Press

APPENDIX 3 (Continued)

Sub-stomatal cavity CO_2 concentration

symbol: c_i (μmol mol^{-1})

$$C_i = \frac{((g_c - \frac{E}{2})c'_{an}) - A}{g_c + \frac{E}{2}} \quad [2]$$

where

$$g_c = \frac{1}{1.6\,r_s + 1.37\,r_b}$$

c'_{an}	CO_2 flowing out from leaf chamber, μmol mol^{-1}, dilution corrected.
E	Transpiration rate, mol m^{-2} s^{-1}
A	photosynthetic rate of CO_2 exchange in the leaf chamber, μmol m^{-2} s^{-1}
r_b	boundary layer resistance to water vapour, m^2 s mol^{-1}
r_s	stomatal resistance to water vapour, m^2 s mol^{-1}

[2] Calculation for Ci, Substomatal CO2 von CAEMMERER, S. and FARQUHAR, G.H. (1981)
Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153:376-387

APPENDIX 3 (Continued)

Saturated vapour pressure of water at leaf surface temperature

symbol: e_s (bar)

For $T_{leaf} >= 0$

$$e_s = 6.13753x10^{-3}e^{\left(\frac{T_{leaf}\left(18.564-\frac{T_{leaf}}{254.4}\right)}{T_{leaf}+255.57}\right)}$$

For $T_{leaf} < 0$*, above water*

$$e_s = 6.13753x10^{-3}e^{\left(\frac{17.966T_{leaf}}{T_{leaf}+247.15}\right)}$$

(Arden L Buck, Journal Appl. Meterology vol 20 1981 pp1527-1532)

where T_{leaf} leaf surface temperature, °C

Stomatal conductance of water vapour

symbol: g_s units: mol m^{-2} s^{-1}

$$g_s = \frac{1}{r_s}$$

where r_s stomatal resistance to water vapour, m^2 s mol^{-1}

P.A.R. incident on leaf surface

symbol: Q_{leaf} units: μmol s^{-1} m^{-2}

$$Q_{leaf} = Q\,x\,Tr_w$$

where Q Photon flux density incident on leaf chamber window, μmol m^{-2} s^{-1}

Tr_w Leaf chamber window transmission factor to P.A.R. (given)

APPENDIX 3 (Continued)

Soil Respiration (Net Molar Flow of CO_2 in/out of the Soil)

symbol: C_e (μ mol s^{-1})

$$C_e = u\ (-\Delta c)$$

where u molar air flow in mol s^{-1}

Δc difference in CO_2 concentration through soil pot, dilution corrected, μmol mol^{-1}.

Net CO_2 Exchange Rate (C_e per unit area)

symbol: ***NCER*** (μmol s^{-1} m^{-2})

$$NCER = u_s\ (-\Delta c)$$

where u_s molar flow of air per square meter of soil, mol m^{-2} s^{-1}

Δc difference in CO_2 concentration through soil pot, dilution corrected, μmol mol^{-1}.

Note: *This is equivalent to -A*

Net H_2O Exchange Rate (Soil Flux)

symbol: W_{flux} (m mol s^{-1} m^{-2})

$$W_{flux} = \frac{\Delta e\, u_s}{p}$$

where u_s molar flow of air per square meter of soil, mol m^{-2} s^{-1}

Δe differential water vapour concentration, mbar, dilution corrected

p atmospheric pressure, mBar

Note: *This is equivalent to E*

APPENDIX 3 (Continued)

Constants

Volume of 1 micro-mole of air at 20˚C and 1 Bar (Vm_{20C})
Value used is 2.4387×10^{-2} m^3.

Latent heat of vaporisation of water (λ)
Value used is 45064.3 - (t_{ch} x 42.9) Joule mol^{-1}

Boltzmann's constant (σ)
Value used is 5.7×10^{-8} W m^{-2} K^{-4}.

Molecular weight of air (M_a)
Value used is 28.97

Specific heat at constant pressure (C_p)
Value used is 1.012 J g^{-1} K^{-1}

APPENDIX 4. DERIVATION AND MEASURED VALUES FOR HFACTOR

The leaf temperature can be calculated from the energy balance, as shown in Appendix 3. This requires knowledge of the total incident radiation H absorbed by the leaf, which in sunlight lies between 0.4 and 3.0 microns. This therefore includes the PAR radiation (0.4 – 0.7μ) and near infrared radiation (0.7 – 3.0μ).

