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CONTENTS

SECTION 1. INTRODUCTION

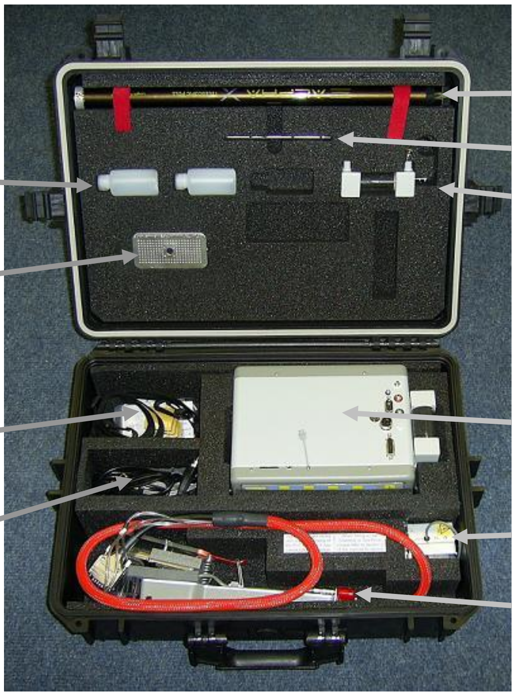
This manual covers the operation and maintenance of the LCpro-SD, Leaf Chamber & Soil Respiration Analysis System.

1.1 Equipment list

The LCpro-SD Analyser is supplied in a convenient carrying case containing the following items.

LCpro-SD Analyser "Console"
LCpro-SD Analyser "Handle" or "PLC"
LCpro-SD Lamp unit (*Broad, Narrow & Conifer leaf chambers only*)
"Wetter" column with co-axial lead
Carrying strap
Battery charger and "mains" lead
Air probe and ground spike
SD card
Leaf thermistor M.PLC-011
Spare chamber gasket set (*Broad, Narrow & Conifer leaf chambers only*)
Bottle for Soda Lime
Bottle for Drierite (Iron II Sulphate 7-Hydrate)
Handy "Menu structure" card
LCpro-SD "User guide" Manual (*This manual*)
LCpro-SD "Getting started" Manual

In addition to the above items there is a boxed "Spares kit" M.SKF-118 which contains some of the spares listed in Appendix 9



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 chips is used to protect both the case and instrument.

1.2 Description

The LCpro-SD (with its leaf chamber/soil pot) is specifically designed for portability and field use, and provides internal battery power suitable for between 4 to 16 hours of continuous operation, depending on the functions used. Its purpose is to measure and control the environment of a leaf contained in 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 with signal conditioning, air supply, microprocessor control, SD card data storage, a 5-button keypad and a leaf chamber connected by an umbilical cord. Where applicable the chamber is equipped with temperature control and a removable light unit. The main console supplies air with controllable CO_2 and H_2O concentrations to the chamber at a measured rate. The CO_2 and H_2O concentrations are measured, and the air is directed over both surfaces of the leaf. The discharged air leaving the chamber is analysed, and its (generally decreased) CO_2 content and (increased) H_2O content determined. In the case of the soil pot the CO_2 concentration of the air entering the hood is measured and the discharged air that has passed over the soil is analysed and its (generally increased) CO_2 content is analysed. An excess of air is provided to the hood over that extracted, 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.

From the differences in gas concentration and the airflow rate, the assimilation and transpiration rates are continuously calculated with a complete analysis cycle taking approximately 16-20 seconds. A small fan in the chamber ensures thorough mixing of the air around the leaf. Measurement of CO_2 is by an infrared gas analyser (IRGA). H_2O measurement is by two high quality humidity sensors. Similarly with the soil pot these measurements are used to calculate soil respiration. The system also measures leaf (or soil) temperature, chamber air temperature, PAR (Photosynthetically Active Radiation), and atmospheric pressure. The PAR level at the leaf and the radiant energy balance of the leaf are calculated, see appendix 3.

Measured and calculated data is displayed on the Liquid Crystal Display (LCD) on the front panel of the console. The first three screens of data, (as listed in the Log? column of Appendix 1), can be logged on to a SD memory card. The card, which is located in a socket at the front of the unit, can be removed by pressing the card. The stored log (file) can be viewed on the display, sent via the serial link to a PC or a printer, or loaded directly into a spreadsheet on a PC equipped with a SD card socket.

The measurements are carried out in an 'Open System' configuration in which fresh gas (air) is passed through the PLC (Plant Leaf Chamber) or soil pot 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.

Further information on photosynthesis and the measurement of it 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 the measurement of it can be found in

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

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.

SECTION 2. GETTING STARTED

WARNING: If fitting or changing a chamber please read section 2.8 for further information and advice before proceeding.

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

2.1 Checking the Chemical Columns (See photo on page 13)

The removable column nearest to the connectors optionally is either empty (for ambient H_2O use) or, using the column with the built-in temperature probe, holds iron sulphate (7 hydrate), which is used to increase the water concentration of air supplied to the leaf chamber.

The middle column is used to decrease the water concentration and should contain a drying chemical such as 'Drierite'. (Drierite is recommended as it contains an indicator).

The furthest column from the connectors contains soda lime, which is used to strip carbon dioxide. This is used both as a zero gas, and as a diluent when controlling the CO_2 concentration in climate control mode. On delivery the soda lime column is filled with an indicating Soda Lime, which is recommended.
To maintain the performance of the LCpro-SD, always replenish the Soda Lime when the colour first changes from white to violet. This colour change indicates that the soda lime is becoming exhausted for practical purposes. See also section 6.1.

IMPORTANT NOTE: The soda lime colour change is temporarily reversible until it is fully depleted.

To remove a column pull it outwards at the top and bottom, lift off the top cap, and fill it to just below the column top with the chemical. Compact the chemical by tapping the column on a solid surface several times. Make sure that there are no chemical granules remaining on the top edge of the column. Replace the top cap and refit the assembly. Ensure that all 'O' rings are lightly greased with the silicone grease supplied and that both ends are located tightly to prevent gas leaks.

2.2 Initial Preparation and air supply

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, but it is recommended first to leave the jaws open overnight, ideally somewhere warm to make certain the gaskets will not recover before replacing. (See Appendix 9 - Spares & Accessories) for part numbers)

With the chemicals installed, the leaf chamber is connected to the analyser with the 26-pin plug, and the three pieces of tubing (matching the three coloured sleeves on the pipes to the entries). Be careful not to put the instrument on a soft surface with these entries downwards, as they may become blocked, e.g. with soil.

The LCpro-SD system requires a fresh air supply and preferably one that will not be affected by operator breathing 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 levels are reasonably stable, preferably 3-4 meters above ground level.

The ADC air probe attached to the ground spike inserted into the ground provides such an arrangement, drawing air in 3 metres above ground level. The Air probe can also be fixed to a tripod. In use, the probe should be extended to its full length. Note that the air probe type LC4-070 shipped up to the end of 2015 is glass fibre, but its replacement type, LC5-070 is carbon fibre, which is conductive and should not be extended under overhead high voltage power lines due to the danger of electrocution. For laboratory use, a length of tube to the outside of the building away from traffic and chimneys will normally suffice. Good buffering against ambient changes can be obtained with a plastic 25-litre container by making two gas chance of water reaching the LCpro-SD. A much smaller volume, typically 4.5 litres may be used to buffer an external air supply used while working inside, see appendix 7.

The instrument contains connections in the lid, and arranging for the inlet pipe to reach to the bottom. This ensures maximum mixing and minimum an internal hydrophobic filter, which will protect against both dust and water, but this will quickly become blocked if the air supply is dusty and an external filter is not fitted. This is especially true in CO_2 climate control mode, when the instrument continuously draws in high flows (about 720 ml/min) of fresh air. To minimise this problem, a plastic bodied filter is supplied in the spares kit and should be fitted using 6mm bore PVC pipe as an adapter, in the air supply pipe, either at the instrument end or the far end, as convenient. Alternatively, there is a metal-bodied filter which is smaller but not so effective for dust. If used, fit it with the largest part of the body on the inlet side.

If elevated CO_2 is needed, a cylinder of gas should be fitted in the holder under the battery cover, see section 6.6.

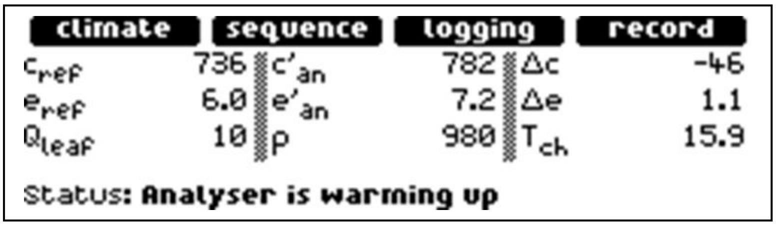
2.3 Switching On

The LCpro-SD is delivered ready for use with the internal battery fully charged and connected and the Soda-lime and Drier columns filled. The LCpro-SD defaults to the factory-installed settings, some of which may need to be changed for immediate use (e.g. time & date, serial link). It can be switched ON by pressing the front panel switch key at the top right-hand side of the display (shown in the text as I).

Note that after first switching on, the LCpro-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. If you wish to bypass the warm up timer, press the left button just after the LCpro-SD has been switched on and is displaying the software version and serial number. Note that if warm-up is bypassed the LCpro-SD will need to complete at least one full analysis cycle before normal readings are displayed.

A few seconds after switch-on, the screen displays a set of parameters and values. Pressing the ‘page’ or ‘on’ key will cycle between the three main pages. Appendix 7 – Menu Structure shows all the pages and how they are related. The ‘function’ headings along the top correspond to keys on the keypad above. The power off key is the only means of turning off (apart from disconnecting the battery). If the screen is very light or dark the contrast may need adjusting (see section 2.5).

Screenshot:



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

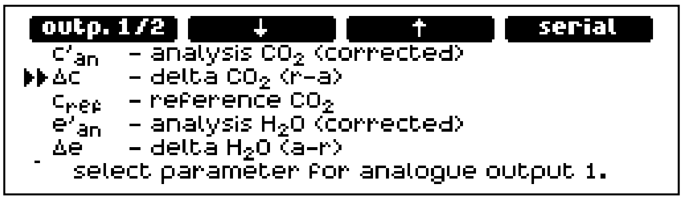
2.4 Electrical Connections (See picture on page 13 for locations)

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 LCpro-SD battery provided that the power requirements are modest.

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

On entry to the output menu page output 1 is shown.
The analogue output parameters are selected from the output menu page. (See screenshot). The outp1/2 key toggles between output 1 & 2 and the ↑ & ↓ keys are used to select the parameter required.



(See “An o/p column in appendix 1 for available parameters).

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

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

USB Connector

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

RS232C Connector

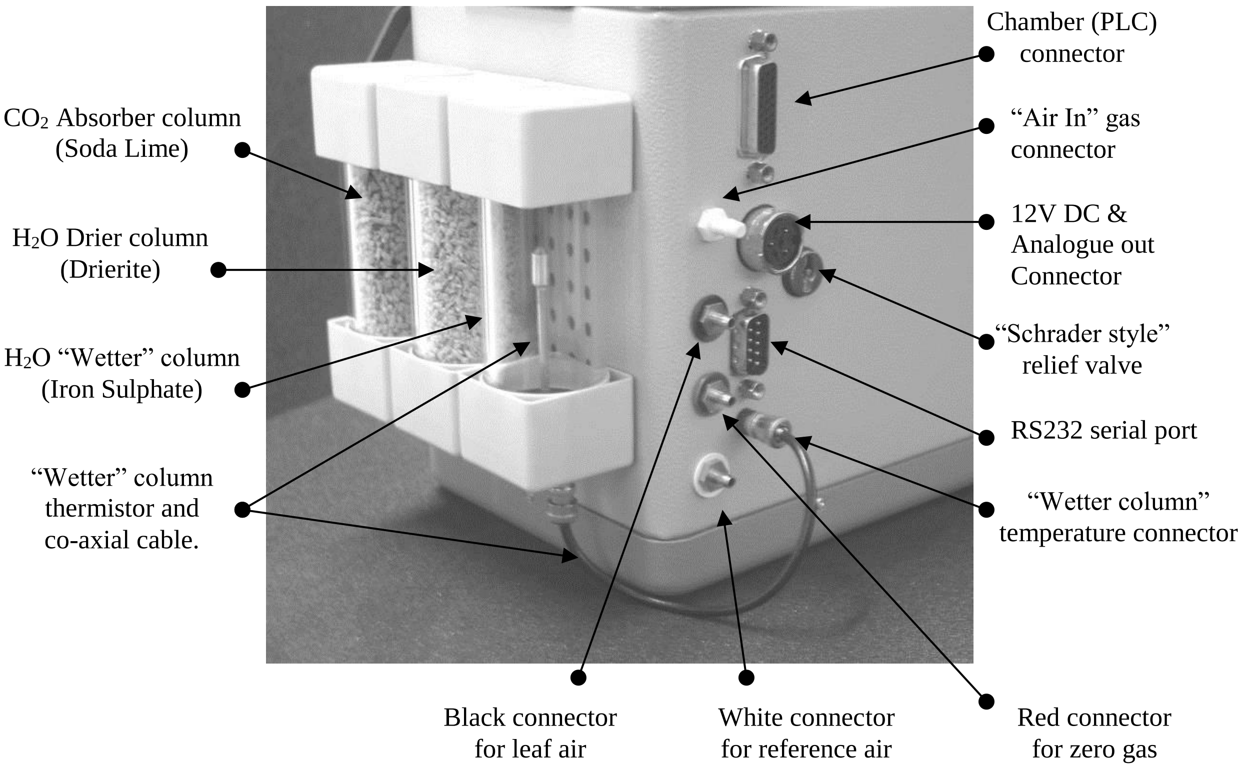
The RS232C connector mates with a standard 9 pin 'D' type null-modem serial link cable socket (female). A suitable cable is included in the spares kit. It provides RS232C signals and handshake lines to suit standard printers, VDU's, PC's etc. The user can set the baud rate and handshake protocols. The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

Column Temperature connector

It is intended that the column assembly fitted with the temperature probe is used with the humidifier chemical (iron sulphate), and connected to this socket with the lead assembly supplied. This allows the instrument to calculate the maximum humidity level available, and set the mix ratio accordingly for any lower level which may be requested.

2.5 Display

The Display unit is a LCD type with an adjustable contrast control. If the user prefers a different contrast level, adjustment is available on the PCA-288 'digital' board. using potentiometer RV102 (Located in the right hand corner of the board).
(See Section 16.2 for how to gain access to the potentiometer)



2.6 Error, Warning & Status Messages

If after switch on, the screen remains blank – check the battery is fitted &/or charged.

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

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.

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

A warning message indicates 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.

2.7 Low Battery Voltage

The internal battery voltage is monitored to detect if the battery is close to being fully discharged. This occurs at 10.8 volts, whereupon a **'Battery Low'** warning message is overwritten on the screen.
At this point, there is typically about 5 minutes life left in the battery. This should be sufficiently long for the user to either connect a charger or complete his current record. If the warning message is ignored the LCpro-SD will switch itself off when the battery voltage has fallen to 10.5 volts!
The battery power is shown as a bar graph at the bottom of screen page 3, and numerically on the diagnostics page. The battery should be recharged (see section 6.3) after any significant period of use or if it is less than 12V

2.8 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 built-in leaf thermistor (where applicable – see next paragraph) and the ground return.

Note that only the Broad and Narrow leaf chamber jaws feature the built-in leaf thermistor. The Conifer leaf chamber jaw, Arabidopsis and Small leaf interface blocks and the Soil pot do not feature a built-in thermistor and the screw is grounded.
In all cases care should be taken as described below.

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

Before fitting the chamber, check to see that the five “O” rings are all in place (two gas stems and three sensor housings) and that the three captive spacers are free to move and not engaged on the screw threads. (There should be about a millimetre free play up and down the shaft of the screw). There is a spare set of ‘O’ rings in the spares kit.
When fitting a chamber, press down on the jaw itself then turn the three captive screws evenly USING THE FINGERS OR AN ADC JAW SCREW ADJUSTMENT TOOL 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.

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

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.

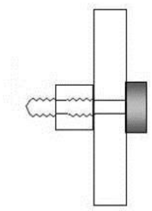
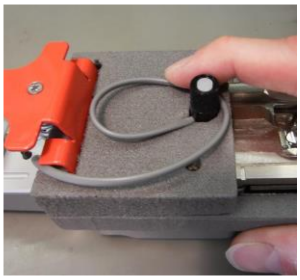
.

Removing and fitting jaws on the LCP system.

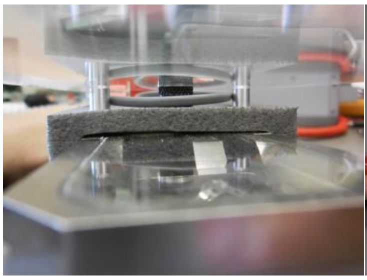
Broad jaws, upper and lower, collectively known as the chamber (first photograph above left). Remove from the handle as follows…
Remove the radiation shield, pull out the PAR sensor then remove the upper jaw as shown.

Use the correct tool (LCi-220) to undo the screws, remove the cable from under the cable clip (LCM-166) and pull the peltier plug out of its socket. If this is difficult then push the plug against the socket, keep it held tightly together (it consists of two parts) and pull it out. DO NOT PULL THE CABLE!

Remove the lower jaw and retrieve any o rings that have come off with the jaw (a cocktail stick or blunt tweezers is ideal), take care not to damage the o rings.
Ensure the spacers/o rings are present and correct on the handle as shown above in the second photograph.
A jaw may now be fitted to the handle…
Make sure the jaw screws each have a threaded nylon spacer, and that each spacer is fully threaded onto the screws as far as they will go, the jaw screw spacers are half threaded and must go onto the screws as shown in the first photograph below (next page).

Push the lower jaw onto the handle, tighten each screw in turn by hand then with the jaw screw tool (LCi-220) until the tool just starts to bend. **Do not over tighten with a coin/screwdriver.**
Attach the jaw spring to the upper jaw and fit as shown above (third photograph).
Mount the PAR sensor as shown in the final photograph above, with the cable laid as shown.

Fit the radiation shield as shown above, taking care not to trap the PAR cable.
Finally plug in the peltier cable, tuck it under the cable clip (LCM-166), and latch the jaw lever open if the jaws are not to be used right away.

