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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 14. APPENDICES **Page**

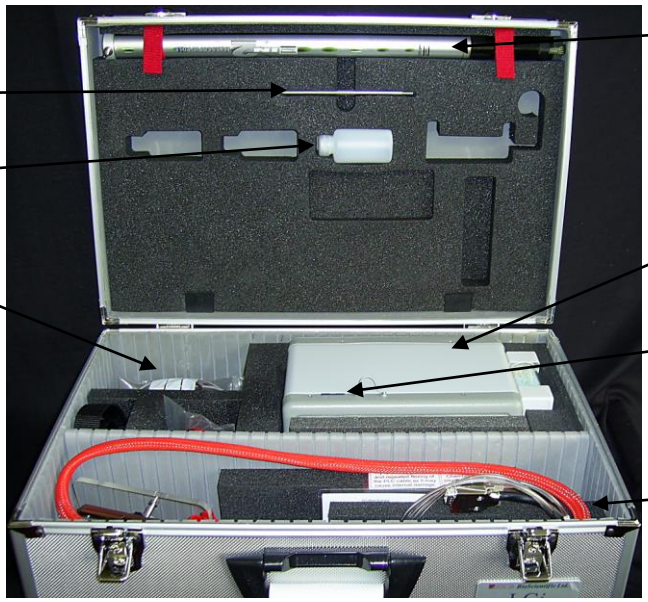
1. INTRODUCTION

This manual covers the operation and maintenance of the LCi-SD Leaf Chamber/Soil Respiration Analysis System.

1.1 Equipment list

The LCi-SD Analyser is supplied in a convenient carrying case containing the following items.
LCi-SD Analyser "Console"
LCi-SD Analyser "Handle" or "PLC"
Carrying strap
Battery charger and power lead
Air probe and ground spike
SD card
Leaf thermistor M.PLC-011 (where applicable *)
Spare leaf chamber gasket set (where applicable *)
Leaf chamber jaw spring (where applicable *)
Handy "Menu structure" card
LCi-SD "User guide" Manual (*This manual)*

In addition to the above items there is a boxed "Spares kit" SKF-115 which contains some of the spares listed in see Appendix 10



* If the LCi-SD system is part of a SRS1000 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. The spring will also be included in any system whose default leaf chamber is either an Arabidopsis leaf or Small leaf style.

Please note – The supplied carry case is for 'By Hand' transportation only, if the instrument is being shipped by courier (for instance back to ADC for servicing) then it is highly recommended that suitable packaging – such as a cardboard box filled with polystyrene chip is used to protect both the case and instrument.

1.2 Description

LCi-SD Console

The LCi-SD (with its leaf chamber / soil pot) 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 pot, to measure the gas exchange associated with soil biomass respiration.

The instrument comprises a main console containing a large Liquid Crystal Display (LCD), a 5-button keypad and a microprocessor controlled operating system with signal conditioning, air supply unit and PC (Personal Computer) card data storage. A Leaf Chamber (PLC) is connected to the Console by an umbilical cord.

The Leaf chamber contains the PCA-275A 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 (or soil pot) is analysed, and its (generally decreased) CO_2 content and (increased) H_2O content determined.

* Except for the Arabidopsis leaf chamber (see section 4)

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 is 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” key. 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 The Internal Calculations

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 to +100 μmol/m^2/s and H_2O flux will be between 0 to 15 mmol/m^2/s.

The analyser performs some checks on magnitudes of readings, particularly of certain settings, which have pre-set limits (for example minimum airflow rate). There is, however, a wide tolerance on 'allowable' settings for which the user is responsible (for example leaf area), 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

"Quantitative Comparison of In Situ Soil CO2 Flux Measurement Methods" by Knoepp and Vose. Research Paper.

2. GETTING STARTED

WARNING: If fitting or changing a chamber please read section 2.9 for further information and advice before proceeding.

Note that this section assumes that a Broad, Narrow or Conifer (conventional) leaf chamber is being used. Please read in conjunction with section 4 if using an Arabidopsis or Small leaf chamber or section 5 if using a soil pot.

2.1 Initial Preparation

The LCi-SD is delivered with the internal battery fully charged and connected and the Soda Lime column filled with fresh self-indicating Soda Lime.
If not using the LCi-SD from new check to ensure the Soda Lime is in good condition (See section 2.8 Checking the Chemical Column for details)

Connect the leaf chamber's (PLC) umbilical cable 15-pin plug to the LCi-SD console connector and the three colour-coded pipes to their respective colour–coded entries (red pipe to red entry etc). (see photograph in section 2.2)

The LCi-SD system requires a fresh air supply and preferably one that will not be unduly influenced by the operator or local crop conditions as far as CO_2 &/or H_2O levels are concerned.

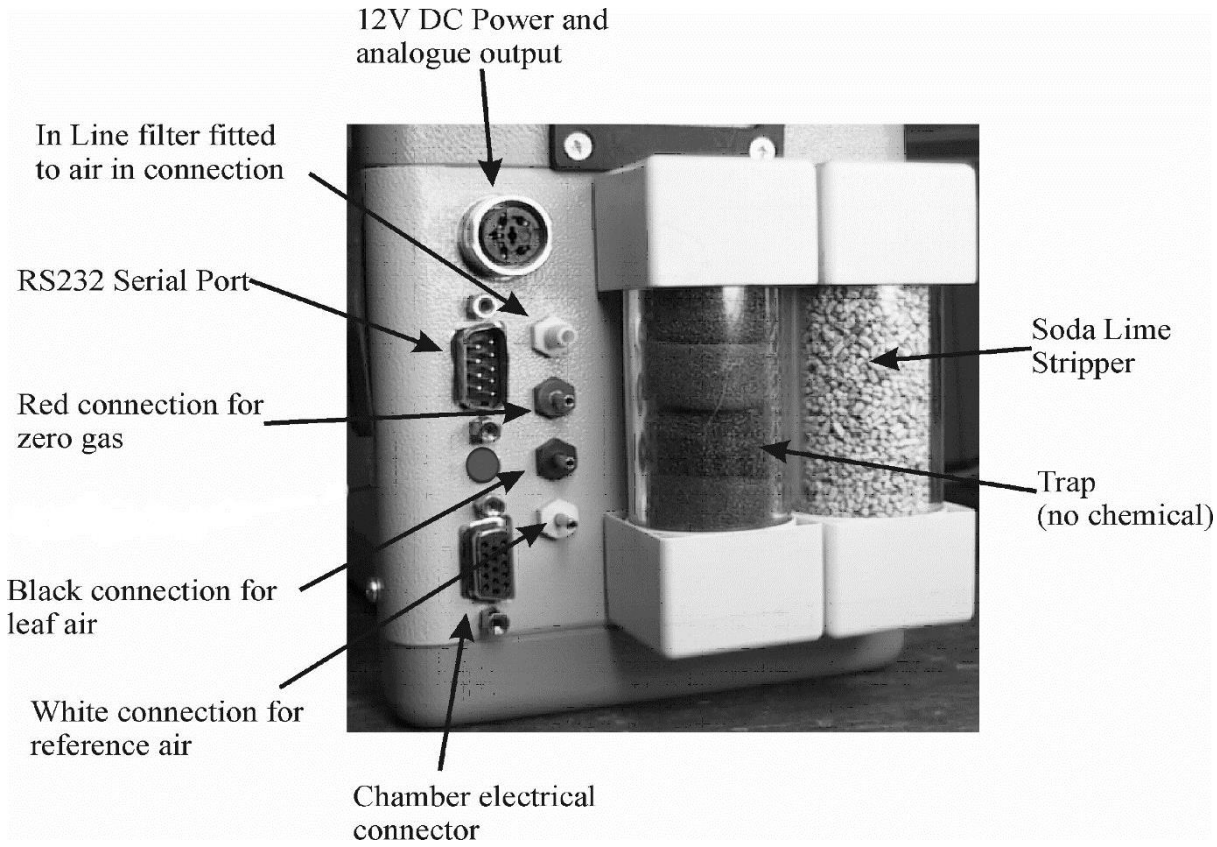
The air supply should be taken from a region where the CO_2 levels are reasonably stable, preferably some 3-4 meters above ground level. The metal-bodied filter supplied in the spares kit should be fitted in the air supply pipe, at the instrument end or the far end, as convenient. It should be fitted with the smallest part of its body nearest to the LCi-SD.

The ADC air probe (supplied) provides such an arrangement. In use the probe should be extended to its full length. The probe can be fitted to a tripod or attached to the ground spike (also supplied) which can then be inserted into the ground.

When using the LCi-SD in a laboratory, a length of tube to the outside of the building away from traffic will normally suffice. Good buffering against ambient changes can be obtained with a plastic 25 litre container by making two gas connections in the lid, and arranging for the inlet pipe to reach to the bottom of the container. This ensures maximum buffering and minimum chance of water reaching the LCi-SD.

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 (longer for badly flattened gaskets). In severe cases, it might be necessary to replace the gaskets, which are self-adhesive. (See Appendix 10 for part numbers and section 12).
It is advisable to latch the chamber jaws open when not in use.

2.2 Electrical Connections



Power Socket

This is provided for an external 12-volt 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-SD battery provided that the power requirements are modest.

The power socket (CON1 on the electrical block diagram) mates with a standard 5 pin 240° DIN audio plug connector. This is provided in the spares kit, pre-wired with red (+) and black (-) power leads terminated in shielded 4mm plugs.

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

The parameter to be output is selected by the user with */output/port/select/*↑/ or /↓/ (see appendix 8). The */ outp1/2 /* key toggles between output 1 & 2 The parameters and their respective scaling are detailed in Appendices 1 & 2

RS232C serial port

The RS232C connector (CON3 on the electrical block diagram) mates with a standard 9 pin 'D' type 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 sets the baud rate and handshake protocols. The socket connectivity is PC standard.

AUXILIARY port (No longer fitted from serial number 32025)

USB Connector (Not shown in picture)

The USB connector is located on the long flat side next to the SD card socket. When connected to a PC the LCi-SD appears as a mass storage device and files can be copied or moved from/to a PC.

2.3 Switching On

Note: The /power off/ key is the only means of turning off the LCi-SD (apart from disconnecting the battery). If the screen is too light or too dark the contrast may need adjusting (see section 2.6 Error, Warning & Status Messages).

Switch ON by pressing the front panel "page" key | at the top right-hand side of the display. The screen will display the ADC trademark, operating system software version and instrument serial number.

A few seconds after switch-on, the screen will display page 1 of three main pages showing a set of parameters and values. The page (on) key will cycle between the three main pages. Appendix 8 (Menu structure) shows all the pages and how they are related. The 'function' headings displayed at the top of each page correspond to the keys on the keypad above.

The parameters displayed on the screen include values for CO_2 & H_2O. With no leaf in the chamber, CO_2 anl should equal ambient CO_2 ref, H_2O anl should equal ambient H_2O ref. T_{ch} (chamber temperature) and Q (PAR) should also reflect ambient conditions.

Note that after first switching on, the LCi-SD requires about five minutes for CO_2 measurements to stabilise. It will display an 'analyser is warming up' message during this time, and will beep when it is ready. Until then the CO_2 readings will display n/a (not available). Once the readings have settled down a check can be made to ensure that the chamber gaskets are sealing. (Reference and Analysis readings will be similar)

Note: If you wish to bypass the warm up timer, press the left button just after it has been switched on and is displaying the software version and serial number.

The LCi-SD comes with factory-installed default settings (see section 8.1), some of which may need to be changed for immediate use (e.g. time & date, serial link).

Close the leaf chamber head (In the case of Conifer chambers ensure that the clip is latched) and check that the chamber fan is rotating (usually it can be heard).

2.4 Display

The Display unit is a LCD type with an adjustable contrast control. If the user prefers a different contrast level, adjustment is available using potentiometer RV92 (Located in the right hand corner of the PCA-288 'digital' board.)

2.5 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-SD 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, 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 is when the value for **Ci** (substomatal CO_2) has stabilised.

After readings are stable, a 'record' may be taken (see section 9.2).

2.6 Error, Warning & Status Messages

Depending on the state of the LCi-SD, or the way it is being operated; various messages may be presented on the screen. These are of three types, 'error', 'warning' or 'status'.

Error messages occur when a serious problem is experienced. If a software problem occurs that results in the LCi-SD becoming inoperative, a message 'fatal error! – cannot continue' appears on the screen. Further lines giving an indication of the type of error that has occurred accompany it.
In the first instance, operating the 'page' key can clear an error. If this action does not clear the error, or the error re-occurs after a short time, switch off the LCi-SD and after a short interval switch it back on.
If the instrument is switched on but does not respond to key presses, pressing simultaneously the page key (top right) and the two leftmost keys will invoke a hardware reset.

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 anyway.

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

2.7 Low Battery Voltage

The internal battery voltage is monitored to detect if the battery is close to being fully discharged. When the battery voltages falls to 10.8 volts a **'Warning: BATTERY LOW!'** message will appear on the status line.

At this point, there is typically about 5 minutes life left in the battery. This should allow enough time for the user to either connect a charger or conclude his current record. If the warning message is ignored, the LCi-SD will switch itself off once the battery voltage falls to 10.5 volts! The message BATTERY EXHAUSTED – SWITCHING OFF will appear just before the LCi-SD switches off.