The Hfactor is used to convert the measured PAR value into a figure for the total energy absorbed, which will depend upon the visible/infrared ratio of the incident radiation. This in turn is determined by the nature of the energy source and conditions, and also by the absorption properties of the leaf and the leaf chamber windows.

$$H = Q \times Hfactor$$

A value for Hfactor is given by the following equation:

$$Hfactor = a.e.f. + a^1.c.d.$$

Where;

H = energy absorbed by the leaf in W/m

Q = PAR in mol m^{-2} s^{-1}

a = conversion from incident photon flux density between 0.4 & 0.7μ to radiant energy

a^1 = conversion from incident photon flux density between 0.7 & 3.0μ to radiant energy

[a & a^1 vary with light source and type of light sensor – a silicon type is used with the LCi T]

c = the fraction of infrared transmitted by the chamber windows and shield if fitted

d = the fraction of infrared absorbed by the leaf

e = the fraction of visible transmitted by the chamber windows and shield if fitted

f = the fraction of visible absorbed by the leaf

Typical values for the above factors are;

a = 0.2188 for sunlight (K.J.McCree,1972,Agricultural Meteorology,10, p443-453 etc.)

a^1 = 0.1205 (based on 361.5wm^{-2}/3000μmol m^{-2} s^{-1} at λ ave = 0.992μ)

c = 0.6

d = 0.2 (for typical leaves)

e = 0.88 (Broad & Narrow chambers), 0.93 (Conifer chamber)

f = 0.8 (for typical leaves)

These values give Hfactor

= 0.168 (Broad & Narrow chambers) – for sunlight

= 0.177 (Conifer chamber)

= 0.168 (Small chamber)

Other values have been obtained for sunlight and various light sources, based on the Broad and Narrow chambers and using a silicon PAR sensor. These are given in the following table, and are generally recommended.

APPENDIX 4 (Continued)

Measured Hfactor values and conditions.

	PLC with Perspex Shield and Windows	
LIGHT SOURCES	**PAR sensor outside chamber**	**PAR sensor inside chamber**
Sun & Sky	0.168	0.214
Tungsten 3000°C	0.340	0.429
Warm white fluorescent	0.109	0.139
Cold white fluorescent	0.113	0.144
Grolux fluorescent	0.118	0.150
Tungsten 3000°C with IR filter		0.160