Always inspect the gaskets on a closed jaw before use to make sure that there are no gaps, gaps may be reduced by temporary use of an elastic band around the jaw or by squeezing and releasing the jaw by hand to compress the foam gaskets.

<u>The Jaw Screw Adjustment Tool (LCi-220).</u>

Tighten the screw as shown opposite <u>, until the tool just starts to bend</u> and then stop.

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

SECTION 3. THE LEAF CHAMBER

Note: Sections 4 and 5 contain further information on the Arabidopsis and Small leaf chambers and on the Soil pot.

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). There are five styles of leaf chamber available. These are Arabidopsis, Small, Broad, Narrow and Conifer leaves. Refer to section 4 for a description of Arabidopsis and Small leaf chambers, which are very different in design to the other chambers. The Broad, Narrow and Conifer leaf chambers consist of a top jaw, which may be fitted with a radiation shield or light unit, and a bottom jaw containing a Peltier cooler (see paragraph 3.6). Broad and Narrow leaf chambers also feature a built-in leaf thermistor commonly known as a “Spider” and “Snail” respectively because of their appearance (see paragraph 3.5).

The handle contains 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 LCpro-SD console.
A cable is attached to the handle linking the electrical signals and gas lines to the LCpro-SD console. Repeated flexing can break the cable. When storing the chamber try to avoid tight bends especially where the cable joins the handle and the “D”-type plug and do not store the cable by wrapping it around the handle.

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

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

In order to access or change any parts of the chamber, loosen the radiation shield mounting screws a few turns (it is not necessary to remove them completely). Lift off the radiation shield and pull the PAR sensor off its mounting plate. While holding the jaw fully open against the spring, twist it slightly so that the hinge pin slides out on the slotted side. To change a chamber or access the temperature and humidity sensors, the three fixing screws and lower jaw can now be unscrewed about 6 turns. It is not necessary to completely remove them, as they remain captive in the jaw. 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 and over-tightening should be avoided as damage may be caused.

If the chamber is changed, it is necessary to inform the analyser using configure setup and change + or change – until the chamber type displayed matches the chamber type fitted. In so doing, the appropriate factory default values of r_b, H_{fac}, and T_{rw} (see below and section 3.3) are automatically chosen, and they may then be individually adjusted if required. Any changes made to the values 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 e.g. conifer needles, small fruits etc.

3.2 Operation

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

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 LCpro-SD display should stabilise to give similar CO_2 levels. The H_2O levels should also be checked for similarity and that the PAR and chamber temperatures (Tch) readings are in accordance with ambient conditions.

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

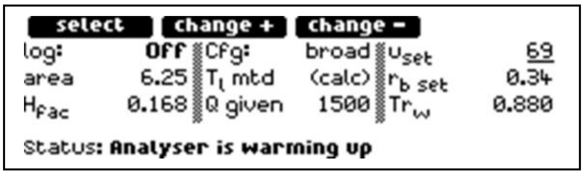
Once the leaf is enclosed in the chamber, it may take up to 2 minutes to re-adjust to its new microclimate. During this period CO_2 & H_2O values will gradually stabilise. Generally a good indication of stability is when the value for Ci (substomatal CO_2) has stabilised.

After readings are stable, a 'record' may be taken (see section 12.2).

3.3 Leaf Chamber Constants

The design of the leaf chamber affects various parameters, which are constants for a particular design or type. 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 to PAR). These constants may be changed with configure set up select . When the appropriate parameter is underlined, it can be modified with the change + and change – keys.

Screenshot:



'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 chamber), 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 shield above the window. The value for PAR at the leaf (Q_{leaf}) is therefore less than that measured (Q) by factor 'Tr_w' – the transmission factor of PAR introduced by the arrangement of the chamber shield &/or window.

See Section 8 for typical values.

3.4 Leaf thermistor

The leaf temperature may be measured as an alternative to calculating it. The parameter used to switch between the two options is *Tl mtd* in the configure setup 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. Broad and Narrow style chambers offer an additional integral microchip thermistor mounted in the leaf chamber. (see paragraph 3.5). This integral thermistor is disabled if the external thermistor is plugged in.

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 Chamber Cooler

Broad, Narrow and Conifer chambers are fitted as standard with a Peltier heat exchange module. The module is fixed directly under the chamber and controls the air within the chamber to a user-selected temperature. In practice this allows temperatures that deviate by a minimum of 10°C from ambient to be achieved. Heat from the module is dissipated at the back with a heatsink and fan. The temperature of the module is directly monitored with a thermistor, independent of the chamber thermistor.

3.7 Light Units

Light units are available suitable for Broad, Narrow and Conifer jaws. They slide or clip onto the top jaw, (after removing the shield), with the lead towards the cable end of the chamber. The cable rests in the narrower of the two grooves in the handle, and it plugs into the adjacent socket. Align the red dots before plugging in. To remove the plug, push in lightly on the end of the connector to depress the spring latch then pull back on the section of the body that has the 4 grooves and a red dot whilst still pushing lightly on the end.

WARNING. The plug will not disengage if you pull on the cable or the rear section of the plug that has the two flats. Pulling on the cable may cause damage.

The Broad and Narrow light unit is removed by first disconnecting the plug, then lifting the spring loaded metal tab on top, above the cable. With the tab lifted, the light unit can be pushed off the jaw. Once the light unit has moved about 2mm, it is not necessary to continue to hold the tab up. The Conifer light unit includes a hood to prevent outside light from entering the chamber through the lower jaw and uses plastic clips to keep it in position. It can be fitted/removed with a moderate pressure.

When the light unit is attached to the top jaw, the join is not totally light proof. For the most accurate results, shield the light unit from direct sunlight when in use, especially when the light unit is running at low light levels.

With a light unit fitted, the transmission loss (T_{rw}) will be for the window only. (See the table below "T_{rw}" in section 8).

The diode array contains blue LED's at 470nm wavelength and red ones at 660nm. Between 5-10% of the photons are blue. The output of the array is monitored with a light sensor, which adjusts the power, so that the light output is constant at the value set by the user.

The Broad and Narrow light units can produce up to 2000µmol of light, and the Conifer can produce up to 1500µmol. The software will set these limits as appropriate provided that the correct chamber type has been selected in the config menu.

If the chamber type has not been set to Conifer, but a Conifer lamp is fitted; the software will allow the user to enter levels as high as 2000µmols without apparent error. In this instance levels greater than 1500 may be set but not achieved due to the higher power demand of the Conifer light unit's larger LED array, and there is the risk that the light power supply may be damaged by the excessive loading.

Conversely, if the chamber type has been set to Conifer but a Broad or Narrow type lamp is fitted, the software will not allow levels above 1500µmols to be set.

WARNING

The console supplies all the light units with around 110V, current limited. Be sure that the light unit is not operated in conditions where moisture could condense or drop on it. Do not poke conductive material inside it during operation as this could result in an electrical shock to the operator.

3.8 options and Q options

The Q menu page has two buttons, (hold Q and release Q) that hold or release the PAR (Q_{leaf}) reading. This feature is not needed with the light unit supplied with the system, as it has its own integral light sensor. It is useful for users who wish to use their own light source, whose dimensions are such that a PAR sensor and a leaf cannot both be simultaneously illuminated. In that case, this feature can be used as follows: The PAR sensor is removed from its usual position and placed in the chamber with the sensor facing the light source. Pressing the hold Q button holds the resultant PAR reading (Qleaf). This value does not have the window transmission factor applied to it because it is assumed that it was made with the sensor under the window. The PAR sensor can then be removed from the chamber, and replaced by the leaf. All subsequent calculations are based on the frozen value, which can be used for many leaves. Normal operation is restored with the release Q button.

3.9 Enter given Q value

In addition to the two buttons referred to in paragraph 3.8, the first main menu page also has a button (given Q) that allows a given value of PAR (Q) outside the chamber to be used. The "given" value is entered from the configure set up menu by selecting */Q set/* then using the change + and change – 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 seven configuration set-ups. Once given Q is pressed the given value will conform to whatever configuration is being used at the time. Note that the corresponding window transmission factor is applied to it, so it will generally be less than the value entered. Press release Q to return to measured values. If hold Q is pressed whilst "*given Q*" is being used, the current value for Q will be held even when changing to an alternative configuration set-up. Note however that when release Q is pressed, the value for Q will return to *measured* not *given*.

3.10 Climate Q

This button displays the value of Qref corresponding to what the climate control system is doing at the time. If it is off, ie at ambient, the climate Q and release Q buttons will both display the Q_{leaf} value as measured by the PAR sensor. If the light unit is switched on, climate Q will display the Q_{leaf} value as measured by the light sensor in the light unit, and release Q will display the value measured by the PAR sensor. Once a non-ambient light level has been set in the climate control menu the Q_c reading will be displayed even if ambient light has been reselected. The release Q button will need to be pressed to return to normal Q readings. Entering a non-ambient value for Q in a sequence programme will also have the effect of placing the Q measurement method to Q_c. The method will remain Q_c even after the sequence has ended.

SECTION 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-SD 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 not in use the jaw should be left in the open position by placing a small wedge such as part of a cocktail stick into the hinge. This will prevent the gaskets from becoming compressed.

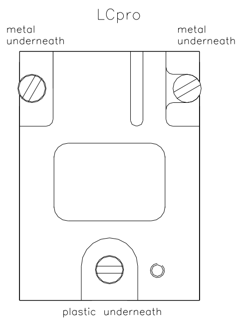
4.2 Configuring the Chamber for use with an LCpro

The three fixing screws that secure the interface block to the chamber handle must each be fitted with a spacer. They ensure correct spacing to suit the handle sensors and correct electrical connection or insulation as appropriate.

The configuration is as described below.

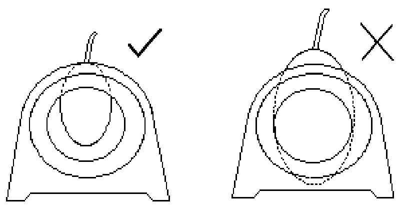
The interface block has a metal spacer fitted onto each of the corner fixing screws on the bottom side of the interface. The screw in the middle of the back edge is fitted with a plastic spacer. (see left-hand figure.)

Note. The spacers are all part threaded and part clearance. To prevent the spacers jamming, fit the spacers onto the screws with the threaded part first. (see right-hand figure)



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) and the message "Tleaf probe error" will appear on the Status line unless the thermistor probe (Part No. PLC-011) is plugged into the jack socket. . Alternatively the calculated rather than measured leaf temperature reading method (Tl $_{(C)}$) can be selected.

4.5 Flow rate 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/LCi-SD and LCpro/LCpro+/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 LCpro-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

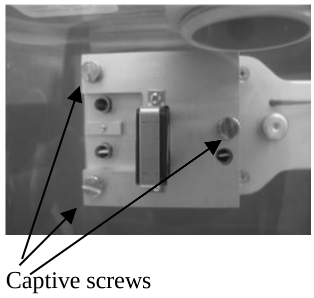
A "Leaf Chamber Jaws OPEN" message will be present until the soil pot has been attached correctly. A "T_{leaf} probe error" will be seen on the instrument's status line if the leaf temperature method is set to "measured" until either the probe supplied or the standard Leaf Thermistor probe (ADC Part 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.

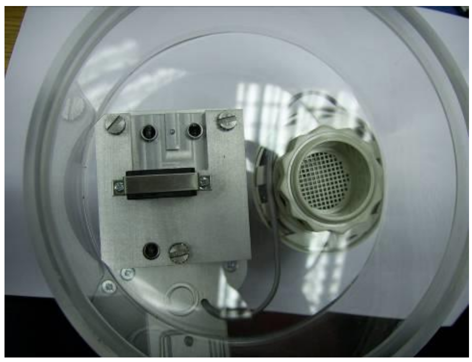


Captive screws

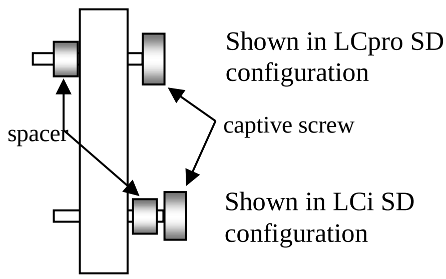
5.3.2 Attaching the soil pot to the handle

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

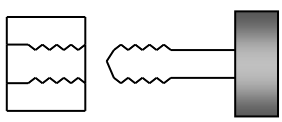
Important Note:
The LCpro SD sensors are longer than the LCi SD, requiring longer screws and spacers to be fitted. In order for the Soil pot to be used on both instruments the same length screws and spacers are used but their configuration is different. In the default configuration (suitable for the LCproplus) 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 gas in the soil pot to reach equilibrium and therefore the instrument to obtain an accurate reading.
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 approximately **839cm^3**

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 with the collar (without soil intrusion) is approximately **803cm^3**

SECTION 6. ROUTINE MAINTENANCE

6.1 Chemicals

CO_2 Stripper.
The performance of the LCpro-SD is dependent on the satisfactory condition of the soda lime stripper, 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, if CO_2 control is not being used. Exhausted soda lime may lead to negative ΔCO_2 readings even with nothing in the chamber. This is especially true when the soda lime needs to work harder to control CO_2 levels in climate control mode. If the soda lime has changed colour by half its length or more it should be replaced for CO_2 climate control work. Otherwise, it will work until 90% has changed colour. The soda lime supplied is an indicating type, which turns from white when fresh, to violet when exhausted. Some water content is necessary to assist the chemical reaction, which is to convert CO_2 to calcium carbonate + H_2O. Re-conversion back to soda lime is not practicable.
Soda lime is commonly available, but is usually a non-indicating type – this will lead to erroneous CO_2 measurements if the soda lime is used (unknowingly) in an exhausted state. It is acceptable to mix indicating and non-indicating types together.
Note: A warning message will appear on the status line if the reference CO_2 reading falls below 100 ppm. The message prompts the user to check the Soda lime, which may be exhausted.

Drier.
This is “Drierite”, anhydrous calcium sulphate, with an indicator, which changes from blue when fresh to a pale pink when exhausted. This can be regenerated as follows: Spread the granules in layers one granule deep and heat for 1 hour at 210° C or 425° F. The regenerated material should be placed in the original glass or metal container and sealed while hot. The colour of the indicating Drierite may become less distinct on successive regenerations due to the migration of the indicator into the interior of the granule and sublimation of the indicator.

Humidifier.
This is iron (ferrous) sulphate, 7 hydrate. It has a colour change from a pale lime green when fresh to white when exhausted. It is not practical to rejuvenate it.

6.2 Dust Filters

The gas connections on the front may become blocked if the instrument is placed with this surface downwards. Note that the bottom three, with metal tubes, are outlets. If they are blocked, it may be possible to poke at the blockage with the instrument running, so that the debris is expelled. As a general precaution, fit two loops of pipe to the four entries when the chamber is not connected. If the instrument is placed with the entry side downwards, the two pipes will protect the ends of the entries against damage and prevent debris entering.

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 341 μmol $sec^{-1.}$ (i.e. the indicated flow ‘u’ is very much less than 341 μmol sec^{-1} and pump “racing”), this can be taken as a sign that filters should be changed (or cleaned if they can be dismantled).

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.

With the exception of the “Wetter” column all filters are made from Vyon which is impervious to the acidic effects of Soda Lime. The “Wetter” column filter is made from foam and should be inspected and changed if signs of degradation are apparent.
The columns should be removed and washed in soapy water from time to time.

6.3 Battery Charging

The LCpro-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 configure diagnose page.

The battery can be re-charged in situ via the five-pin power socket on the side, using the charger lead supplied. The LCpro-SD can also operate from an external 12-volt supply of at least 2A 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 thermal self-resetting 5A fuse). If the charger is disconnected from the mains it should also be disconnected from the LCpro-SD to prevent draining the battery.

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. An ADC battery charger or 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.

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

When the battery in the LCpro-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 LCpro-SD off and, either recharge, or replace the battery. If a suitable external DC power source is on hand, connect it to the LCpro-SD as soon as the message appears. In this case, work can continue undisturbed.

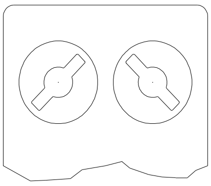
If you plan to store the instrument, fully charge the battery first. Giving it an 8-hour top up charge at least once every 6 months will maximise its life. It is not necessary to remove the battery, but if it is removed for more than a few weeks, the rechargeable clock battery may become discharged. In this case the clock will require resetting.

6.4 Battery Replacement

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

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

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



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

6.5 Battery Fuse

The battery fuse is a 20mm glass type located in a bayonet type holder next to the two fasteners under the base plate. This 3.15 Amp time delay glass fuse is connected in series with the battery ‘positive’.
Under normal conditions, the fuse should not fail. If it does, it could be due to an internal fault, by a high voltage applied externally, by an external supply reversal or by the battery over-charging which can cause its terminal voltage to increase. Providing the cause of fuse failure/s is removed, and the fuse is replaced (a spare is provided), the LCpro-SD will have been protected from permanent damage.

6.6 CO_2 cartridge

The CO_2 cartridge is located under the battery cover, next to the battery fuse.. The cartridge holder can be loosened with the special “key” provided in the spares kit (M.LCM-146) or with a well-fitting coin, then unscrewed by hand. The instrument is supplied with an empty test cartridge fitted. This is to help exclude atmospheric water vapour, which will freeze with the sudden expansion of the gas from a new cartridge. The resulting ice crystals will cause unstable CO_2 control for the first few hours. It is recommended that you leave an empty cartridge in place to keep moisture excluded, until you need CO_2 control again.

When replacing with a full cartridge, the cover can be screwed most of the way by hand, until resistance is felt. This is caused by a sharp pin inside the regulator about to pierce the seal on the cartridge. Continue to tighten with the special “key” or well fitting coin. After about ¼ turn, the housing will become much stiffer to turn as the cartridge is pierced and high-pressure gas (about 8Mpa) is released into the regulator. The gas is prevented from escaping by the ‘O’ ring seal but the pressure on the end of the cartridge causes friction on the housing threads. To be sure the ‘O’ ring is completely sealed and the cartridge is completely pierced, continue to tighten for about two turns. Using the special “key” is recommended as it provides sufficient leverage to ensure that the cartridge housing is tightened sufficiently. The “ground spike” can also be inserted through the hole in the key to give additional leverage if required.