The battery power is shown as a bar graph at the bottom of screen page 3, and also numerically on the diagnostics page. The battery should be recharged (see section **Error! Reference source not found.**) after any significant period of use, or if it is less than 12V.

2.8 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-SD, always replenish the soda lime when it is exhausted. This is shown by a colour change of green to brown. (See also 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-SD 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.

2.9 Fitting/changing a chamber

This information applies to all chamber types and to the Soil pot.
Note that only the “conventional” broad, narrow and conifer leaf chambers have separate upper and lower jaws whilst the Arabidopsis and Small leaf chambers and the Soil pot feature an “interface block”. All references to “jaw” in this section also apply to the “interface block” where applicable.

Description

The jaw is fitted to the handle using three captive screws. The three screws carry the analysis stirrer fan signal, the "Jaw closed" sensor switch signal.and the ground return.
The Arabidopsis and Small leaf chambers and the Soil pot do not contain a “Jaw closed” sensor switch and so the screw is grounded.
Care should be taken as described below.

Fitting a chamber

Before fitting the chamber, check to see that the five “O” rings are all in place (two gas stems and three sensor housings.
When fitting a chamber, press down on the jaw itself then turn the three captive screws USING THE FINGERS ONLY.

DO NOT USE A SCREWDRIVER OR 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 good gas-tight seal it is only necessary to push down on the jaw itself (a small gap between the jaw and the handle baseplate is permissable as the "O" ring seals will ensure a gas-tight seal)

Removing a chamber

When removing a chamber it is permissable to use a small coin to unscrew the three captive screws but again it should be stressed that no downwards pressure should be applied to the screwheads.

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.

3. THE LEAF CHAMBER

3.1 General Description

The PLC consists of a handle and an interchangeable leaf chamber or soil pot (See section 5 for Soil pot description and Appendix 6 for an "exploded" view of the handle assembly).

There are five styles of leaf chamber available. These are Arabidopsis, Small, Broad, Narrow and Conifer leaves. Refer to section 0 for a description of Arabidopsis and Small leaf chambers, which are very different in design to the other chambers.

The handle houses a jack socket for use with a detachable leaf temperature sensor, a 'record' switch, and an electronics board providing sensor amplifiers for signals to the LCi-SD console.
An umbilical cable is attached to the handle linking the electrical signals and gas lines to the LCi-SD console. Repeated bending can damage this cable. When storing the chamber, try to avoid tight bends in the cable especially where it joins the handle and plug.

To minimise noise on the measurements, the chamber should be held as steady as possible during the measurement. To assist the user in this regard, the underside of the chamber has a thread for a ¼" Whitworth tripod screw.

The Broad, Narrow and Conifer leaf chambers consist of an upper and lower head section and a radiation shield. The radiation shield can be easily removed without affecting the functionality of the chamber. You may wish to do this where solar radiation is not a problem, and the shield is too bulky.

The PAR sensor is mounted on the upper head section and is accessed by removing the heat shield. The sensor housing is an "interference fit" in its mounting bracket.

The upper head section can be removed to give access to the gaskets, the stirrer, and the three lower jaw fixing screws. Remove the jaw by pressing down to compress the spring, then twisting the jaw to disengage the hinge pin on the slotted side then withdrawing the other hinge pin. This

The three fixing screws and lower section can be removed to access the temperature and humidity sensors.

To change a chamber (see Appendix 6), unscrew the two mounting screws in the radiation shield by about 10 turns, it is not necessary to remove the screws completely as they are "captive".
Lift off the radiation shield and pull the PAR sensor off its mounting plate.

While holding the upper jaw fully open, twist it slightly so the hinge pin slides out on the slot side. The upper jaw can now be lifted away from the handle, exposing the lower jaw fixings.

Unscrew the three knurled captive screws, which retain the bottom jaw, about 6 turns. It is not necessary to completely remove them. The bottom jaw can now be removed, exposing the two humidity sensors, Chamber temperature sensor and the two gas entry stems. Note that the gas entries and the three sensor housing all have an "O" ring seal. It is important that these seals are not lost. Spare "O" rings are supplied in the Spares kit (Also see Appendix 10).

When replacing the jaws, note that the coin slots in the knurled screws are intended to assist with removal rather than tightening, finger tight is generally sufficient.

If the chamber is changed for a different style, it is necessary to inform the analyser using */config/* and /+/ or /-/ until the chamber displayed is the chamber type fitted.
Note: Selecting the correct configuration and performing a flow check is essential if changing between "conventional" leaf chambers and the Arabidopsis/Small leaf chambers or the Soil pot.

When the correct configuration is selected the appropriate factory default values of r_b, H_{fac}, and T_{rw} (see below and section 3.2) are automatically chosen, and they may then be individually adjusted if required.

The chosen configuration and any manual changes made to the values by the user are saved at power off.

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 i.e. conifer needles, small fruits etc.

3.2 Leaf Chamber Constants

The design of the leaf chamber affects various parameters, which are constants for a particular design or type. These include 'r_b' (boundary layer resistance), 'H_{factor}' (the level of radiation energy affecting the leaf (referred to as 'Trans' on LCA2 & 3)), and 'Tr_w' (the transmission factor of the chamber windows {and radiation shield where applicable} to PAR). These constants may be changed with */config/select/*. When the appropriate parameter is highlighted, it can be modified with the /+/ and /-/ keys.

'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. This is due to the different transmission factors at the wavelengths in the visible and infrared regions, the position of the PAR sensor (inside or outside the cuvette), and the type of light source. [see Appendix 4].

'Tr_w'

On the chambers, the measurement of PAR is via a sensor mounted on the upper jaw adjacent to 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 &/or window.
(See Section 8.1 for typical values, with and without the shield.)

3.3 Leaf thermistor

The leaf temperature may be measured as an alternative method to calculating it. The software switch between the two options is *Tl mtd* in the */config/* menu.

In general, if the broad chamber has a large broad leaf with a known area, or is so big that it completely fills the chamber, so that its area is 6.25cm^2, then calculated leaf temperature is best.

If the area is uncertain, e.g. conifers, the temperature will need to be measured. This measurement is made with a microchip thermistor attached to a jack plug with thin wires (supplied). The plug connects to a socket on the chamber handle and the thermistor is rested 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 in a small cut made in the leaf with a scalpel, or by taping the wires to the edge of the chamber.

3.5 Leaf Spider (Broad and Narrow style heads only)

The integral thermistor is a similar microchip on a springy 'spider' mounting that is fitted in the Broad and Narrow jaws and touches the underside of the leaf. It is held in place in the lower jaw with two pins. To fit it, 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 Hold Q reading

The first main menu page has two buttons (*/Q hold/ & /Q rel./*) that hold or release the PAR (Q_{leaf}) reading. This facility can be used with a light unit as follows: The PAR sensor is removed from its usual position, and placed in the chamber. The resultant PAR reading (Q_{leaf}) is held by pressing the */Q hold/* button. The PAR sensor is 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 */Q rel./* button

3.7 Enter given Q value

This facility allows the use of an alternative light source with a known radiation output.

In addition to the two buttons referred to in paragraph 3.4 the first main menu page also has a button (*/Q given/*) that allows a given value of PAR (Q) to be used.

The "given" value is entered from the /*config*/ menu by selecting Q then using the +/- buttons to enter the required value. The default value is 1500µmols m^{-2} s^{-1}. Any value between 0 and 3000 in increments of 5 may be entered in each of the eight leaf chamber configuration set-ups. Once the */Q given/* button is pressed the given value will conform to whatever configuration is being used at the time. Press the */Q rel/* button to return to measured values.
If the */Q hold/* button 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 however that when the */Q rel./* button is pressed the value for Q will return to *measured* not *given*.

Note: The given value entered in the configuration set-up is for PAR (Q) and <u>not</u> PAR (Q_{leaf}) which takes window and shield transmission factors into account. To obtain a specific value for Q_{leaf} the given value will need to be calculated. Given = Q_{leaf} / T_{rw}
E.g. Required Q_{leaf} = 2000µmols m^2 s^{-1} Q given = 2000 / 0.87 = 2299

4. ARABIDOPSIS & SMALL LEAF CHAMBERS

4.1 General description

These chambers are designed specifically to access small leaves that grow close to the ground. Due to their very small size they do not have light or temperature climate controls available and do not have a radiation heat 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 LCpro+ 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.

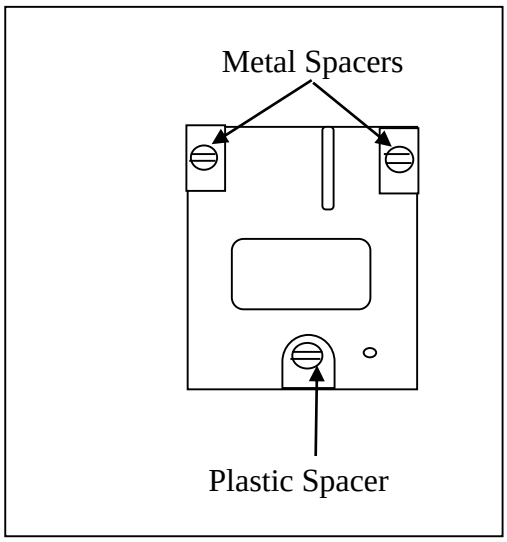
The chamber jaw has an offset spring that holds the jaw closed. When the jaw is opened manually the spring passes through the fulcrum point and holds the jaw open. When not in use the jaw should be left in the open position to prevent the gaskets from becoming compressed.

4.2 Configuring the Chamber for use with an LCi-SD

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 LCpro 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-SD these spacers must be fitted directly under the head of the captive screws as shown in the right–hand figure below.

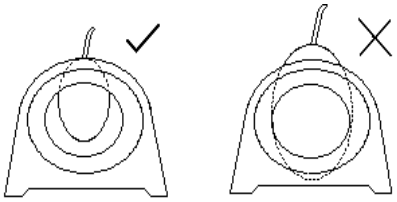
The configuration is as described below.

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:

The Arabidopsis leaf chamber (active window diameter 11mm) has an air supply in its base. A leaf in this chamber should be arranged so that it does not fully cover the chamber (see figure), otherwise there would not be any airflow over the top surface.



There is however, 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 these chambers, 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 both these chambers is small (being a maximum of $0.95cm^2$ for the Arabidopsis chamber and $2.14cm^2$ for the Small leaf chamber). 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. This will give a ΔCO_2 of about 10-ppm for the Arabidopsis chamber with a large active leaf. 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 an Arabidopsis leaf or 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 LCi/LCpro 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-SD and LCpro-SD.

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

To use the soil pot it should be selected as the chamber type in the configuration menu (see section 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 done. Note that 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 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-SD. An excess of air is provided to the hood over that extracted for measurement, and a pressure relief vent ensures that the hood 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 is monitored in the normal fashion by the chamber sensors T_{ch}, E_{an}, E_{ref}.
The soil temperature is measured with the special 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 "T_{leaf} probe error " will be seen on the instrument's 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 always use a temperature probe and configure the leaf temperature method to "measured" (T_lm).

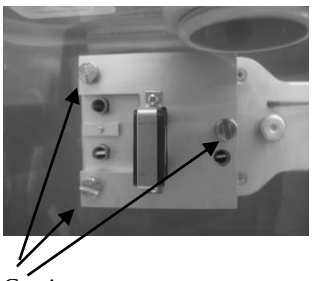
Since the air above soil can be near dew point the warning "analyser condensation risk" is more likely to occur than with leaf chambers. The risk of condensation can be removed if the instrument is at ambient temperature or above so ensure that the instrument is left on without making a measurement for 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.

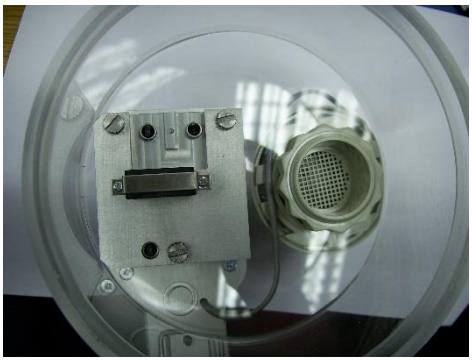


5.3.2 Attaching the soil pot to the handle

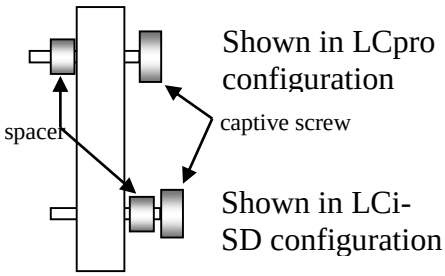
The soil pot is attached to the LCi-SD handle in the same manner as a leaf chamber, using the three captive screws. (See photo).

Important Note:

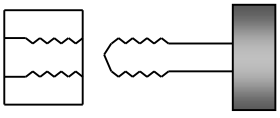
The LCpro-SD sensors are longer than the LCi-SD, requiring longer screws and spacers to be fitted. In order for the Soil pot to be used on both instruments the same length screws and spacers are used but their configuration is different. In the default configuration (suitable for the LCpro-SD) the spacers are fitted on the outside of the hood (see figure) and the fan drive screw's spacer (bottom screw in photo) is plastic to avoid a short circuit to the handle baseplate.



If the soil pot is to be used with an LCi-SD analyser, the spacers on the three screws should all be metal and fitted directly under the heads of the captive screws. (See figure right). An extra metal spacer is provided in the spares kit for this purpose.