APPENDIX 5. SATURATED VAPOUR PRESSURE

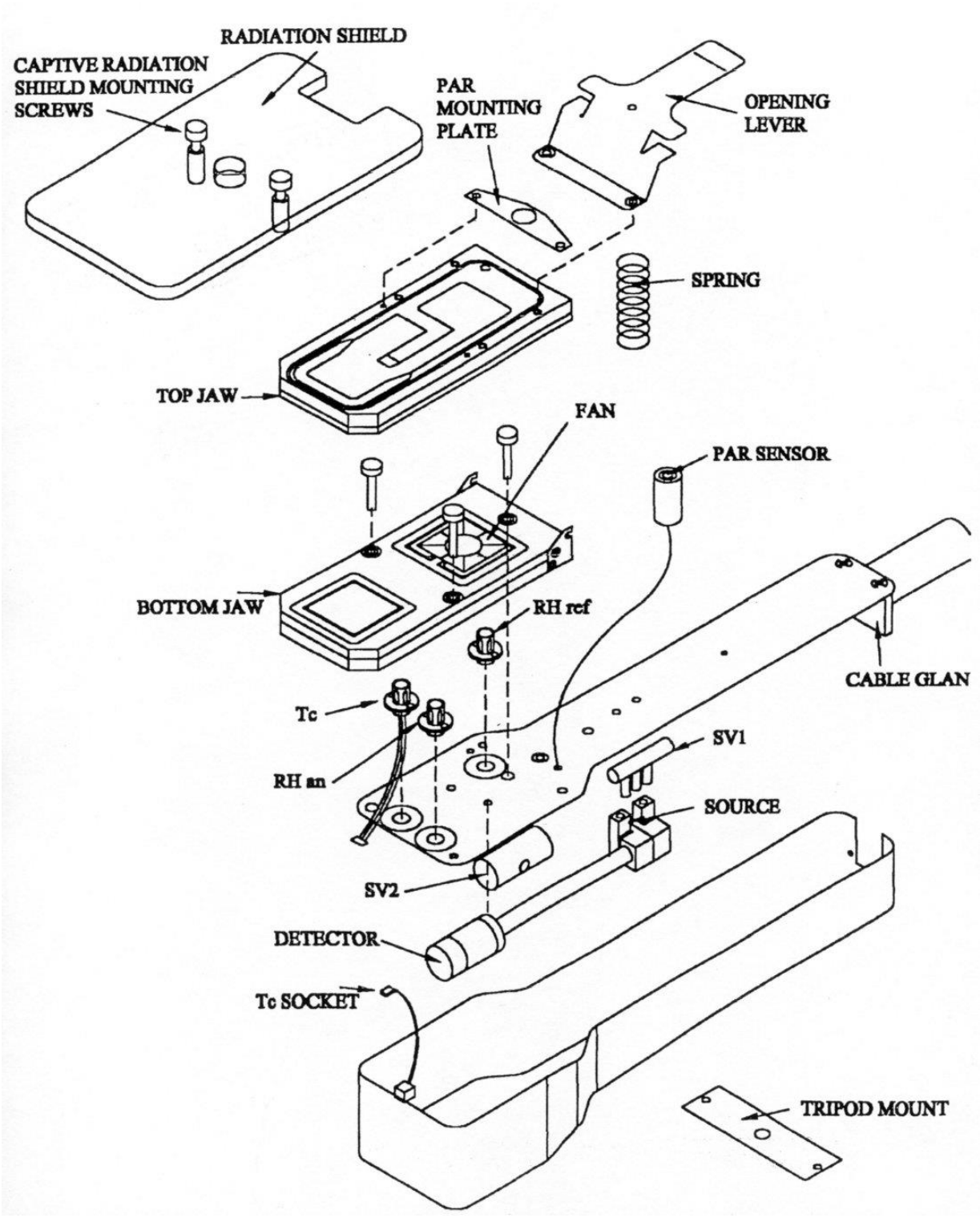
SATURATION VAPOUR PRESSURE OVER WATER (SVP)