If the cartridge holder is removed before the cartridge is empty gas will escape rapidly through the side of the housing, and the ‘O’ ring may be damaged. To prevent this happening use the special “key” or a coin to depress the “Schrader style” valve located at the front of the console (see photo on page 13) to bleed off the remaining gas, or screw in the knurled brass plug LCM-039 supplied in the spares kit. This valve should be kept open for 30 minutes, even if the gas can no longer heard as it hisses out. If the valve is released sooner then the O ring which seals the gas bottle may balloon to several times its size and require replacement (ADC part number 650-652).

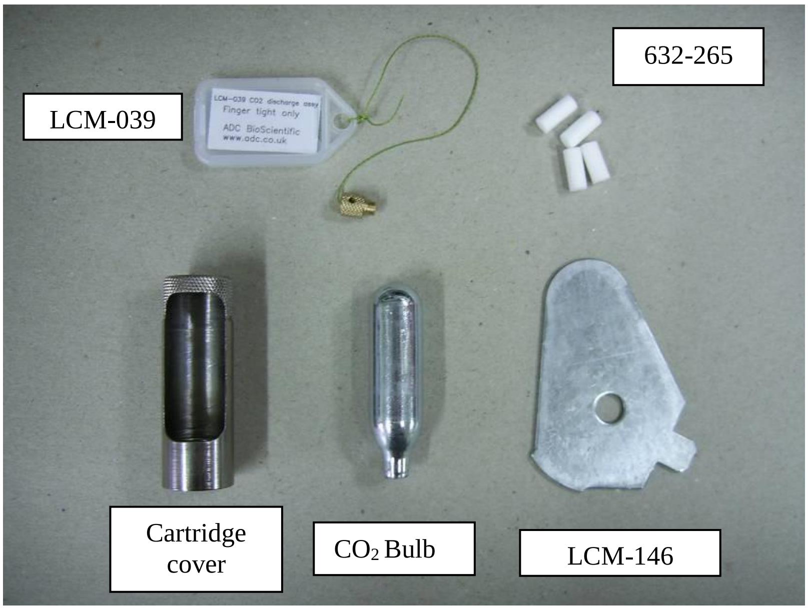
The “Schrader style” valve should be also used if you need to remove the cartridge when it might have a significant quantity of gas remaining in it. After the gas has been released there may still be CO_2 molecules under pressure contained within the rubber “O” ring.
To prevent the “O” ring seal from being damaged by sudden decompression, allow 30 minutes before finally unscrewing the cartridge holder.

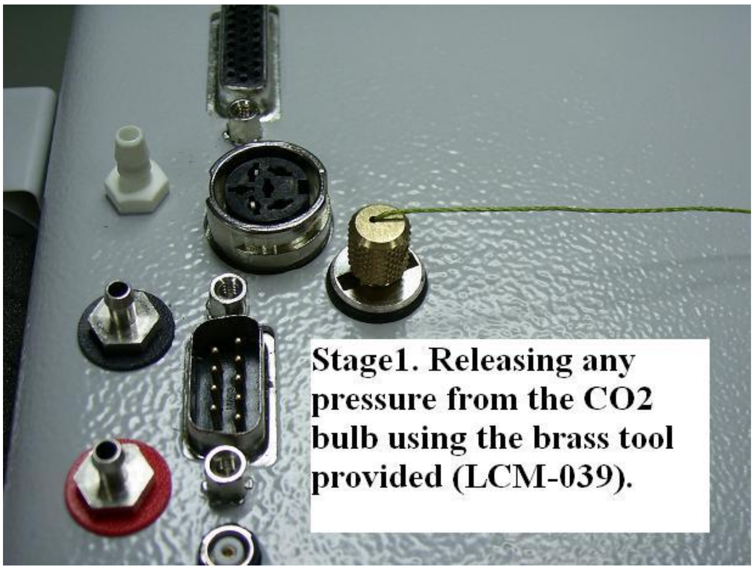
After every ten cartridges the filter (632-265) in the “Schrader style” valve housing should be changed. Using the special “key” provided or a coin, depress the “Schrader style” valve and unscrew the housing in the front of the console.

WARNING!

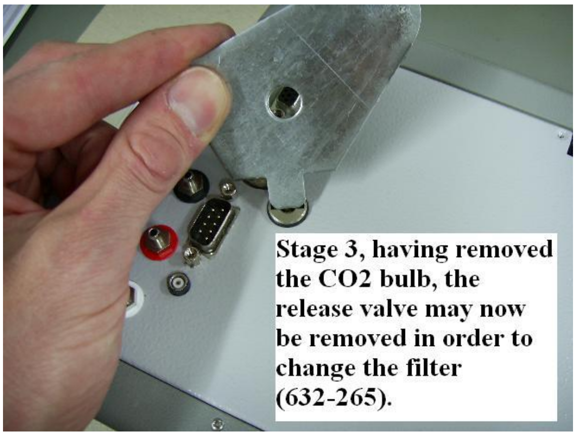
DO NOT ATTEMPT TO REMOVE THE FILTER HOUSING WITHOUT RELEASING THE PRESSURE VIA THE VALVE. FAILURE TO DO SO MAY RESULT IN THE FILTER HOUSING BEING BLOWN OUT AND CAUSING INJURY.

Once the housing is removed the filter can be hooked out with a small screwdriver, tweezers or a paper clip. Fit the new filter by simply pushing into the housing as far as it will go then replace the Schrader valve housing into the regulator (see photographs on following page).


632-265
LCM-039
Cartridge cover
CO2 Bulb
LCM-146


Stage1. Releasing any pressure from the CO2 bulb using the brass tool provided (LCM-039).


Stage 2. Removing the CO2 holder and the CO2 Bulb, using the tool provided. (LCM-146).


Stage 3, having removed the CO2 bulb, the release valve may now be removed in order to change the filter (632-265).


Stage 4. Remove and replace the old filter, a sharp pair of tweezers is ideal, as shown below.

6.7 Suggested Maintenance Schedule.

1. O-rings, check the handle o-rings for wear or damage each time a jaw set is changed or removed. Check the o-rings on the chemical columns each time they are removed. A tiny amount of silicone grease on all o-rings helps to make a good seal, damaged o-rings should be replaced using the spare o-rings provided in the spares kit. Additional o-rings may be ordered from ADC or an approved agent.

2. Chemicals, should be replaced when the colour changing indication shows that approximately 80% of the chemical has been used, take care not to damage the large o-rings on the columns when re assembling the columns, keep these o-rings free from chemical granules and lightly greased with silicone grease (supplied in the spares kit).

3. External filters should be used with the console and inspected every time the system is setup for use, two types are provided in the spares kit, x2 plastic ones which are disposable and very effective at stopping fine dust (630-980), and a metal one (631-180) which can be dismantled and cleaned out (both supplied in the spares kit). Great care must be taken to make sure these filters are always connected in the same direction of air flow, otherwise dust will get into the console which may clog the internal filter. These filters should be regularly inspected to ensure they are not clogged. A badly clogged filter may damage the console as the console has to work harder to overcome the impedance caused by the restricted airflow.

4. The internal filter (630-693), this should be checked if it is suspected that an external filter has failed. See section 16.2 and 16.5.

5. The CO_2 regulator is expensive, so it's filter should be replaced after ten CO2 bulbs, because they contain traces of oil which will damage the mechanism (see section 6.6).

6. Carry case drier (black plastic flight cases), this changes colour from blue to red when saturated, and can be baked in an oven to dry it out, see the instruction card in the flight case for details (normally located under the drier canister). Inspect every time the instrument is put away after use in the field, and keep the case closed at all times when access is not required.

7. Solenoid valve in the handle, when the system is switched on a clicking noise should be heard on start-up, if not then a valve exercise function should be used to get the valve working (it may be stuck after a period of inactivity), this is done in the console screen using *config>diagnose>sys.info>SV check*. If the valve still does not click then it may be faulty.

8. Leak tests, once a year or if a user suspects the instrument's results may not be correct. See section 16.4.

9. Recalibration, every 4 years is the recommended interval for recalibration, best done by ADC Bioscientific Ltd. Calibration dates are to be found in the calibration screen. See section 7 for more details.

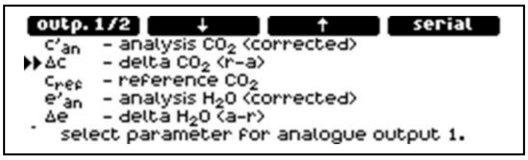
SECTION 7 SET-UP AND CALIBRATION

All the current attributes and settings are retained indefinitely by a non-volatile electrically alterable ROM (EEPROM). These settings are read into Random Access Memory (RAM) when the LCpro-SD is switched on and resaved from RAM to EEPROM when the LCpro-SD is switched off. This ensures that any changes to the configurations made by the user are retained. A small rechargeable battery supplies the clock. If the LCpro-SD supply is removed (e.g. its battery is discharged), this battery will become discharged, typically after 7 weeks. It will automatically be re-charged when LCpro-SD power is re-applied, but it will be necessary for the user to re-set the date and time.

7.1 Analogue Output Port Set-up

Pressing output displays the parameters list, from which two can be selected for the two chart recorder outputs. Pressing outp 1/2 toggles between analogue output channels 1 and 2

Screenshot:



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

7.2 Serial Link Port Set-up

Pressing output then serial displays the menu from which the the baud rate and handshake protocol can be selected.
Set the required baud rate by highlighting it with select then use change + and change - to cycle through the options of 300, 1200, 2400, 4800, 9600, 19200 and 38400 baud. Highlight the handshake to cycle through the options of “CTS”, “use CTS for record”, “xon-xoff”, and “none”.
Note that if “CTS for record” is selected it is not possible to send recorded data over the serial port. Any attempt to do so will result in the message ‘Serial port set for record trigger’.

7.3 Time & Date Set-up

Pressing configure then 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 CO2 signal phase correction (stable air supply required).

Pressing configure diagnose sys.info. displays the system information page and the auto-phase function soft key. It is not normally necessary to re-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. Typically, the phase correction angle is between 70 and 80 degrees. When the scan is completed, it will ask whether you wish to save the new setting.

7.5 Calibration Menu

Pressing calibrate accesses the calibration menu. From here the various options can be chosen using the select key and the + and – keys to set the value where applicable. Press do calib. to start the calibration.

7.5.1 Flow check (stable air supply required)

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

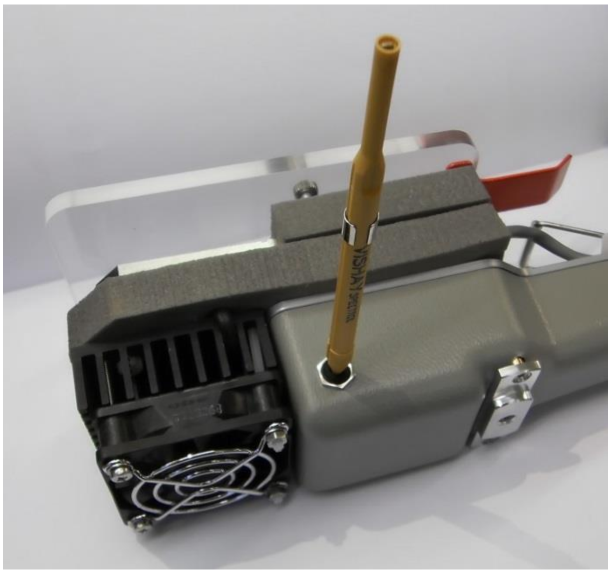
ASU set flow (µmols s^{-1})	Settling time (seconds)		Estimated flow (µmols s^{-1})	
	Reference	Analysis	Reference	Analysis
200	4.45	3.86	83	97
300	4.32	3.36	85	110
Variation	5%	10% - 25%	5%	10% - 20%

7.5.2 CO2 Zero

The CO_2 zero setting is automatically maintained by a software adjustment during each zero cycle. The adjustment effectively changes the gain in order that the signal level, when zero gas is flowing, is constant. For this to be performed correctly, the soda lime column must be kept 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 configure diagnose The C(z) reading should lie between 45,000 and 60,000 counts (with the optimum being 52500). If this is not the case, the warning message "cref low, check absorber" will already be displayed and a hardware adjustment can be made.

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



In the calibration menu, select *CO_2 zero*, then press do calib. Adjust the pot to reduce the displayed count to within 200 counts of zero, turning it clockwise if the displayed value shows a down arrow. A value within 10% of the range will be functional, and will cause 'OK' to be displayed. 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.**

7.5.3 CO_2 span

Occasional calibration of CO_2 '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 LCpro-SD values are in disagreement with another similar instrument, or a known gas concentration. In this case however, note also that if the 'zero' chemical is exhausted, a false zero measurement will occur, resulting in lower values!
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 400ppm, a coastal location with an onshore breeze is ideal.
This menu option should be used if you have access to a suitable CO_2 span gas of known concentration. The menu allows the calibrating gas concentration to be set to the value that you have available.

To calibrate the span setting for CO2, a supply of CO2 of known concentration is required. The CO2 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 1200-2700 ppm.
There are two methods of connection for calibrating CO2. Method 1 is preferable but slower and requires more Calibration gas.
Method 1: Ensure that the wetter column is empty. Apply CO2 span gas to the "Air In" inlet of the Console 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 3 minutes)
Method 2: Disconnect the reference gas tubing (coded with a white sleeve) from the console. Apply CO2 span gas to the tubing in series with a glass flowmeter. This is to check that the chamber is periodically taking flow of about 200ml/min. The span gas pressure should be set to about 20cm water gauge. Wait until the CO2 reference reading is stable (C'an can be ignored as it will be receiving ambient air rather than the span gas) before starting the span operation with do calib.

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

7.5.4 H2O Zero

Note: It is not normally necessary to check or calibrate the water vapour zero unless a RH sensor has been replaced or the two sensors have been swapped.

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.
Making sure that the chamber jaws are closed, pull off the tubing with the black sleeve from the console and introduce the dry gas into this tubing. There will be a very slow downward drift of the readings, typically taking up to 30 minutes to stabilise (the analysis reading takes considerably longer than the reference to settle). If the Analysis reading remains much higher than the Reference, it is likely that the chamber gaskets are not sealing correctly. Once both readings appear to have stabilised select */H_2O zero*. The processor looks for a stable reading before doing the zero, but will not detect very slowly changing readings.

7.5.5 H2O Span Gas

The H2O span gas can be most conveniently supplied from a water vapour or dew point generator. H2O span gas should be applied to the chamber as described for H2O zero in section 7.5.4 and with an applied pressure of 11cm water gauge. There will be an extended stabilisation time of up to 30 minutes due to the nature of the H2O gas 'sticking' in the piping.

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 6.

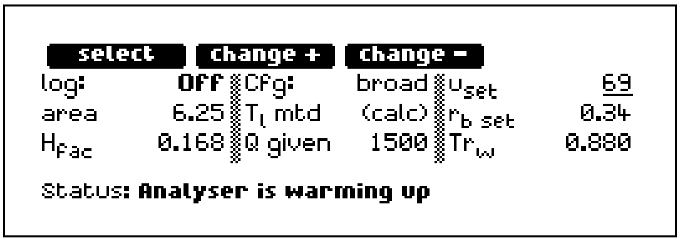
SECTION 8. MEASUREMENT CONFIGURATION

8.1 The 'config' Function Menu

Refer to Appendix 7 for the menu tree

Use configure to get to menu time/date set up diagnose SD card The various options can be chosen with set up select. Use change + and change - to alter the parameter selected.
The type of chamber */Cfg/* you are using can be selected from: Broad, Narrow, Conifer, Soil pot, Small, Arabdidopsis, user1, user2, user3. The chamber parameters, uset, area, T_l method, rb, Hfac, Qgiven and Trw are stored separately for each type, and the LCpro-SD is factory set with suitable default values. You can change the parameters to suit your chamber and the leaf being measured. Note that when the soil pot is selected some of these parameters are not used and therefore not displayed.

Screenshot:



When the LCpro-SD is switched on, it will select whatever configuration was last in use.
The table below defines the default values:

	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 *²	n/a	0.1 to 1.00	0.1 to 1.000	0.25 to 1.000	
Steps *¹	1	0.01 *²	n/a	0.01	0.001	0.01	
Chamber						with shield	without shield
Broad	200	6.25	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, the value given is for a version 2 soilhood and assumes use with a soil collar.
*³The Tl method cannot be changed from measured.

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

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

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

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

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

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

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

/H_{fac}/ is used to enter the absorption factor of the broad band radiant energy onto the leaf chamber by the exposed leaf surface. This factor is dependent upon the materials used in the construction of the shield and/or window of the Leaf Chamber. (For LCA2 & 3 types of analysers, this factor is referred to as '*Trans*'). Appendix 4 gives the derivation of H_{fac}.
H_{fac} is not applicable to the Soil pot

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

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

SECTION 9 MICROCLIMATE CONTROL

9.1 The climate menu (Single Point Environmental Control)

Pressing climate displays the microclimate control menu. With the select change+ change- and ambient keys it is possible to separately set the chamber temperature (T_{set}), light level (Q_{set}), CO_2 concentration (c_{set}) and humidity (e_{set}). Press the select key to scroll through the functions and the change+ or change- keys to set the value. Holding down the change+ or change- keys will increase the size of the steps that the value is incremented or decremented by. The selected value is held continuously, and is shown as both the set and ctl value. Temperature and light levels are not relevant when used with the Soil pot and also with the Arabidopsis and Small leaf chambers as they do not have this facility.
(*Note: A Broad leaf Light may be used with Arabidopsis and Small leaf chambers:- Application notes can be requested and are automatically supplied with both chambers when purchased*).
Pressing the ambient key disables the climate control for whatever function is selected at the time.

Screenshot:

select		change +		change –	ambient
T_{set}	15	T_{ctl}	15	T_{ch}	14.6
Q_{set}	1000	Q_{ctl}	1000	Q (c)	1000
c_{set}	570	c_{ctl}	570	c_{ref}	569
e_{set}	6	e_{ctl}	6	e'_{an}	6.1

9.1.1 Temperature

The temperature can be set in steps of 1°C over the range 1°C to 40°C or it can be set to track the temperature as measured at the Taux input. The starting point is 20°C. To set the tracking to the Taux input simply press the change+ or change- keys until 'track' is displayed.

The cooling or heating is done with a solid state Peltier module. This is an array of semiconductor blocks sandwiched between two thin ceramic plates. Heat is pumped from one plate to the other, with a magnitude and direction dependent on the current flow.