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"

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 is in order to minimise 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 Photo).
Using the Insertion pad minimises the possibility of damage to the collar.

Note: Depending on the soil condition the user may feel the collar is not required and may insert the soil pot directly. This may disturb the soil to a lesser degree and allow measurements to be taken sooner than would otherwise be the case.
See "*5.5 other considerations*"

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, it provides best support 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 umbilical 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 (See also section 5.5 "Other considerations")

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 µmols 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.

5.4 Soil respiration measurements

The soil pot is now ready to begin soil respiration measurement, but 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 Calculated parameters and constants*".

Note: at a flow rate of 200 µmols s^{-1} it will take 15-20 minutes for the instrument to obtain an accurate reading starting from either the end of stage six if just done, or from the instrument having completed its warm up (indicated by a short bleep) having been switched on.

Important Note:
After refitting the leaf chamber it is important to repeat the flow check calibration.

5.5 Other considerations

The "Collar insertion pad" should not be left on top of the collar before a measurement, as the soil should be allowed to 'breathe' naturally.

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 enabling several test sites to be defined and the collars left in place. This also has the advantage that the collar is only inserted once, avoiding further soil disturbance, which is known to upset soil respiration.

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 cycle and should preferably be done at the same flow as the user intends to operate the soil pot.
The recommendations above are suitable for most applications but 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 µmols s^{-1}

When a soil pot is fitted, neither the temperature nor the light control should be activated either in a sequence or in climate control. This is because the control circuit will consume battery power to no good effect.

5.6 Soil pot constants

The only soil pot constant relevant for respiration calculations is the area so other leaf chamber associated constants are not displayed once the soil pot is selected. This has been pre-set to 97.5 cm^2 which assumes the collar is used (see section 3.3). This can be altered in the usual way changed with configure set up select.

Screenshot:

5.7 Soil pot Dimensions

5.7.1 Using the soil pot without a collar

The surface area of the enclosed soil is nominally **132.5cm^2**
The volume of the soil pot (without soil intrusion) is nominally **839cm^3 (839ml)**

5.7.2 Using the soil pot with a collar:

The surface area of the enclosed soil is nominally **97.5cm^2**
The volume of the soil pot (without soil intrusion) is nominally **803cm^3 (803ml)**

6. ROUTINE MAINTENANCE

6.1 Chemicals

The performance of the LCi-SD 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 green when fresh, to brown when exhausted. Some water content is necessary to assist the chemical reaction, which is to convert CO_2 to caLCi-SDum carbonate + H_2O. Re-conversion back to soda lime is not practicable.

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-SD 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, 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 one 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, 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-SD has an internal sealed re-chargeable lead-acid battery, which, when fully charged, operates the system for about 10 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-SD 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-SD off and, either recharge, or replace the battery. If a suitable external DC power source is on hand, connect it to the LCi-SD 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 Battery Replacement) and charged directly. The LCi-SD 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-SD 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.

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-SD OFF via the */power off/* function. Data held at the time will then be preserved. Batteries cannot be expected to last beyond 5 years. 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.

With the instrument upside down, undo the two fasteners on the base plate of the LCi-SD by rotating them a quarter turn; the base plate can then be removed to expose the battery. Disconnect the battery by gripping 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-SD RED lead terminal is connected to + and the black terminal to –. Fit the battery into the LCi-SD, and replace the base plate by rotating the two fasteners a quarter turn then pressing firmly until they are heard to click.

6.6 Battery Fuse

The battery fuse is a 20mm glass type located in a clip type holder alongside the battery under the base plate. This 1Amp fuse is connected in series with the battery 'positive'. The battery will need to be removed to access and change the fuse.
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-SD will have been protected from permanent damage.

7. SET-UP AND CALIBRATION

While in use, all the current attributes and settings are retained indefinitely by a non-volatile electrically alterable RAM. A small rechargeable battery supplies the clock. If the LCi-SD 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-SD power is re-applied, but it will be necessary for the user to set the date and time (See section 7.3).

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

The type of parameter which can be output is selected from those which are measured directly or indirectly by the LCi-SD or its leaf chamber, and usually after any compensation has been applied.

Appendix 1 lists the parameters available for analogue output, together with their expected 'offset', if any, and full scale output range.
The port output is scaled at 0.0V = zero or offset and +5.0V = full scale readings (see Appendix 2 for further details)

7.3 Time & Date Set-up

Pressing */configure / 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.

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.

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 below.
Analysis times for Soil chambers and Arabidopsis style 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 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 doing a flow check may result in insufficient settling time which may cause measurement errors because the gas concentration in the cell will not have had time to stabilise. It can cause an offset in the ΔCO_2 readings even with nothing in the chamber.

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

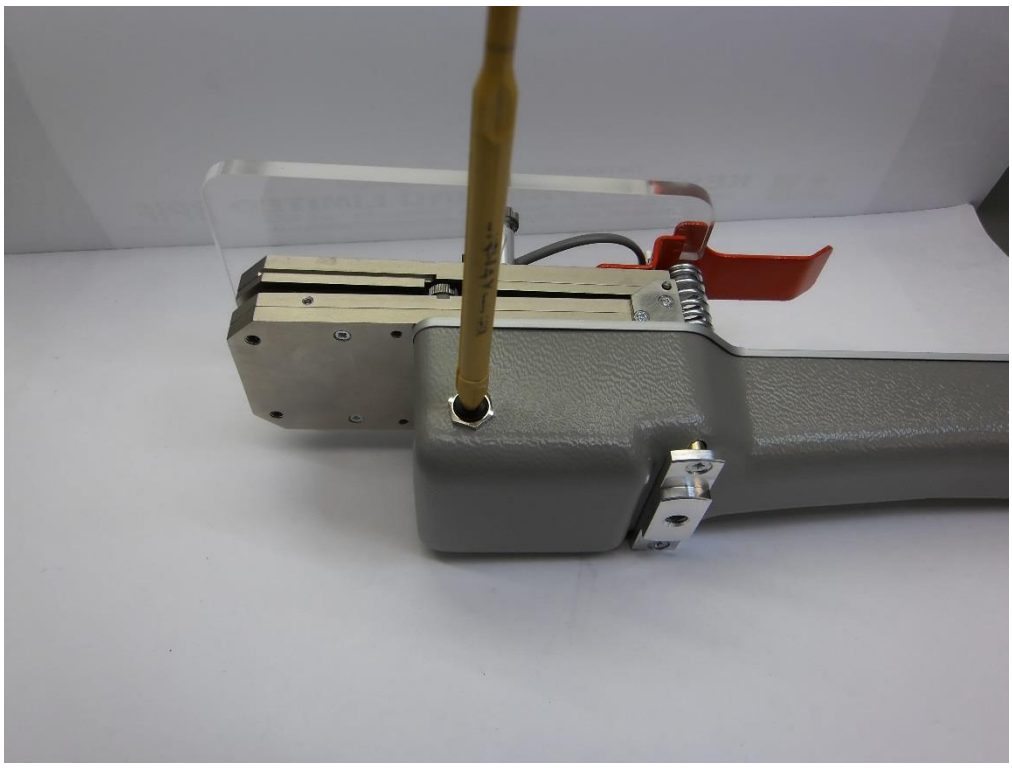
ASU set flow (µmols s^{-1})	Settling time (seconds)		Estimated flow (µmols s^{-1})	
	Reference	Analysis	Reference	Analysis
200	4.45	3.86	83	97
300	4.32	3.36	85	110
Variation	10%	10% - 25%	5%	10% - 20%

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 'zero' soda lime column must be kept in a non-exhausted state. 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 completely 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 */config/diagnose/*. The C(z) reading should lie between 50,000 and 60,000 counts. If this is not the case, the warning message "cref low, check absorber" will already be displayed and a hardware adjustment can be made.

To perform a CO_2 zero enter the calibrate menu, and select *CO_2 zero, do cal.* Adjust the relevant pot using the pot adjustment tool provided in the spares kit (see the following photograph below) to reduce the displayed count to within 100 counts of zero, turning it clockwise if the display shows a down arrow. A value within 10% of the range will be functional, and will cause 'OK' to be displayed. 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 one-degree steps between 65 degrees and 100 degrees 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 75 and 85 degrees. Anything outside this range may be an early indication of impending failure of the source or detector due to ageing or of contamination in the optical bench tubeset.

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

7.4.4 H_2O Zero Gas

Zero gas is most conveniently obtained from a cylinder of compressed gas, either air or nitrogen or any gas which is non-flammable and non toxic. If you are using an ADC type water vapour generator, the 'ref gas' outlet is dry.

It is not normally necessary to check the water vapour zero unless the sensor has been replaced.

Apply zero gas the same way as for water span gas in section 7.4.5 while the analyser is in normal analysis mode. Watch the water readings slowly fall and wait till they look stable before you select */H_2O zero/*. If you are not applying the zero gas directly to the back of the chamber, there will be a very slow downward drift of the readings. The processor looks for a stable reading before doing the zero, but will not detect very slowly changing readings

If you have calibrated the LCi-SD with the handle lid removed, be sure not to kink or squash any pipes when you replace it.

7.4.5 /CO_2span/ and /H_2Ospan/

This menu option should be used if you have access to suitable CO_2 and H_2O span gases of known concentration. The menu allows the calibrating gas concentration to be set to the value that you have available.

To check that the CO2 calibration is within reasonable limits, or to do an approximate calibration, unpolluted outside air can be used. Choose a location upwind of dense population or fossil fuel power stations, and use a figure of 390ppm.

Water vapour may also be checked against atmospheric air, once measurements have been made with wet and dry bulb thermometers converted to partial pressure. Alternatively, two bubblers may be used, connected in series, with the water no hotter than air temperature to avoid condensation in the pipes. Measure the water temperature in the second bubbler, and convert to partial pressure using the graph in Appendix 5.

Note; subsequent measurements will be compared with the span calibration values and therefore, at best, the absolute measurement accuracy will have the same tolerance as that of the span gas used.

7.4.5.1 CO_2 Span Gas

To calibrate the span setting for CO_2, a supply of CO_2 of known concentration is required. The CO_2 span gas can be in an 'air' type of mixture, i.e. with about 20% oxygen, or with pure nitrogen as the diluent. **In either case the gas must be dry**. Pressurised air, which is supplied from a cylinder, can be considered dry. By preference, the concentration should be between 40% and 90% of full-scale range; that is 800-1800 ppm.

There are two methods of connection for calibrating CO_2. Method 1 is preferable but slower and requires more Calibration gas.

Method 1: Ensure that the wetter column is empty. Apply CO_2 span gas to the "Air In" inlet at a pressure of 1.4Bar and T'eed off to relieve excess pressure. Wait for the Cref and C'an readings to stabilise then commence the calibration. (Note that setting a higher flow rate of about 300µmols s^{-1} will decrease the settling time to about 4 minutes)

Method 2: CO_2 span gas should be applied to the reference gas pipe coded with a white sleeve leading to the chamber. Apply a pressure of about 20cm water gauge, arranging a glass flowmeter in series to check that the chamber is periodically taking flow of about 200ml/min. Wait until the readings are stable before starting the span operation with */do cal/*.

7.4.5.2 H_2O Span Gas

The H2O span gas can be most conveniently supplied from a water vapour or dew point generator. H_2O span gas should be applied to the "leaf" gas pipe coded with a black sleeve leading to the chamber. Apply a pressure of about 11cm water gauge. There will be an extended stabilisation time of around 20 minutes due to the response times of the piping. Wait until the readings are stable before starting the span calibration with */do cal/*.

Water vapour may also be checked against atmospheric air, once measurements have been made with wet and dry bulb thermometers converted to partial pressure. Alternatively, two bubblers may be used, connected in series, with the water no hotter than air temperature to avoid condensation in the pipes. Measure the water temperature in the second bubbler, and convert to partial pressure using the graph in Appendix 5.

Although not advised, the following method may also be used.

Should a shorter stabilisation be necessary, the gas can be applied directly to the chamber. Remove the handle lid, pull off the pipe coded black, and apply the gas directly to the chamber. Only a very low pressure should be applied. A flow of between 200 to 500ml/min should be obtained, with the faster flow giving a faster settling time. Ensure that the chamber jaws are fully closed and wait for a stable reading before calibrating.

8. MEASUREMENT CONFIGURATION

8.1 The 'config' Function Menu

Refer to Appendix 8 for the menu tree
Use */config/* to get to menu */select/+/-/diagnose/*.
The various options can be chosen with */select/*.
Use /+/ &/-/ to alter the parameter selected. The type of chamber (cfg) you are using can be selected from: broad, narrow, conifer, soil pot, arab., small, user1, user2, user3. The chamber parameters, uset, area, Tl method, rb, Hfac, and Trw are stored separately for each type, and the LCi-SD is factory set with suitable default values that match the chamber supplied. You can change the parameters to suit your chamber and experiment conditions.

When the LCi-SD is switched on it will select whatever configuration was last in use.
User 1, 2 & 3 parameters mirror the Broad, Narrow & Conifer defaults respectively except for flow (Broad & Narrow) and Trw (Conifer).

See the table on page 36 for default values.

/*log*/ goes to the menu accessed from /*output*/*logging*/. See Section 9 for details.