Values obtained using the LCP_SD software based on A Buck formula 1981

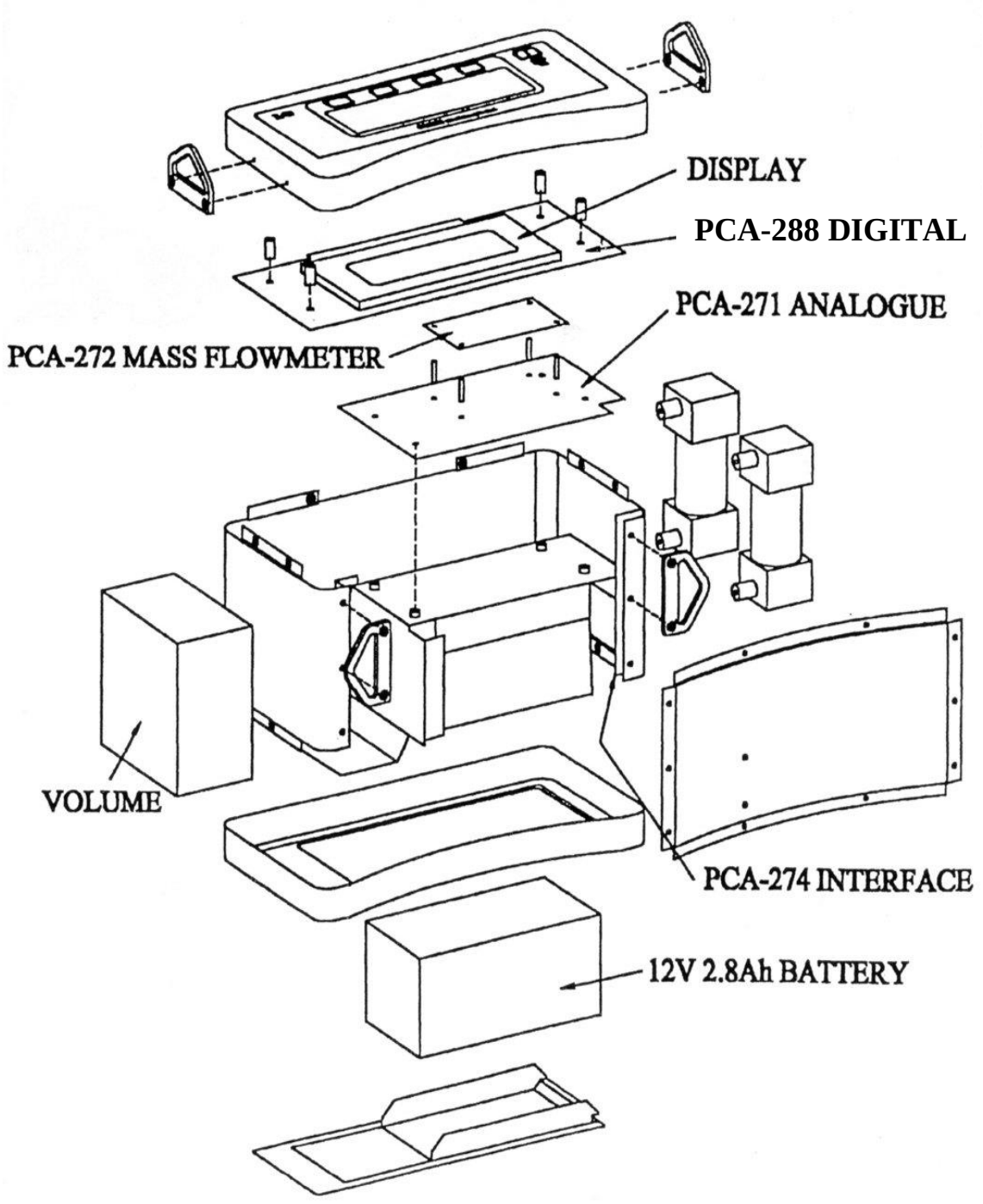
Metric Units (millibars)