To achieve the fastest stable control, the temperature of the metalwork is monitored next to the Peltier element. A feedback loop will make this point the same as the set temperature. The air temperature inside the chamber will differ by a few degrees due to the gradient across the metal-air interface. The air is monitored by a separate precision thermistor (Tch), and this value is used for logging and the calculations. If necessary, the set-point can be increased or decreased by a few degrees to offset the difference.

9.1.2 Light

The light level in the illuminator is measured with a sensor adjacent to the LED array. This is used to maintain a constant level, independent of age and temperature. The light level is calibrated so that the value achieved in the chamber is the level set on the screen, reduced by the window and radiation shield transmission factor. This is so that the illuminator calibration is the same as using the PAR sensor with sunlight. Since the LED array is not used with the radiation shield, the transmission factor should be changed to 0.92 or 0.91 as shown in the table. Do not forget to change the value back again when the LED array is not used. The light can be set in steps of 10 between 0 and 1500µmols $m^{-2} s^{-1}$ for Conifer heads and 0 and 2000µmols $m^{-2}s^{-1}$ for all other chamber and user configurations.

9.1.3 Carbon Dioxide

The CO_2 concentration is controlled using a solenoid valve (SV10) driven by a variable duty cycle. (see gas circuit, section 15). The duty cycle of the valve is varied by the instrument to maintain the setpoint requested by the user. The CO_2 level can be set between 0 and 2000 ppm in steps of 10ppm. To set above ambient levels a CO_2 cartridge will need to be installed. The maximum achievable concentration is reported in the CO_2 options page. Once the cartridge's pressure drops below a useable level, and the set concentration can no longer be achieved, a warning message will appear. The control system will set the level as requested until the cartridge pressure drops, when it will eventually fail to control, and the controlled level will fall. A full cartridge with a good seal on the 'O' ring will last at least a whole day. The cartridge is used at a constant rate even if the CO_2 control is turned off.

The CO2 control function works best at a flowrate of u=200 or u=68. For other user determined flowrates, it is suggested that a leafless log be performed and the average offset of the photosynthetic rate determined from the log file, by plotting "A" as a simple line graph and noting the middle position of the line. This can then be added or subtracted to the results obtained from the leaf present logfile later on.
A flowrate of u=200 is maximum that should be used in elevated CO2 mode.

In elevated CO2 mode it is highly recommended that log files be used with the logging rate set to the highest possible frequency for reasons given below, see "timing mode" in section 12.2 of this manual.
Cref and Can will fluctuate up and down slightly due to the mixing action of the solenoid valves and some small variation in the CO2 regulator flowrate (the calculated value for photosynthetic rate will also fluctuate as Cref and Can are factors of the photosynthetic rate), so an instantaneous value of Cref/Can/A may not be the most representative value of what is going on.

The instrument can be used to control at moderate CO_2 levels, all the way down to zero, using ambient air, i.e. with an empty cartridge.

At high, elevated CO_2 levels, there is a tendency for diffusion out of the chamber through the gaskets. This is made worse by draughts and by small leaks caused, for example, by very uneven leaves. A small positive ΔC will be caused, and can be checked for by closing the jaw without any leaf in it, or with an inactive (dead) leaf.

If there is a problem, it can be eliminated or minimised by holding the jaws closed more than the spring would normally achieve. Using a rubber band wrapped round the upper and lower jaws for example. In addition, enclosing the jaws, as much as possible, in a plastic bag, can eliminate draughts.

"Bottle Average" is shown in the options CO2 mode page. When the LCpro-SD is first switched on this will show a default value of 3600 (ppm). When a cartridge is installed and CO_2 climate control started this value will start to change, eventually stabilising at a nominal value of 3000. This value is the maximum level of CO_2 concentration generated by the instrument before reaching the solenoid valve mixer control. When the cartridge approaches exhaustion this value will start to fall, eventually dropping below 2000 ppm (which is the maximum available climate setting) then falling below whatever level has been set by the user. At this point a status message will appear warning the user that the required concentration can no longer be held.

Refer to the maintenance section 6.6 for details on replacing the CO_2 cartridge and filter. We advise that the filter should be replaced every tenth cartridge.

9.1.4 Carbon Dioxide Control Options

The analyser will control the CO_2, and H_2O levels of either reference or analysis. It is usual to control reference, i.e. the air supplied to the chamber. However, it may be useful to control analysis, i.e. the stirred air in which the leaf is working. The disadvantage of this arrangement is that changes in photosynthesis need to be matched by changes in the control of the analyser. This method therefore has longer settling times.

To change between the two (See Appendix 7 - Menu Structure) select options then either CO_2 mode or H_2O mode as required. In both cases, the option of reference or analysis is presented. In the CO_2 mode page the "bottle average" is also shown. (See section 9.1.3 for further details).

Further options have been added to the options CO2 mode page with version 3.00 software. These are norm/fast which determines the mode of operation and source which is set dependent upon the gas input.

norm/fast toggles the mode between and fast. Normal mode controls the CO2 to that requested by making an initial duty cycle estimate and then homing in on the value after which constant adjustments are made to maintain it. In fast mode the controller makes an estimate of the duty cycle to achieve the requested CO2 concentration but makes no attempt to adjust it subsequently until a new CO2 value is entered, in which case it makes a new estimate based upon the data obtained from the previous request. Fast mode is intended under circumstances where a rapid change is required with a relative short time spent at each CO2 concentration such as A/ci curves. Since the estimate is made from the previous setting, to get the best results the instrument should be first used in normal mode set at a high level between 1500 and 2000ppm. This will provide live data upon which to make the estimation, otherwise a default value is used which can give poor estimates. Once a setting has been reached the data for the estimate is retained until the instrument is switched off.

source toggles the gas input setting between ambient air and zero and should be set according to the gas input used by the user. It is used only at initialization to give a better estimate of the PWM setting for the requested CO2 level.

9.1.5 Humidity

As with the CO_2 controller, the H_2O level is controlled using a solenoid valves (SV12) with a variable duty cycle. (See gas circuit, section 15).

The Instrument is provided with two columns, one being the “wetter” column fitted with a thermistor and the other being a normal “empty” column. The Instrument is despatched with the “empty” column installed and the “wetter” option set to empty. In this configuration only below ambient levels can be set.

Note: care should be taken to always ensure that the instrument configuration matches the column installed. If for example, the wetter column is installed but the configuration is set to empty. The air will be saturated as all the flow will pass through the wetter column.

The humidity level can be set in 1 mb steps. It is controlled between zero and the maximum level achievable at the temperature of the humidifier (wetter) column. This temperature is monitored by a thermistor in the column, connected to the console by a double-ended coaxial cable. The instrument will only permit the user to set a humidity level up to the maximum achievable, as shown in the left-hand table:

Crystal Temperature (°C)	Vapour Pressure (mb)
20	13.1
22	14.2
23	15.3
24	17.7
25	18.9
26	20.4
27	21.8
28	23.5
29	25.2
30	27.0
31	28.9
32	31.0
33	33.1
34	35.3
35	38.0
36	41.8
37	43.4
38	46.4
39	49.4
40	52.3

If desired, it is possible to increase the maximum available by warming the column. However, care must be taken to ensure that the maximum humidity available from the column does not exceed the dew point of the instrument, as shown in the right-hand table.

Ambient Temperature (°C)	Vapour Pressure (mb)
15	17.0
16	18.2
17	19.4
18	20.6
19	22.0
20	23.4
21	24.9
22	26.4
23	28.1
24	29.8
25	31.7
26	33.6
27	35.7
28	37.8
29	40.1
30	42.4
31	44.9
32	47.6
33	50.3
34	53.2
35	56.2

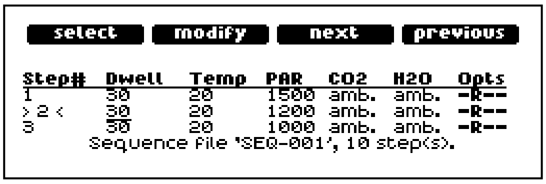
If a sequence is running, the sequence value will take preference, and the ctl value will be that at which the sequence is controlling. At the end of the sequence, the control value will go back to the set value.

SECTION 10 THE "SEQUENCE" FUNCTION

10.1 Description

Pressing sequence enters the sequence menu page. From here the user may write a new sequence file, using edit, load or delete an existing file from the SD card, using file load seq. then load seq. or delete seq. or save a sequence by using save seq.. The recv.seq. and trans.seq. keys are used to receive or transmit a sequence file to or from a computer over the serial link. The format for sequences produced on a computer is shown in appendix 5.

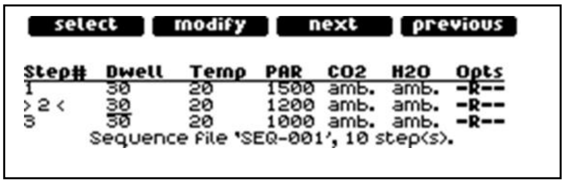
Screenshot:



If the file is new or to be edited, press edit, the select modify next previous menu keys are then displayed. The next and previous buttons move up and down the list of steps, as indicated by the < > symbols.
Note that temperature and light are available even when a Soil pot configuration is selected even though the Soil pot does not have these facilities. This maintains compatibility of sequence files. Setting temperature or light when using a Soil pot will cause no harm except a small power penalty.

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

Screenshot:



When the desired time has been chosen, pressing the page key will cause the menu to change back to the select modify next previous menu so that the next item for change can be selected. The default setting for the four variables is ambient, which means that the control is turned off.

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

Ignore where the step does nothing. This is a way of turning off a step, (since there is no delete function) and being able to easily turn it back on.

Record which causes a record to be made at the end of the dwell time, prior to the next step starting.

End seq which stops the climate sequence running, even if it is not the last entry. (This is a way of changing the length of a sequence).

Power dn which turns off the analyser completely at the end of the step, and is useful for lengthy unattended experiments.

Each of these four buttons toggles on/off. When the climate sequence is complete, it can be saved using file, using either the default name which has been assigned (seq-nnn), or changing it with the + and – keys.

The sequence can be initiated with start, which changes the menu to run next previous
The last two keys allow the sequence to start from a point that is not the start of the file.
run actually starts the sequence, which can be left running in the background by pressing the page key | . When the sequence has finished, a message "Control sequence stopped. Encountered stop flag in step NN" appears.
If more than one record per step is required then the timed log function can be run simultaneously (see section 12.2).

The SD card is supplied with an example sequence file named demo, which exercises each of the four chamber variables that the analyser can control i.e. light, temperature, CO_2, and H_2O. The files consist of lines of information. Each line has a sequential step number, a dwell time for which it is active, the values of the four variables, and an option to ignore, log, power off or finish.

SECTION 11. GRAPHICAL DISPLAY

11.1 Introduction

The LCpro-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 7.1)

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.

1. O/P 1 parameter against time
2. O/P 1 parameter against record number

Dual parameter X,Y plot chart.

3. O/P 1 parameter against O/P 2 parameter (triggered by time)
4. O/P 1 parameter against O/P 2 parameter (triggered by record number)

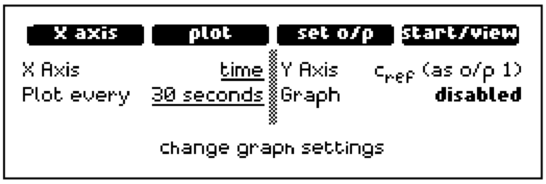
Time may be set to 15 or 30 Seconds.

11.2 Operation

Before entering the graphs menu it is advisable to set up the analogue outputs to the parameters required. This is detailed in section 7.1. Although the analogue outputs page can be accessed from the graph set up, once exited the LCpro-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 from the output, calibrate, graph, record menu followed by set up.

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'.

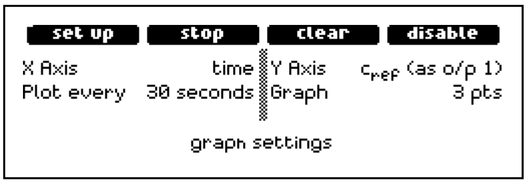
The set o/p button accesses the analogue output page where the graph parameters may be set.

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.

11.3 Pause Function

The graph may be paused. This allows an operation to be carried out which would otherwise alter the scaling of the graph. Changing the jaws for example. Data is ignored during pause but the time function is maintained so no data is shown during pause.

To activate the pause function press any soft key on the graph page which will pop up the pause button. To restart the graph again press any soft key and press the resume button.

11.4 Copy Function

A bit map copy of the graph screen can be made to the SD card.

To create the copy press any soft key on the graph page which cause the copy button to pop up. A pop up message giving the filename will be displayed once the copy has been made.

SECTION 12. RECORDING A LOG

12.1 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 1 of Appendix 1). The number of records that can be accumulated depends on the size of the SD card and the amount of data already on it. A warning message is displayed when the SD card is full.

12.2 Taking a record

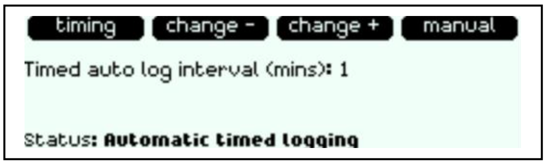
A record can be taken by any one of four methods.

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

After a record is successfully taken, the LCpro-SD will beep. 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 can be cleared by a second ‘record’ action or by pressing the No button. When a record is ‘taken’, it is appended sequentially in the current log ‘filename’ on the SD card. The ‘record number’, which starts at ‘1’, is automatically incremented. 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.

12.3 Deleting a record

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

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

12.4 Sending a serial record

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

Screenshot:

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

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

12.5 Deleting a serial record

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

12.6 Receiving a serial record

This applies to Windows 95, 98, ME, NT & XP. For non-Windows systems, you will need to use a terminal emulator.

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

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

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

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

Select :	bits per second	9600 (or as set on the LCpro-SD)
	data bits	8
	parity	none
	stop bits	1
	flow control	xon-xoff

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

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

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

8. Enter a filename and click on “start”

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

SECTION 13. 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.

13.1 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 LCpro-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. If your file names are numeric, the numeric part should not have leading zeroes suppressed if you wish the filing system to display them in correct order, for example log-100 will be displayed before log-2, but after log-002.

Screenshot:

13.2 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).
Note: Reviewing a log file in reverse (previous) takes longer to step through. Depending on the length of the file and the position of the record to be reviewed it may be preferable to select the first record then step through using next.

13.3 SD Card Data Format

SD cards are preformatted in a DOS format and the LCpro-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 LCpro-SD. In the unlikely event that the format of a card has been corrupted then it can be formatted on a PC.

13.4 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.

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

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

13.6 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.

13.7 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 LCpro-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.

SECTION 14. HOW THE ANALYSER WORKS

14.1 Infrared Gas Analysis

The LCpro-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.

14.2 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 its computed corrections are applied.

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 filter 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.

14.3 Other measurements

PAR is measured with a silicon-based sensor.

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

Leaf temperature is measured by a miniature thermistor mounted on a spring, which presses against the leaf (Broad and Narrow chamber types only). An optional miniature loose thermistor sensor can be positioned in the chamber at the user's discretion (used for the Conifer, Arabidopsis and Small leaf chambers). This thermistor plugs into the jack socket on the handle lid and disables the spring-mounted thermistor. The user can also select between the value measured with the thermistor or an internally calculated value derived from the energy balance equation (See Appendix 3 – Leaf surface temperature).

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

SECTION 15. GAS CIRCUIT DESCRIPTION

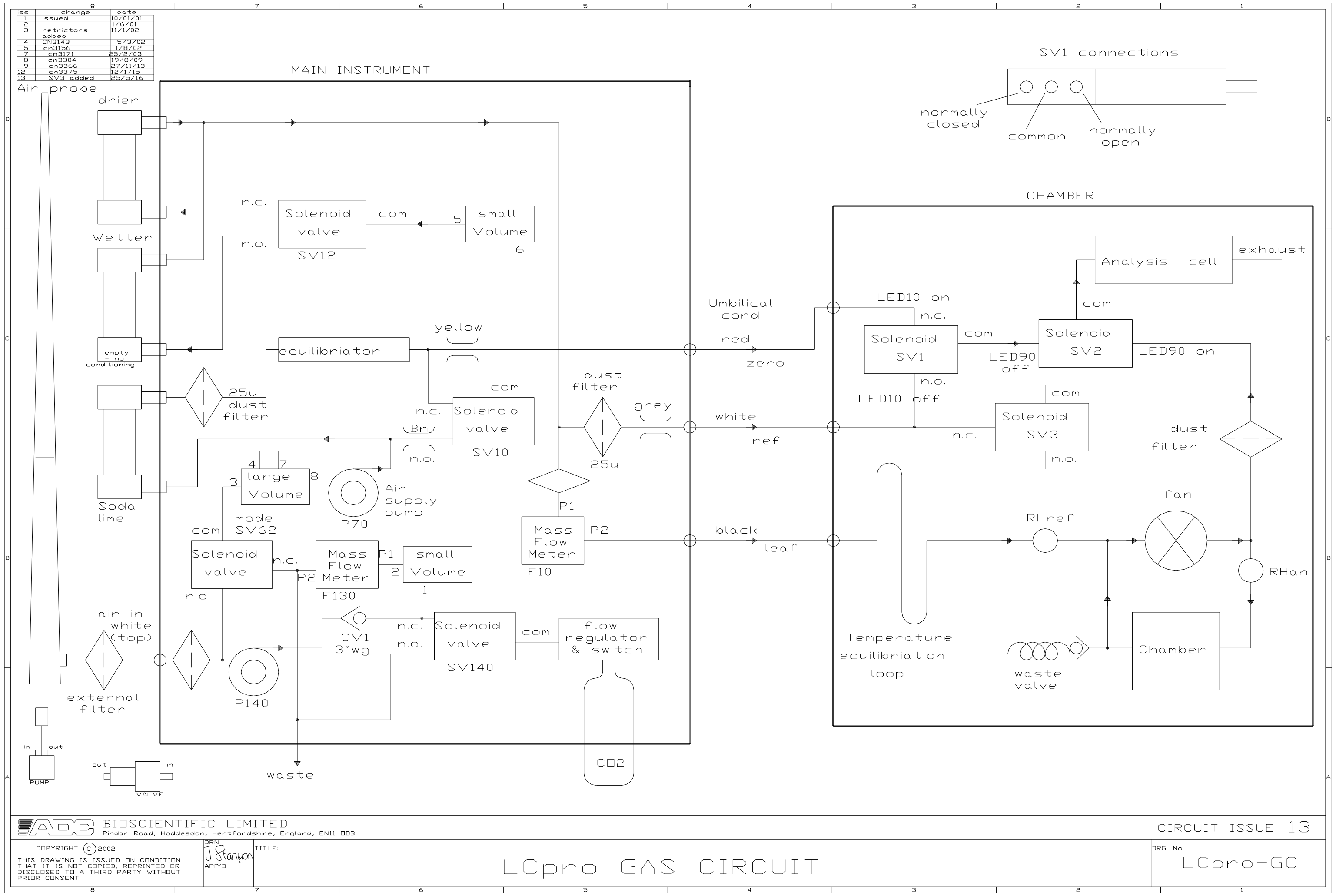
Fresh air is drawn in by the internal air supply pump P70 via the external particulate filter, and then the hydrophobic filter. The hydrophobic filter removes dust particles and helps to prevent water being sucked in. It contains a porous PTFE membrane, which prevents the flow of water by using the effect of surface tension. If the water contains impurities, which substantially reduce the surface tension, e.g. detergent, the water may be sucked in. Just before the pump is a solenoid valve SV62, to switch in the CO_2 enhancement system, and the internal (large) 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 to reduce noise, having a nominal volume of 460cc when extended.