/*cfg*/ is the leaf chamber type which may be /*broad*/, /*narrow*/, /*conifer*/ /*Soil pot*/ /*arab.*/ /*small*/ or three user defined types /*user1,2 & 3*/.

/*Uset*/ is used to set flow rates through the Leaf Chamber:

/*area*/ is used to input the effective leaf area exposed to PAR.

The area exposed depends upon the type of Leaf Chamber in use, and how much of the leaf is within the window area. . It is not permissible to cover the whole area when using the Arabidopsis chamber and so the user should set the area to match that of the leaf area exposed in the chamber.
When using Conifer Chambers, the 'area' may have to be established by experiment.
With Broad, Narrow and Small leaf chambers it is permissible for the leaf to cover the whole chamber so the FULL default area may be used
For the FULL leaf areas for each chamber see the table below.

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 the method with which the leaf temperature is obtained and toggles between /*calc* / and /*meas*/.

Note: the toggle function is disabled in the soil pot configuration, which defaults to measured

/*calc/* selects the value as calculated by the LCi-SD from the energy balance equation.

/*meas/* uses the temperature measured by the leaf temperature thermistor.

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

For Conifer type chambers, rb will be about 0.35, but is dependent on plant morphology and should be determined.
For Arabidopsis and Small type chambers rb has not yet been determined by experimentation but is expected to be in the order of 0.25 m^2 s mol^{-1}

/H_{fac}/ is used to enter the transmission factor of the total radiant energy into the leaf chamber at the exposed leaf surface. This factor is dependant upon the materials used in the construction of the shield and/or window of the Leaf Chamber. (For LCA2 & 3 types of analysers, this factor is referred to as '*Trans*'). Appendix 4 gives the derivation of H_{fac}.

/T_{rw}/ is the transmission factor of PAR into the leaf chamber at the exposed leaf surface ie 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 shield and window of the Leaf Chamber.
Arabidopsis & Small leaf chambers do not possess a radiation heat shield and so their transmission factor is 0.92

	U set	Area	Tl mtd	rb	Hfac	Trw	
Units	µmols s^{-1}	cm^2	n/a	m^2 s mol^{-1}	n/a	n/a	
Range	68 to 341	0 to 100 *	n/a	0.1 to 1.00	0.1 to 1.000	0.25 to 1.000	
Steps *[1]	1	0.01 *	n/a	0.01	0.001	0.01	
Chamber						with shield	without shield
Broad	200	6.25	Calc.	0.17	0.168	0.870	0.920
Narrow	200	5.80	Calc.	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	n/a
Small	68	2.16	Calc.	0.25	0.168	n/a	0.920
Arab.	68	0.95	Calc.	0.25	0.168	n/a	0.920
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	

*[1] The steps are greater when the /+/ or /-/ keys are held down.
*[2] The soil-hood range is 0 to 400cm^2 in 0.5cm^2 steps – given value is for a version 2 soilhood with a soil collar.
*[3]The Tl method cannot be changed from measured.

9. GRAPHICAL DISPLAY

9.1 Introduction

The LCi-SD 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 single parameter (bar chart) or dual parameter (X-Y plot). Dual parameter 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. The parameter(s) to be plotted are selected from the analogue output settings (See section 7.2)

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 single parameter Bar chart 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:

Single parameter bar chart.
O/P 1 parameter against time
O/P 1 parameter against record number

Dual parameter X,Y plot chart.
O/P 1 parameter against O/P 2 parameter (triggered by time)
O/P 1 parameter against O/P 2 parameter (triggered by record number)

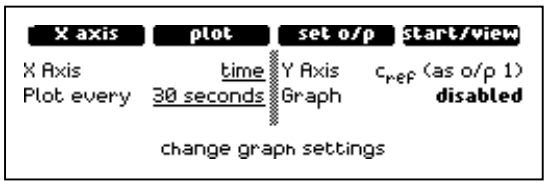
Time may be set to 15 or 30 Seconds.

9.2 Operation

Before entering the graphs menu it is advisable to set up the analogue outputs to the parameters required. This is detailed in section 7.2. Although the analogue outputs page can be accessed from the graph set up, once exited the LCi-SD returns to the top level menu necessitating re-entering the graph set up menu once again to complete the setting-up procedure.

Graphs are set up by pressing /*graph/setup* in the / *output /*, / *calibrate* / , / *graph /*, / *record* / screen./.

Screenshot:



The /*X axis/* button toggles the *X axis* setting between '(as o/p2)' and 'time' or 'log record' the latter being determined by the plot setting.

The /*plot/* button determines when a plot is taken. It cycles the *plot every* value between '15 seconds', '30 seconds' and 'log record'.

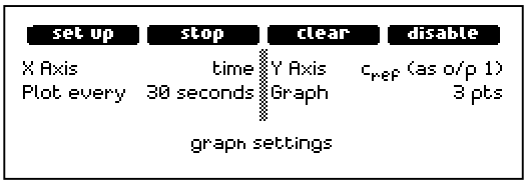
The / *set o/p /* button accesses the analogue output page where the graph parameters may be set.

The / *start/view /* button starts the plotting. It opens up the graphical display screen as a fourth top level screen.

To set O/P 1 against time for example first use /*X axis/* and select either 15 or 30 seconds. Use /*X axis/* to toggle to 'time' and press / *start/view /* when ready.

To stop the graph press / *graph /* in the / *output /,* / *calibrate / ,* / *graph /,* / *record /* screen.

Screenshot:



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

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.

Finally the /*set up/* button may be used to start a graph with new parameters as previously explained.

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 number of log files. The maximum number of log files that can be accessed is 60. 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 of Appendix 1. Parameter Information. 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

Taking a record can be initiated by any one of four methods:
1/ via the keypad, by pressing the "record" key when displayed.
2/ via the 'record' pushbutton switch on the handle of the PLC
3/ by closing a remote switch connected between pins 7 (12V) and 8 (CTS) on the 9 pin RS232 connector (it is necessary to set up the serial port to "use CTS for record" (see Section 7.1).
4/ by sending "r" or "R" over the serial port from a "dumb terminal" such as WINDOWS hyperterminal..

After a record is successfully taken, the LCi-SD beeps. If a log file has not been set, a message appears "log file not set, set now?". If you do not wish to take a record, the message is cleared by a second 'record' action or by pressing the */no/* button. When a record is 'taken', it is appended sequentially to previous records on the SD card. It is stored in the current log 'filename', as chosen by the user. The 'record number', which starts at '1', is automatically incremented. Parameter values are stored as signed integers, or in exponential form; the associated units of measurement are NOT stored.

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. The time can be scrolled from 1 minute to 100 minutes using */change-/* allowing longer times to be selected quickly.
Select */logging/timed log/ change+ or change-*. The analyser will default to 1 minute increments and automatically take a record and store the results after the selected number of minutes has passed. In order to select intervals synchronised with the gas cycle press */timing/* which toggles the mode.

Screenshot:

Selection of intervals synchronised to the gas cycles allows the maximum meaningful update rate and optimises noise performance.

The timed log will continue until it is switched off by selecting */logging/timed log/manual/* or the SD card becomes full. This 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" key or the record pushbutton on the chamber handle down continuously until the message "hold record key to delete last record" appears. Continue to hold the key or pushbutton pressed until "last record deleted" appears. If you release the key or pushbutton before the second message, no action is taken, and the message "record not stored" appears.

10.4 Sending a serial record

Rather than taking a record, it can be sent to the serial port. In this case, the record is not appended to the log file. Sending a record requires the serial link to have been set-up beforehand. (see Section 7.1). If this is attempted when the serial port has its CTS line enabled to initiate a record (see above), an error message will be displayed..

The record can also be requested via the serial port: a “P” or “p” sent to the port will cause the LCi-SD to transmit a single record. The serial data is sent in csv format, without labels or headers, in the following sequence:

record number, date, time, e ref, delta e, c ref, delta c, PAR leaf, t chamber, t leaf, flow mol, p mbar, ci, E, gs, A, area cm, rb.

Or if the soil pot is used:

record number, date, time, e ref, delta e, c ref, delta c, PAR leaf, t chamber, t leaf, flow mol, p mbar, ce, Wflux, *, NCER, area cm, rb.

Where * = no data

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 above, the ‘record number’ for the deleted record is transmitted a second time, with the message, ‘record deleted’. As in 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, NT and XP. For non-Windows systems, you will need to use a terminal emulator.

Note: The */xmodem/* option on the LCi-SD will not work with Hyperterminal on Windows systems.

1. Select Hyperterminal from the start menu: "START", "PROGRAMS", "ACCESSORIES", In WIN95 select "HYPERTERMINAL", in later versions select "COMMUNICATIONS"

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

3. Name your new connection e.g. LCi-SD, 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. The system will ask you to type in a phone number as it assumes you will be connecting via a modem. Ignore this 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	9600 (default) or as set on the LCi-SD
	data bits	8
	parity	none
	stop bits	1
	flow control	xon-xoff

5. Click on "OK"
   Ensure the settings match those on your LCi-SD before transmitting data
   (see section 6.1)

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-SD, which can be sent by pressing */send/ASCII/* on the LCi-SD.

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.

11. 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 1GB. 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.

11.1 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-SD will choose a default file name with a value one higher that that currently on the card. You can change the name if you wish by using the />/ /+/ /-/ and /*del*/ buttons.

Screenshot:

11.2 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).

11.3 SD Card Data Format

SD cards are preformatted in a DOS format and the LCi-SD stores data on the SD card using this format so files may be read with a PC which has a suitable card reader. Most current PC's and laptops have a card reader and if not external card readers are readily available at a modest cost. Since SD cards are suitably preformatted a format function is not required on the LCi-SD. In the unlikely event that the format of a card has been corrupted then it can be formatted on a PC.

11.4 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.

11.5 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-SD will looks like a mass storage device and will appear as another drive on the PC.

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

11.6 Storing Cards

In common with all computer storage media, they 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.

11.7 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-SD. 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 recognised manufacturers such as **Sandisk, Kingston** or **Transend**, are used.

12. HOW THE ANALYSER WORKS

12.1 Infrared Gas Analysis

The LCi-SD 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.

12.2 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.

As an interferent, 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.

12.3 Other measurements

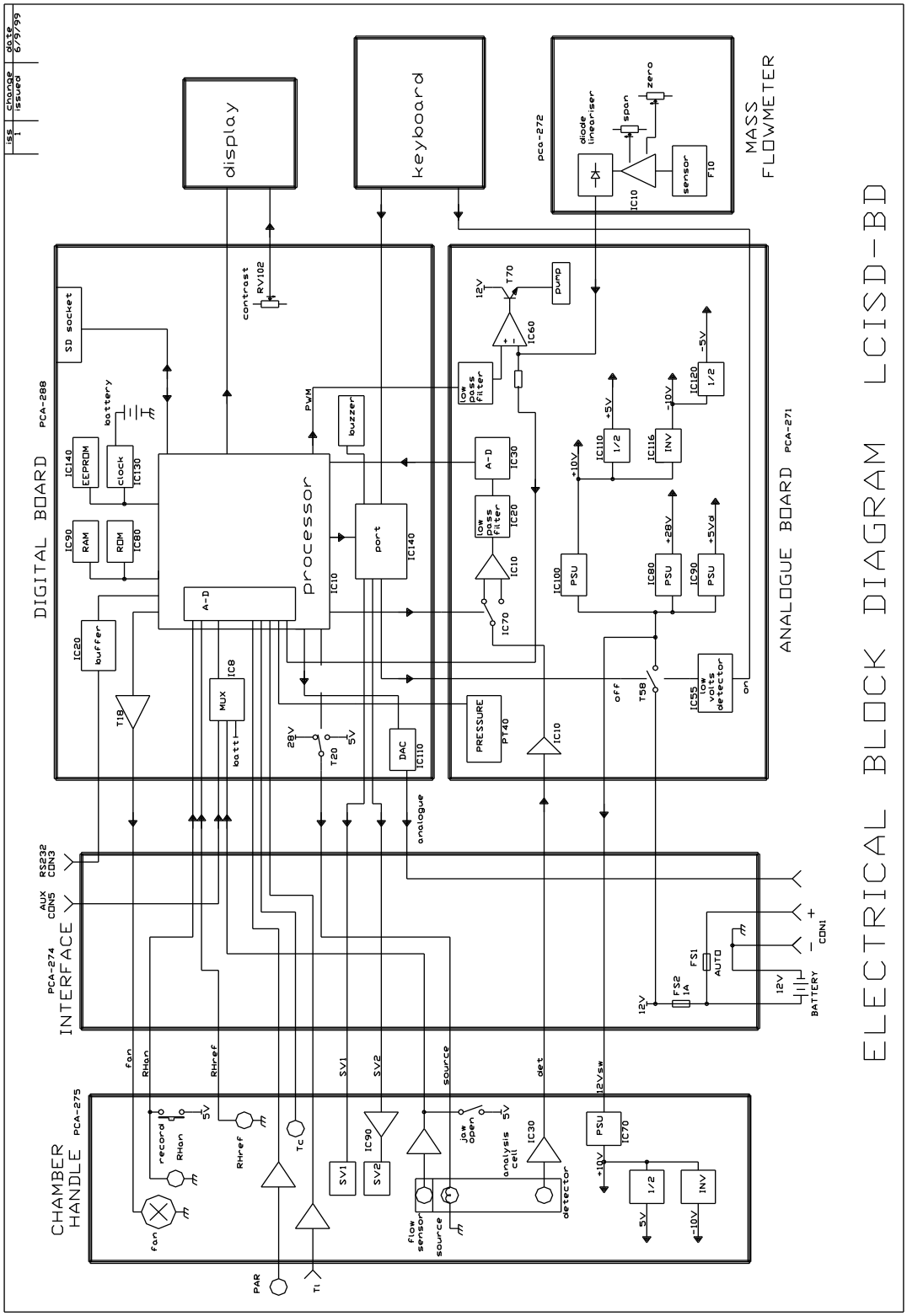
PAR (Q) is measured with a silicon-based sensor.