°C	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	17.1	17.2	17.3	17.5	17.6	17.7	17.8	17.9	18.0	18.1
16	18.3	18.4	18.5	18.6	18.7	18.8	19.0	19.1	19.2	19.3
17	19.5	19.6	19.7	19.8	20.0	20.1	20.2	20.3	20.5	20.6
18	20.7	20.9	21.0	21.1	21.2	21.4	21.5	21.7	21.8	21.9
19	22.1	22.2	22.3	22.5	22.6	22.8	22.9	23.0	23.2	23.3
20	23.5	23.6	23.8	23.9	24.1	24.2	24.4	24.5	24.7	24.8
21	25.0	25.1	25.3	25.4	25.6	25.7	25.9	26.1	26.2	26.4
22	26.5	26.7	26.9	27.0	27.2	27.4	27.5	27.7	27.9	28.0
23	28.2	28.4	28.6	28.7	28.9	29.1	29.3	29.4	29.6	29.8
24	30.0	30.1	30.3	30.5	30.7	30.9	31.1	31.2	31.4	31.6
25	31.8	32.0	32.2	32.4	32.6	32.8	33.0	33.2	33.4	33.6
26	33.8	34.0	34.2	34.4	34.6	34.8	35.0	35.2	35.4	35.6
27	35.8	36.0	36.2	36.4	36.7	36.9	37.1	37.3	37.5	37.7
28	38.0	38.2	38.4	38.6	38.9	39.1	39.3	39.5	39.8	40.0
29	40.2	40.5	40.7	40.9	41.2	41.4	41.6	41.9	42.1	42.4
30	42.6	42.9	43.1	43.4	43.6	43.9	44.1	44.4	44.6	44.9
31	45.1	45.4	45.6	45.9	46.2	46.4	46.7	47.0	47.2	47.5
32	47.8	48.0	48.3	48.6	48.9	49.1	49.4	49.7	50.0	50.2
33	50.5	50.8	51.1	51.4	51.7	52.0	52.3	52.5	52.8	53.1
34	53.4	53.7	54.0	54.3	54.6	54.9	55.2	55.6	55.9	56.2
35	56.5	56.8	57.1	57.4	57.7	58.1	58.4	58.7	59.0	59.4
36	59.7	60.0	60.3	60.7	61.0	61.3	61.7	62.0	62.4	62.7
37	63.0	63.4	63.7	64.1	64.4	64.8	65.1	65.5	65.8	66.2
38	66.6	66.9	67.3	67.6	68.0	68.4	68.7	69.1	69.5	69.9
39	70.2	70.6	71.0	71.4	71.8	72.1	72.5	72.9	73.3	73.7