The air then passes either directly through SV10 or via the soda lime column. In the latter case the air passes through the soda lime column to remove CO_2 and then through a dust filter to remove any soda lime dust. Soda lime generates water vapour as a by-product of the conversion process. This causes the air leaving the column to be very damp and, if the analyser is 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.

The stripped air is then passed directly to the analysis cell as 'zero' air when SV1 is on and SV2 is off. In addition, the stripped air can be mixed with non-stripped air in a variable ratio dependant on the duty cycle of the solenoid valve SV10. This air, containing a controllable concentration of CO_2 passes, via a buffer volume, through a second solenoid valve SV12, which also has a variable duty cycle, allowing the air to be either wetted or dried. Small dust filters after the wetter and drier columns remove any dust.
The air then passes either directly to the analysis cell as 'reference' air when SV1 and SV2 are both off, and continuously through the mass flow meter as air supply to the leaf in the chamber. The mass flow meter F10 acts with the pump P70 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 on. 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.

When CO_2 climate control is selected and a non-ambient concentration set, pump P140 and solenoid valves SV62 and SV140 will all be turned on. Normal air is then drawn through CV1, and mixed with pure CO_2 from the cylinder. The ratio of the flow through CV1 and the flow through SV140 define the available concentration of CO_2. The two gasses pass through a volume to allow them to mix thoroughly before passing through a mass flow meter F130. The flow meter is in a closed feedback loop with P140 to maintain a constant flow and hence a constant mix. The air leaving F130 through SV62 is used by P70 in the usual way, with excess flow escaping to waste via a tee. When ambient climate is set, P140, SV62 and SV140 are all off. SV140 then wastes the CO_2 (which continues to be released from the flow controller) to atmosphere (to avoid over pressurising). SV62 then only allows air to flow directly from the filter.


MAIN INSTRUMENT
Air probe
drier
Wetter
empty = no conditioning
Soda lime
n.c.
Solenoid valve
SV12
com
small Volume
5
6
n.o.
equilibriator
yellow
25u dust filter
com
Solenoid valve
SV10
n.c.
Bn
n.o.
large Volume
4
7
3
8
Air supply pump
P70
mode SV62
com
Solenoid valve
n.c.
n.o.
Mass Flow Meter
F130
P1
P2
small Volume
2
1
dust filter
25u
grey
P1
Mass Flow Meter
P2
F10
air in white (top)
external filter
P140
CV1 3"wg
n.c.
n.o.
Solenoid valve
SV140
com
flow regulator & switch
CO2
waste
in
out
PUMP
VALVE
Umbilical cord
red
zero
white
ref
black
leaf
SV1 connections
normally closed
common
normally open
CHAMBER
Analysis cell
exhaust
com
LED10 on
n.c.
Solenoid SV1
com
LED90 off
Solenoid SV2
LED90 on
n.o.
LED10 off
com
Solenoid SV3
n.c.
n.o.
dust filter
fan
RHref
RHan
Temperature equilibriation loop
waste valve
Chamber
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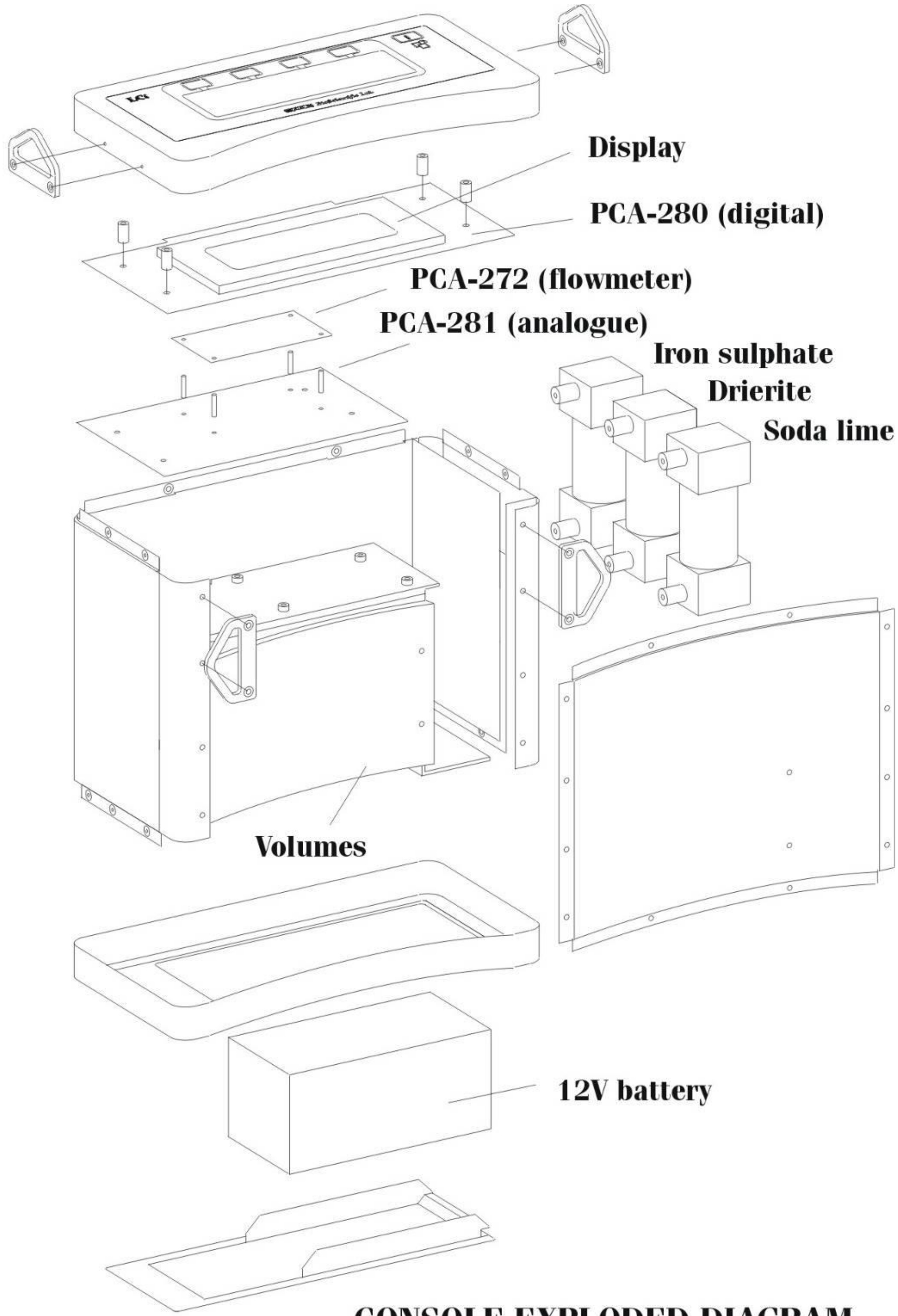
DRN
APP'D
TITLE:
LCpro GAS CIRCUIT
DRG. No
LCpro-GC



CONSOLE EXPLODED DIAGRAM

SECTION 16. MAINTENANCE

16.1 Tools

Note: When the LCpro-SD is first switched on, the screen shows the 'Software version', and 'Instrument Serial Number'. Always quote these in correspondence relating to the instrument.

There are no special tools needed to dismantle the LCpro-SD and replace parts. The use of a small sized thermostatically controlled s**oldering 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 could introduce a small leak.

16.2 Accessing the Inside of the Main Instrument

With the LCpro-SD switched off, unscrew the 4 M3 screws securing the two upper strap clips, and then the 5 M2 securing screws around the top bezel. The display panel can then be lifted up and to one side.

CAUTION:
Care should be taken to protect the display membrane as it can be easily damaged.
The digital board (PCA-288p) 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-281) and the piping. Unclip and remove the battery cover plate then remove the six M2 screws on the outside of the lower bezel, and the two M3 screws fixing the lower bezel under the battery cover then lift off the lower bezel. (*Note the position of the long M2 screw at the opposite end to the chemical columns*). Now remove the four M3 screws at either side of the curved plate and the two nearer to the middle. Extract the spacer (if fitted) from between the volume housing and the central chassis bracket. The curved plate can now be depressed slightly and withdrawn upwards, taking care to prevent fouling the hank bushes on the volume and gas piping.

CAUTION:

Do not try to spring the right hand edge of the case, as this may cause the 12-way connector between the analogue and interface boards to unplug. The angle at which it rests does not allow it to be easily reconnected.

There is usually no advantage in dismantling the LCpro-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.

16.3 Air Flow (Mass Flowmeter)

The mass flow meters are in closed feedback loops with their pumps, and will drive them faster or slower until the set flow is achieved. If a pump has stopped or is going as fast as possible, the mass flow meter may be faulty. If there is a leak inside the console, in the piping between a flow meter and its pump, the pump will run faster than normal, but insufficient flow will emerge from the flow meter. See leak testing, below.

The air mass flow meter 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 flow meter 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 16.1 if you experience difficulty], and pulling the flow meter 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 into the socket on the analogue board (PCA-281) before pushing the board onto its pillars. Support the flow meter with one hand while pushing the pipes back on with the other. In the case of F130, which is soldered to the board, a replacement flow meter could be fitted. Calibration consists of setting zero volts at TP130 (using RV130), with the pump disconnected electrically, and a flow of 715 to 730ml/min (using RV134) when it is switched on. i.e. CO_2 control is requested.

16.4 Leak Testing

There is an easy method for testing for a leak anywhere in the console that requires the use of a water filled manometer. First wait until the CO_2 cylinder, if fitted, is empty. Ensure the wetter column is empty (the vapour pressure from a full column will confuse results). Link or block the three connections to the chamber, red, white, and black, and apply about 10cm water gauge of pressure to the manometer and inlet. Wait a few seconds for the manometer reading to settle then note the reading. Wait a further 10 seconds then, if you cannot detect a fall in the reading the system is sufficiently leak tight.
Repeat the test but pressurise to between 25cm and 30cm water gauge. The pressure will drop fairly rapidly to between 15cm to 25cm, then stop suddenly. This tests the operation of the 3“ water one way valve CV1 and waste pipe.

16.5 Filters

Filters must be replaced if there is evidence that the pump is being overloaded, 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 on visual inspection.

There is a main filter inside the console and filters at each end of the columns (see section 16.7). The filters in the console unit can be accessed by removal of the top (and side for maximum convenience) described under section 16.2 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. (See Appendix 9 for details). If a section of pipe is seen to contain any debris, it is easier and safer to replace the pipe. The spares and accessories list (Appendix 9) 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 lower jaw from the handle and 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 should not blow backwards through the valve, which is delicate.

16.6 Pumps

The pumps are held in position on the analogue board by a “tiewrap” which enables easy access for servicing. The pumps are supported by a foam pad which acts as an anti-vibration mount and reduces pump noise. To remove a pump simply unplug its electrical lead, ease the tie-wrap towards the back of the pump (away from the pipes) then gently ease the front end of the pump upwards and forwards from under the tie-wrap. Once free of the tie-warp the pipes can be disconnected if required but note should be taken which pipe attaches to which entry on the pump. Refitting is the reverse of removal but care should be taken to ensure that the pipes do not become kinked over and collapse as this will restrict the flow.
The most common pump problem is insufficient flow and is caused by dirt contamination under the flap valves. These 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 will work! 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. The two pumps are identical, and since P140 is only used when the CO_2 supply system is running, it may be substituted for P70 as an emergency repair or for fault finding.

16.7 Chemical Column filters

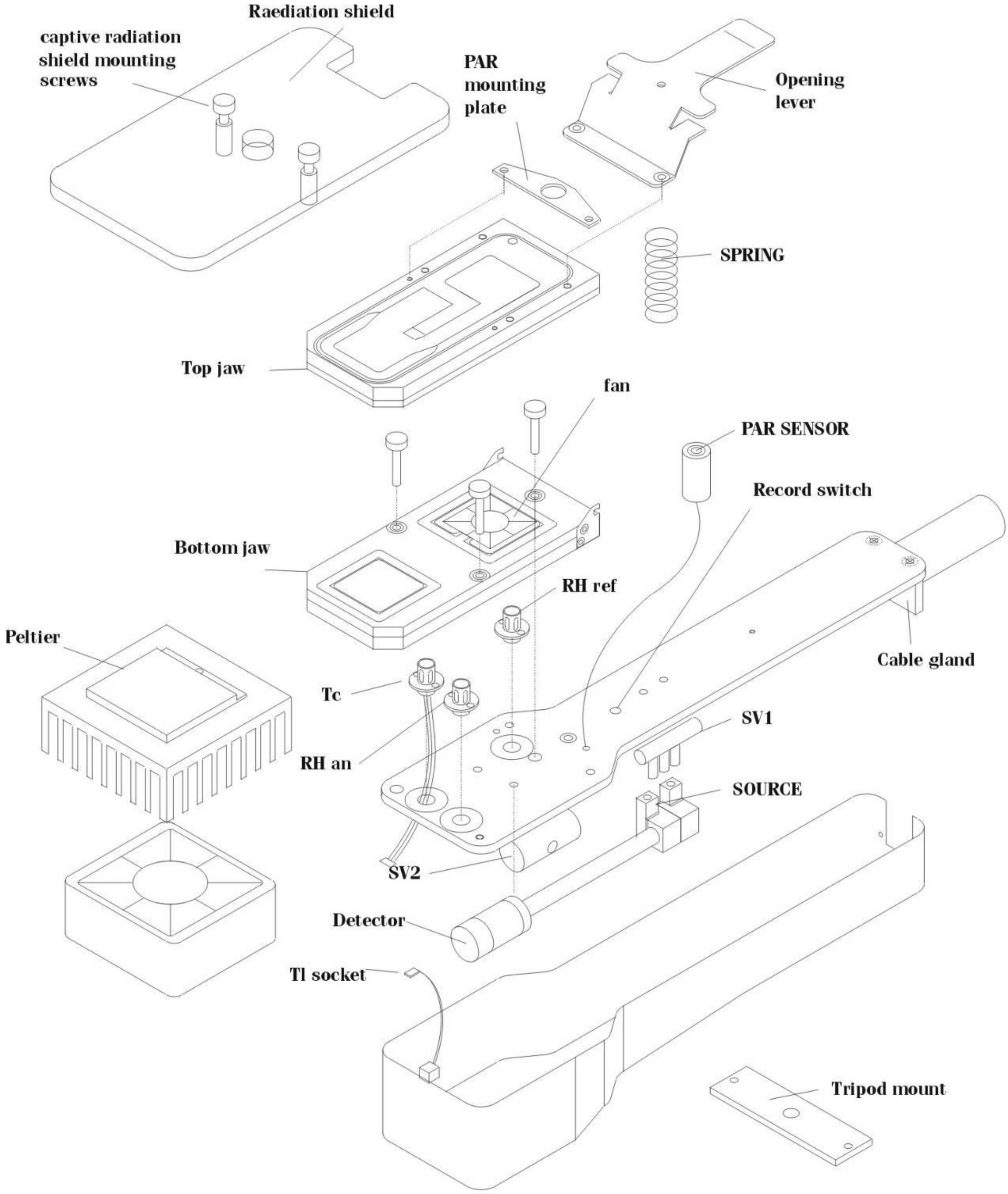
Maintenance on the chemical columns is limited to checking the general condition of the 'O' rings and the filters in the column caps. Occasionally the columns should be cleaned in soapy water and left to dry before replacement.
Air seals should be maintained around all of the 'O' rings. The use of silicon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

16.8 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-288p indicated in section 2.5. This can be accessed by removal of the top display section of the LCpro-SD as previously described.

16.9 Software and Serial Number

The Software Part number and version and the instrument Serial number for the LCpro-SD are shown on the display when the LCpro-SD is first switched on. If, for some reason, the LCpro-SD cannot be switched on the software part number and version are shown on the label attached to the digital board (PCA-288p) and the Serial number label is attached to the battery cover. **These details should be quoted in any correspondence.** The current ADC part number for the software is PRD1063.



CHAMBER EXPLODED DIAGRAM

16.10 Dismantling the Chamber

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. Loosen, but do not fully remove, the two knurled screws, and slide it away from the opening lever. From serial number 31453 the shield is hard coated on both sides to minimise scratching.

The par sensor is permanently connected electrically but the sensor head can now be removed by pulling it out of its mounting plate. This is preferable if you wish to remove the upper jaw.

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. If the leaf spider thermistor is present, either it should be removed, see section 3.5, or care should be taken not to damage it while the top jaw is being removed. The top jaw (Narrow and Broad only) contains the waste valve, which is only likely to cause problems if dirt gets on the seat. The valve spring is in a hole that can be seen through the window. The bottom of the spring pushes on the diaphragm, which is transparent, and the valve seat can be seen through it. The top jaw also contains a magnet to operate the jaw-open detector switch.

The Broad and Narrow windows are made from polycarbonate. If one is badly scratched, it should be polished or replaced. For chambers manufactured from 2003 onwards, the polycarbonate windows are hard coated, which greatly reduces the risk of scratching. Scratches cannot be polished out of these coated windows. Conifer windows are made from PTEG, and cannot be hard coated.

The bottom jaw can be removed by unscrewing the three knurled screws. Take care not to lose the three captive nylon spacers on the knurled screws. If the screws 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. While the bottom jaw is 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. It is important for electrical continuity that the screws between the jaw pairs are tight, especially the hinge screws. There are wires between the plates, connecting from the fixing screws to the fan and jaw-open 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.

Once the lower jaw has been removed the reference and analysis humidity sensors and the chamber temperature sensor (which looks like a black bead inside its metal housing) are exposed. Take care not to lose the three spacers and ‘O’ rings on the sensors or the two ‘O’ rings on the gas stems. (The two gas stem ‘O’ rings can sometimes be caught up in the foam insulation in the lower jaw assembly. If you spot an ‘O’ ring missing that is the first place to look).

The humidity sensors can be withdrawn by unplugging them after the two M1.6 slot-headed countersunk 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. Lightly grease the five ‘O’ rings with the silicone grease supplied before re-assembly, and be sure that the Nylon spacers and ‘O’ rings around the two humidity sensors and the temperature sensor are pushed completely down to the flange before re-assembly.

The temperature sensor has wires and a socket on the back and it can only be removed by taking off the handle lid (see below) and disconnecting it. 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. 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.

The handle lid is removed by extracting the two upper M2 screws either side of the cable gland, and the two M3 screws that fix the tripod mount. Remove it carefully as the leaf temperature jack socket assembly has two twisted wire cables and two sockets, which should be unplugged. The detector socket (white twisted pair) is polarised but the leaf thermistor socket has no polarising key, so make a note of the orientation before removal. The position and function of the connectors and the potentiometers is shown on a label inside the lid.

Before proceeding further, note that the metal plate is at ground potential. If you remove the circuit board or do anything which will short circuit the back of the board to the plate while the instrument is switched on and connected to the chamber, you are likely to blow the fuse and/or damage the electrical components.

The status of the solenoid valves is indicated by the light emitting diodes LED10 and LED90 (see gas circuit). The solenoid valves are both replaceable items and cannot be dismantled. If leak testing them, note that SV2 is of a latching type; that is, it stays in its last position without power, while SV1 has a spring return. 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.

A low detector signal can be attributed to a faulty source, faulty detector or a contaminated cell

The infrared source is the first item to check, as it is the easiest. A source with a working filament has enough light escaping through the exhaust of the tubeset for it to be visibly flashing under normal indoor illumination. Alternatively the filament can be tested for continuity with a multi-meter, it should read about 125 ohms. To change the source it is necessary to, at least, partially remove the cell. Unscrew the single M3 screw under the lower jaw, then the two M3 screws that retain the jaw open clip. The cell can then be raised high enough to access the two M2 screws that hold the source housing to the cell. Remove the housing complete with the source and insulation. The source 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. The envelope on a good source should be clear. If it looks black or silvery, it should 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. Unplug its connector, and remove the large piece of insulation around the detector housing. Unscrew the knurled nut by turning it counter-clockwise, but try to avoid turning the circuit board. The detector complete with socket and lead, 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 removed from its socket, note its orientation with respect to the circuit board. (The “tab” on the detector case should line up with the semi-circular cut-out on the socket. 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 the detector signal falls so far that CO_2 zero cannot be manually corrected with the potentiometer or dirty water has entered the analyser, it is possible that the analysis cell will need cleaning. It is best to first remove the cell as described above then pull the cell off the pipe that connects it to SV2. ***Note that the detector is static sensitive and suitable precautions should be taken.*** Unplug the detector and source leads from the board. 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 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 buds or cotton wool wrapped around a thin stick. For persistent dirt, alcohol or acetone can be used. If the cell has had aqueous 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 BioScientific.

16.11 Removing the Handle Cover

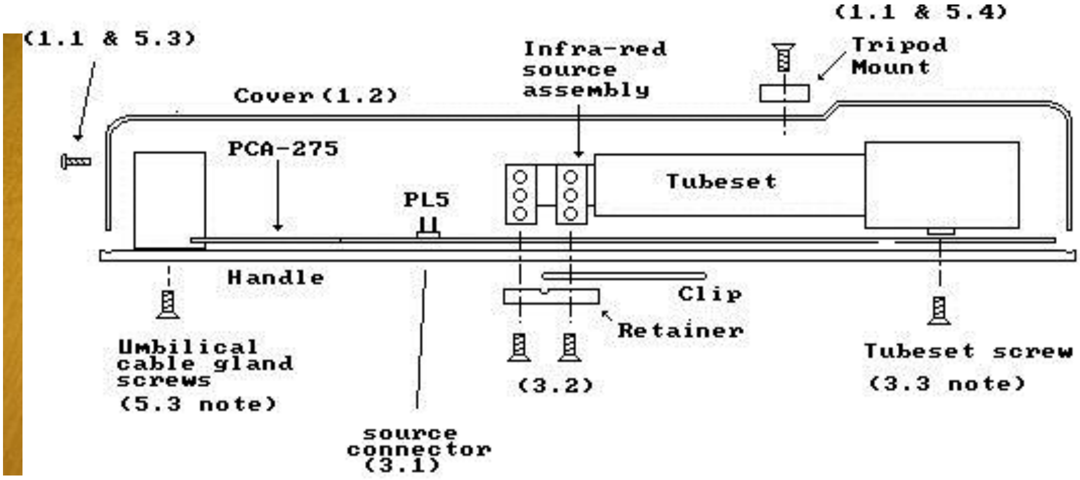
Unscrew the two retaining screws from the tripod boss.
Note the orientation of the boss – On some instruments the fixing screws are not in the middle.

Remove the two screws furthest from the baseplate, which pass through the cable gland assembly.

Sometimes these screws are cross head rather than slotted.

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.

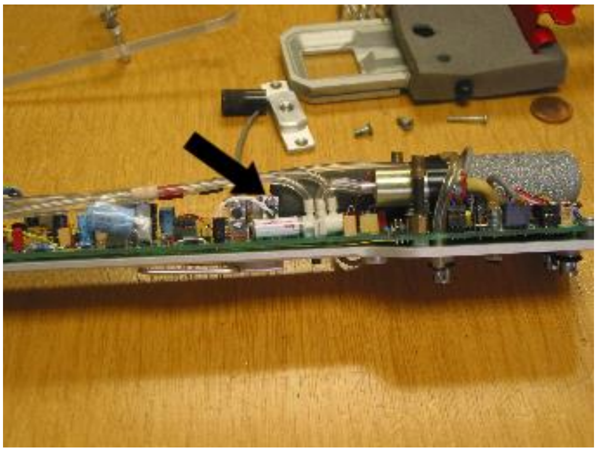


Later models have the CO2 zero potentiometer mounted in the handle cover instead of on the board so that an additional twisted pair of wires runs from the jack-socket assembly to RV9 on the board

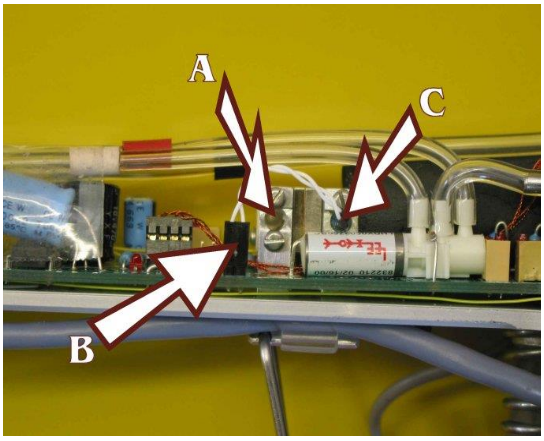
On the diagram/label in the handle:

R indicates red
B indicates black
W indicates white
X indicates no connection (polarising pin)

16.12 Checking the Source



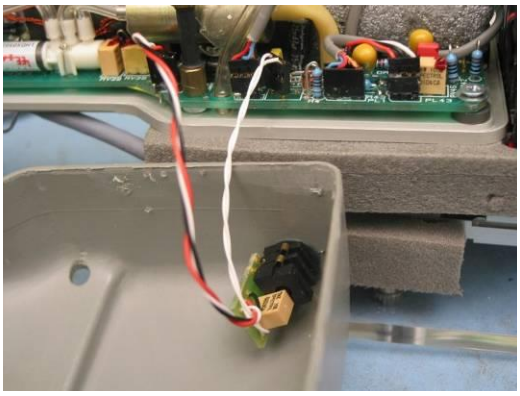
First remove the jaws and then the handle cover, (see previously). It is not necessary to completely remove the cover.
The source is indicated by the black arrow in the above picture. It is a small light bulb, which has been pre-aged to minimise drift. It has a thin envelope to minimise infrared loss,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

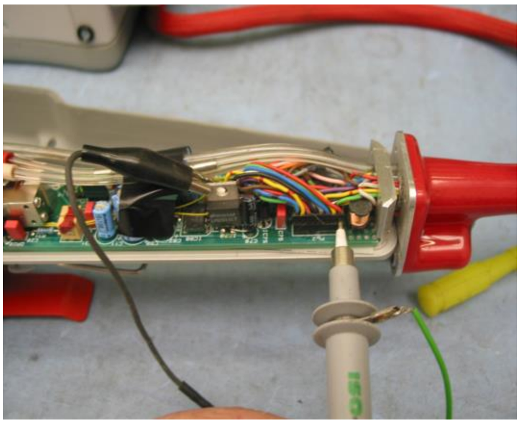
The resistance of a good source is about 125 ohms. If there is flashing then carry out the next test.

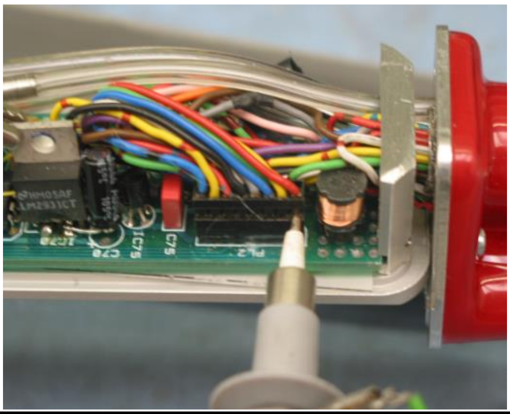
16.13 Checking the Detector



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.

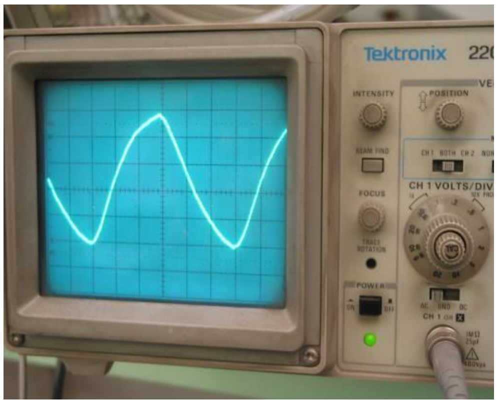
Place the earth clip of an oscilloscope probe on the metal body of the regulator as shown.





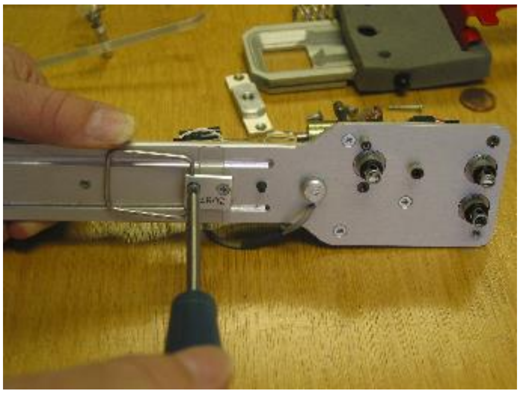
With a narrow oscilloscope probe measure the signal on the red wire of the connector. This can be done through the small hole in the side of the connector.

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.



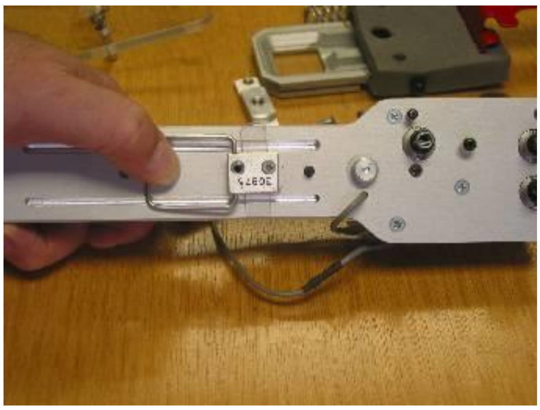
The detector can be removed with the cell in place. It is a static sensitive device and so static precautions should be observed as for changing the EPROM. Unplug its connector, and remove the large piece of insulation around the detector housing. Unscrew the knurled nut by turning it counter-clockwise,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

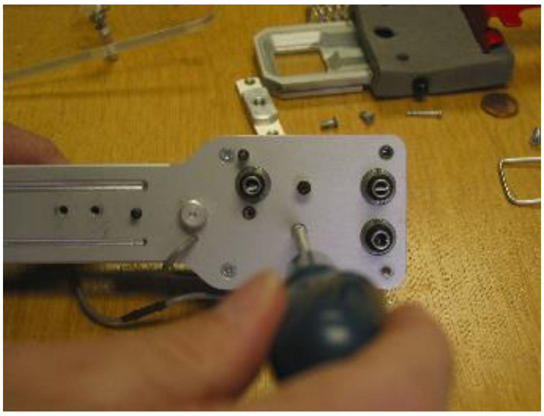
16.14 Replacing the Source



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

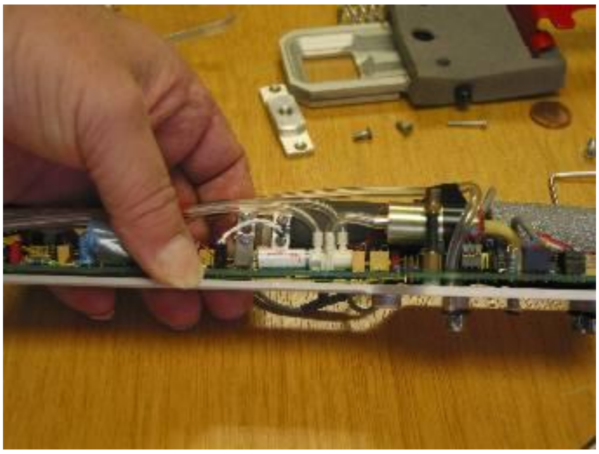
Note that the retaining screws are off-set and not central. Remember this when reassembling the handle.

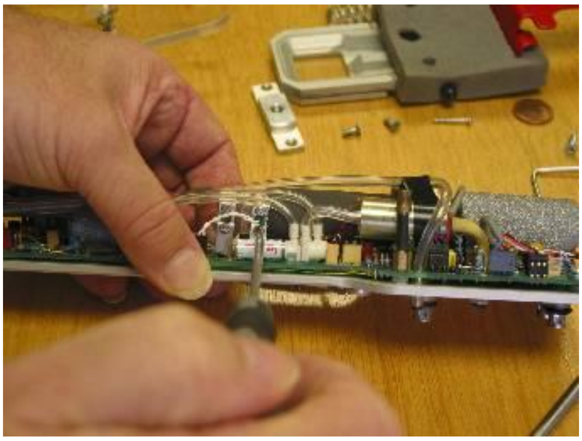




Unscrew the analyzer retaining screw TWO TURNS. Do not remove this screw completely because it locates the analyser cell at the detector end and prevents its pipe connection and detector wires being strained.

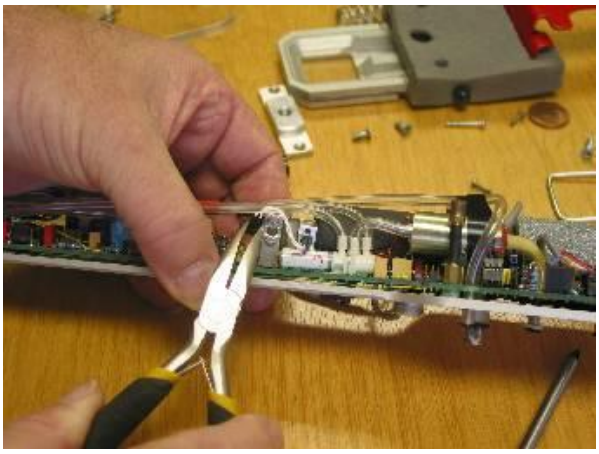
This will give you just enough slack to lift the source end of the analysis cell, giving you access to the lower source retaining screw. If there is not enough movement to get a screwdriver on to the sources lower screw then go back to the previous instruction and unscrew the analyzer retaining screw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





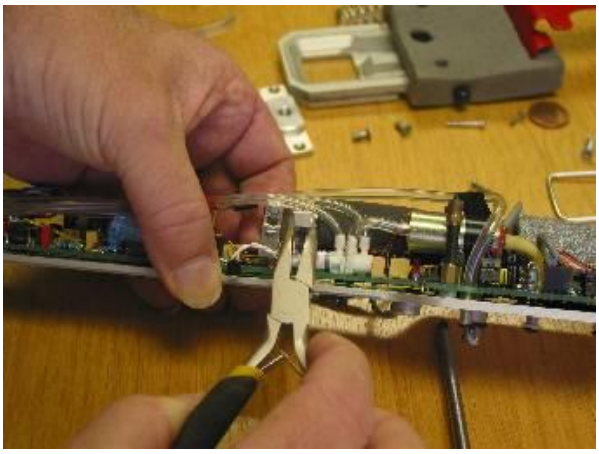
Using a small flat bladed screwdriver, unscrew and remove the upper and lower source retaining screws. These screws are stainless steel – Do not replace them with mild steel types.

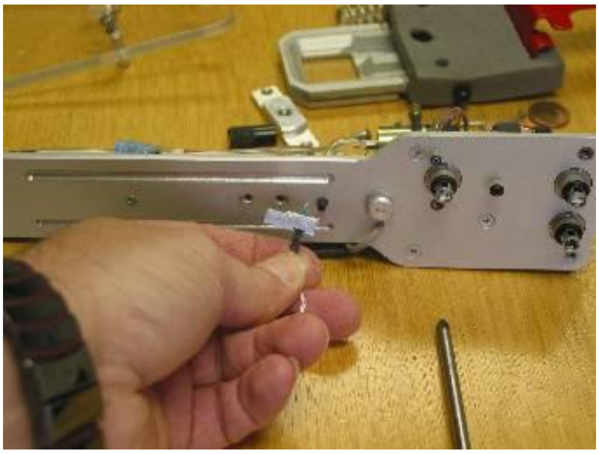
Using tweezers or long nose pliers gently pull out the old source from the analyzer cell. Take care not to allow any debris to get inside the analysis cell.