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

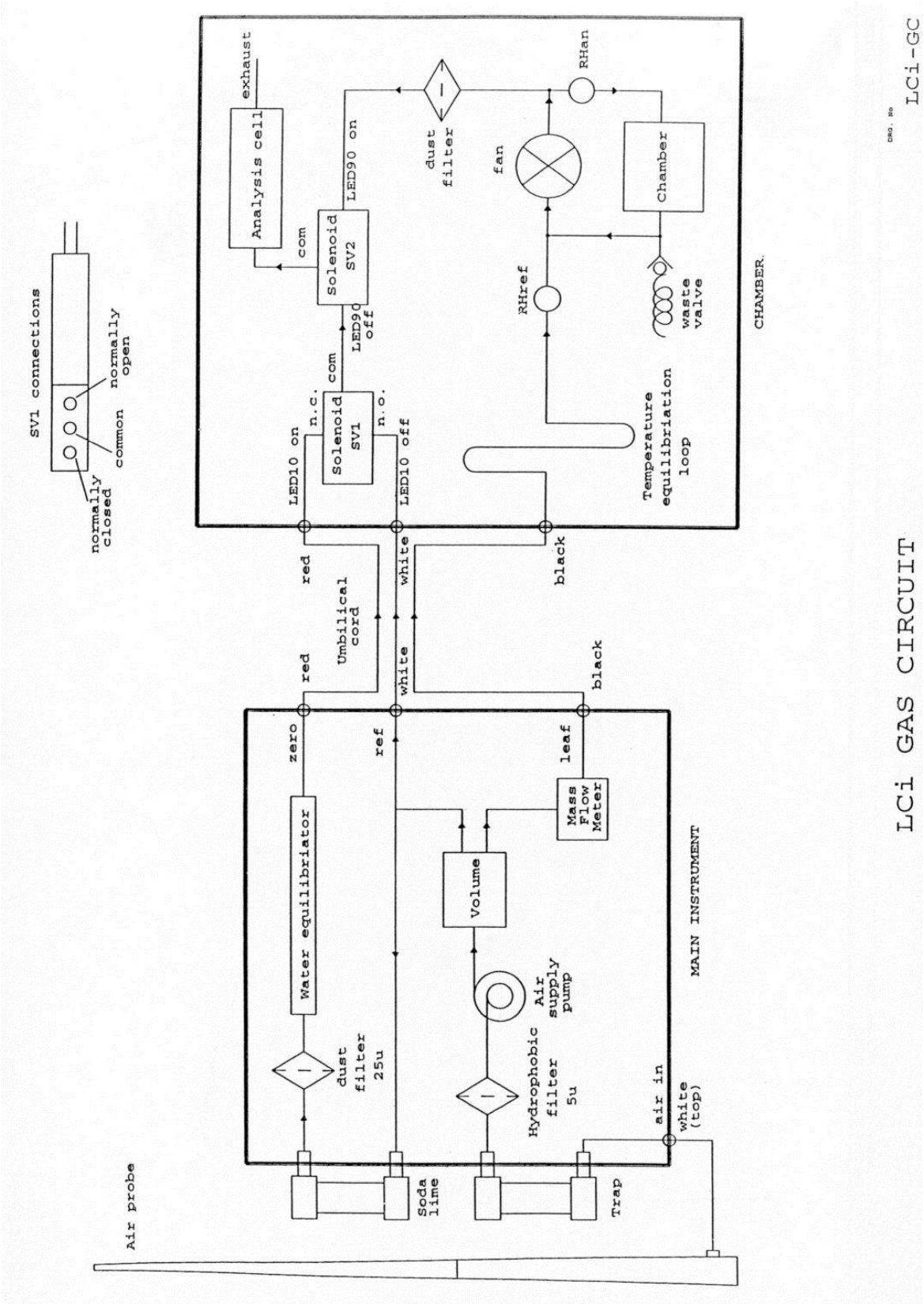
Leaf temperature (Tl) is measured by a miniature thermistor sensor. The thermistor can be positioned against the surface of the leaf. You can select an internally calculated value derived from the energy balance equation or the value measured with the thermistor.

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).

ELECTRICAL BLOCK DIAGRAM LCI-SD-BD



LCi-SD GAS CIRCUIT LCi-SD-GC



12.4 The gas circuit

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. 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 equilibriator 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.

13. MAINTENANCE

Note: When the LCi-SD is first switched on, the display shows the 'Instrument Serial Number' and 'Software version'. Always quote these in correspondence about the instrument

13.1 Tools

There are no special tools needed to dismantle the LCi-SD 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.

13.2 Accessing the Inside of the Main Instrument

With the LCi-SD switched off, unscrew the 4 screws securing the strap clips, then the 5 securing screws around the top bezel of the LCi-SD 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-SD 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.

13.3 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.

13.4 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.
Appendix 10 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.

13.5 Display Contrast Setting

The normal contrast setting for the display changes little with variations in ambient temperature. Manual re-adjustment to suit operator preferences is via the 'contrast' potentiometer on circuit board PCA-288 indicated in section 2.4. This can be accessed by removal of the top display section of the LCi-SD as previously described. See Appendix 7 LCi-SD Console exploded diagram.

13.6 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.

13.7 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.

13.8 Dismantling the Chamber

The radiation shield is removed by loosening (but not fully removing), the two knurled captive screws. The shield can then be slid out from the retaining slots on the jaw-opening lever. From serial number 31392 on onwards, the shield is hard faced both sides to minimise scratching.

The par sensor is permanently connected electrically and must be detached 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, (which is only likely to cause problems if dirt gets on the seat).

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 five ‘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 five '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 the gas circuit on page 48). 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.

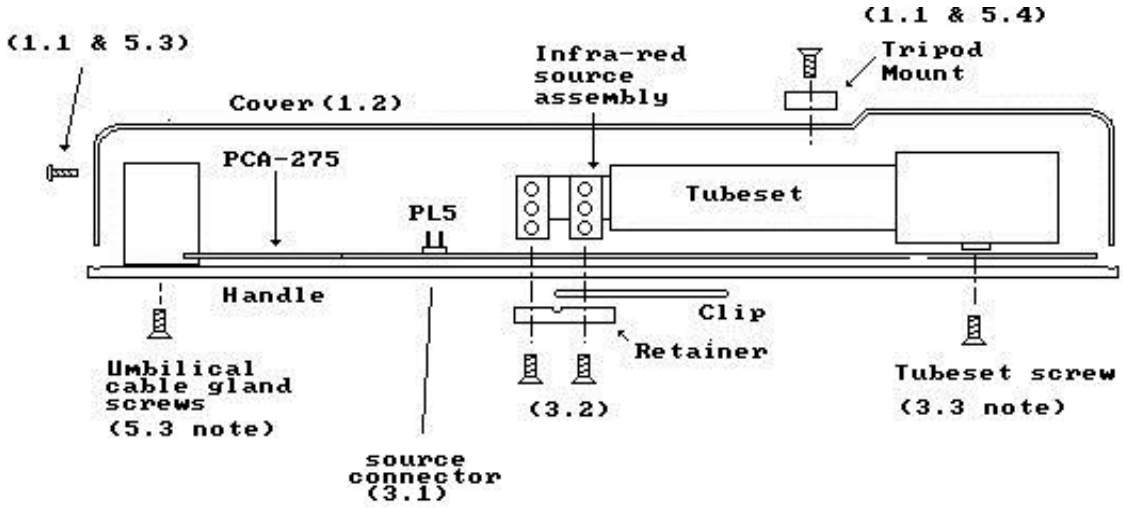
13.9 Removing the Handle Cover

Unscrew the two retaining screws from the tripod boss.
Note the orientation of the boss – On some instruments the fixing screws are not in the middle.

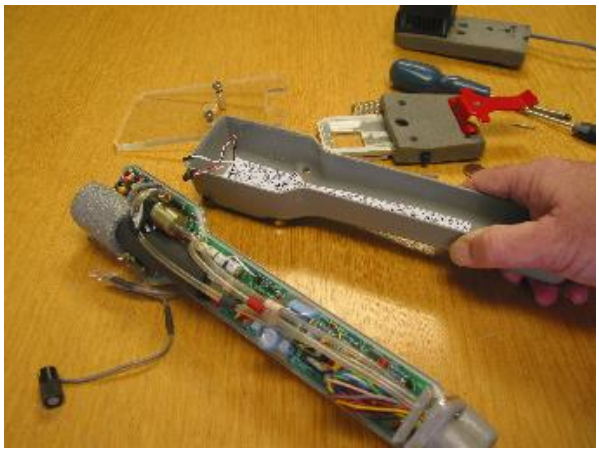
There are two screws holding the cable gland in place. Remove them both

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 CO2 zero potentiometer wires from the PCB.

On early models that have not been upgraded there is only a single twisted pair of wires from the leaf thermistor jack socket to PL20 on the board.

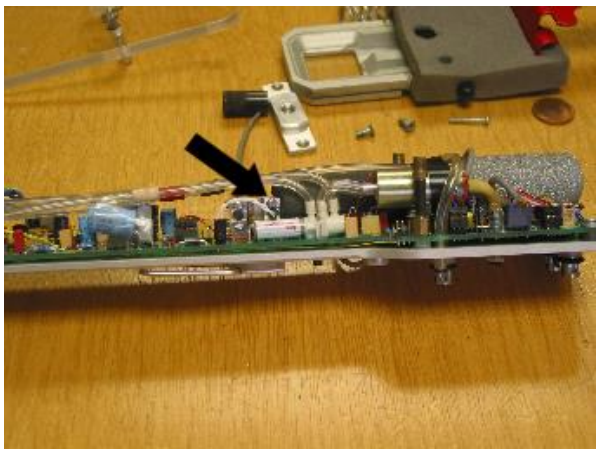


Later models have the CO2 zero potentiometer mounted in the handle cover instead of on the board so that an additional twisted pair of wires runs from the jack-socket assembly to RV9 on the board

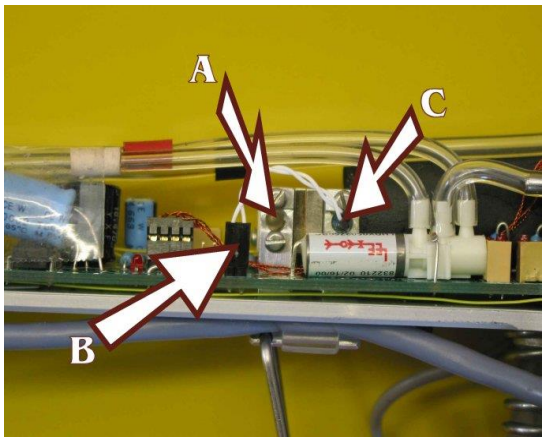


On the diagram/label in the handle:
R indicates red
B indicates black
W indicates white
X indicates no connection (polarising pin)

13.10 Checking the Source



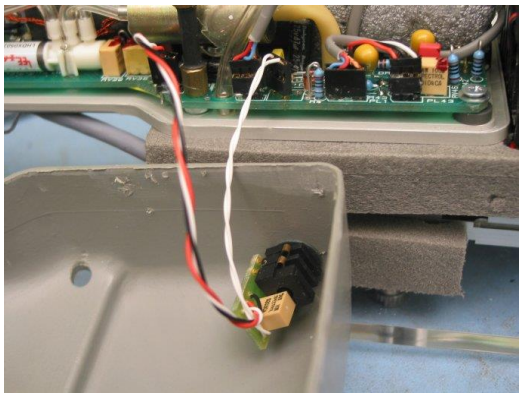
First remove the jaws and then the handle cover, (see previously). It is not necessary to completely remove the cover.
The source is indicated by the black arrow in the above picture**.** It is a small light bulb, which has been pre-aged to minimise drift. It has a thin envelope to minimise infrared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



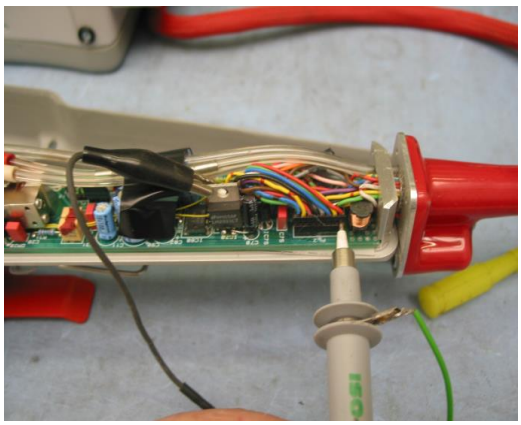
Look for flashing coming from the small window (A). This is best done in a dark area.
If the source has a white body then light can be seen through the body.
If there is no sign of flashing then unplug the source connector (B) and check resistance to see if the source bulb is open circuit.
If there is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

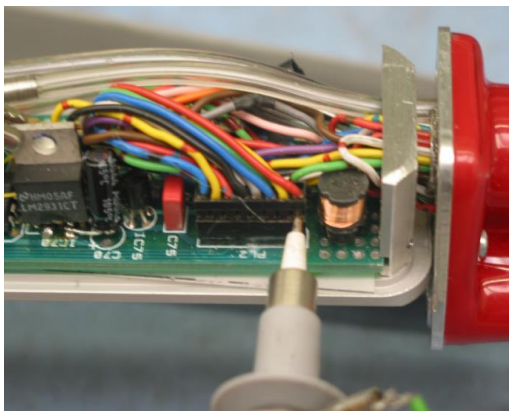
13.11 Checking the Detector



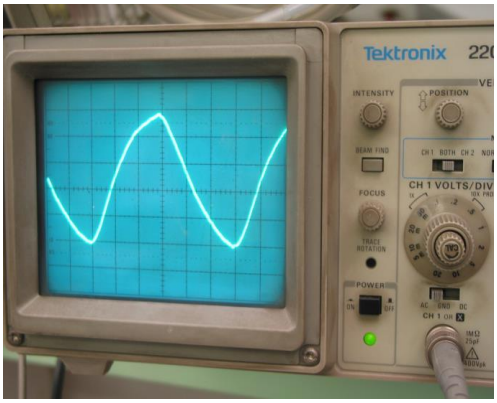
Before checking the detector, check the source is OK. Remove the jaws and handle cover, without disconnecting it electrically.
Check that the wires are not broken and that the connector is securely fitted to the PCB pins.



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



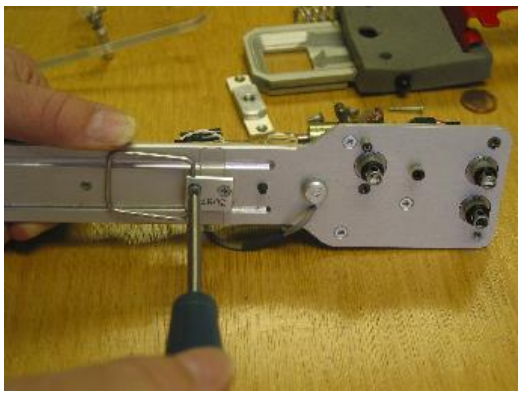
With a narrow oscilloscope probe measure the signal on the red wire of the connector. This can be done through the small hole in the side of the connector.



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 CO2 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.

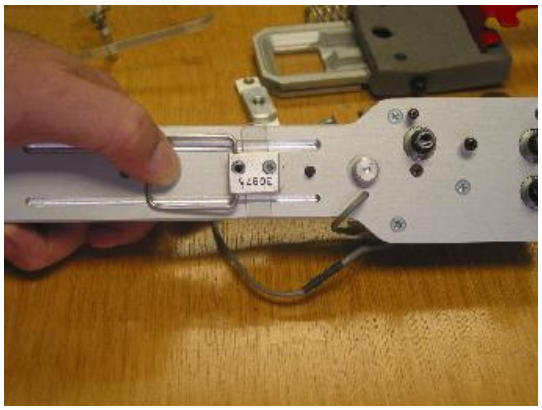
The detector can be removed with the cell in place. It is a static sensitive device and so static precautions should be observed as for changing the EPROM. Unplug its connector, and remove the large piece of insulation around the detector housing. Unscrew the knurled nut by turning it counter-clockwise, 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 instrument to warm up for 10 minutes and reset the CO2 zero as indicated in the manual.

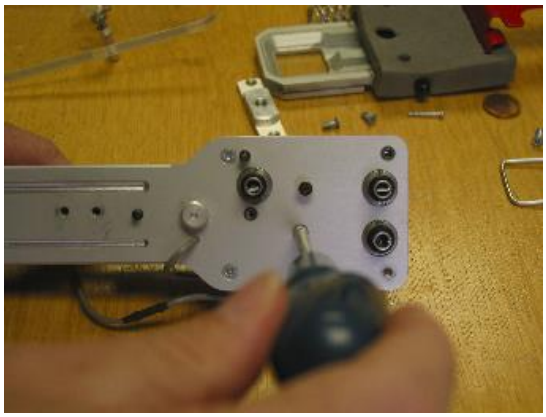
13.12 Replacing the Source



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

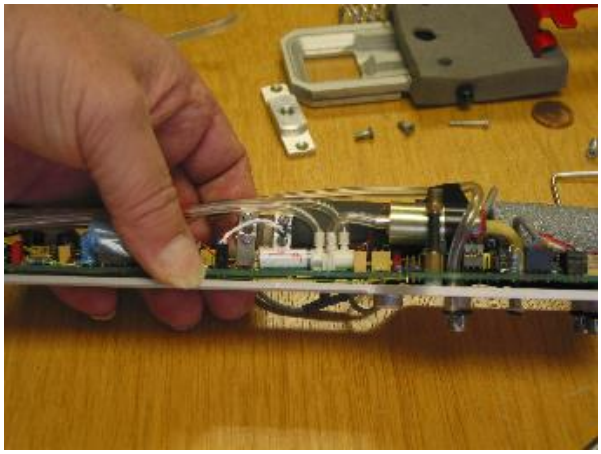
Note that the retaining screws are off-set and not central. Remember this when reassembling the handle.

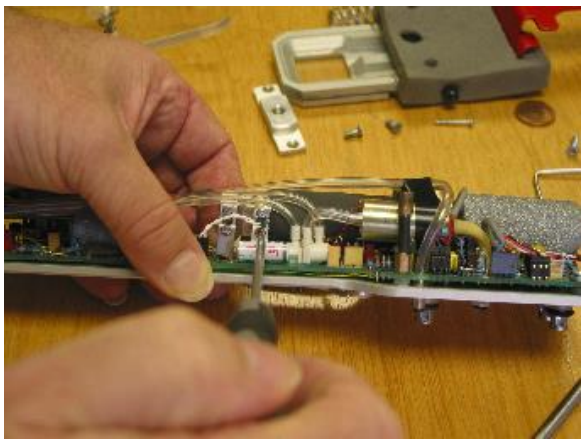




Unscrew the analyzer retaining screw TWO TURNS. Do not remove this screw completely because it locates the analyser cell at the detector end and prevents its pipe connection and detector wires being strained.

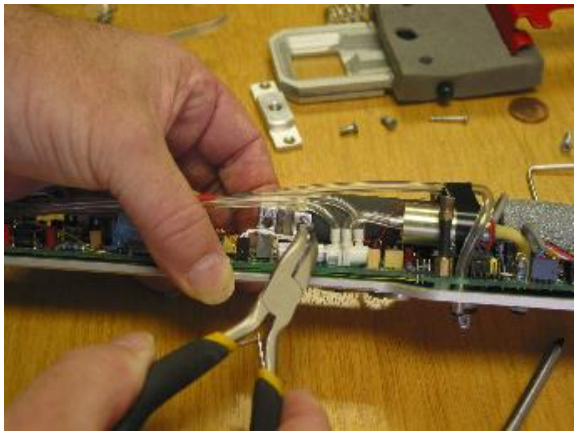
This will give you just enough slack to lift the source end of the analysis cell, giving you access to the lower source retaining screw. If there is not enough movement to get a screwdriver on to the sources lower screw then go back to the previous instruction and unscrew the analyzer retaining screw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

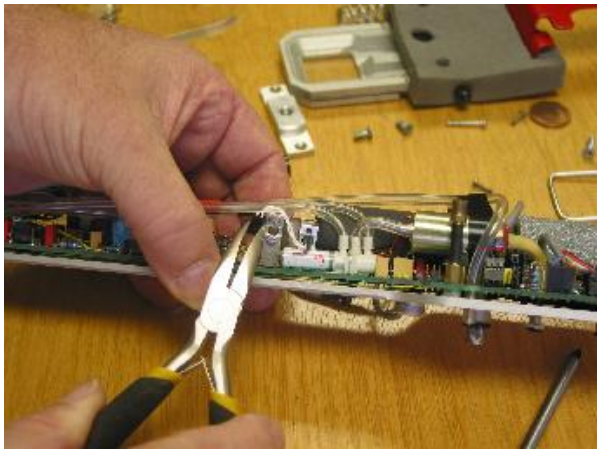




Using a small flat bladed screwdriver, unscrew and remove the upper and lower source retaining screws. These screws are stainless steel – Do not replace them with mild steel types.

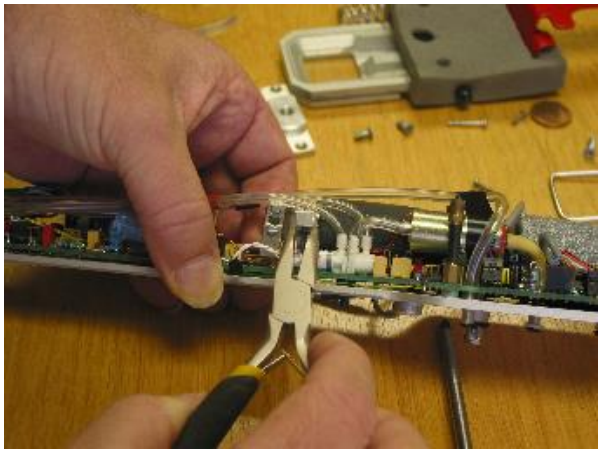
Using tweezers or long nose pliers gently pull out the old source from the analyzer cell. Take care not to allow any debris to get inside the analysis cell.

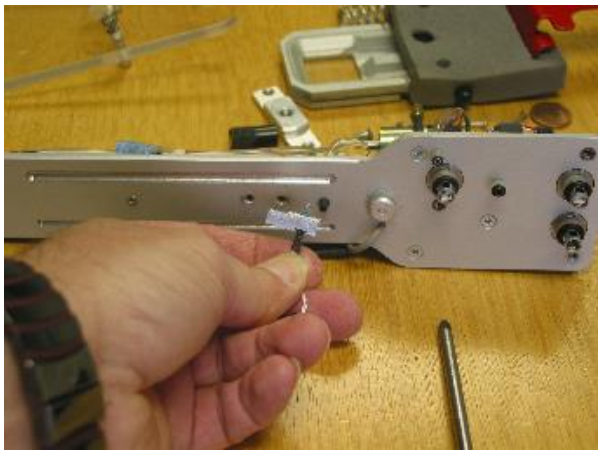




Disconnect the sources electrical connection from the circuit board.

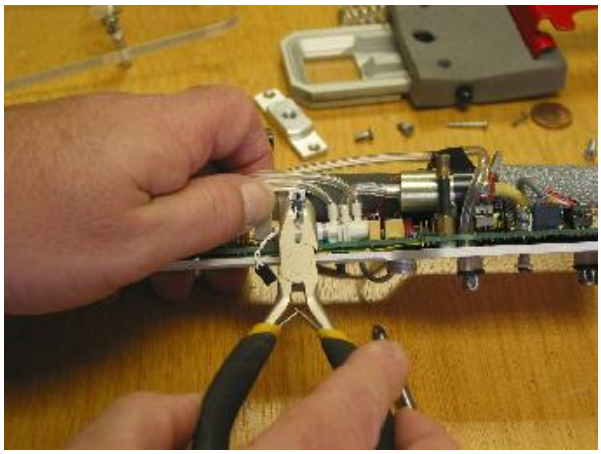
Then remove the old source.



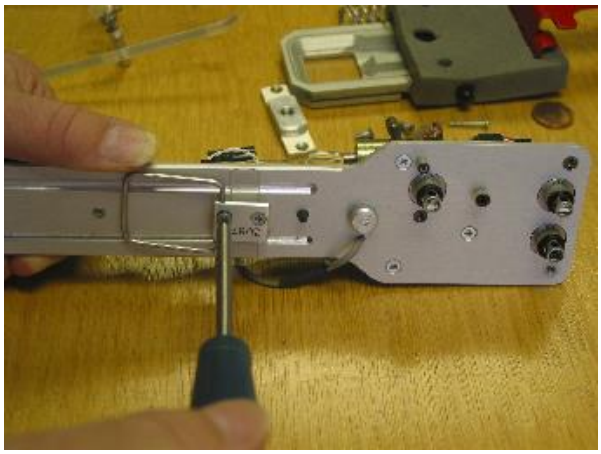


A thermal isolation gasket should have come off with the old source.

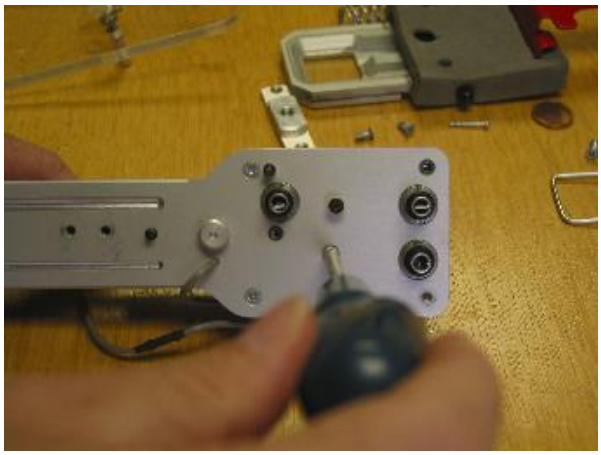
Remove the thermal isolation gasket from the old source and fit it onto the new replacement source.



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

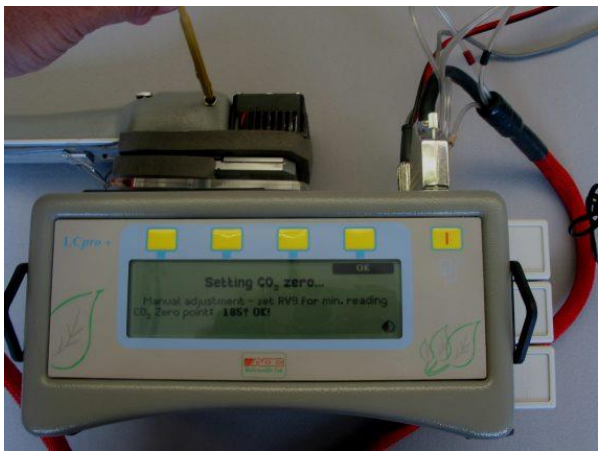


Refit the lever catch body, ensuring the correct orientation so that the body sits centrally on the handle.



Tighten the analyzer 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 CO2 Zero will need to be set. Follow the instructions in this manual or in the maintenance guide “Setting the CO2 zero on the LCi-SD”. If you attempt a zero before the analyzer has warmed up, it will prevent the zero taking place. Either wait for the warming up period or turn off, turn back on and press the left hand button while the serial number and software version are still on the screen. This will bypass the warm-up and allow the CO2 zero to be set faster.



13.13 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?	Analog o/p?	Screen	Units	Type	Range
Uset	Desired molar air flowrate			2 3 cfg	µmols s^{-1}	G	68-341
Us	Flow per unit leaf area				µmols m^{-2} s^{-1}	Ca	-
P	atmospheric pressure	12	y	1 hid	mBar	M	600-1100
Log:	Name of log file			3 cfg log		G	-
Power	Bargraph showing battery state			2		M	10.5-14.3
Rb	Boundary resistance to H2O	18		3	m^2 s mol^{-1}	G	0.1-9
rb set	Boundary resistance at full flow			cfg	m^2 s mol^{-1}	G	0.1-9
C'an	CO2 analysis (corrected for dilution)		y	1 *	vpm	M,Co	0-2000
^C	Delta CO2 (Cref - C'an)	7	y	1 *	vpm	Ca	+/-2000
Cref	CO2 reference	6	y	1 *	vpm	M,Co	0-2000
Ci	Sub-stomatal CO2	13		2	vpm	Ca	0-2000
Dt	Date (text)	2		diag			
Hfac	H factor - energy conversion factor			3 cfg		F,G	0.1-1
e'ad	H2Oanalysis, dilution corrected		y	1	mBar	Ca,Co	0-75
w'ad	H2O analysis, dilution corrected		y	diag	%RH	Ca,Co	0-100
^e	Delta H2O (w'an-Wref), partial p.	5	y	1	mBar	Ca	+/-75
^w	Delta H2O (w'an-Wref), as %RH		y		%RH	Ca	+/-100
Eref	H2O reference, as partial pressure	4	y	1	mBar	Ca,Co	0-75
Wref	H2O reference, as %RH		y	diag	%RH	M,Co	0-100
Area	projected leaf surface area	17		3 cfg	cm^2	G	0.1-100
Tch	leaf chamber temperature	9	y	1	°C	M	-5 to +50
u	ASU mass flow (measured)	11	y	2	µmol s^{-1}	M	68-341
Trw	Chamber window transmission factor			3 cfg		F,G	0.25-1
tleaf	Leaf surface temperature	10	y	2	°C	M,G	-5 to +50
Q	P.A.R. at window			hid	µmol m^{-2} s^{-1}	M	0-3000
Qleaf	P.A.R. incident on leaf surface	8	y	1	µmol m^{-2} s^{-1}	Ca	0-3000
A	Photosynthetic rate	16		2	µmol m^{-2} s^{-1}	Ca	0-100
Cfg:	Chamber type / configuration set			3 cfg			
Mem.	Free space on memory card			log	k bytes		
Record	Current record number	1		2 log			

The parameter list is continued overleaf.

The "type" column indicates the method of derivation, according to the following code:

- 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-SD)

(H_{fac} was Trans on LCA-3)

APPENDIX 1 PARAMETER INFORMATION (CONTINUED)

Symbol	Description	Log?	Analog o/p?	Screen	Units	Type	Range
gs	Stomatal conductance of H_2O	15		2	mol m^{-2} s^{-1}	Ca	0.00-1.00
rs	Stomatal resistance to H_2O				m^2 s mol^{-1}	Ca	0-100
Tl mtd	Leaf temperature determination method			3 cfg			
E	Transpiration rate	14		2	mmol m^{-2} s^{-1}	Ca	0-1
tm	Time of day	3		diag			
Vaux	Aux input, scaled as volts				Volts		
[cab]a	Infra-red absorption due to analysis CO_2			diag hid	%		0-40
[w]a	Raw H_2O analysis reading			hid	adc counts		
Vbatt	Battery voltage			diag	Volts		10.5 -14.3
Va(±20%)	Measured analyser flow				µmol s^{-1}		
phase	CO_2 rectifier phase shift			hid	°		
[cab]r	Infra-red absorption due to reference CO_2			diag hid	%		0-40
[w]r	Raw H_2O reference reading			hid	adc counts		
[c]z	Raw CO_2 zero reading		y	#REF!	adc counts		
W_{flux}	Net H_2O Exchange Rate	14†		2	Mmol m^{-2} s^{-1}	Ca	
C_e	Soil Respiration	13†		2	µmol s^{-1}	Ca	
NCER	Net CO_2 Exchange Rate	16†		2	µmol m^{-2} s^{-1}	Ca	0-100

† Indicates position in log when soil pot is selected

APPENDIX 2 ANALOGUE OUTPUT SCALING

Parameter & Symbol		Units	Reading @ 0V	Reading @ 5V	Units/V
Atmospheric pressure	(p)	mBar	600	1100	100
Analysis CO2	(c'an)	vpm	0	2000	400
Delta CO2	(Δc)	vpm	-200	+200	80
Reference CO2	(cref)	vpm	0	2000	400
Analysis H2O	(e'an)	mBar	0	100	20
Delta H2O	(Δe)	mBar	-5	+5	2
Reference H2O	(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 CO2 zero at TP20 [*1]	([c]z)	Volts	4.05	5	0.19
Raw CO2 zero Diagnostic [*2]	([c]z)	A-D count	53000	60000	1400

[*1] Volts measured at TP20 during zero parts of gas cycle or CO2 zero calibration.
[*2] A-D count optimally 56500 for "perfect" CO2 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} ($^{\circ}$C)

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

where

T_{ch}	leaf chamber temperature, $^{\circ}$C
Q	photon flux density incident on leaf chamber window, µmol m^{-2} s^{-1}
H_{factor}	energy conversion factor (was TRANS on LCA-3) 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^{-1} 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}

* 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})

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

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

† 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 $T_{leaf} >= 0$

$$e_s = 6.13753\,10^{-3}\, e^{\left(\frac{T_{leaf}\left(18.564-\frac{T_{leaf}}{254.4}\right)}{T_{leaf}+255.57}\right)}$$

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^{-1} 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 $45064.3 - (t_{ch} \times 42.9)$ 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 x 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-SD]

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 (Arab. & Small chambers)

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 generally are to be recommended.

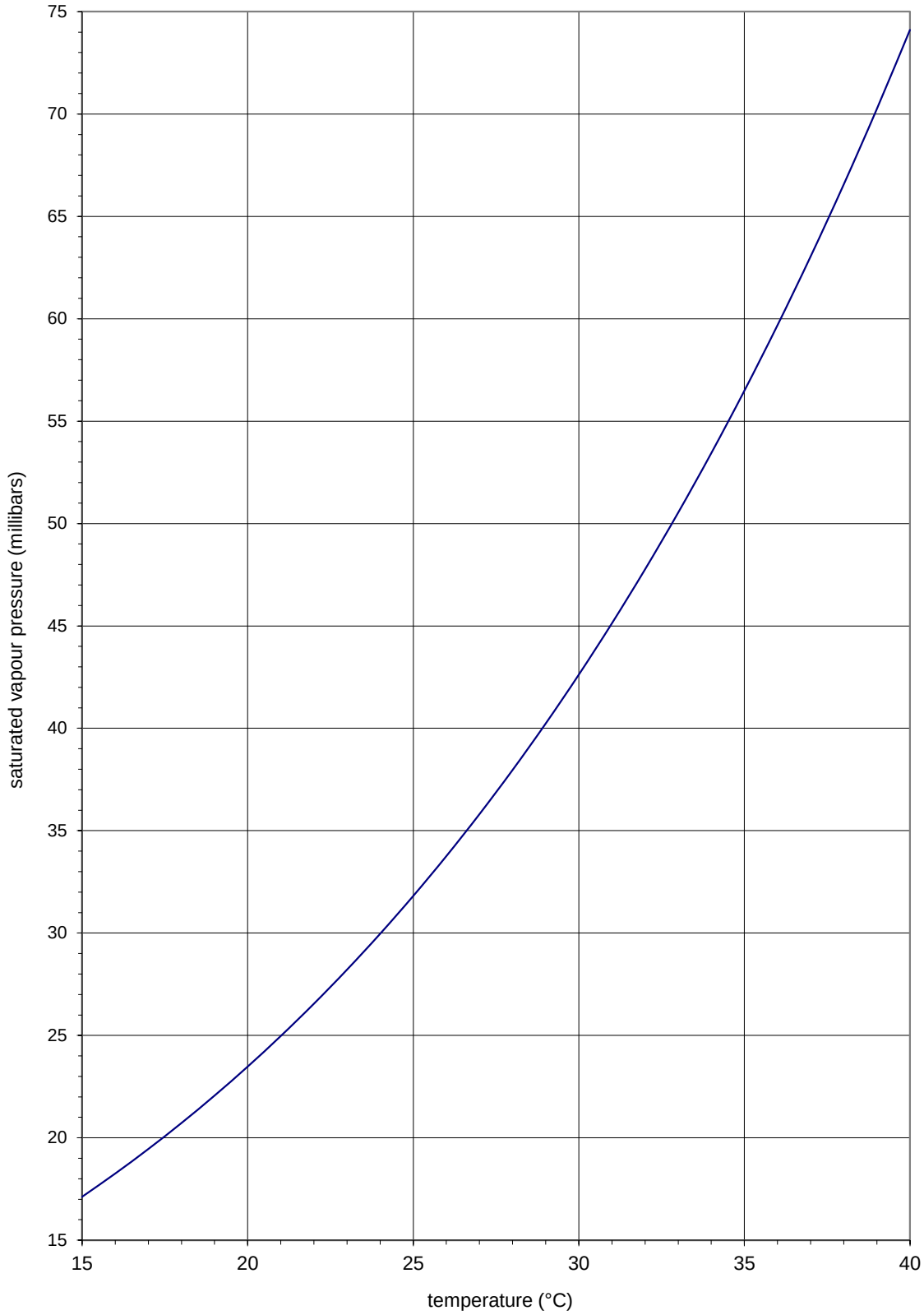
APPENDIX 4 (Continued)

Measured Hfactor values and conditions.

	PLC with Perspex Shield and Windows	
	PAR sensor outside chamber	**PAR sensor inside chamber**
LIGHT SOURCES		
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*

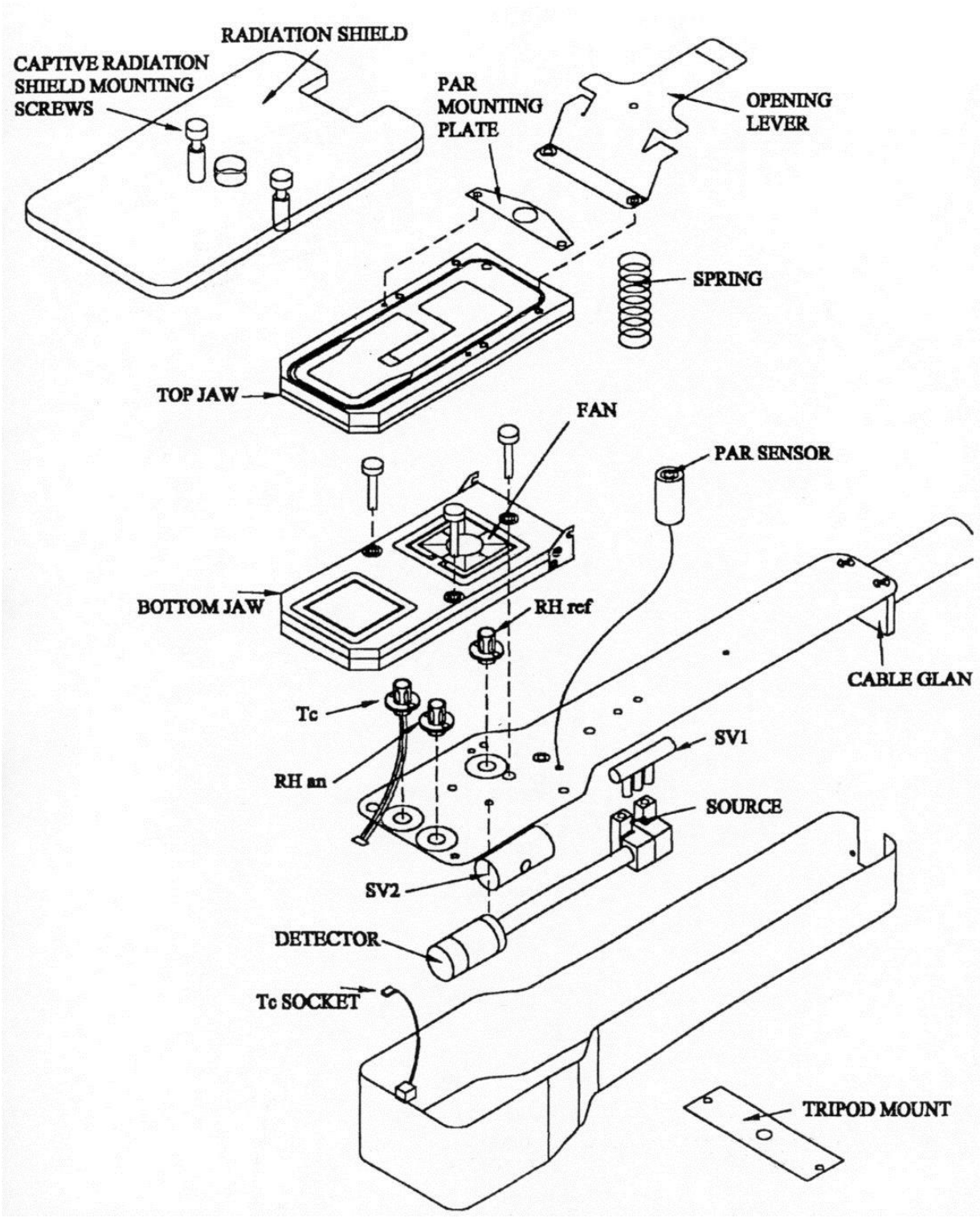
*Configuration used with the ADC Light Unit

APPENDIX 5 SATURATED VAPOUR PRESSURE

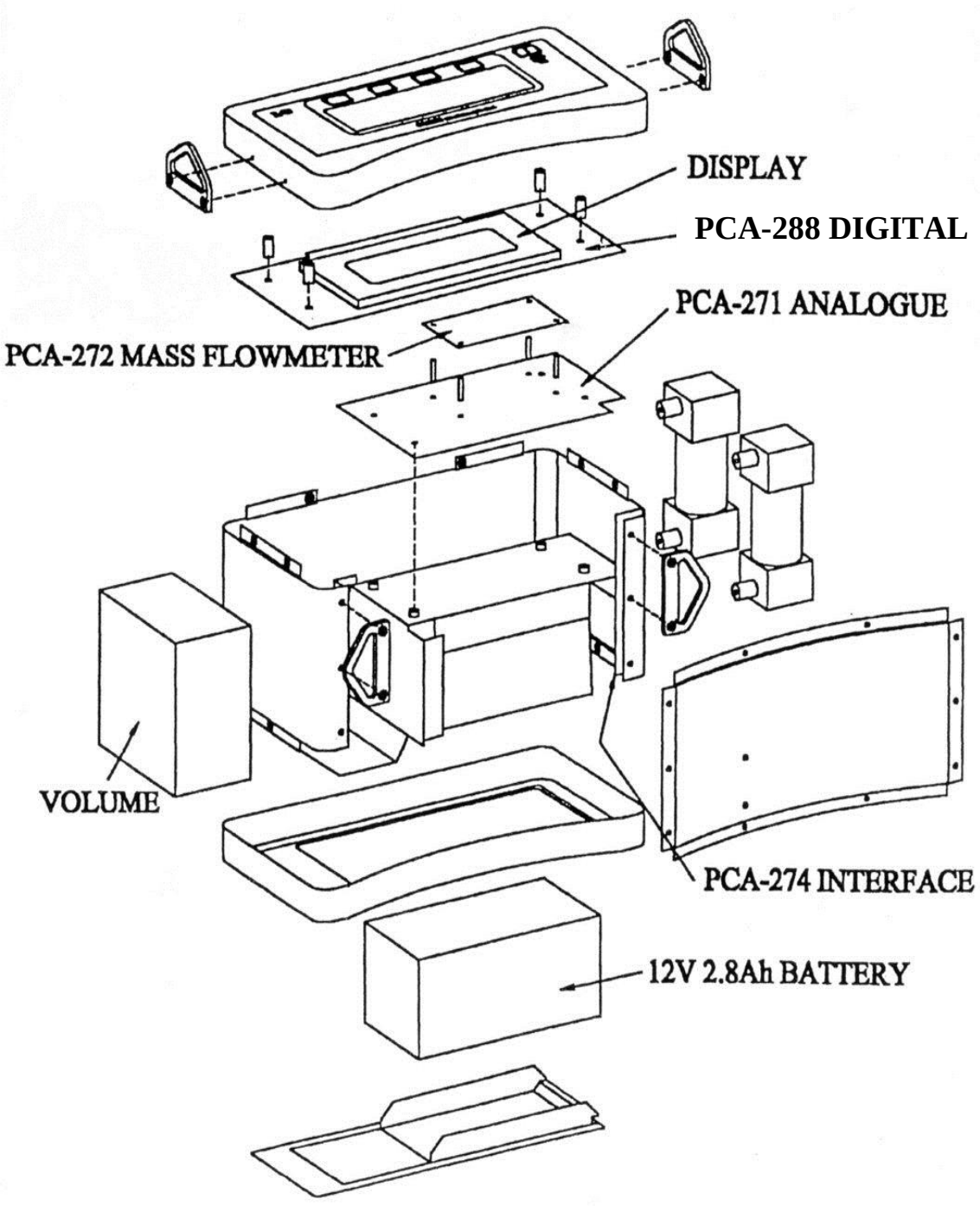


Graph derived from Table 94 of Smithsonian Meteorological Tables

Appendix 6 Chamber Exploded diagram

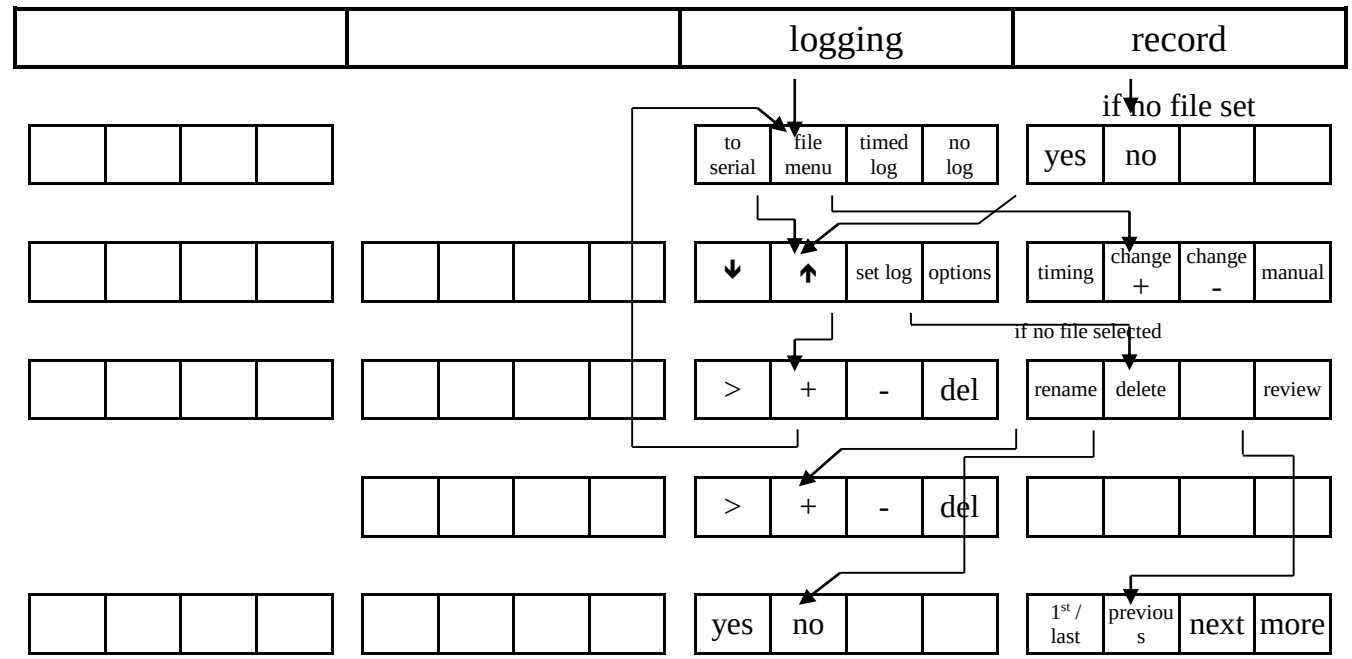


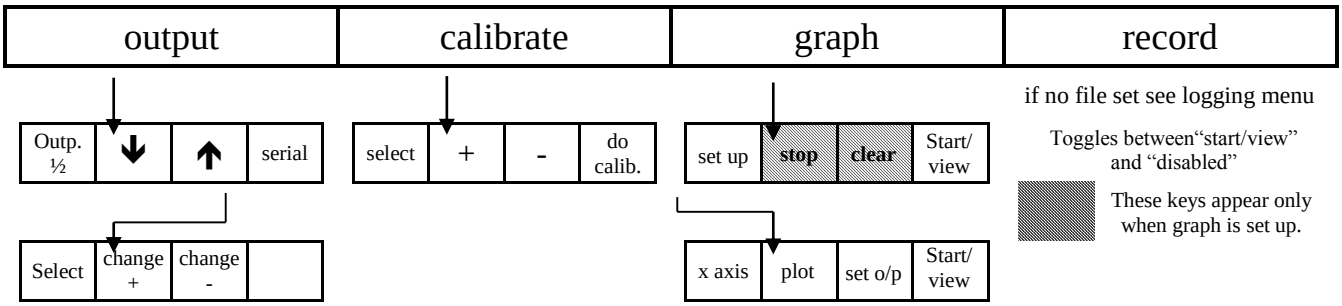
APPENDIX 7 CONSOLE EXPLODED DIAGRAM

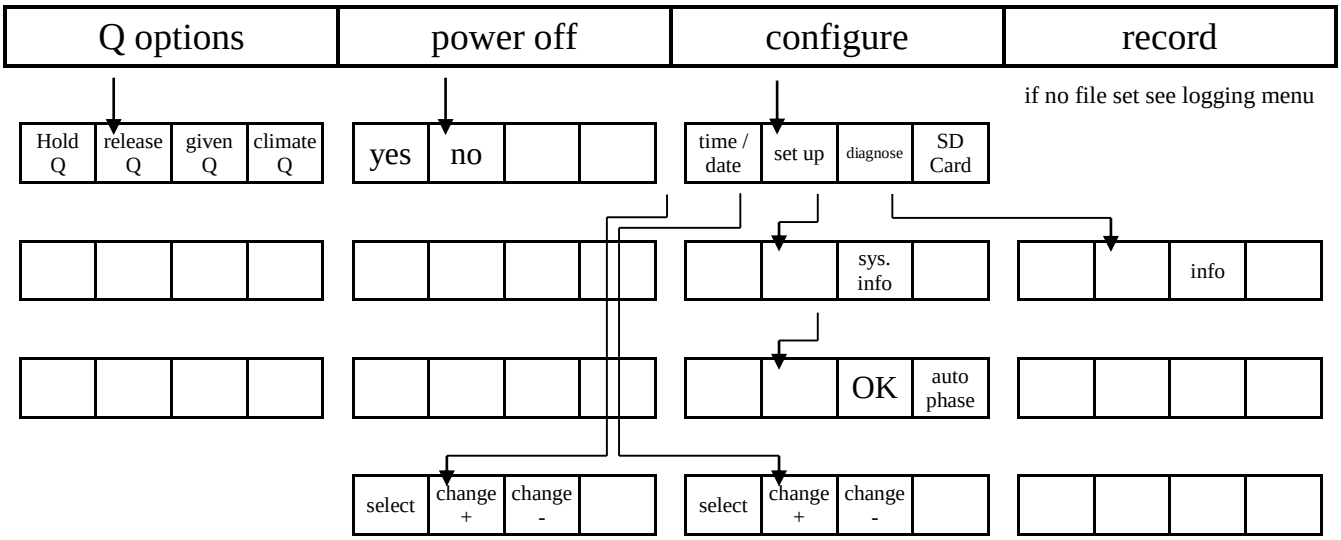


APPENDIX 8 LCI-SD MENU STRUCTURE

Pressing the "Page" key in "sub-level" menus returns to previous level except where shown. Pressing the "Page" key in the "top-level" menu steps through the three main pages.







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 in PLC:	100ml to 500ml min^{-1}	
Flow rate accuracy:	± 2% of f.s.d.	
Display:	240 x 64 dot matrix super twist LCD	
Warm up time:	5 minutes at 20°C	
Recorded data:	SD Card	
Battery:	2.6 AH lead acid 12V 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 (typical)	Console: Chamber:	2.4 kgs 0.6 kgs

APPENDIX 10 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
630-963	Hydrophobic filter
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
802-656	soda lime indicating 8-14 mesh
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
OP2-134	Column gas mixer
PLC-011	leaf temperature thermistor assembly