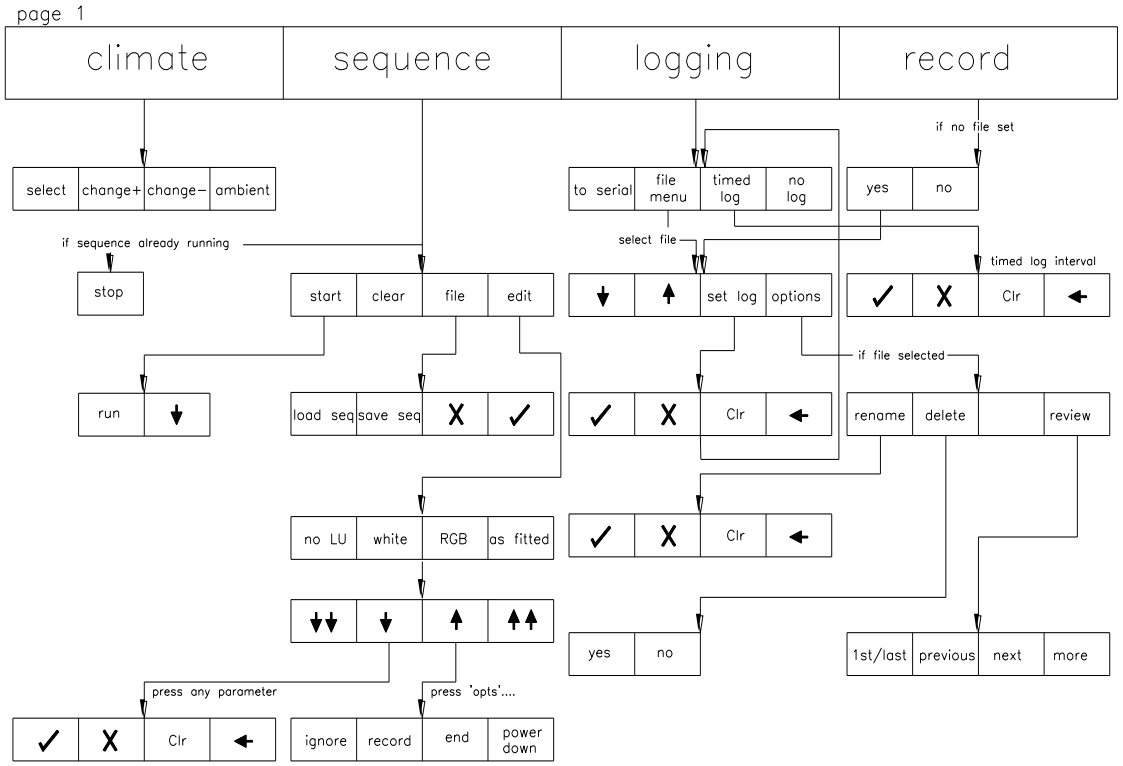
APPENDIX 6. CHAMBER EXPLODED DIAGRAM

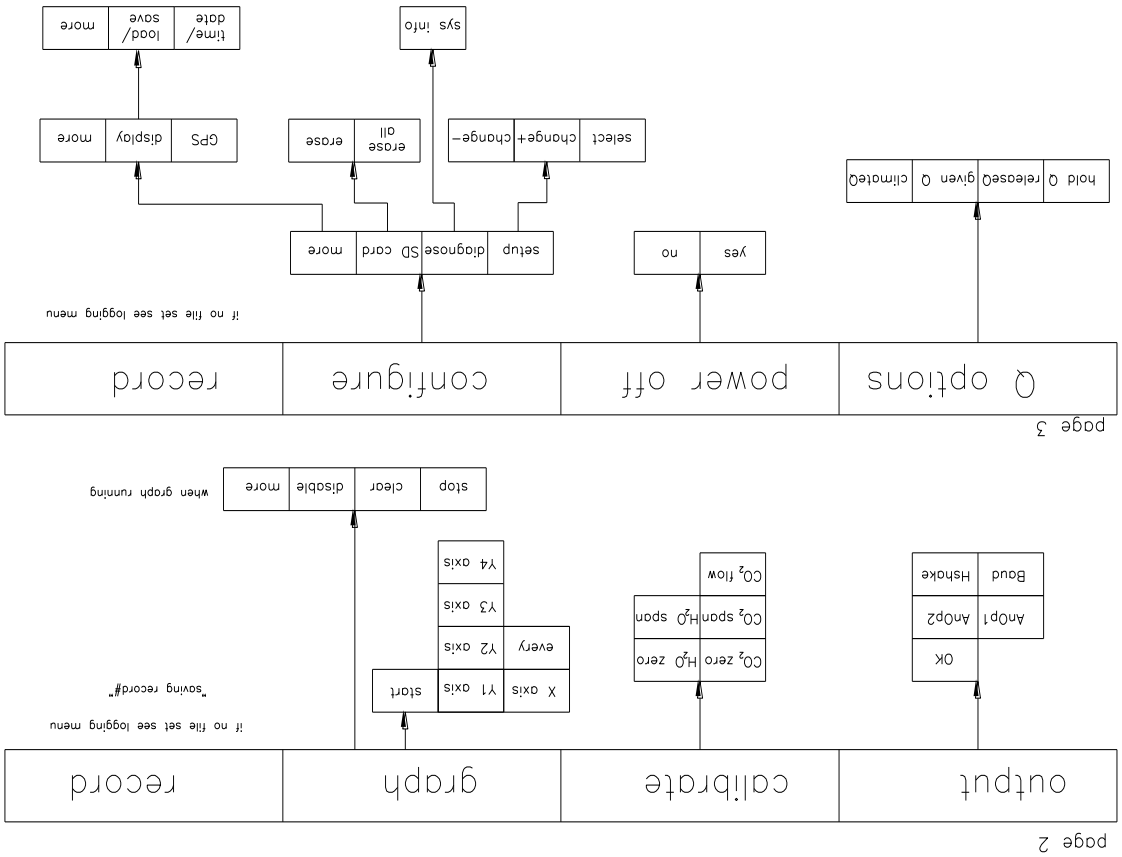


APPENDIX 7. CONSOLE EXPLODED DIAGRAM



APPENDIX 8. LCI T MENU STRUCTURE (TO PHOTOCOPY)