Disconnect the sources electrical connection from the circuit board.

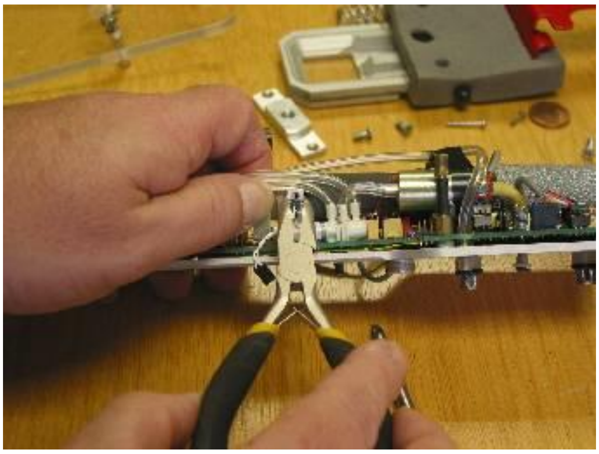
Then remove the old source.





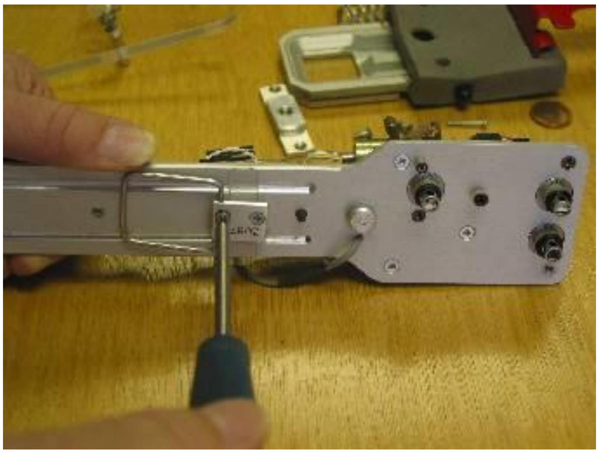
A thermal isolation gasket should have come off with the old source.

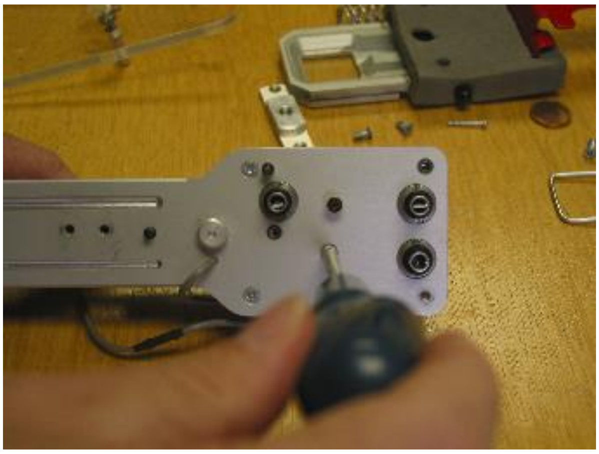
Remove the thermal isolation gasket from the old source and fit it onto the new replacement source.



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.

Refit the Handle cover and Jaws.

IMPORTANT! TWO THINGS TO RECALIBRATE AFTER FITTING A NEW IR SOURCE.

- Allow the machine to warm up and perform a CO2 zero calibration, see section 7.5.2 of this manual.
- Run a phase check, see section 7.4 of this manual

16.15 Peltier Cooler and Light Unit.

The peltier cooler, mounted on the lower jaw, is not serviceable by the user, and should be returned to ADC BioScientific or your local Service Centre if there is a problem with it. It is made from semiconductor blocks sandwiched between thin ceramic plates, and is brittle, so it can easily be broken if the jaw is dropped.

Servicing the light unit is limited to loosening any dirt with a soft brush, and blowing it out. Contact ADC BioScientific or your local Service Centre for any other problem with the light unit. (See inside front page for contact details)

SECTION 17. ERROR MESSAGES AND 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 dis-mantling chemical column	'O' ring seals are dry	Apply a thin wipe of silicone grease to the 'O' rings.
"CO_2 signal failure"	The detector signal is out of range of the A-D converter. Due to: either CO_2 zero cal. or Source failure or Detector failure	Recalibrate CO_2 zero. Look for source flashing- light escapes through the base. Measure resistance (125Ω) Using oscilloscope look for about 15mVpk-pk triangle wave on pin 2 (red) of PL1, on PCA-275A
"CO_2 low energy"	Gain set too high Soda lime exhausted Dirt in the cell	Recalibrate CO_2 zero. Check soda lime Remove and clean cell
"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 Normally Open (NO) position	Check soda lime, if OK check pipe, if OK check SV1
Low or negative CO_2 values (reference and analysis)	Soda lime exhausted SV2 is stuck	Check soda lime Use the exercise SV2 option in config>diagnose>sys info>sv check , the valve should click loud enough to be heard within 1 metre of the instrument. Contact ADC for help if the valve does not work.
Only C_{an} low or zero	Fan stopped (this happens if jaws are open) Or if a jaw screw has been over tightened, which can break a wire attached to the jaw. No jaw pressure, caused by a big leak. Fan outlet blocked	Check fan, shut jaws. Check jaw gasket and O rings. Check outlet filter
"CO_2 signal over range"	Signal at A-D converter is out of range. Gain is set too high	Recalibrate CO_2 zero.
"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)
Both the "C" readings are the same or nearly the same and do not change.	Confirm this by briefly opening the jaw and blowing into it then closing, C_{an} should go very high or o/r (over range), try this twice. SV2 may be stuck	Use the exercise SV2 option in config>diagnose>sys info>sv check , the valve should click loud enough to be heard within 1 metre of the instrument. Contact ADC for help if the valve does not work.

SECTION 18 APPENDICES

APPENDIX 1 PARAMETER INFORMATION

Symbol	Description	Screen	Log?	An o/p	Units	Range	Type
A	Photosynthetic rate	2	16	-	µmol m^{-2} s^{-1}	0-100	Ca
Area	projected leaf surface area	3, cfg	17	-	cm2	0.1-100	G
c_{ref}	CO_2 reference	1	6	y	vpm	0-2000	M,Co
c'_{an}	CO_2 analysis (corrected for dilution)	1	-	y	vpm	0-2000	M,Co
Δc	Delta CO_2 (Cref - C'an)	1	7	y	vpm	+/-2000	Ca
c_I	Sub-stomatal CO_2	2	13	y	vpm	0-2000	Ca
[cab]a	Infra-red absorption due to analysis CO_2	diag	-	-	%	0-40	-
[cab]r	Infra-red absorption due to ref CO_2	diag	-	-	%	0-40	-
[c]z	Raw CO_2 zero reading	diag	-	y	adc counts	-	-
C_e	Soil Respiration	2	-	y	µmol s^{-1}		Ca
Cfg:	Chamber type / configuration set	3, cfg	-	-	-	-	-
Dt	Date (text)	diag	2	-	-	-	-
E	Transpiration rate	2	14	-	mol m^{-2} s^{-1}		Ca
e_{ref}	H_2O reference, as partial pressure	1	4	y	mBar	0-75	Ca,Co
e'ad	H_2Oanalysis, dilution corrected	1	-	y	mBar	0-75	Ca,Co
Δe	Delta H_2O (e'_{an}-e_{ref}), partial p.	1	5	y	mBar	+/-75	Ca
gs	Stomatal conductance of H_2O	2	15	y	mol m^{-2} s^{-1}	0-100	Ca
Hfac	H factor - energy conversion factor	3, cfg	-	-	-	0.1-1	F,G
Log:	Name of log file	3, cfg, log	-	-	-	--	G
Mem.	Free space on memory card	log	-	-	k bytes	-	-
NCER	Net CO_2 Exchange Rate	2	-	y	µmol m^{-2} s^{-1}	0-100	Ca
P	atmospheric pressure	1, hid	12	y	mBar	600-1100.	M
Phase	CO_2 rectifier phase shift	hid	-	-	°	-	-
Power	Bar graph showing battery state	2	-	-	-	10.5-14.3	M
Q	P.A.R. at window	hid	-	-	µmol m^{-2} s^{-1}	0-3000	M
Qleaf	P.A.R. incident on leaf surface	1	8	y	µmol m^{-2} s^{-1}	0-3000	Ca
Q_{mode}	Light measurement method	-	20	-	-	-	-
r_b	Boundary resistance to H_2O	3	18	-	m^2 s mol^{-1}	0.1-9	G
r_b set	Boundary resistance at full flow	cfg	-	-	m^2 s mol^{-1}	0.1-9	G
Record	Current record number	2, log	1	-	-	-	-
rs	Stomatal resistance to H_2O	-	-	-	m^2 s mol^{-1}	0-100	Ca
Tch	leaf chamber temperature	1	9	y	°C	-5 to +50	M
Tl mtd	Leaf temperature determination method	3, cfg	19	-	-	-	-
Tleaf	Leaf surface temperature	2	10	y	°C	-5 to +50	M,G
Tm	Time of day	diag	3	-	-	-	-
Trw	Chamber window transmission factor	3, cfg	-	-	-	0.25-1	F,G
u	ASU mass flow (measured)	2	11	y	µmol s^{-1}	68-341	M
U_a	Last value of an flo, from flowcheck	cfg	-	-	µmol s^{-1}	-	Ca
u_s	Flow per unit leaf area	-	-	-	mol m^{-2} s^{-1}	-	Ca
u_{set}	Desired molar air flowrate	2, 3, cfg	-	-	µmol s^{-1}	68-341	G
Va(±20%)	Measured analyser flow	-	-	-	µmol s^{-1}	-	-
Vaux	Aux input, scaled as volts	-	-	-	Volts	-	-
Vbatt	Battery voltage	diag	-	-	Volts	10.5 -14.3	-
W_{ref}	H_2O reference, as %RH	diag	-	y	%RH	0-100	M,Co
w'_{an}	H_2O analysis, corrected, as %RH	cfg	-	-	%RH	0-100	M,Co
w'_{ad}	H_2O analysis, dilution corrected	diag	-	y	%RH	0-100	Ca,Co
Δw	Delta H_2O (w'an-Wref), as %RH	-	-	y	%RH	+/-100	Ca
[w]a	Raw H_2O analysis reading	hid	-	-	adc counts	-	-
[w]r	Raw H_2O reference reading	hid	-	-	adc counts	-	-
W_{flux}	Net H_2O Exchange Rate	2	-	y	mmol m^{-2} s^{-1}	-	Ca

Column explanations and type derivation codes

"Screen" column.
This gives the location (where applicable) of displayed parameters.
There are three main screens (1, 2, & 3) and four sub screens (described below).
The sub screens are diag = diagnostics screen
cfg = configuration set up screen
log = log set up screen
hid = hidden screen for ADC use only

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

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

"Type" column
This 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 LCpro-SD)
(H_{fac} was Trans on LCA-3)

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
Sub-stomatal CO2	(C_i)	vpm	0	20	4
Photosynthetic Rate	(A)	μmol m^{-2} s^{-1}	-2.5	25	5.5
Transpiration Rate	(E)	mmol m^{-2} s^{-1}	0	50	10
Net CO_2 Exchange Rate [*1]	(NCER)	μmol m^{-2} s^{-1}	0	100	20
Net H_2O Exchange Rate [*1]	(W_{flux})	mmol m^{-2} s^{-1}	0	50	10
Soil Respiration [*1]	(C_e)	vpm	0	20	4
Raw CO2 zero at TP20 [*2]	([c]z)	Volts	4.05	5	0.19
Raw CO2 zero Diagnostic [*3]	([c]z)	A-D count	45000	60000	3000
Stomatal Conductance	(G_s)	mol m^{-2} s^{-1}	0	100	20
Column Temperature	(Taux)	°C	-5	50	11
CO2 Bottle Mix. Conc.	(CO_2bot)	vpm	300	10000	1940

[*1] Applies to Soil pot configuration only.
[*2] Volts as measured at TP20 during zero parts of gas cycle or CO2 zero calibration
[*3] A-D count optimally 52500 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 reading is now linearised and scaled according to 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 LCpro-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})

$$u_s = \frac{u}{100 * area}$$

Where u molar air flow in μmol s^{-1}
$area$ projected leaf area in cm^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} (^{O}C)

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

where

T_{ch}	leaf chamber temperature, ^{O}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})

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

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

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

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

[*1] Energy Balance Equation for calculating leaf temperature: PARKINSON, K.J. (1983) Porometry in S.E.B. Symposium of Instrumentation for Environmental Physiology, Cambridge University Press

APPENDIX 3 (Continued)

Sub-stomatal cavity CO_2 concentration

symbol: c_i (µmol mol^{-1})

$$C_i = \frac{((g_c - \frac{E}{2})c'_{an}) - A}{g_c + \frac{E}{2}}$$ [*1]

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}

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

$$e_s = 6.13753x\, 10^{-3}\, e^{\left(\frac{17.966\, T_{leaf}}{T_{leaf} + 247.15}\right)}$$

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

where T_{leaf} leaf surface temperature, °C

[*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)

Stomatal conductance of water vapour

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

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

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

P.A.R. incident on leaf surface

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

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

where $\boldsymbol{Q}$ Photon flux density incident on leaf chamber window, μmol m^{-2} s^{-1}
$\boldsymbol{Tr_w}$ Leaf chamber window transmission factor to P.A.R. (given)

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

symbol: $\boldsymbol{C_e}$ (μ mol s^{-1})

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

where $\boldsymbol{u}$ molar air flow in mol s^{-1}
$\boldsymbol{\Delta c}$ 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 $\boldsymbol{u_s}$ molar flow of air per square meter of soil, mol m^{-2} s^{-1}
$\boldsymbol{\Delta c}$ difference in CO_2 concentration through soil pot, dilution corrected, μmol mol^{-1}.

Note: *This is equivalent to -A*

APPENDIX 3 (Continued)

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*

Constants

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

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

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

Molecular weight of air (M_a)
Value used is 28.97

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

APPENDIX 4. DERIVATION AND MEASURED VALUES FOR HFACTOR

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

The Hfactor is used to convert the measured PAR value into a figure for the total energy absorbed, by the leaf, 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^2

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 LCpro-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)

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 MEASURED HFACTOR VALUES/CONDITIONS.

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

APPENDIX 5 SPECIFICATION FOR SEQUENCE FILES

Basic Specification

The climate sequence file is a comma-separated text file, which can be easily read, created and generated on a PC.

The file consists of lines of text, which contain either the detail for one step in the sequence, or comment (descriptive notes or other text which is ignored when the sequence runs.)

Blank lines are not acceptable (even at the end of the file).

Mandatory Sections

The first *two* lines in a climate sequence file *must* be comment lines. Any additional comment lines are optional.

The first comment line normally contains details about the creator of the file, but the content is unimportant. Only the initial '#' character is mandatory.

The second comment line holds the column headings. The presence of the heading is used to validate the file, so at a minimum, the second line in a sequence file must start with: '#Dwell'. We recommend that the standard second line is used as this identifies the columns when the sequence file is viewed on a spreadsheet. See the example file on page 94.

Comment Lines

If a line starts with a '#' character at the START of the line, it is treated as comment, and will not be displayed or executed. Any text up to the end of the line is ignored.

Comment lines (after the first two lines in the file) are optional. Be aware that comment lines use space, and excessive comment may make the sequence file too big.

The LCpro-SD on loading a sequence file will strip off any optional comment lines, so these will be lost if the LCpro-SD subsequently saves the file onto a memory card. Optional comment is not removed when the file is *first* transferred to the LCpro-SD.

Data Lines

Each data line in the climate sequence file consists of one step, and these are numbered and executed in sequence from the start to the end of the file.

The line consists of 6 'fields', separated with commas. Except for the last, each field must be present, with a number or indicator as allowed. The LCpro-SD will attempt to interpret invalid fields, but the result may be unexpected.

NOTE: The step number (as shown on the LCpro-SD screen) is *not* present - the analyser adds it when the file is loaded.

Indicators

Generally numbers are required for the fields, but the following 'indicators' can be used in place of the number for special values:

PREVIOUS - use the value from this field in the previous step.

Notes

This indicator is not allowed in the first step.

This indicator can be abbreviated to 'p', 'prev.' or indeed anything beginning with upper or lower case P.

AMBIENT - this parameter is no longer controlled, and where possible, will revert to ambient.

This indicator can be abbreviated to 'a', 'amb.' or indeed anything beginning with upper or lower case A.

Only ONE indicator is allowed per field.

Field Descriptions

The fields are as follows (numbered left to right):

1. Dwell Time

This field sets the time for which this step executes in minutes. The 'p' indicator is allowed. Integer values between 1 and 100 are accepted. Invalid values are changed to 5 minutes.

2. Temperature

This field sets the temperature control demand value in Celsius. The acceptable temperature range is currently 1 to 40°C. Integer values are required. Temperature control is turned off if the 'a' indicator is used, and the 'p' indicator is also allowed.

3. PAR

Sets the light level, where a suitable illuminator is fitted. Valid PAR values range from 20 to 2000 (subject to illuminator), and the value of zero is accepted as dark. If the ambient indicator is used, this also turns off the lamp. The 'p' indicator is allowed.

4. CO_2 Concentration

This field sets the reference or analysis concentration in vpm. The channel controlled will depend on the CO_2 option setting. The range of concentrations will depend on whether or not a CO_2 cylinder is fitted. The 'a' and 'p' indicators are allowed, but note that truly ambient CO_2 is not possible with the cylinder fitted, as all incoming air is enriched by the cylinder.

5. H_2O Concentration

This field sets the reference or analysis water concentration. The channel controlled will depend on the H_2O option setting. The range of concentrations will depend on whether or not a 'wetter' column is fitted. The 'a' and 'p' indicators are allowed, but note that truly ambient H_2O is not possible with the wetter column fitted, as all incoming air is wetted.

6. Options

This field is unique in that it can be blank, and can only hold 'flag' letters. Each flag enables a particular option for the step, and flags can be present in any combination. Any flag can appear once only.

The flags are single letters, (either case) as follows

- **I** Ignore - this step is skipped when the sequence runs
- **R** Record - take a log record at the end of this step
- **E** End - stop the sequence running at the end of this step (after any log record taken)
- **P** Power down - as 'E', but turn off the power as well

Creating A Climate Sequence With Excel™

A spreadsheet program is the best tool to create and edit climate sequence files. Providing simple rules are followed, a file can be created very quickly.

Starting with a blank sheet, insert the mandatory comment lines at the top:

1. The top left cell should hold '#' followed by any note you may want to make about the file - keep this text in the first cell.
2. On the second row, enter the following column headings into the left six cells:

   #Dwell | Temp | PAR | CO2 | H20 | Flags

   (take care with this - it must be on the second row in the sheet, and the first cell must read exactly as shown, or the file will be rejected.)

Now, simply enter the climate steps in subsequent rows. Do not use commas - the spreadsheet software will insert these automatically when you export the data. Do not add spaces. Use only integer numbers (no decimals).

Comments

If you want to add a comment line, put a '#' in the leftmost cell, with the comment following it in the same cell.

Saving the File

From the file menu select 'Save As'. From the 'Save as Type' drop down list, select 'CSV (Comma Delimited)'. Select a file name as usual. Excel will use the extension '.CSV' at the end of the file name.

If you are saving onto a memory card directly, note that the file must be renamed with a '.SQS' extension for the LCpro-SD to recognise it. If you are using transfer to send the file to the LCpro-SD, the extension will be changed automatically.

Editing an Existing File With Excel™

If necessary, select 'All files (*.*)' from the list - this is necessary if the file has been loaded from a memory card directly, as the file will have a '.SQS' extension that Excel does not normally recognise.

The file will be loaded ready for editing. Follow the rules given in the previous section.

When saving the file, ensure that the 'save as' option is 'CSV' and, if the file extension is changed to '.CSV', remember to change it.

Technical Notes

File Size Limits
Sequence files are currently limited to 8000 characters maximum, including comments and carriage return/linefeeds. There is also a limit of 100 data lines.

Attempting to load or transmit an oversize file to the LCpro-SD will result in the file being truncated.

End-Of-Line
The LCpro-SD recognises the end of line conventions used by both DOS/Windows (carriage return, linefeed pairs) and UNIX type systems (carriage return only). Files created on the LCpro-SD, or saved after editing on the analyser will use DOS/Windows conventions.

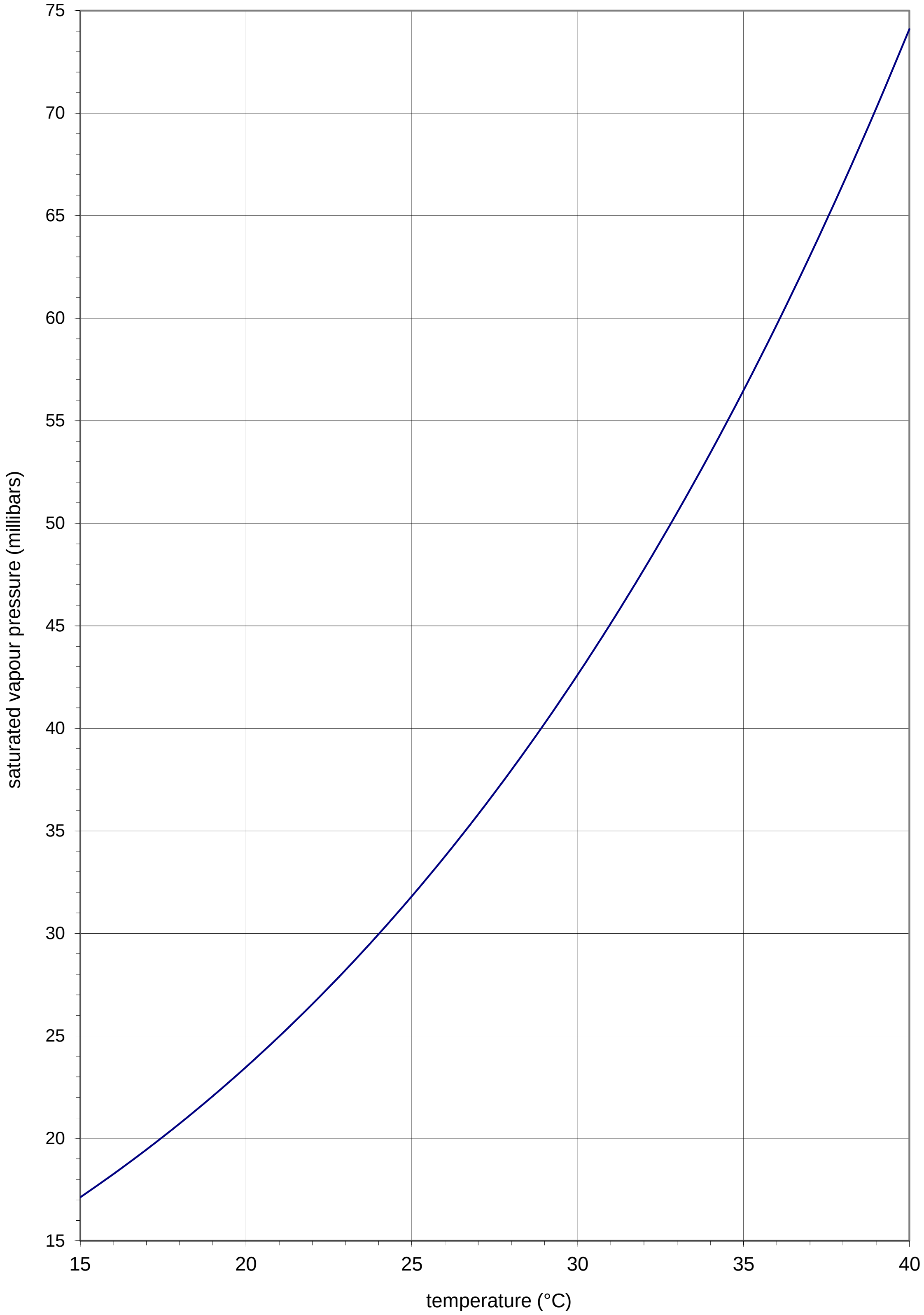
Be cautious when creating files on a Mac, as the Apple convention for end of line is linefeed only - this is not acceptable to the LCpro-SD.

Spaces
The LCpro-SD is fairly tolerant of trailing spaces in the file, but these waste space. Avoid leading spaces in fields.

Example File

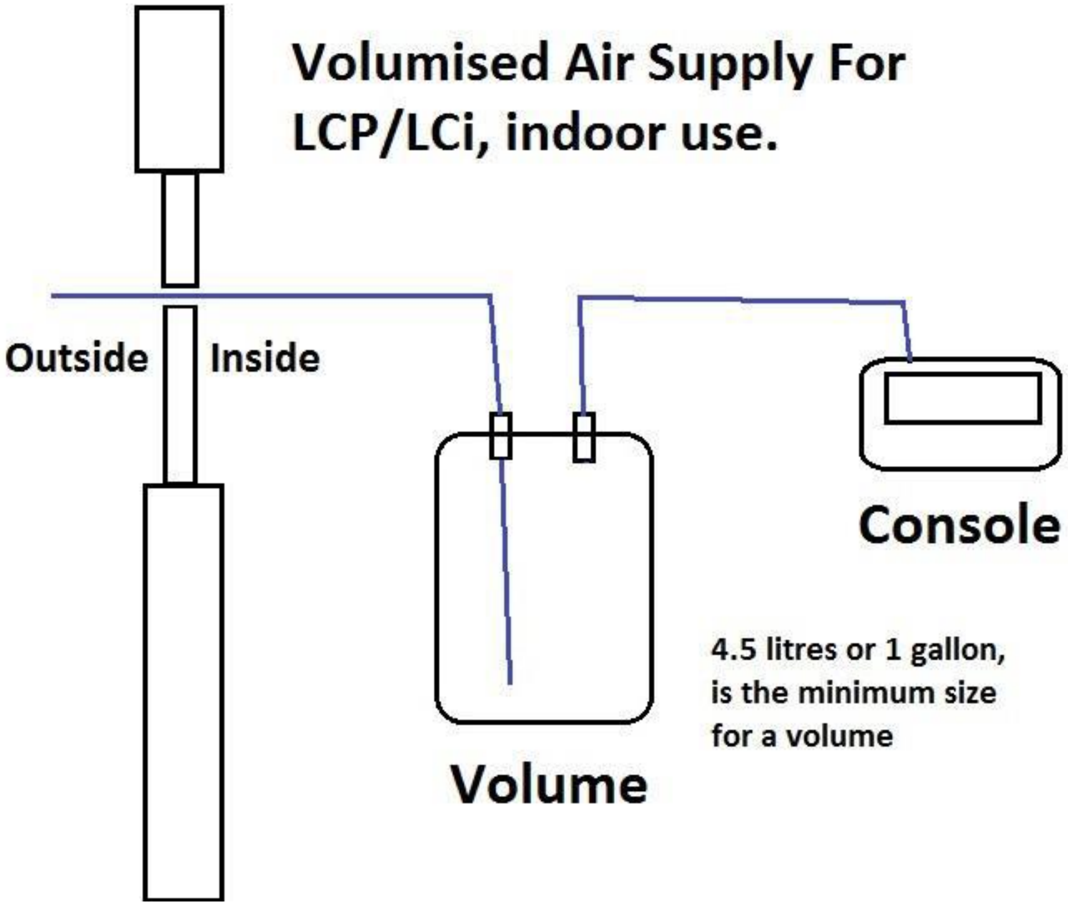
```
# ADC BioScientific  LCpro-SD  System Climate Sequence
#Dwell,Temp,PAR,CO2,H2O,Options
1,amb.,1,amb.,amb.,
2,amb.,200,amb.,amb.,R
2,amb.,300,amb.,amb.,IR
2,amb.,450,amb.,amb.,R
1,prv.,prv.,prv.,prv.,R
prv.,prv.,prv.,prv.,prv.,
1,35,prv.,prv.,prv.,RE
```

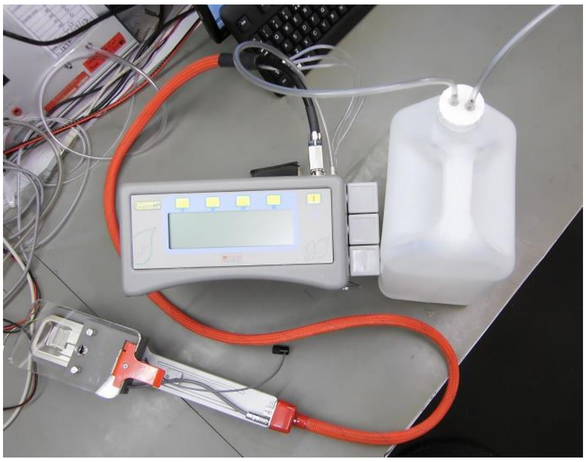
APPENDIX 6. SATURATED VAPOUR PRESSURE



Graph derived from table 94 of Smithsonian Meteorological Tables

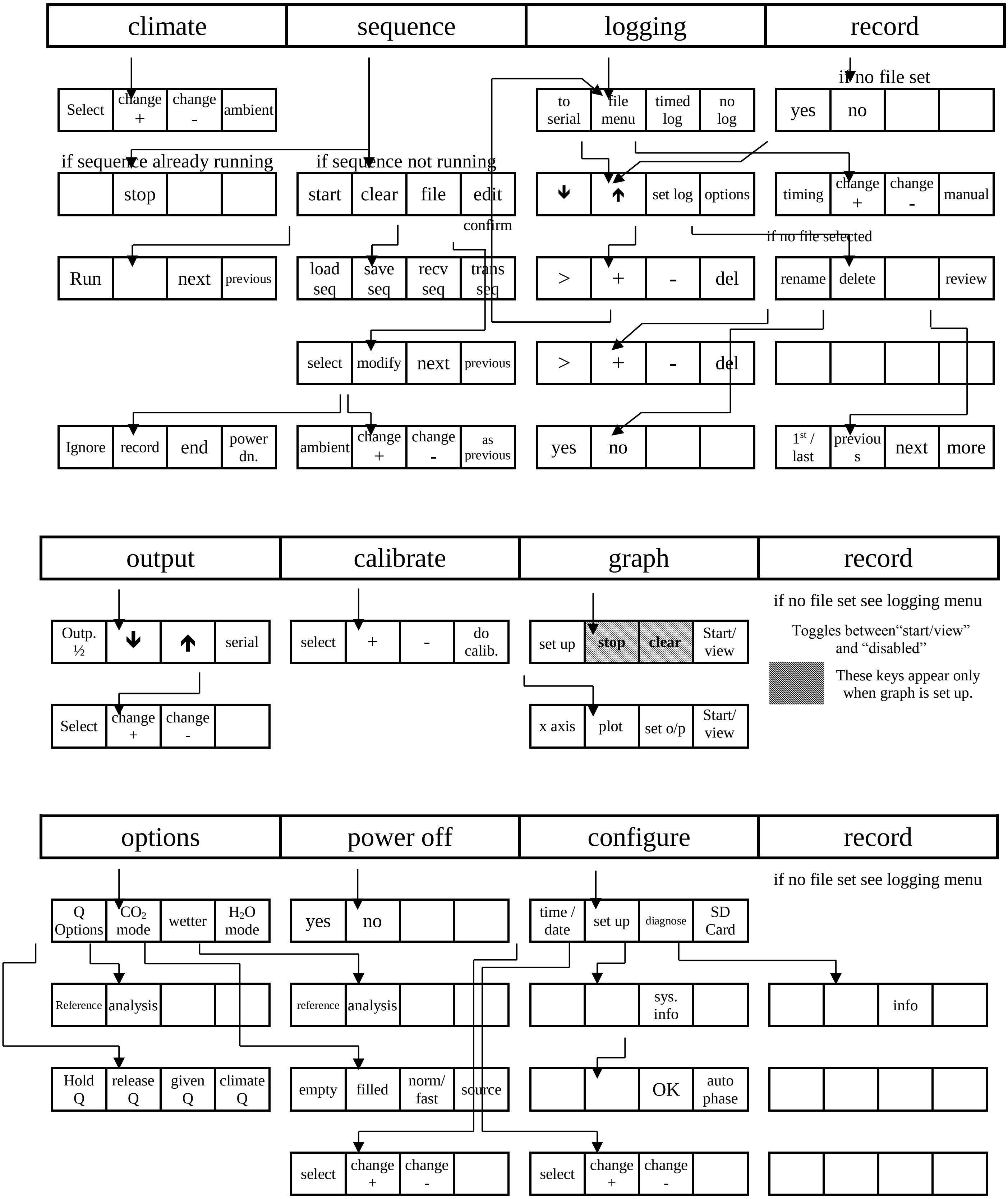
Appendix 7 Volumised Air Supply for Indoor Use.





APPENDIX 8 LCPRO-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:	0-3000 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:		Energy balance or microchip thermistor or self positioning thermistor
Gas Exchange Repeatability:		CO_2: 0.1% of reading @ 370ppm H_2O: 0.5% R.H.
Linearity:		CO_2: 0.5% of reading H_2O: 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.
Automatic environmental control: CO_2:		Up to 2000 ppm with integral controller
H_2O:		Above ambient, down to zero
Temperature		±10°C or better from ambient. (Software limited between 1 to 40)
PAR		Up to 2000 μmol m^{-2} sec^{-1} by red/blue LED array
Display:		240 x 64 dot matrix super twist LCD
Warm up time:		5 minutes at 20°C
Recorded data:		Secure Digital.
Battery:		7 AH lead acid 12V to give 16 hours max
Battery charger:		90 to 260V, 50/60 Hz
Analogue output:		0 to 5V on user selected parameter

APPENDIX 9 TECHNICAL SPECIFICATION (CONTINUED)

RS232 output: USB Slave Peripheral		User selected rates up to 19200 baud
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:		2A @ 12V DC
Operating temperature:		5°C to 45°C
Dimensions H x W x D overall	Console: Chamber:	280 x 135 x 190 mm 300 x 80 x 75 mm
Weight (typical)	Console: Chamber:	4.4 kgs 0.8 kgs

APPENDIX 10 SPARES AND ACCESSORIES

Part No.	Description
022-658	3.15A fuse glass time delay
192-151	Lead acid battery, 7Ah, 12V
197-710	SD card 2G
299-484	Lead acid charger, 12V
612-354	Tee, green, plastic
631-180	Aluminium dismantable filter
630-963	Hydrophobic filter (27mm diameter 1.0µm mesh)
630-980	Filter plastic disposable
632-265	CO_2 cylinder filter
650-652	'O' ring 6.07 bore x 1.78 (for column entries)
651-551	'O' ring 28.3 bore x 1.78 (for column tubes)
653-085	'O' ring 2.54 bore x1.02 (for analysis pipe from chamber)
650-240	'O' ring 2.0 bore x 1 (for air supply pipe to chamber)
653-126	'O' ring 8.73 bore x 1.78 (for cylinder seal in CO_2 regulator)
706-150	Tube PVC 4mm bore
706-555	Tube PVC 2mm bore
708-101	Tube PVC 6mm bore (*for use with optional exterior filter*)
708-656	Tube PVC 3mm bore
708-454	Tube butyl 3mm bore
802-151	Calcium Sulphate (drier), 10-20 mesh
802-253	Iron Sulphate, granules
809-151	Silicone grease
843-296	CO2 bulbs
867-056	Trimming tool
867-167	Core trim double ended
994-151	Cable 9 fem to 9 fem 2 metre
LC4-070	Air probe assembly
LC4-170	Air probe ground spike
LCB-129	Gasket broad front
LCI-023A	Source assembly
LCI-056	Car power supply lead
LCI-059	Lead assy. power/chart
LCI-131	Gasket broad back
LCI-159	Solenoid entry
LCI-168	Belt/neck strap
LCM-033	"Spider" temperature assembly for broad leaf chamber
LCM-034	"Snail" temperature assembly for narrow leaf chamber
LCM-039	Regulator dump assembly
LCM-068	Soda Lime white to violet 500g glass jar.
LCM-139	LCpro RH sensor spacer
LCM-140	LCpro jaw fixing spacer
LCM-146	CO_2 regulator "key"
LCM-187	Narrow gasket
LCM-203	Conifer gasket
LCM-189	Handle air out (out from jaws, brass)
LCM-165	Handle air in (in to jaws, brass)
PLC-011	Leaf temperature thermistor assembly
	AC power "mains" lead (UK, Euro or USA)
MAN-LCpro-SD	this manual.