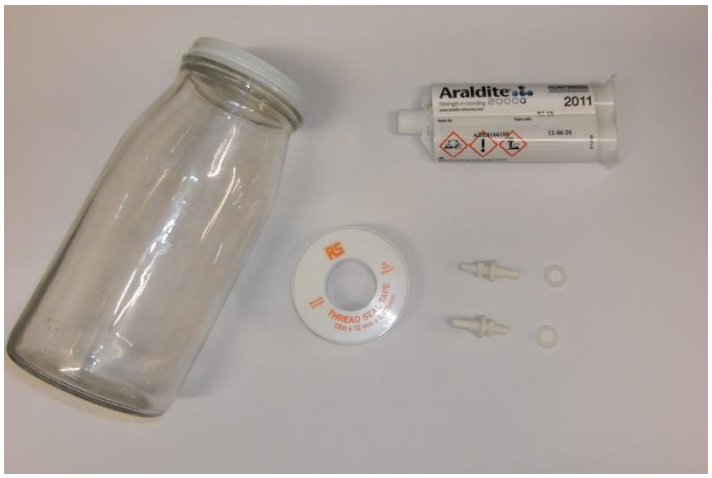
APPENDIX 9. TECHNICAL SPECIFICATION

Measurement range and technique:	CO_2:	0-2000 ppm, 1ppm resolution Infra red gas analysis, differential open system, auto zero, automatic atmospheric pressure and temperature compensation.
	H_2O:	0-75mbar, 0.1 mbar resolution Two laser trimmed, fast response RH sensors.
PAR:	0-3000 μmol m^{-2} sec^{-1} Silicon photocell	
Chamber temperature:	-5°C to +50°C	Precision thermistor. ±0.2°C accuracy
Leaf temperature:	-5°C to +50°C	Energy balance or microchip thermistor
Gas Exchange Repeatability:	CO_2: H_2O:	0.1% of reading @ 370ppm 0.5% R.H.
Linearity:	CO_2: H_2O:	0.5% of reading 0.5% RH
Temperature effect on span	CO_2:	<0.05% of f.s.d. per °C
Flow rate to PLC:	68 to 340μmol m^{-2} sec^{-1}	
Flow rate accuracy:	± 2% of f.s.d.	
Display:	Colour WQVGA touch sensitive LCD	
Warm up time:	5 minutes at 20°C	
Recorded data:	SD Card. 32GB supported.	
Battery:	2.8 Ah 12V lead acid to give 10 hours	
Battery charger:	90 to 260V, 50/60 Hz	
Analogue output:	0 to 5V on user selected parameter	
RS232 output:	User selected rates up to 19200 baud	
USB Slave Peripheral		
Electrical connections	Power: Analogue out: RS232: Chamber: USB:	5 pin DIN 5 pin DIN 9 pin D type. “AT” pin configuration. 15 pin high density D type USB Mini B
Gas connections:	3mm barbed	
Power requirements:	0.3A @ 12V DC	
Operating temperature:	5°C to 45°C	
Dimensions (H x W x D overall)	Console: Chamber:	240 x 125 x 140 mm 300 x 80 x 75 mm
Weight	Console: P.L.Chamber:	2.4 kg 0.6 kg

APPENDIX 10. SMALL BUFFER VOLUME CONSTRUCTION

A useful accessory for the LCi T is a small buffer volume made from a clean glass jar. Clean glass has very little gas "hangup" and when water is added to the jar it can be used as a water bubbler for making 100% RH air if two are connected in series, useful if a H_2O recalibration needs to be done.
The main purpose however is to average out or stabilize the CO_2 level going into a console.

The small buffer consists of a glass jar with two air entries (also known as 1/8" bulkhead connectors) mounted through the lid. The assembly must be air tight, this being achieved with the use of two part glue and PTFE tape.

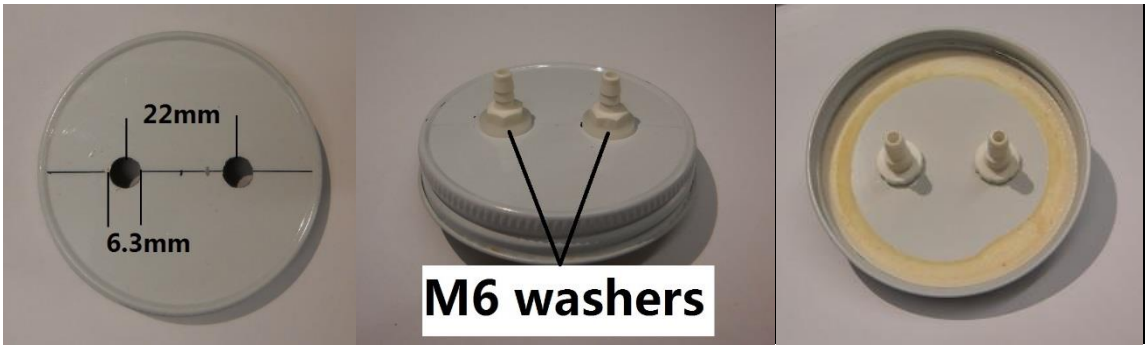


The small buffer volume is shown above left, the parts required to make one are shown above right.

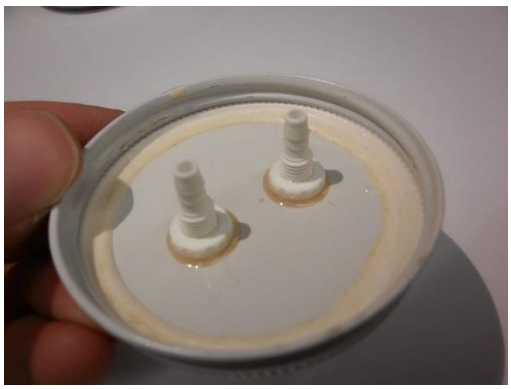
Parts used (above right): A glass jar at least 500 ml in volume, some PTFE tape, two plastic M6 washers, two 1/8" barbed bulkhead connectors (ADC part number 614-802). Some slow setting araldite 2011 glue, (quick setting glues may be used but they are not suitable for use as a water bubbler) and a short length of 3mm bore PVC tubing to go inside the jar.

One of the air entries of the buffer volume has an internal tube attached which drops to the bottom of the jar. When connecting to a console, be sure to connect the other entry without the internal tube attached. This means that any water that finds its way into the jar is left on the bottom of the jar while the air is drawn out from the top. It also allows the air to be volumised by being drawn through the length of the jaw from the bottom to the top which helps to average the CO_2 readings. If the buffer is used to wet the air by adding water, then this tube, located well below the waterline, means that air will exit the tube in the form of bubbles moving through the water then into the air pocket above, which results in the air being wetted. Two such water bubblers in series are sufficient to produce 100% RH or fully saturated air. Provided the end of the internal tube is capped with a suitable diffuser.

First, drill or punch two 6.3mm holes in the lid approximately 22mm apart as shown below left. Next mount the bulkhead connectors as shown below centre and below right.



Next apply some two part glue using a cocktail stick to make a seal around the bulkhead connectors on both sides of the lid as shown below.



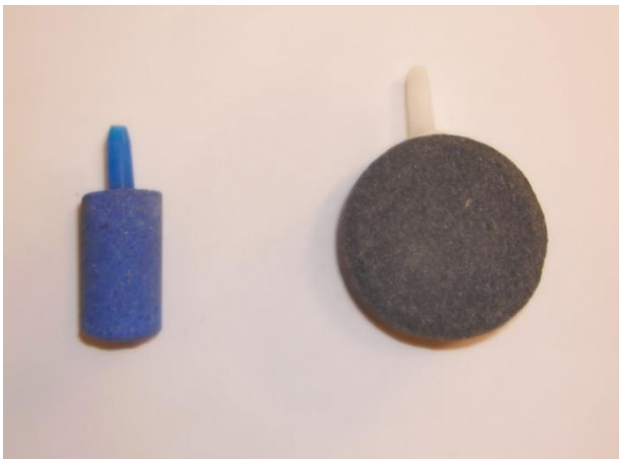
Next apply a few turns of PTFE tape to the glass thread on the jar, be sure to apply in the direction as shown (clockwise) so that the lid screws on with the same direction as the tape (see below left). Before screwing on the lid, cut a 3 mm bore length of tubing to length of the jar minus 20mm (see below right).

Connect this length of tubing to one of the bulkhead connectors on the inside of the lid (see left). If this buffer is connected to a console then the console “air in” entry connects to the buffer entry without the long tube on it, the “short” air entry.

Screw the lid onto the jar quite tightly, if the PTFE tape is unravelled by doing this then it has probably been put on in the wrong direction. If you have a manometer then you can leak test the volume by connecting to one entry and blocking the other.

Note on Water Bubblers.

In order to use the buffer volume as a 100% RH generator or “water bubbler” it will be necessary to make and connect two in series and fit an “air stone” to the internal tube before adding water to the jar to half fill it. Two such “air stones” are shown below and can be obtained from suppliers of aquarium equipment.



APPENDIX 11. SPARES AND ACCESSORIES

Part No.	Description
022-204	800mA fuse glass time delay
197-710	SD card 2G
299-494	13.8V lead acid charger for 12 V battery
631-100	Aluminium dismantleable filter
630-967	Hydrophobic filter, 3 micron (subject to change)
630-980	Filter plastic disposable
650-952	'O' ring 6.07 bore x 1.78
651-551	'O' ring 28.3 bore x 1.78
653-085	'O' ring 2.54 bore x1.02
650-240	'O' ring 2 bore x 1
706-555	tube PVC 2 bore
708-656	tube PVC 3 bore
708-454	tube butyl 3 bore
809-151	silicone grease
867-056	trimming tool
994-151	cable 9-way female to female (3 metre)
994-283	Cable USB A to mini B
LCB-129	gasket broad front
LCi-SD-023A	Source assembly
LCi-SD-053	V probe lead assy.
LCi-SD-059	lead assy. power/chart
LCi-SD-131	gasket broad back
LCi-SD-168	belt/neck strap
LCM-068	soda lime – white to violet indicating
OP2-134	Column gas mixer
PLC-011	leaf temperature thermistor assembly

NOTE:
This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

USER NOTES:

USER NOTES:

USER NOTES: