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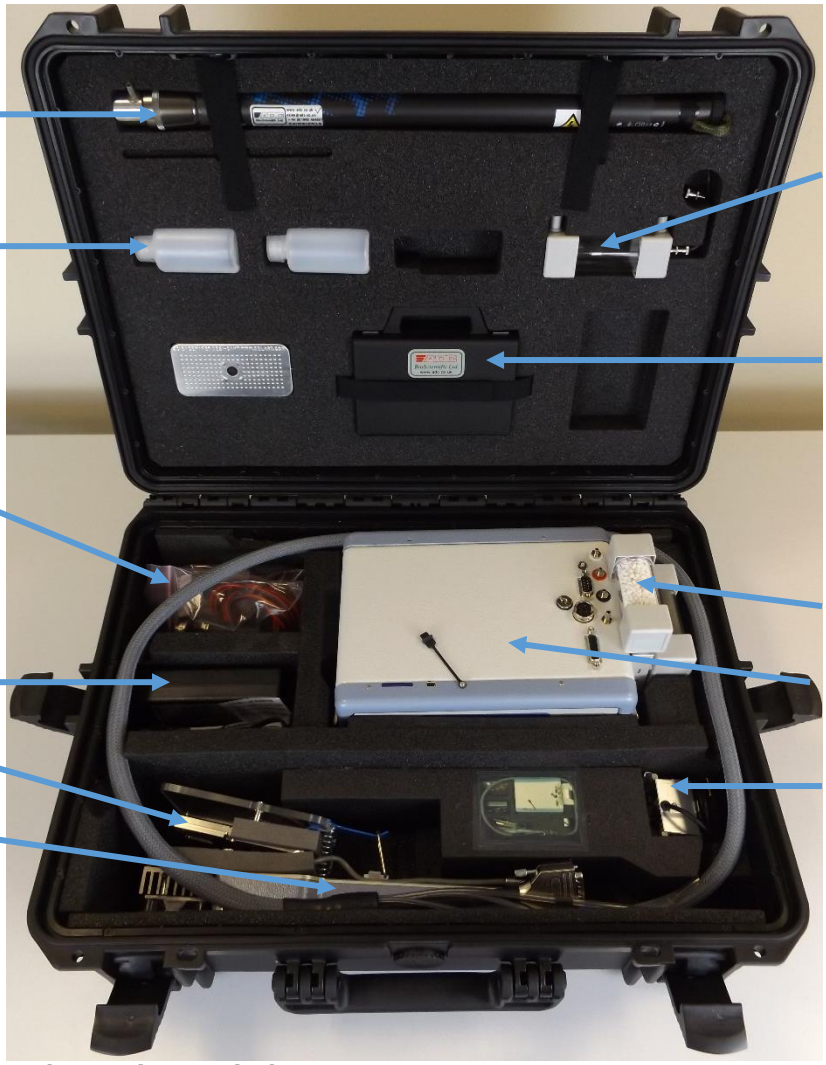
Contents

SECTION 1. INTRODUCTION

This manual covers the operation and maintenance of the LCpro T, Leaf Chamber & Soil Respiration System (SRS2000 T).

1.1 Equipment list

The LCpro T is supplied in a carrying case, containing:



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

Also with the carrying case is a **spares kit**, which includes all required chemicals, CO_2 cartridges and a selection of spare parts (all listed in Appendix 13). Lastly, the LCpro T User Manual and Quick Start Guide.

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

1.2 Description

The LCpro T (with Leaf chamber/Soil pot) is designed for portability and field use, providing internal battery power for up to 16 hours of continuous operation, depending on the functions used. The LCpro T measures and controls the environment around a leaf contained in the chamber, and calculates the photosynthetic activity of the leaf. Or, when used with a Soil pot, measures 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, and a Plant Leaf Chamber (PLC) connected by a multi-way cord. Where applicable, the PLC 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 air is directed over both surfaces of the leaf. The discharged air leaving the chamber is analysed for CO_2 concentration (generally decreased) and H_2O concentration (increased). In the case of the Soil pot, the CO_2 concentration of the air entering the pot is measured and the discharged air that has passed over the soil is also analysed for (generally increased) CO_2 concentration. An excess of air is provided to the Soil pot over that extracted, and a pressure relief vent ensures that the pot is not pressurised, preventing interference with 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. A complete analysis cycle takes approximately 16 to 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 LCpro T 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 are displayed on the colour touch sensitive 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 SD card, located in a socket at the front of the console, 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 card reader.

The measurements are carried out in an ‘Open System’ configuration in which fresh gas (air) is passed through the PLC 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 its measurement can be found in
“Photosynthesis” by Hall and Rao, Pub. Cambridge University Press

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

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

"Quantitative Comparison of In Situ Soil CO_2 Flux Measurement Methods" by Knoepp and Vose. Research Paper.

1.3 Calculated Values

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

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

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

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

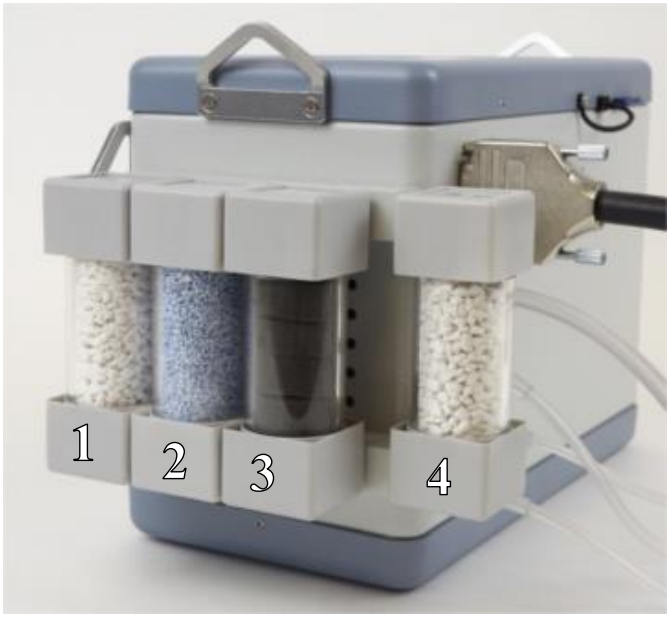
The LCpro T performs checks on magnitudes of readings, particularly of certain settings which have pre-set limits (minimum airflow rate, for example). There is, however, a wide tolerance on 'allowable' settings for which the user is responsible (leaf area, for example) and which can significantly affect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

SECTION 2. GETTING STARTED

WARNING: Before fitting or changing a chamber, please read section 2.8 for guidance.

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

2.1 Checking the Chemical Columns



The column labelled '4' in the photograph, opposite is only necessary when CO_2 control is active, and in this case it is filled with soda lime, otherwise it can be removed.

The column labelled '3' opposite, 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 column labelled '2' opposite, 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 (labelled '1' above) 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 T, 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

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 T 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 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 T. 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 a 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^{-1}) of fresh air. To minimise this problem, a plastic disposable 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 an aluminium 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 T is delivered ready for use with the internal battery fully charged and connected and the Soda-lime and Drier columns filled.

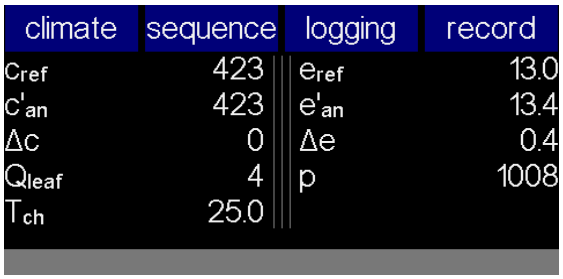
The LCpro T can be switched ON by pressing the front panel switch key at the top right-hand side of the display (shown in the text as |).

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

The LCpro T will display an ‘analyser is warming up’ message during this time, and will beep when ready. If you wish to bypass the warm up timer, press the left button just after the LCpro T has been switched on and is displaying the software version and serial number.

Note that if warm-up is bypassed the LCpro T will need to complete at least one full analysis cycle before normal readings are displayed.

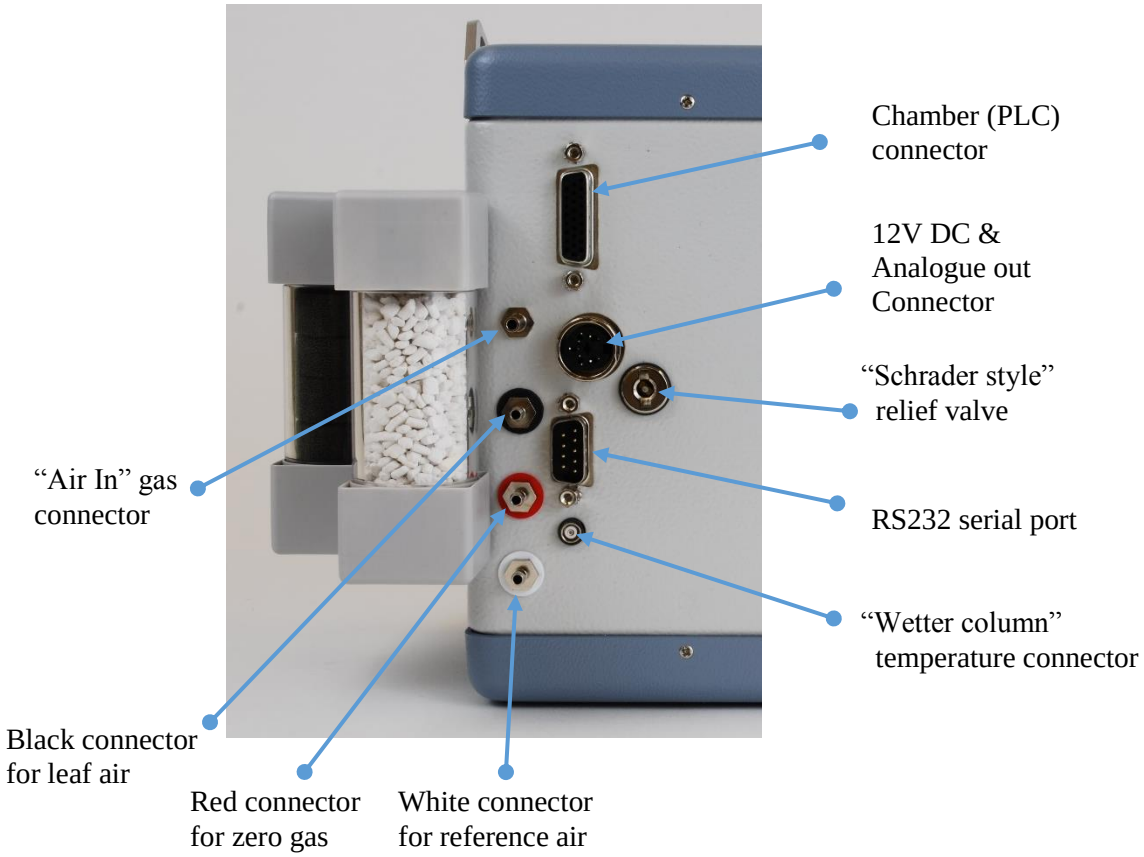
Some default factory settings may need editing; for example time & date, serial link.



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

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 for new gaskets to be compressed sufficiently by the spring. In the case of Conifer chambers, ensure that the clip is latched.

2.4 Electrical Connections



Power Socket

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

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

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

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

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

USB Connector

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

RS232C Connector

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

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.

2.6 Error, Warning & Status Messages

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

Warning messages 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.

Troubleshooting:

If the LCD remains blank after switching on the LCpro T, check that the battery is fitted and/or charged.

To restart the LCpro T, press and hold down the power (on/off) button on the front panel.

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

2.7 Low Battery Voltage

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

2.8 Fitting/changing a chamber

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

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

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

Description

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

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

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

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

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

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

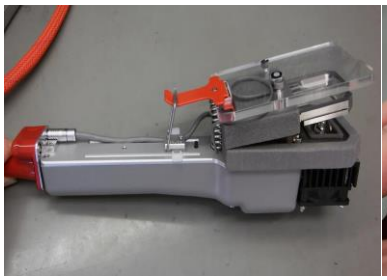
Do NOT push down on the screws as this may dislodge the mounting bushes from the handle baseplate, causing loss of the electrical connections. To ensure that the jaw forms a gas-tight seal, it is only necessary to push down on the jaw itself.

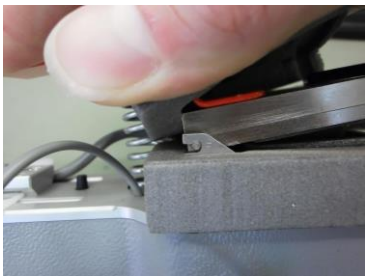
Removing a chamber (see photographs on the following two pages)

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

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

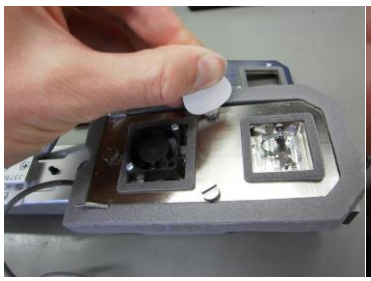
Removing and fitting jaws:



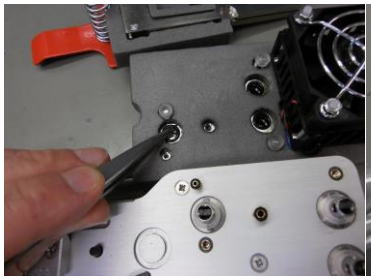


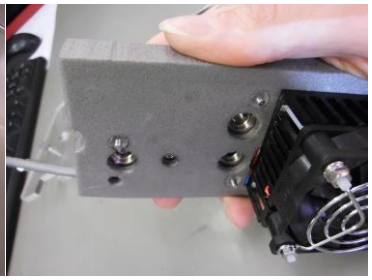
The photographs demonstrate a set of **Broad** jaws, upper and lower, collectively known as the Plant Leaf Chamber.

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



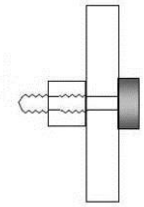
2. Use the correct tool (LCi-220) to undo the screws, remove the cable from under the cable clip (LCM-166) and pull the Peltier plug out of its socket. If this is difficult, push the plug against the socket, keep it held tightly together (it consists of two parts) and pull it out. PLEASE DO NOT PULL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

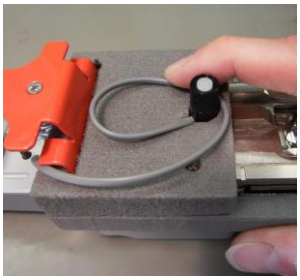




3. Remove the lower jaw and retrieve any O rings that have come off with the jaw (a pair of blunt tweezers are ideal). Take care not to damage the O rings.
Ensure the O rings are present and correct on the handle as shown above, centre.

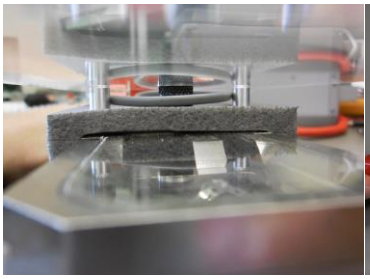
A jaw may now be fitted to the handle:
4. Make sure the jaw screws each have a threaded nylon spacer, and that each spacer is fully threaded onto the screws as far as they will go. The jaw screw spacers are half threaded and must go onto the screws as shown in the first photograph below.



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

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


7. Fit the radiation shield as shown above, taking care not to trap the PAR cable.
8. 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 for any gaps, before use. Gaps may be reduced by temporary use of an elastic band around the jaw, or by squeezing and releasing the jaw by hand to compress the foam gaskets.

The Jaw Screw Adjustment Tool (LCi-220):

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

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

SECTION 3. THE PLANT LEAF CHAMBER

Note: Sections 4 and 5 contain information on the Small leaf chamber and Soil pot.

3.1 General Description

The Plant Leaf Chamber (PLC) consists of a handle and an interchangeable leaf chamber or soil pot (See section 5 for Soil pot description). There are four styles of leaf chamber available. These are Small, Broad, Narrow and Conifer. Refer to section 4 for a description of Small leaf chambers, which are very different in design from 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 for instantaneously recording a measurement, and an electronics board providing sensor amplifiers for signals to the LCpro T console.
A cable is attached to the handle linking the electrical signals and gas lines to the LCpro T 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 white or colour light unit is fitted, see section 8 for alternative values.

Removing and fitting leaf chambers:

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

6) 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.

7) A 'flow check' should now be performed. See section 4.5 for instructions.

3.2 Operation

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

Prior to taking measurements on a leaf, the chamber sensors can be checked as follows: With the chamber closed, view the CO_2ref & CO_2anl readings on the LCpro T display, after a few seconds these should stabilise to give similar CO_2 concentrations.

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

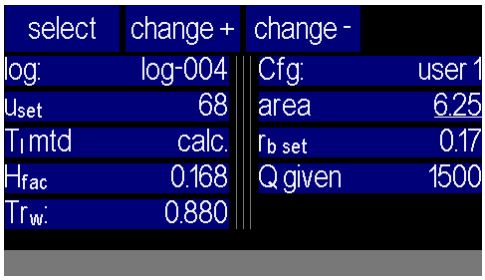
If these checks are satisfactory, leaf measurements can be made.

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

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

3.3 Leaf Chamber Constants

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



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

'H_{factor}' **(**Previously defined as 'Trans' in LCA2 & 3 references) Hfactor is affected by the material used for the shield (if fitted) and the chamber window. Wavelengths in the visible and infrared regions have different transmission factors. The position of the PAR sensor (inside or outside the chamber), and the type of light source (see Appendix 5) all influence this parameter.

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

$T_l$mtd Toggle between 'calc and 'meas'.
These constants may be changed with configure set up select.
When the appropriate parameter is underlined, it can be modified with the change + and change – keys, or by pressing a parameter (in blue) on the touch screen.

3.4 Leaf Thermistor

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

3.5 Leaf Spider

(Broad and Narrow style heads only)

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

3.6 Chamber Cooler

Broad, Narrow and Conifer chambers are fitted with a Peltier heat exchange module as standard. The module is fixed directly under the chamber and controls the air within the chamber to a user-selected temperature. 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 in colour (with red, green and blue LEDs), or in white (with white LEDs only). Both types are available for the Broad and Narrow leaf chambers. Only white light is available for the Conifer leaf chamber.

Fitting:
With the radiation shield removed, a light unit slides (Broad, Narrow) or clips (Conifer) onto the top jaw with the lead towards the cable end of the chamber. The cable rests in the narrower of the two grooves in the handle, and it plugs into the adjacent socket (with a 3 pole jack plug). The conifer light unit also has a reflector which clips to the lower jaw. The light unit cable can be tidied together with the main handle-to-console cord using the cable sheath kit supplied.

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

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

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

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

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

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

QTotal output for red, green and blue LEDs is 800µmol m^{-2} s^{-1}, when all three colours are equally proportioned at a ratio of 33:33:33 %*.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Trw factor changes Q at the leaf plane!

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

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

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

3.9 Enter given Q value

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 1500µ mol m^{-2} s^{-1}. Any value between 0 and 3000 may be entered. Once given Q is pressed, the given value will conform to whatever configuration is being used at the time. **Note:** The corresponding window transmission factor is applied to it, so it will generally be less than the value entered. Press release Q to return to measured values. If hold Q is pressed whilst "*given Q*" is being used, the current value for Q will be held even when changing to an alternative configuration set-up. **Note:** When release Q is pressed, the value for Q will return to *measured* (not *given*).

3.10 Climate Q

This button causes the console to use the value of Q corresponding to the current climate control settings. If climate Q is off, ie at ambient, the climate Q and release Q buttons will both cause the Q_{leaf} value to be displayed as the value 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 causing the Q value to be Q_c. It will remain Q_c even after the sequence has ended.

SECTION 4. SMALL LEAF CHAMBER

4.1 General description

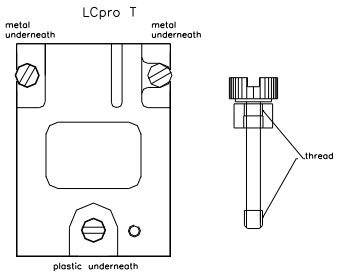
This chamber is designed specifically to access small leaves that grow close to the ground. Due to their very small size Small chambers do not have light or temperature climate controls available and do not have a radiation heat shield. The head consists of an "interface block" that attaches to the handle using three captive screws and spacers (see following paragraph and figure for LCpro T configuration) and a leaf chamber that is carried at the end of a flexible neck or "snake". The flexible neck allows the leaf chamber to be positioned where needed. The "snake" can then be locked into position by means of a lever on the interface block.
The chamber jaw has an offset spring that holds the jaw closed. When not in use the jaw should be left in the open position. This will prevent the gaskets from becoming compressed.
There are two additional clips that should be slid over the closed chamber to hold it firmly shut in the closed position. When not in use, the clips should be moved back so that the chamber can be stored open.

4.2 Configuring the Chamber for use with an LCpro T

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:

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

4.4 Leaf Temperature reading

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

4.5 Flowrate and stability

The exposed leaf area in 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 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 LCpro T (and LCi T).

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

5.2 Operation

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

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

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

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

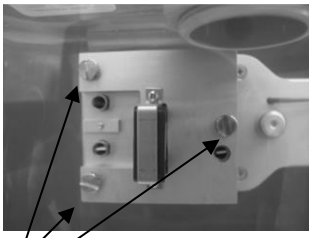
Since the air above soil can be near dew point, the warning "analyser condensation risk" is more likely to occur than with leaf chambers. The risk of condensation can be removed if the instrument is at ambient temperature or above. **Ensure that the instrument is left on without making a measurement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

5.3 Preparing the Soil pot for use

5.3.1 Removing the existing leaf chamber

Remove the Shield from the current leaf chamber upper jaw, unplug the PAR sensor then unhinge the upper jaw from the handle. Using a suitable coin (if required), unscrew the three captive screws from the handle and detach the lower jaw from the handle, unplugging the Peltier cable if necessary. Safely store the upper and lower jaws, shield and spring.

Note: When swapping between leaf chambers and the soil pot, be careful not to lose the 'O' rings, particularly the two small ones. If these two remain in the chamber jaw, poke them out and fit them to the ends of their pipes before fitting the Soil pot. Tweezers are useful for this.

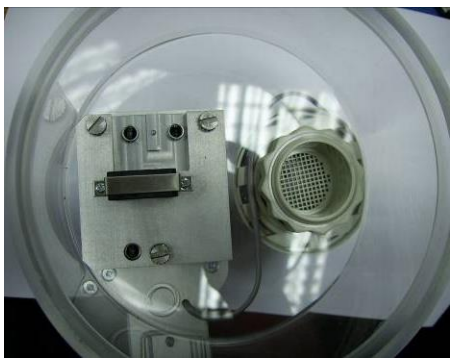


5.3.2 Attaching the soil pot to the handle

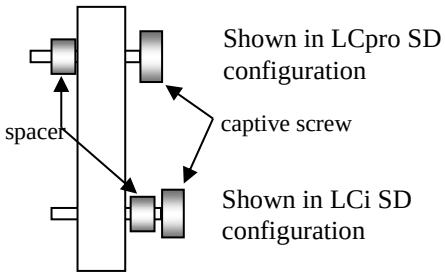
The soil pot is attached to the handle in the same manner as a leaf chamber, using the three captive screws, see photo.

Important Note:

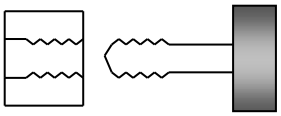
The LCpro T sensors are longer than the LCi T, requiring longer screws and spacers to be fitted. In order for the Soil pot to be used on both instruments the same length screws and spacers are used but their configuration is different. In the default configuration (suitable for the LCpro T) the spacers 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 T 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"

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

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

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

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

5.3.4 Locating the hood on the collar

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

5.3.5 Attaching the "ground spike" and PAR sensor

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

5.3.6 Flow check calibration

A flow check calibration will now need to be performed, preferably be done at the same flow as the user intends to operate the Soil pot.. This is important as the fan in the ssoil pot has different characteristics compared with the leaf chambers which can affect the analysis gas settling time, especially at very low flow rates. The flow check ensure that the analyser allows a long enough time for gas readings to become constant during the reference and analysis parts of the cycle If the settling time is too short then inaccurate readings may be obtained.
The suggested flow rate is 200 µmol s^{-1}, 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 µ mol $s^{-1.}$ 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 µ mol 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

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

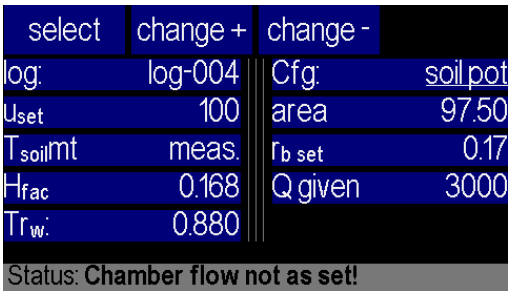
Additional collars may be purchased to enable several test sites to be defined and the collars left in place

Flow check calibration is performed to allow the 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 µ mol 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 area, other leaf chamber associated constants are not displayed once the Soil pot is selected. The area has been pre-set to 97.5 cm^2 which assumes the Collar is used. Chamber type be changed with configure, Cfg (also called ChCfg).



5.7 Soil pot Dimensions

5.7.1 Using the soil pot without a collar

The surface area of the enclosed soil is nominally **132.5cm^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**

5.8 Using other, non-standard chambers

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

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

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

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

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

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

If for any reason a user did need to adjust 'respiration' mode data to photosynthesis data, the parameters required for adjusting NCER to plant gas exchange or A values, are:

Reversed NCER, re-labelled accordingly. NCER values should be reversed from + to – delta C values or vice versa).

Differential CO_2 (ΔC column in a data file)

Flow rate (already provided in column 'U' of a data file, units µmol m^{-2} s^{-1})

Active leaf area of the sample, entered manually. Use this data to calculate the flow per unit leaf area, in ml min^{-1}.

SECTION 6. ROUTINE MAINTENANCE

6.1 Chemicals

CO_2 Stripper

The performance of the LCpro T is dependent on the satisfactory condition of the soda lime stripper, which is in the column furthest from the connectors. The soda lime supplied is an indicating type, which turns from white when fresh, to violet when exhausted. Some water content is necessary to assist the chemical reaction, which is to convert CO_2 to calcium carbonate + H_2O. Re-conversion back to soda lime is not practicable.

The life expectancy of the soda lime 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. 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 may become blocked if the console is placed with them 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 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 disposable 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 aluminium 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.

All column filters are made from porous polymer which is impervious to the acidic effects of Soda Lime.
The columns should be removed and washed in soapy water from time to time.

6.3 Battery Charging

The LCpro T is shipped with an internal sealed re-chargeable 12V, 7.5Ah lithium-iron-phosphate battery, which, when fully charged, operates the system for about 16 hours. A similarly sized lead-acid battery may be substituted without loss of performance. 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 T 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 T to prevent draining the battery.

The main battery will give several years of 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 its temperature. When the instrument is being used in the field on a daily basis, an overnight charge will be sufficient; do not leave the battery on continuous charge for more than a day.

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

Never charge the battery using a constant current supply, commonly used to charge Ni-cad batteries – this can over-charge it. 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 T is near to a discharged state, a **warning** – **low battery voltage** message is flashed on the display. In this event, terminate the work as soon as possible, switch the LCpro T off and, either recharge, or replace the battery. If a suitable external DC power source is on hand, connect it to the LCpro T as soon as the message appears. In this case, work can continue undisturbed.

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

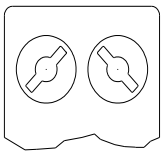
6.4 Battery Replacement

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

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

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

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



6.5 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 T 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 (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. Alternatively use the

knurled brass plug LCM-039 supplied in the spares kit; screw it in finger tight then back out one turn. 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 653-126).

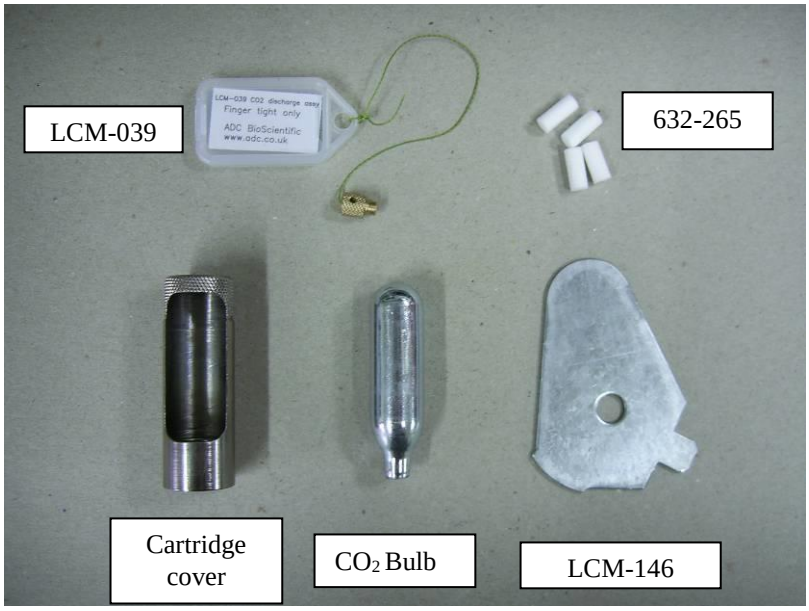
The "Schrader style" valve should be also used if you need to remove the cartridge when it might have a significant quantity of gas remaining in it. After the gas has been released there may still be CO_2 molecules under pressure contained within the rubber "O" ring.
To prevent the "O" ring seal from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

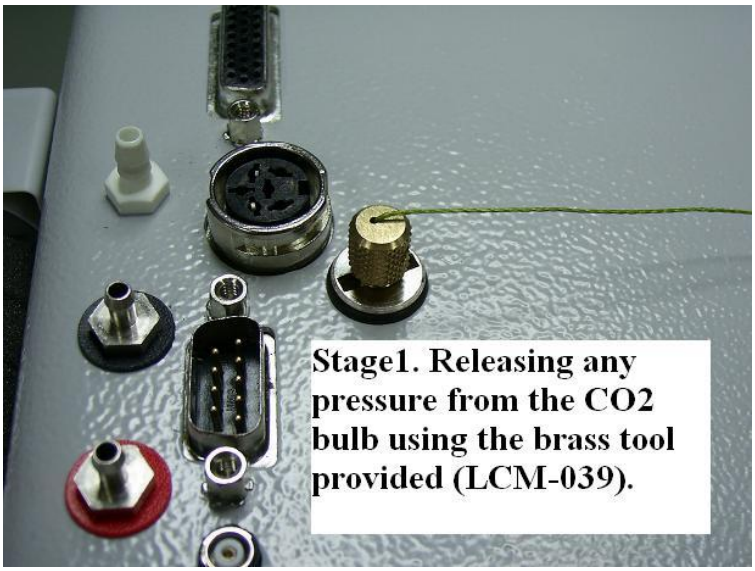
After every ten cartridges the filter (632-265) in the valve housing should be changed. Using the special "key" provided, depress the valve and unscrew the housing in the front of the console.

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.

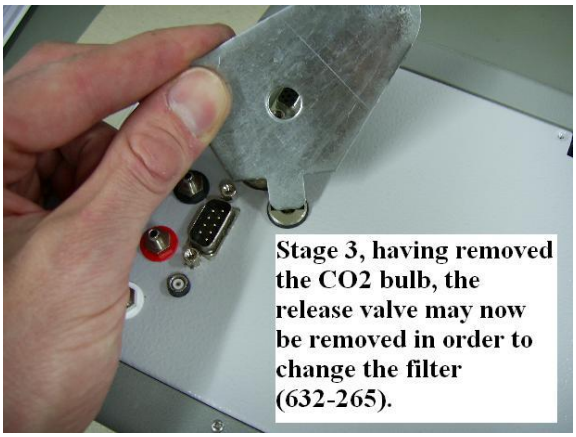
Once the housing is removed the filter can be hooked out with a small screwdriver, tweezers or a paper clip. Fit the new filter by simply pushing into the housing as far as it will go then replace the valve housing into the regulator (see photographs on following page).





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

Recalibration, every 5 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.

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 (630-964), 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. Leak tests, once a year or if a user suspects the instrument's results may not be correct. See section 16.4.

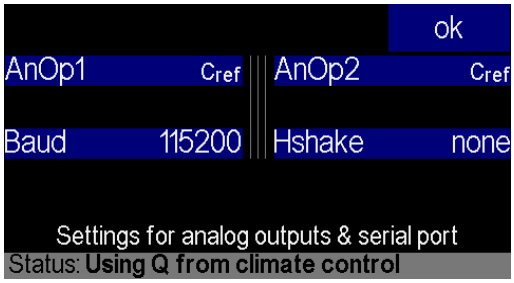
SECTION 7. SET-UP AND CALIBRATION

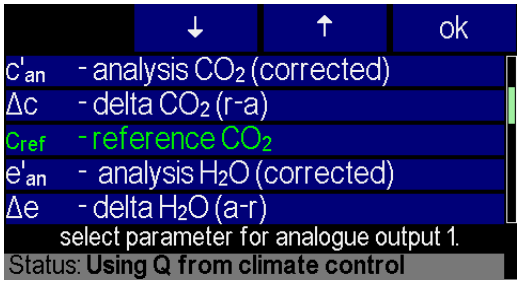
Recalibration, every 5 years is the recommended interval for recalibration, best done by ADC Bioscientific Ltd. Calibration dates are to be found in the calibration screen. See section 7 for more details.

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 T is switched on and resaved from RAM to EEPROM when the LCpro T 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 T 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 T power is re-applied. Date and time will need to be re-set.

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 by pressing AnOp1 or AnOp2.





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

7.2 Serial Link Port Set-up

The menu obtained above by pressing output also allows the baud rate and handshake protocol to be set.
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, 38400, 76800, 115200 and 230400 baud. Handshake options of "none", "CTS", "CTS+X", "xon-xoff", and "CTSrec.trig" are also available.
Note that if the last option of CTS record trigger 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 more time/date displays the Time and Date menu. Press select to step through hours; minutes; seconds; day; month; year. Pressing change + or change - increments or decrements the chosen parameter (except for seconds which resets to zero).
The clock is in a 24-hour format.

7.4 CO_2 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 the power 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 greatest 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 there are 5 options: CO_2 zero and span, H_2O zero and span, and flow check.

7.6 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 Small chambers may be longer due to the larger chamber volume and lower advised ASU flow respectively.

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

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

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

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

7.7 CO_2 Zero

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

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

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

In the calibration menu, select CO2zero

Adjust the pot to reduce the displayed count to within 200 counts of zero, turning it clockwise if the displayed value shows a down arrow. A value within 10% of the range will be functional, and will cause 'OK' to be displayed and the displayed value to be in green. Press quit OK or press the power key (|) to exit. If the adjustment is very wrong, or if there is another fault, other messages will be displayed; "CO_2 low energy", or "CO_2 signal over-range".
The chemical in the column MUST be in a good condition at all times for correct zero operation. **If the check indicates maladjustment, check the state of the chemical before any potentiometer adjustment.**

7.8 CO_2 span

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

Note before using either method

Using a stable air supply either from a small volume or from the extended air probe (or the bottled gas if using method 2)
Set the flowrate to 341µmol s^{-1}, perform a phasecheck: configure diagnose sys.info. autophase, followed by a CO_2 zero calibration (in the calibration menu – you will need a potentiometer adjustment tool to insert into the handle jack socket and rotate until the screen displays "ok" when in CO_2 zero calibration mode).
Lastly perform a CO_2 flowcheck, from the calibration menu (the jaws must be correctly fitted with all 5 O rings making a good seal from the jaws to the handle. Make sure the jaw gaskets have no gap between them, a small gap can be closed with an elastic band around the jaws).

Method 1. The ambient method.

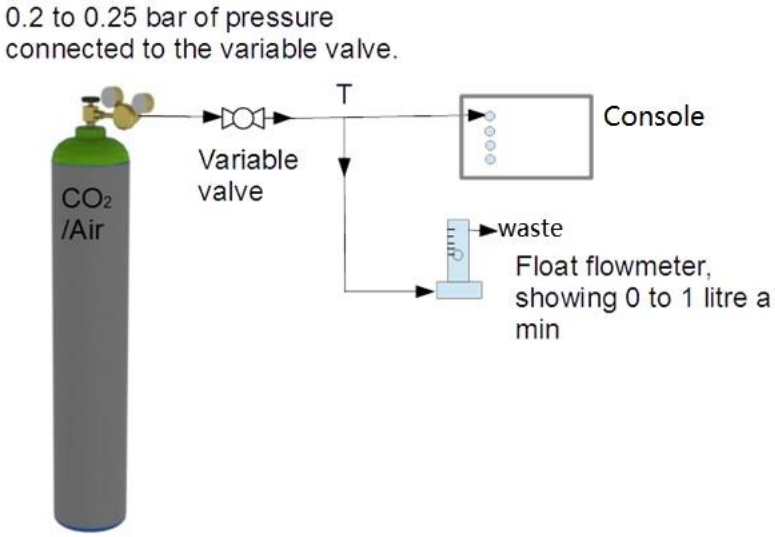
This can only be done in an open area, several km away from and ideally not downwind of any major sources or sinks of CO_2 such as cars, buildings or a thickly wooded area. A good location would be on a coast with light wind or an onshore breeze. Connect the console 'air-in' port to a buffer volume or the air probe (extended and held upright by use of the ground-spike) using 3 or 4mm bore PVC tubing.
Next enter the calibration menu and perform a CO_2 span calibration, having first adjusted the span gas ppm level in the calibration menu to 404 ppm (in 2017) this being a typical global average. After calibration, exit the calibration menu and monitor Cref for a couple of minutes, and redo the calibration if Cref deviates more than 10ppm away from the span gas value.

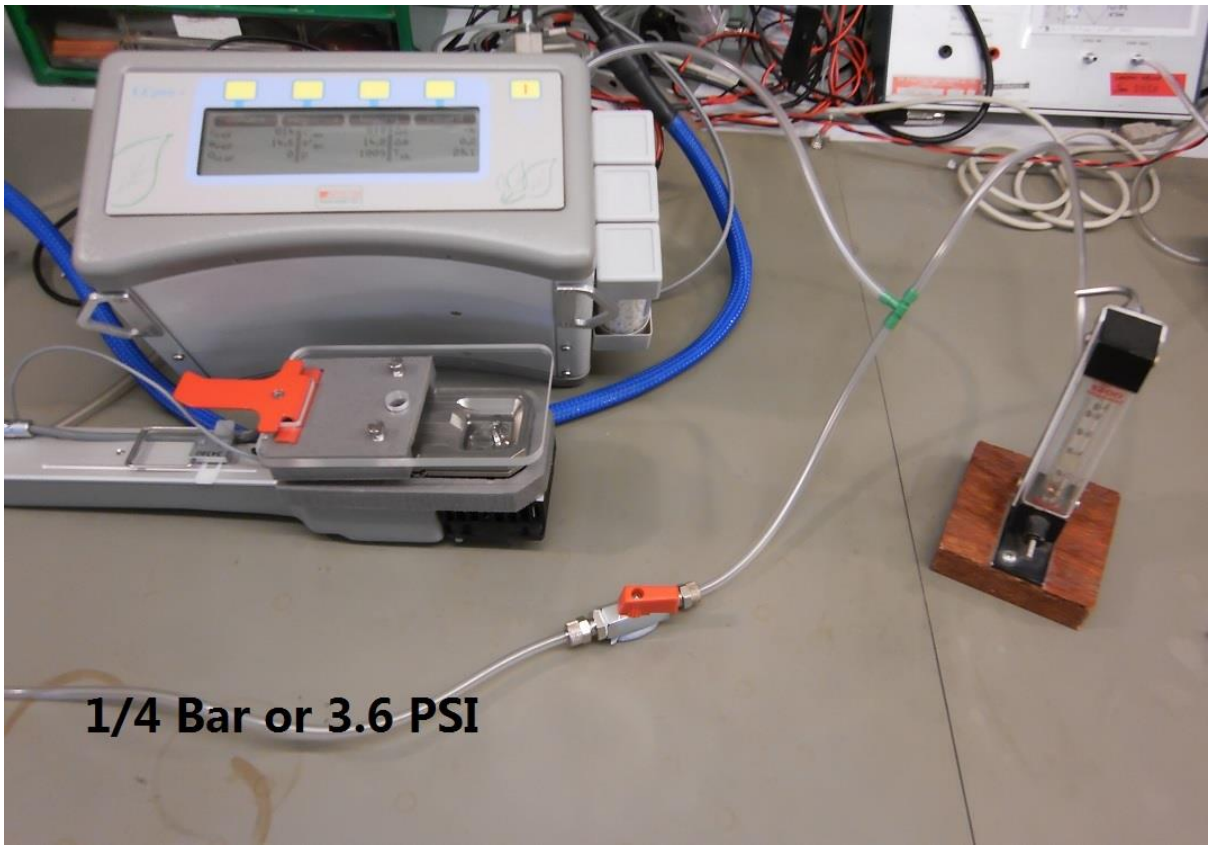
Method 2. The bottled gas method.

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

Equipment:
You will also need a two stage pressure regulator fitted to the gas bottle/cylinder to reduce the pressure to approximately ¼ bar or 3.6 PSI, a ball or needle valve, some 3 or 4mm bore PVC tubing, a T piece and a float flowmeter with a range of or close to 100ml to 1000 ml or more per minute. The flowmeter must allow enough reverse flow for the console to run at maximum flow rate – most float flowmeters do but some ball type flowmeters do not, this should be tested as follows:
Set the console flowrate to 341µmol s^{-1}, use a piece of PVC tubing, 3 or 4 mm bore, to connect the inlet of the flowmeter to the air in port of the console. If the console pump becomes very noisy then disconnect the flowmeter quickly – it will not be suitable. A small increase in pump noise is acceptable.

Setting up the Equipment:
Connect the output of the two stage regulator to the ball/needle valve, then connect the remaining entry of the valve to one air entry of the T piece. Connect one of the remaining air entries of the T piece to the 'air-in' port of the console. Connect the last air entry of the T piece to the flowmeter air in entry. The diagram and photograph below show this setup:





Method:

Turn on the LCpro T and set the flow to 341µmol s^{-1}. Turn off the variable valve (ball or needle).
Next use the two stage pressure regulator to set the pressure to or slightly under 0.25BAR or 3.6 PSI. Very slowly open the variable valve until the flow-meter reads about 200 ml min^{-1}. This reading will fluctuate over the CO_2 cycle of the LCpro T.
Adjust the control valve so that the flow-meter never drops below 100 ml min^{-1}, watch this for a minute to make sure and continue to monitor this while performing the calibration. The excess flow ensures that the system always has a surplus of span gas and never dilutes this by sucking in unknown gas.
After the system has finished its warm up cycle, (the 'warming up' message will clear from the status line of the display and the console will make a beep noise to indicate this) perform the steps laid out in "notes before using either method".
After 5 minutes, enter the calibration menu and adjust the CO_2 span value to the value of the gas being used, then perform the CO_2 span.
After calibration, exit the calibration menu and watch the Cref reading for a couple of minutes. Repeat the span calibration if Cref deviates more than 0.5%+4ppm away from the span gas value.

7.9 H_2O Calibration

Recalibration and Small ∆e offsets.

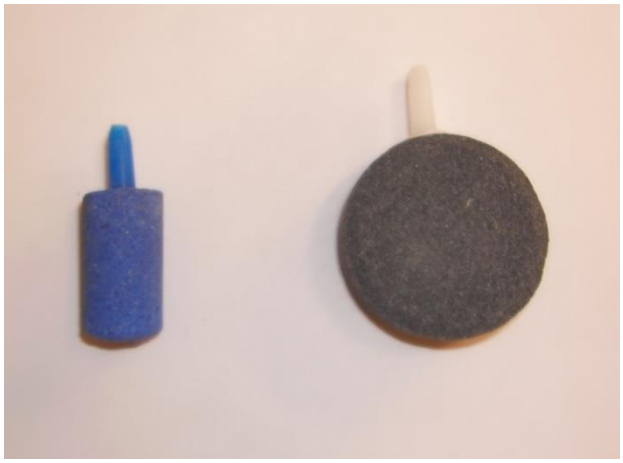
RH recalibration **should not normally be required**, unless a sensor has become faulty and been replaced. As long as a system is returned every 4-5 years for service by ADC (which includes RH calibration and a linearity test), then recalibration should not be necessary.
A small ∆**e** error due to component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

Full H_2O Calibration

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

1. A **source of dry air or granular drying agent**.
2. A **float flowmeter** (air) of, or close to, the range 0-500ml min^{-1} (1000 ml min^{-1} if using method 2 of the H_2O zero calibration). The company, Cole Parmer, supply suitable flowmeters.

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



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

Method:

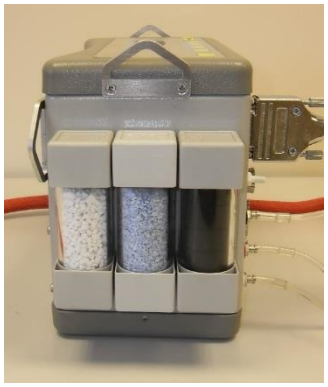
H_2O zero calibration

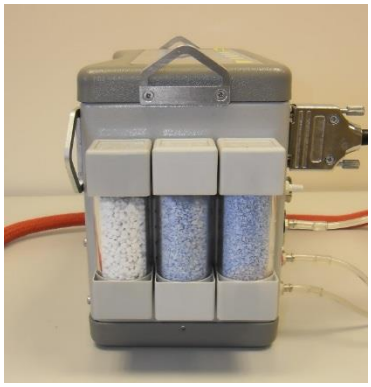
Set the console with the correct time and date see section 7.3.

Method 1.

This method requires a granular drying agent such as Drierite, it is easier to do than method 2 but slightly less accurate. The normally inert chemical column of the LCpro T (normally contains four pieces of removable foam) should be removed (switch the console off first), and the pieces of foam removed and replaced with the granular drying agent. Refit the chemical column, turn on the instrument and run the machine at a flowrate of 341 µmol s^{-1} for 20 minutes, reduce the flowrate to 200 µmol s^{-1} for 20 minutes then perform a H_2O zero from the calibration menu. Afterwards monitor the **e'ref** and **e'an** values which should be within 0.1mb of 0.0 mb over a period of 5 minutes; if not, repeat the zero calibration.

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





Method 2 (recommended).

With the instrument switched on and warmed up, supply dry air into the black ringed handle tube at a rate of 800-1000ml min^{-1}, this normally connects to the console as one of the three colour coded tubes. Pure nitrogen may be used for this purpose. The air must be completely dry. The black ringed handle tube goes directly to the closed jaws which is where the two RH sensors are located.
Allow 20 minutes at this flowrate of 800-1000ml min^{-1}, then reduce the flowrate to about 300 ml min^{-1}, allow this to run for 20 minutes, then enter the calibration menu and calibrate by selecting the H_2O zero option.
Afterwards, monitor the **e'ref** and **e'an** values, they should be within 0.1mb of 0.0 mb over a period of 5 minutes, if not then repeat the zero calibration.

H_2O Span Calibration

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

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

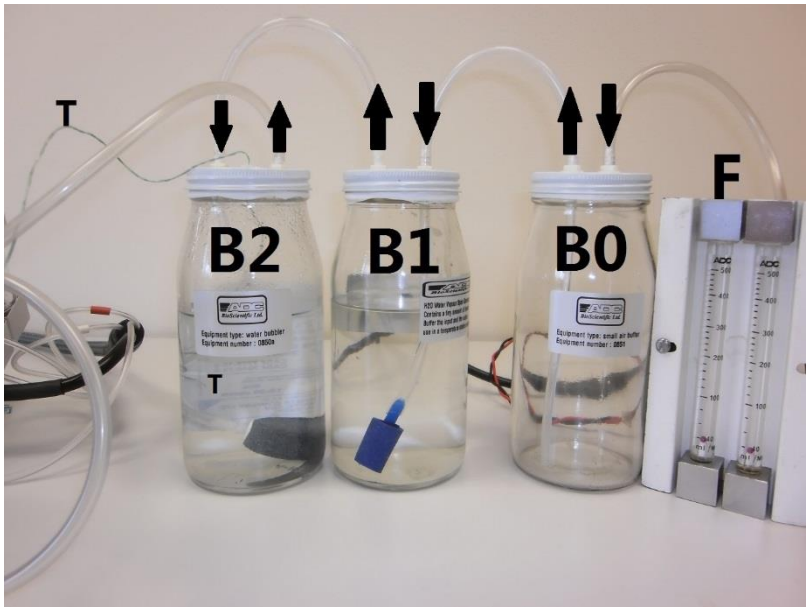
Dew Point Generators

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

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

Connect the “air out” entry of the pump to the “air in” port of the flowmeter, leaving the “air in” entry of the pump free to suck in room air.
Connect the “air out” port of the flowmeter (F) to the buffer jar (B0) “short” port (the one without the internal tube fitted), connect the other port of the buffer jar to the first bubbler (B1) “air in” port (the one with the tube that connects to the air stone), connect the “air out” of the first bubbler to the “air in” port (the one with the tube that connects to the “air stone”) of the second bubbler (B2), this second bubbler should have some means of measuring its water temperature e.g a submerged thermocouple probe.

Finally connect the “air out” port of the second bubbler to the black ringed handle pipe (P), use a piece of 4mm bore PVC tubing about 60cm long. Form a loop in the 4mm section secured with a cable tie as shown in the second photograph below, this way if water vapour condensates in this piece of connecting pipe it can be seen and quickly disconnected.
The first photo below shows the buffer jar and the two water bubblers connected in series, the arrows indicate the direction of air flow. The second photo below shows complete setup including the loop in the section of pipe which connects to the black ringed handle pipe.



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

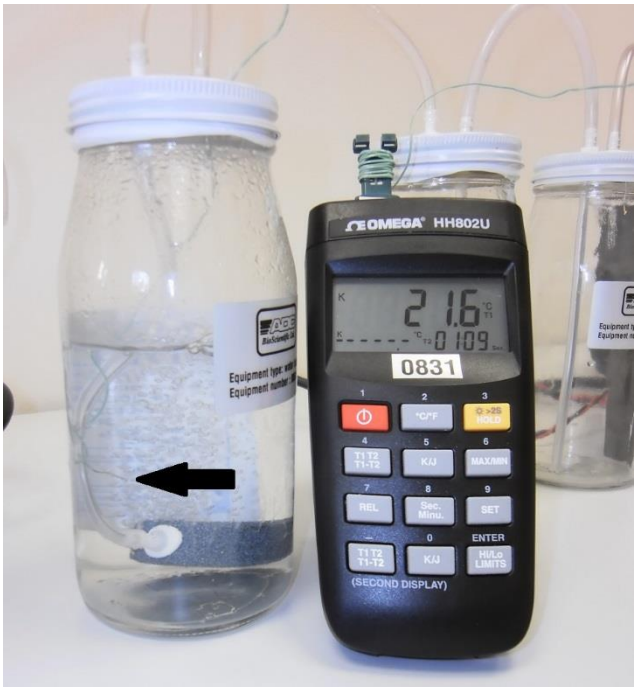
The photo below shows the complete setup for H_2O span calibration. Note that the loop formed in the connecting pipe is attached to the black ringed handle pipe with the connection made above the lowest part of the loop. Watch this loop during calibration and disconnect the handle pipe quickly if water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

Before powering up the pump (shown above connected to a variable power supply), check that the water temperature is slightly cooler than ambient conditions, power up the pump at a flowrate of 500ml min^{-1}. Carefully watch the pipework coming out of the bubbler system and make sure no condcondensation is visible. Stop at once if it is present! **As a precaution you can disconnect the black ringed handle pipe and start the pump and see if condensation occurs before reconnecting the black ringed handle pipe.**

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

IMPORTANT NOTE:

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

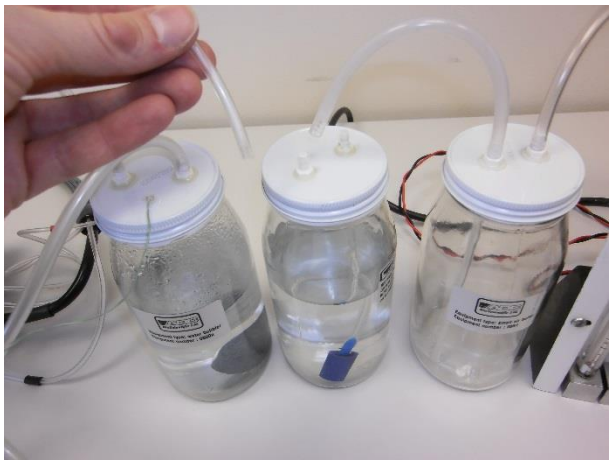


IMPORTANT NOTE!
Make sure the thermocouple lead is sealed around the hole in the lid where it enters the second water bubbler as shown opposite. Glue from a hot glue gun is good for a few weeks or months but may need to be replaced over time. Two part slow setting resin based glues are best for long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

Run the pump at a flowrate of 500ml min^{-1} for 10-15 minutes, reduce the flowrate to 250-300ml min^{-1} and continue to run the pump for another 10-15 minutes.
With the pump still running you are now ready to perform a H_2O span calibration from the calibration menu. First you must calculate the H_2O saturated vapour pressure (SVP) in mb value which is determined by the water temperature and the fact that the water bubblers give an output of 100% RH.
Using the same formula as the LCP/I which is based on the Arden Buck 1981 formula for saturated vapour pressure, the table in **Appendix 8** can be used to quickly give this value in mb.

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

Switching off



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

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

Linearity Test (optional)

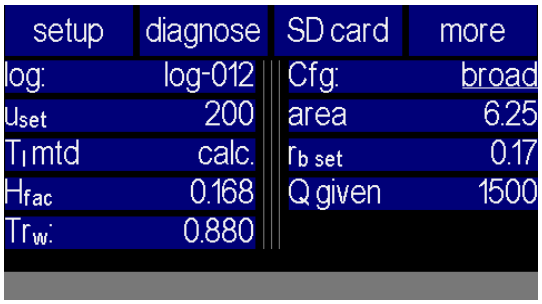
This can be done as a basic check but is not necessary. You will need a good RH sensor and a thermometer next to the console and close to the "air in" entry on the console.
Connect the black ringed handle pipe to the black coloured air port on the console.
Position the LCpro T system in a quiet corner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

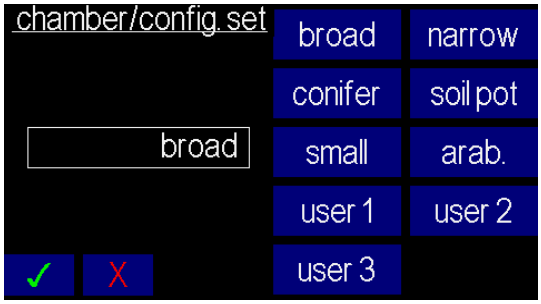
SECTION 8. MEASUREMENT CONFIGURATION

8.1 The 'config' Function Menu

Refer to Appendix 7 for the menu structure.

Use configure to get to menu set up diagnose SD card more.
The various options can be chosen with set up or by touching on them directly.
The type of chamber can be selected from: Broad, Narrow, Conifer, Soil pot, Small.
User1, user2, user3 are intended for use only with bespoke or non-standard ADC chambers.





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

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

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

*1 The steps are greater when the /+/ or /-/ keys are held down.
*2 The Soil pot range is 0 to 400cm^2 in 0.5cm^2 steps, assuming use with a soil collar.
*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 T from the energy balance equation./*meas/*; uses the temperature measured by whichever leaf temperature thermistor is connected.

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

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

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

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

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

8.2 GPS

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

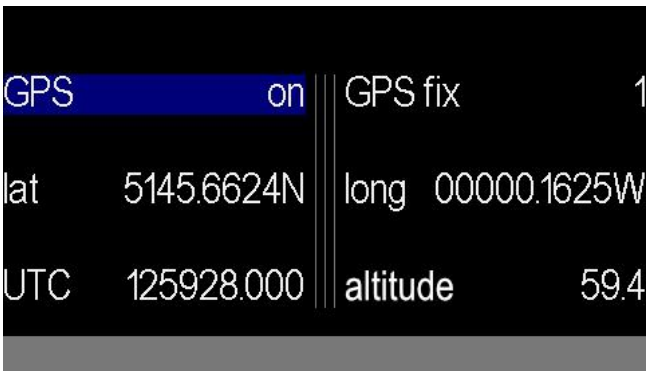
The GPS data screen is accessed through configure and more.

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

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

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

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



The GPS format is dddmm.mmmm where ddd (or dd in the case of lat) = degrees, mm = minutes and .mmmm = fractions of a minute.
To convert .mmmm into seconds simply multiply the 0.mmmm part by 60.

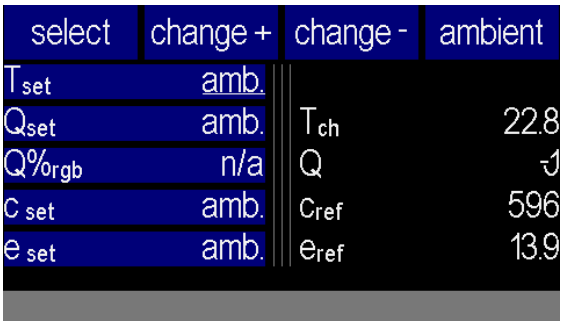
For example in the screenshot 5145.6624N = 51°45'39.7" north of the equator and 00000.1525 = 000°00'9.2" west of the Greenwich meridian.

To convert seconds into the 0.mmmm format simply divide by 60.

SECTION 9. MICROCLIMATE CONTROL

9.1 The climate menu (Single Point Environmental Control)

Touching 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}). Touch the select key to scroll through the functions and the change+ or change- keys to set the value. Touch the parameter to select it directly, or by 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 the set value. Temperature and light levels are not relevant when used with the Soil pot or with Small leaf chambers as they do not have this facility.



(*Note: A Broad leaf Light may be used with 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 the selected parameter.

9.2 Temperature, T

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, or touch Tset then select track.

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.

9.3 Light, Q

In microclimate control, irradiance or Q is measured and controlled with a sensor adjacent to the LED array in both white or colour light units. Q is calibrated so that Q at the leaf plane (within the leaf chamber) is **reduced from the user-set value, by the window and radiation shield transmission factors**. The light unit calibration is equivalent to using the PAR sensor in sunlight. The radiation shield is not used when either light unit is fitted, so the transmission factor, Trw should be changed to either **0.92 or 0.91** in the "configure" menu**,** when a light unit is in use, as shown in the table found in **section 8.1**. **Remember to change the value back again when a light unit is removed**.

To calculate Q at the leaf plane when a light unit is fitted:

Qleaf = Qset x Trw (0.92 for Broad and Narrow, 0.91 for Conifer chambers).

The user must manually calculate the desired Q values using the appropriate Trw factor, before entering these values into microclimate control.

1. Enter the "config" menu and change the Trw value. For example, using a Broad light unit, Trw is changed to 0.92.
2. Calculate and note down all desired Q value(s) using the formula above (Q = Qset x Trw).
3. Enter the "climate" menu, select "Qtot" and use the number keypad to enter this corrected value.
4. If using a colour, RGB light unit: select "Q%rgb" and enter the desired ratio of R:G:B colour LEDs. This ratio will not be affected by Trw.
   If you choose to edit these values individually by PAR/Q, you will need to calculate the individual, corrected Q values for each colour, as above.

Q can be set between 0 and 2400µmol m^{-2} s^{-1} for Broad or Narrow colour light units and 2500µmol m^{-2} s^{-1} for Broad or Narrow white light units. For conifer light units, Q can be set to a maximum of 1500 µmol m^{-2} s^{-1}. All of these maximum values are only achievable with no correction factors in place. The maximum Q at the leaf plane will be reduced by Trw, and these corrected values will be recorded in any logged data files.

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

9.4 Carbon Dioxide, CO_2

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 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 CO_2 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 log file later on.

A flowrate of u=200 is the maximum that should be used in elevated CO_2 mode.

In elevated CO_2 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.

Cref and Can will fluctuate up and down slightly due to the mixing action of the solenoid valves and some small variation in the CO_2 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, rather monitor the value of C_i, see 3.2.

LCpro T can 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 temporarily 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 T 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 3000ppm. 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 the user-set level. 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**.

Every time the LCpro T is turned off and back on again, the bottle average is reset to the default value of 3000ppm. The performance of the CO_2 control will be optimised if the system is using a bottle average value more accurately known.

For the LCpro T to determine the bottle average, follow these 3 steps:

1. Close the leaf chamber jaws, supply a stable air supply (via a volume or air probe) to the console and make sure there is a CO_2 bulb in the console which has been there for <24 hours.
2. Run a flow check, through the "calibration" menu.
3. Set the CO_2 level in the climate menu to 2000ppm and select "normal" CO_2 mode. After about 20 minutes, the bottle average value should be accurately determined by the software and cref should be 2000ppm ±10ppm.

This procedure will speed up the LCpro T response when changing from one CO_2 level to another at the start of an experiment, as long as the system is not switched off. The determined bottle average value will be automatically updated by the software during the experiment.

9.5 Carbon Dioxide Control Options

To change the CO_2 level the C set keys in the menu shown in section 9.1.

LCpro T will control the CO_2 level on either reference or analysis values. It is usual to control on 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 controlling on analysis is that changes in photosynthesis need to be matched by changes in the control of LCpro T, resulting in longer settling times.

To change between the two (see Appendix 7) select options then CO_2 mode. The option of reference or analysis is presented, as is "bottle average" (see 9.4).

The other options on the options CO_2 mode page 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 ‘normal’ and ‘fast’.

Normal mode controls the CO_2 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 CO_2 concentration but makes no attempt to adjust it subsequently until a new CO_2 value is entered, in which case it makes a new estimate based upon the previous request. Fast mode is intended under circumstances where a rapid change is required with a relatively short time spent at each CO_2 concentration such as A/Ci curves. Since the estimate is made from the previous setting, to get the best results the LCpro T 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 LCpro T 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 controller setting for the requested CO_2 level.

9.6 Humidity, e

Parameters relating to humidity are denoted by 'e'.
In the climate menu, "**eset**" will allow the user to set a humidity level in mb.
Water vapour humidity is monitored using two RH sensors, one for **e'an** (analysis) and the other for **e'ref** (reference). As with the CO_2 controller, the humidity level can be controlled on either reference or analysis, selected through "options", "H_2O mode" (see 9.5).
The default H_2O mode is **e'ref** for faster settling times, and this is most commonly used.
Humidity is controlled using a solenoid valve (SV12) with a variable duty cycle (see gas circuit, section 15).

The LCpro T is shipped with the humidifier/wetter column in the carrying case and the "empty" column installed. The configuration for H_2O mode is set to "empty". In this configuration, only humidity levels of below ambient can be set.

To control humidity, the wetter column is fitted with a thermistor, filled with iron sulphate, and fitted in place of the column containing foam pieces.

Note: Always ensure that the LCpro T configuration (set in the "configure" menu) matches the column installed. If for example, the wetter column is installed but the H_2O mode is set to "empty", the air will be saturated as all the flow will pass through the wetter column.

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

The humidity, either e'ref or e'an, can be set in 1 mb steps. Either e'ref or e'an are controlled between zero and the maximum level achievable at the temperature of the wetter column, as shown in the left-hand table. This temperature is monitored by a thermistor in the column, connected by cable.

If desired, it is possible to increase the maximum available humidity 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.

Entering the "config", "diagnose" menu, there are two parameters called w'an and w'ref. These are the equivalent % RH values **at that temperature**, these will not be the same as the RH% value outside of the system unless the temperature is the same inside (handle/console) and outside.

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

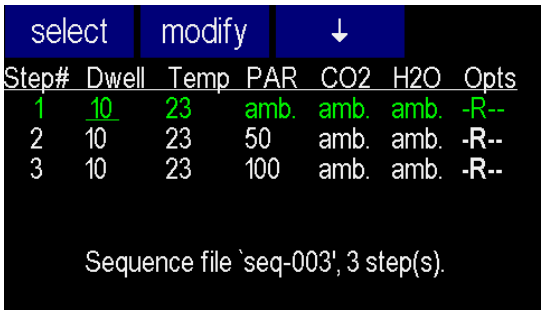
SECTION 10. THE "SEQUENCE" FUNCTION

Description

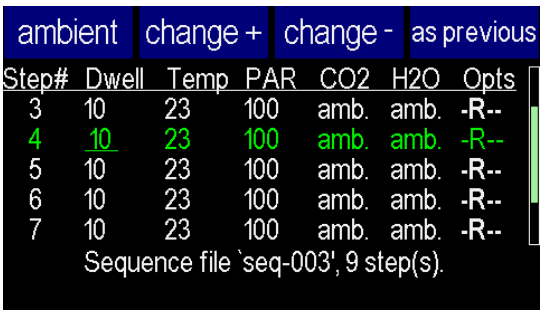
A 'climate sequence file' is a series of steps through which one of several parameters can be incremented or decremented or held either at a defined value or at 'ambient'. Sequences allow a complex experiment to be performed automatically by selecting and running a file. A file can be used repeatedly, saved and edited on the LCpro T or on a PC.
Sequence files are typically used to generate A/Ci and Q/Ci plots to analyse the photosynthetic response rates to step changes in CO_2 or PAR (Q).

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 or save a sequence by using save seq.. The format for sequences produced on a computer is shown in Appendix 5.

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



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.



When the desired time has been chosen, pressing the page key will cause the menu to change back to the select modify ↓ ↑ keys 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. 'I' is inserted in the 'opts' column.

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

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

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

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

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

Example File

The SD card is supplied with an example sequence file named "demo", 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 called "steps". 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 T has the facility to display parameters in graph form.
The graphing function is particularly useful to see if an experiment has settled and/or proceeding as expected.

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

For all modes, the graphs are scaled automatically to make best use of the display resolution. The parameter(s) to be plotted are selected in a similar manor to analogue output settings (see section 7.1).

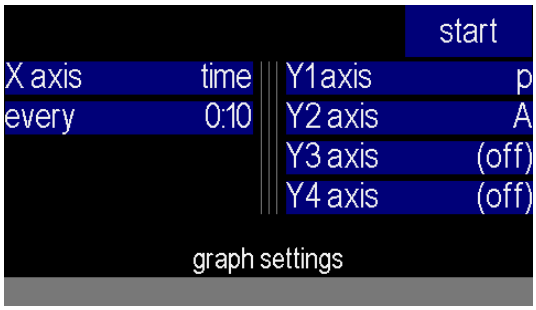
Either type of graph is capable of displaying up to 200 data sets. After this, the earliest sets will be replaced by the most recent set. In the case of the Y-T type, this has the effect of appearing to scroll the graph from right to left as each new data set is added.

The graph options are:

Y-T plot

1. One to four parameters against time
2. One to four parameters against record number X-Y plot.
3. One to four parameters against another parameter (triggered by time)
4. One to four parameters against another parameter (triggered by record number)

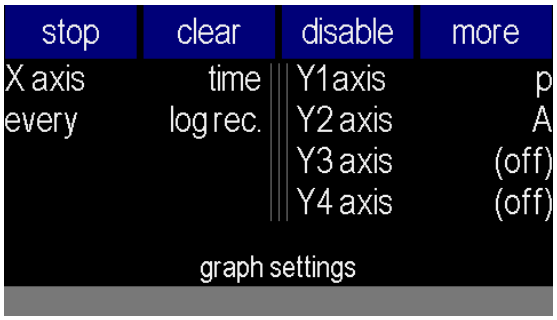
11.2 Operation



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

To set a parameter against time for example use X axis to set to 'time' then press every and select the desired time between 2 to 30 seconds. Select the Y axis parameter by pressing Y1axis and selecting from the list. To graph other parameters use Y2axis. Y4axis. Press start when ready.

When ‘every is set to 30 seconds (0:30), one graph screen fills up over 3 hours, giving 3 hours of data points. If set to 0:02, one screen fills up in 12 minutes.



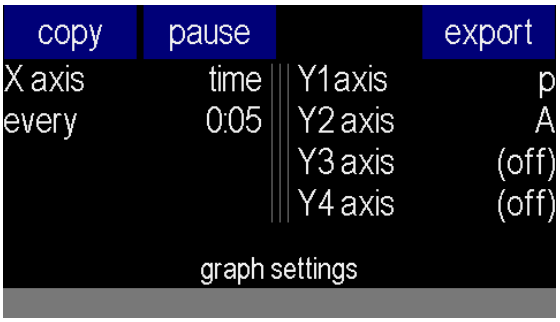
To stop the graph, press the page button and select the page shown by pressing graph :

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

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

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

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



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

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

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

SECTION 12. RECORDING A LOG

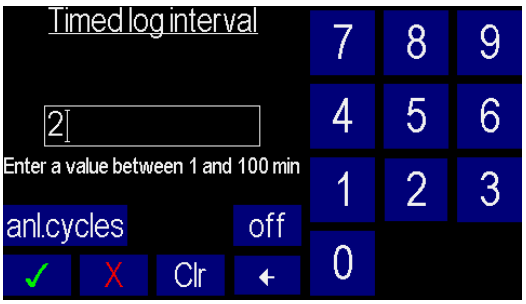
12.1 The nature of a record

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

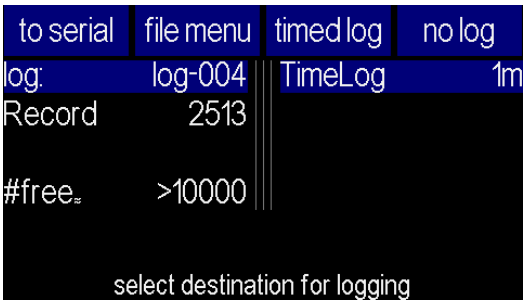
12.2 Taking a record

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

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



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



After a record is successfully taken, the LCpro T will beep. If a log file has not been set, a message appears "log file not set, would you like to set a log file now?" When a record is 'taken', it is appended sequentially in the current log 'filename' on the SD card. The 'record number', which starts at '1', is automatically incremented. The number of records in the .csv file is stored as the first entry. Parameter values are stored as signed integers, or in exponential form; the associated units of measurement are NOT stored.

Timed log

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

Selection of intervals synchronised to the gas cycles is preferred as it allows the maximum meaningful update rate and optimises noise performance. The fastest is about 19 seconds, using the highest air flow.

The timed log will continue until it is switched off by selecting no log in which case the top menu will display log: off, or by selecting "off" as the timed log interval. The timed log function can be used simultaneously with the sequence function to give more records for each step of the sequence.

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.

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

12.4 Sending a serial record

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

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

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

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.
For Windows 7, 8 and 10, Hyperterminal is no longer included as standard, but Hilgraeve do allow a trial download or a purchased download for a modest fee.

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

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

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

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

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

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

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

7. Click on the "transfer" button and select "capture text".

8. Enter a filename and click on "start"

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

10. To stop data transfer, click on "call", "disconnect".

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

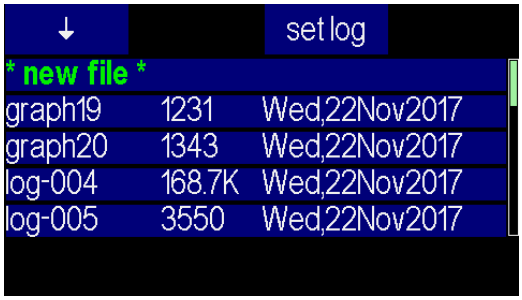
SECTION 13. DATA FILES & USING THE SD CARD

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

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

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



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).
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 T stores data on the SD card using this format. 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 T. 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 T will look like a mass storage device and will appear as another drive on the PC.

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

13.6 Storing Cards

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

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

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 T. However only those supplied by ADC BioScientific have been tested and guaranteed to work. If using SD cards supplied from elsewhere it is suggested that cards from well known recognised manufacturers such as **Sandisk, Kingston** or **Transend**, are used.

SECTION 14. HOW THE ANALYSER WORKS

14.1 Infrared Gas Analysis

The LCpro T uses the principal of Non Dispersive Infrared (NDIR) for the CO_2 measurement. This relies on the fact that CO_2 absorbs energy in the infrared region in a proportion related to the concentration of the gas. The gas sample to be measured is passed through a tube (or IRGA cell). A source of infrared is directed down the IRGA cell, which is gold plated to maximise the intensity of the source. A solid state detector at the receiving end of the IRGA 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 ratio metrically 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 IRGA 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, 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

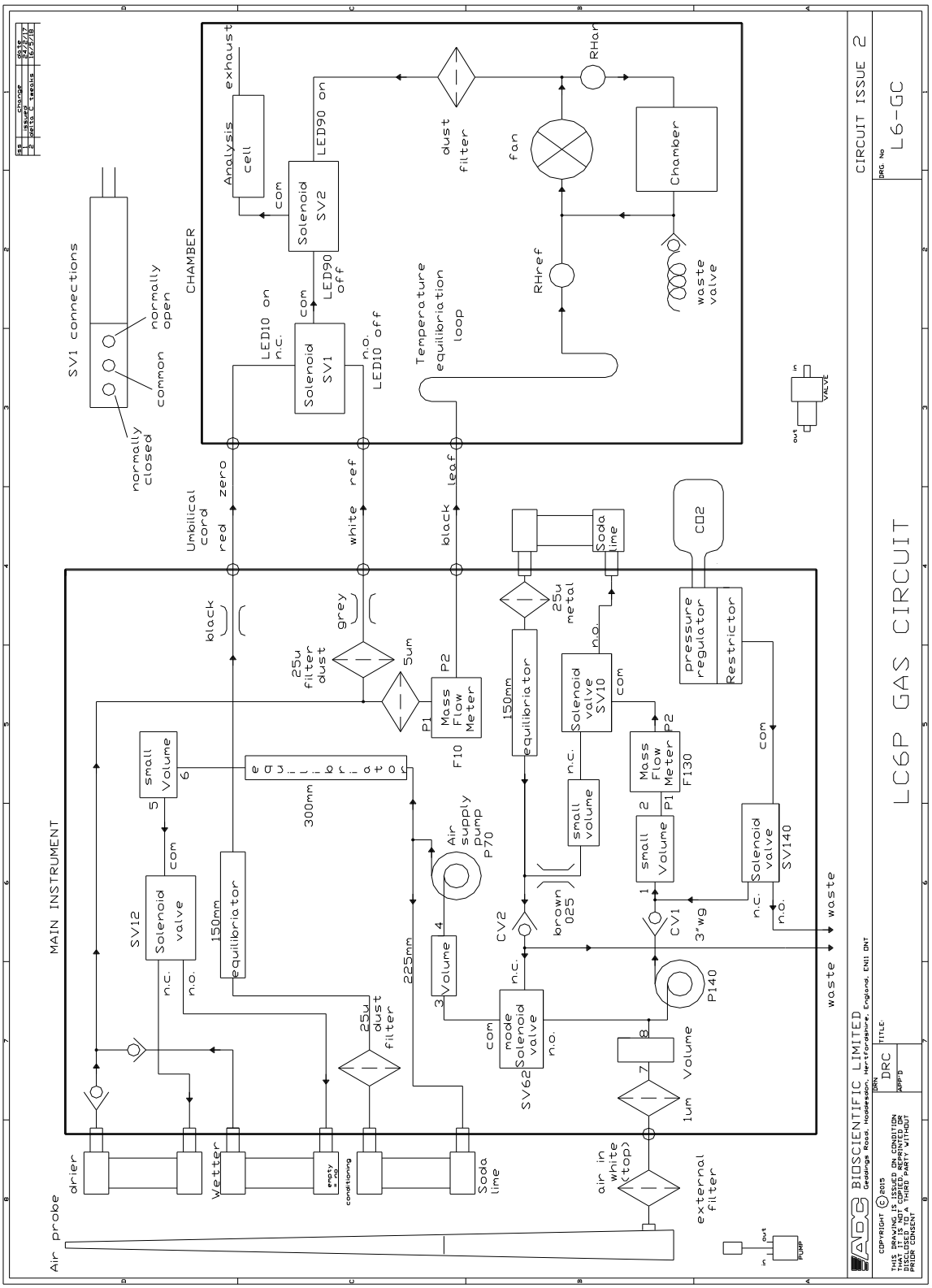
Fresh air is drawn in by the internal air supply pump P70 via the external particulate filter, and then the hydrophobic filter. The hydrophobic filter removes dust particles and helps to prevent water being sucked in. It contains a porous PTFE membrane, which prevents the flow of water by using the effect 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 IRGA 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 IRGA 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 IRGA 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.


LC6P GAS CIRCUIT
CIRCUIT ISSUE 2
L6-GC
BIOSCIENTIFIC LIMITED
Geddings Road, Hoddesdon, Hertfordshire, England, EN11 0NT
MAIN INSTRUMENT
CHAMBER
Analysis cell
exhaust
Solenoid SV2
LED90 on
LED90 off
com
dust filter
fan
RHar
Chamber
RHref
waste valve
Temperature equilibriation loop
Solenoid SV1
LED10 on
n.c.
n.o.
LED10 off
SV1 connections
normally open
common
normally closed
Umbilical cord
red zero
white ref
black leaf
black
grey
25u filter dust
5um
P1
Mass Flow Meter
P2
F10
Soda lime
25u metal
n.o.
CO2
pressure regulator
Restrictor
150mm equilibriator
Solenoid valve SV10
com
n.c.
small Volume
6
5
equilibriator
300mm
Mass Flow Meter P2
F130
small Volume 2
P1
Air supply pump P70
SV12
Solenoid valve
150mm equilibriator
CV2
brown 025
CV1
3"wg
Solenoid valve SV140
n.c.
n.o.
waste
Volume
4
3
225mm
25u dust filter
mode Solenoid valve
SV62
P140
8
7
1um Volume
air in white (top)
external filter
Air probe
drier
Wetter
empty
conditioning
Soda lime
VALVE
PUMP
in
out

SECTION 16. MAINTENANCE

16.1 Tools

Note: When the LCpro T 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 T 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 IRGA cell

16.2 Accessing the Inside of the Main Instrument

With the LCpro T 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.
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.

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 T further.

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

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^{-1} (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 multi-way 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 cable tie 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 unplug its electrical lead, ease the cable tie 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 cable tie. Once free of the cable tie 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 will fail, and the pump will need replacing.

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.

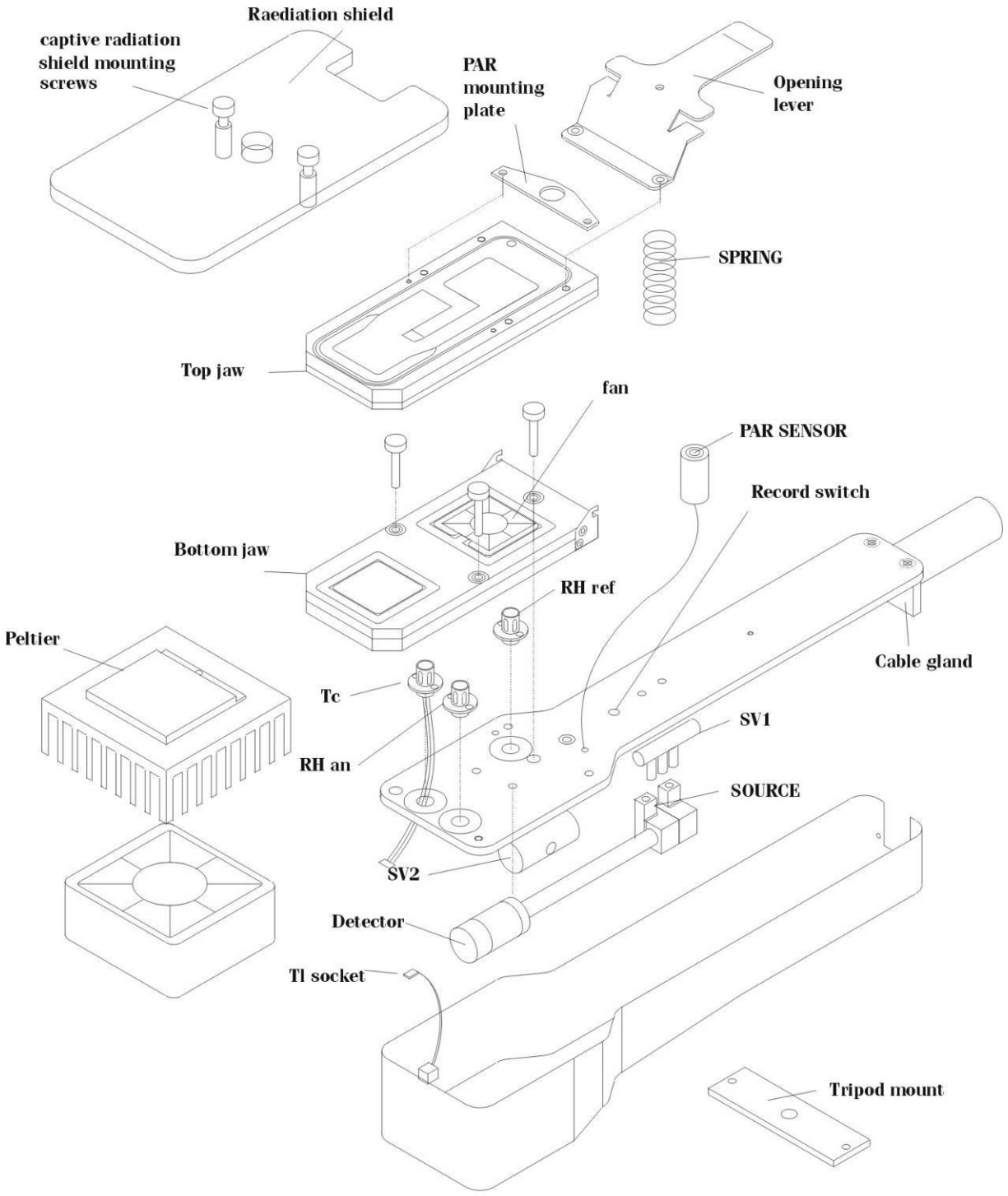
16.8 Display Brightness Setting

The normal contrast setting for the display changes little with variations in ambient temperature and is pre-set. Manual re-adjustment of brightness to suit operator preferences is via the configure more display keys.
The display is dimmed to save power if the screen has not been touched after a pre-set time between 1 and 60. This time can be user set with the same key sequence as above.

16.9 Software and Serial Number

The Software Part number and version and the instrument Serial number for the LCpro T are shown on the display when the LCpro T is first switched on. It is also shown on the screen reached via configure diagnose sys.info. If, for some reason, the LCpro T 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 PRD1076.

16.10 Dismantling the Chamber



CHAMBER EXPLODED DIAGRAM

1) 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.
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.

2) 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 which is hard coated, to reduce scratching. Scratches cannot be polished out of these coated windows. Conifer windows are made from PTEG, and cannot be hard coated.

3) 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. Do not detach the screws; 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 made of two pieces, sealed 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. Do not attempt to dismantle it, but instead return the jaw to ADC BioScientific or your local Service Centre if you have problems with the fan or sensor.

4) 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 an ‘O’ ring is 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. The two humidity sensors must be put them back in their original locations to avoid re-calibration. If the sensors might have become swapped when you reassemble it, choose the locations that make the sensors most closely agree with no leaf in the chamber. Lightly grease the five ‘O’ rings with the silicone grease supplied before re-assembly, and ensure 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 can only be removed by taking off the handle lid (see below). The sensor 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.

5) 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.

A low detector signal can be attributed to a faulty source, faulty detector or a contaminated IRGA 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 IRGA cell 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 IRGA cell can then be raised high enough to access the two M2 screws that hold the source housing to the IRGA 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 IRGA 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 IRGA cell. 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 IRGA cell will need cleaning. It is best to first remove the IRGA cell as described above then pull the IRGA 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 IRGA 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 IRGA cell, which should appear uniformly shiny. If it appears dull or patchy, it may be possible to clean it.

The IRGA 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 IRGA 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

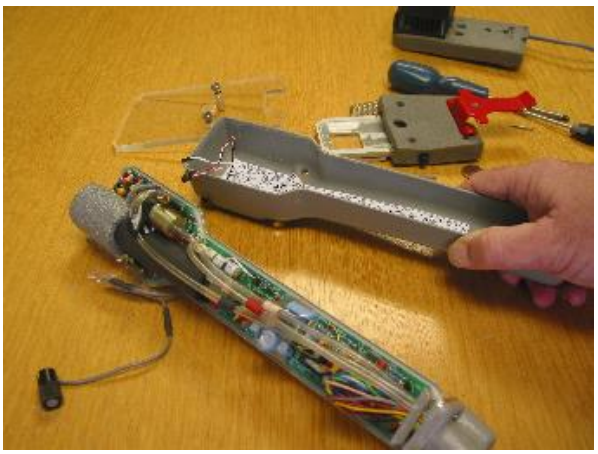
Unscrew the two retaining screws from the tripod boss.
Note the orientation of the boss as the fixing screws are not on the centre line.

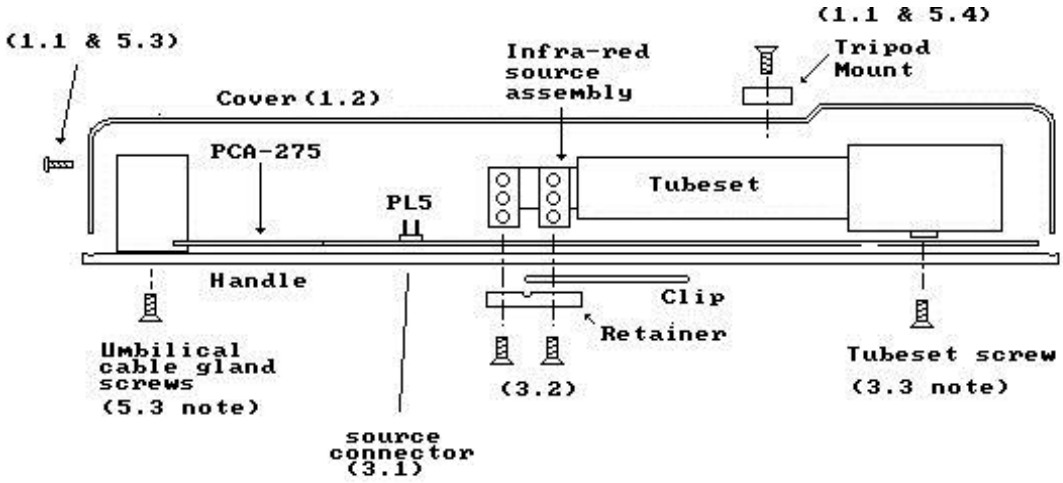
Remove the two screws furthest from the baseplate, which pass through the cable gland assembly.

Sometimes these screws are cross head rather than slotted.

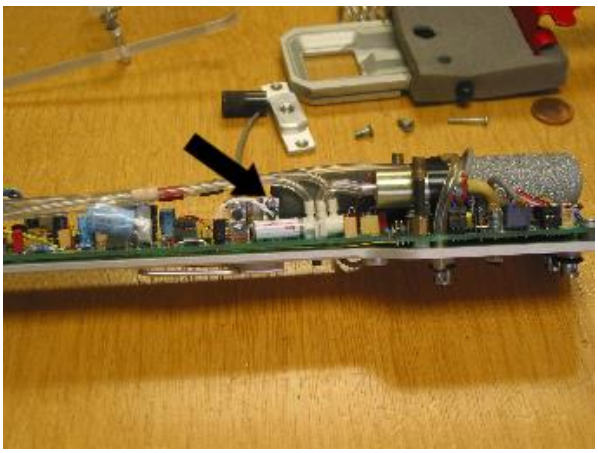
If you wish to completely remove the handle cover, take a note of the orientation of the connectors (there is a diagram inside the handle cover) and unplug the two sockets of the Tleaf thermistor and the CO2 zero potentiometer wires from the PCB.

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

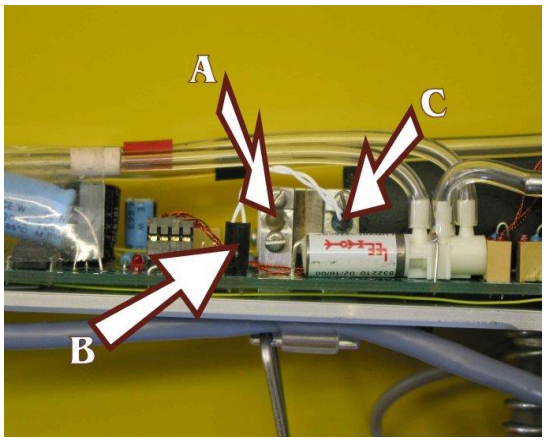




16.12 Checking the Source



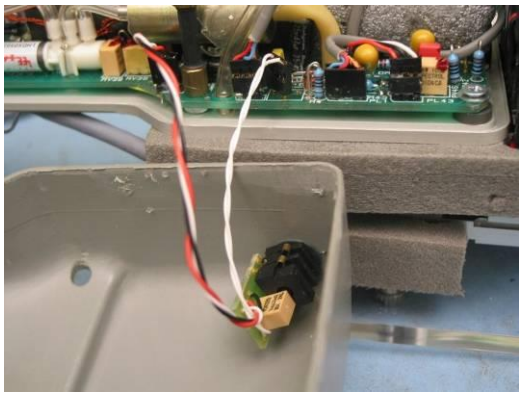
First remove the jaws and then the handle cover, (see previously). It is not necessary to completely remove the cover.
The source is indicated by the black arrow in the above picture. It is a small light bulb, which has been pre-aged to minimise drift. It has a thin envelope to minimise infrared loss,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



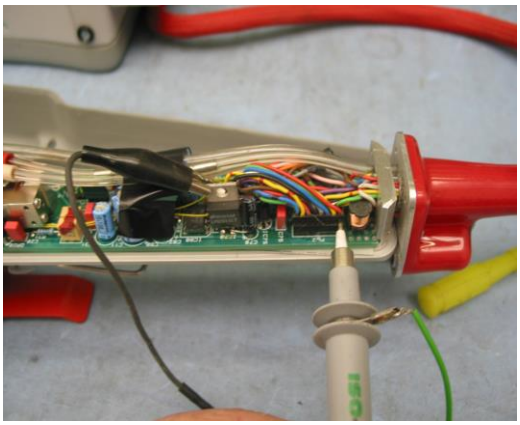
Look for flashing coming from the small window (A). This is best done in a dark area.
If the source has a white body then light can be seen through the body.
If there is no sign of flashing then unplug the source connector (B) and check resistance to see if the source bulb is open circuit.
If there is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

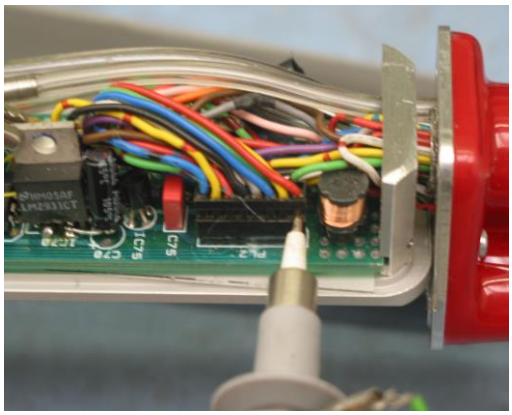
16.13 Checking the Detector



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.

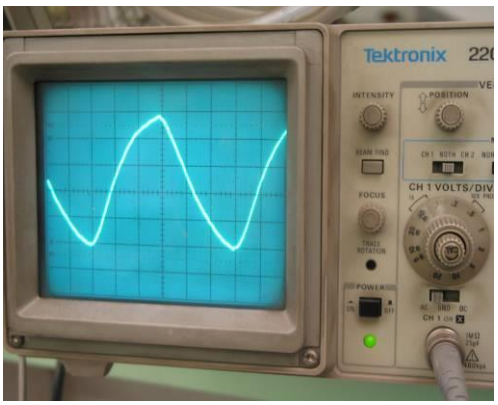


Place the earth clip of an oscilloscope probe on the metal body of the regulator as shown.



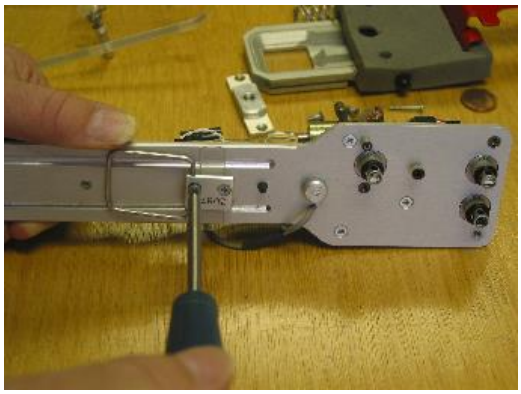
With a narrow oscilloscope probe measure the signal on the red wire of the connector. This can be done through the small hole in the side of the connector.

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 CO_2 zero pot. If you do not have an oscilloscope measure the voltage with an AC Voltmeter. If there is no detector signal, then the detector is probably faulty and will need to be replaced.

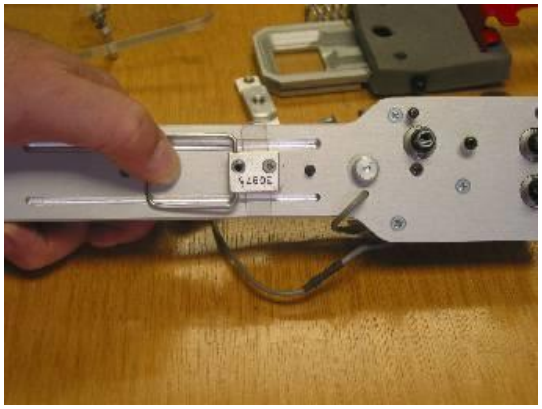


The detector can be removed with the IRGA cell in place. It is a static sensitive device and so static precautions should be observed as for changing the EPROM. Unplug its connector, and remove the large piece of insulation around the detector housing. Unscrew the knurled nut by turning it counter-clockwise,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

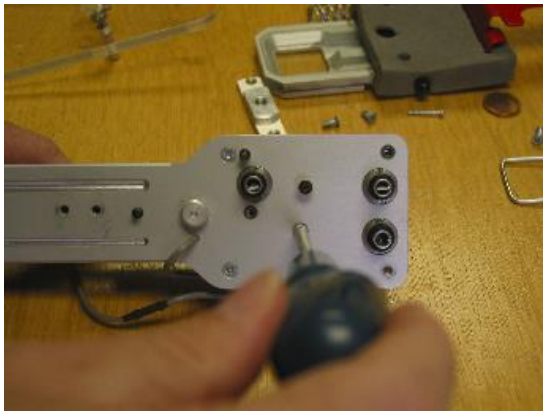
16.14 Replacing the Source



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

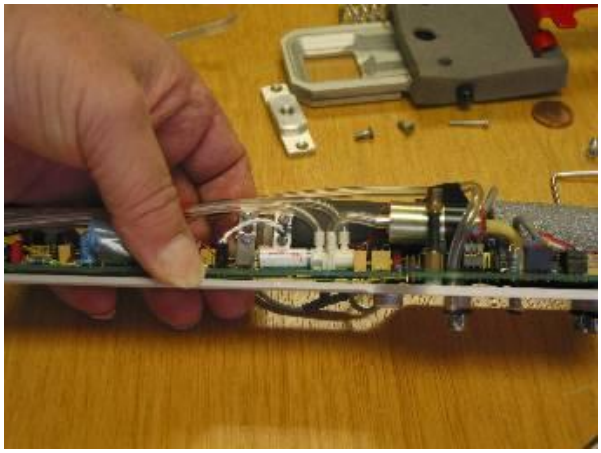


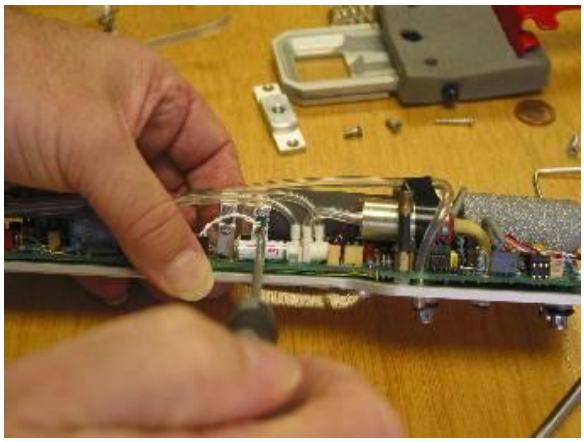
Note that the retaining screws are off-set and not central. Remember this when reassembling the handle.



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

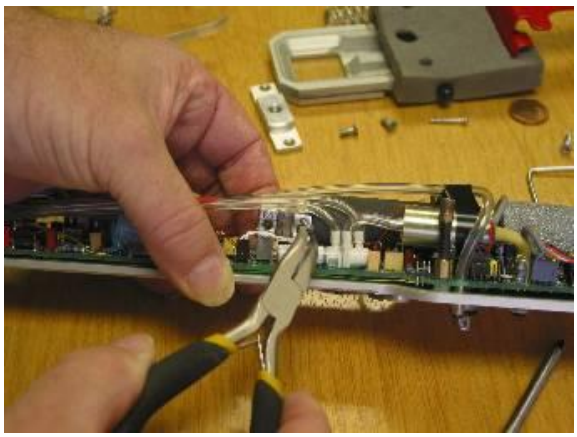
This will give you just enough slack to lift the source end of the analysis IRGA cell, giving you access to the lower source retaining screw. If there is not enough movement to get a screwdriver on to the sources lower screw then go back to the previous instruction and unscrew the analyser retaining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

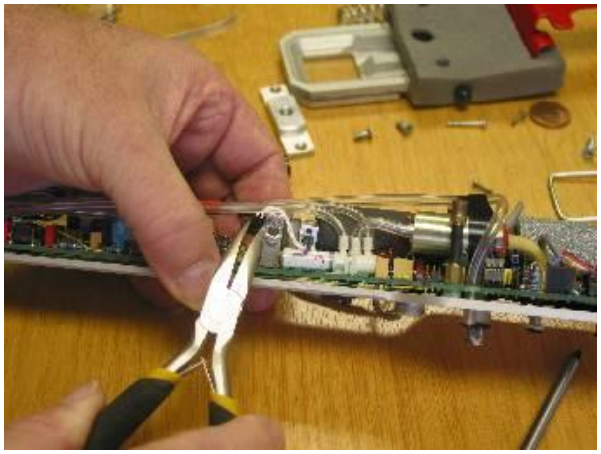




Using a small flat bladed screwdriver, unscrew and remove the upper and lower source retaining screws. These screws are stainless steel – Do not replace them with mild steel types.

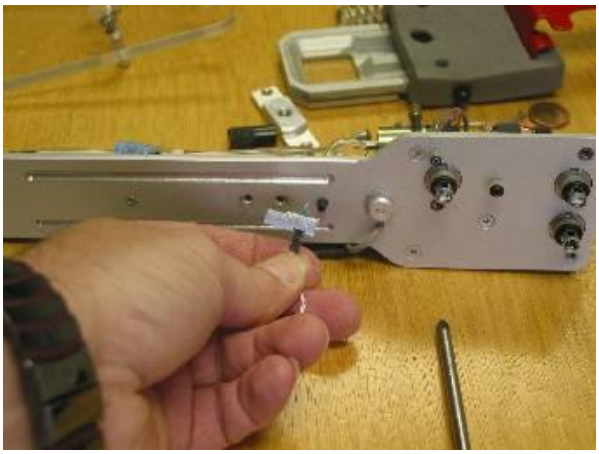
Using tweezers or long nose pliers gently pull out the old source from the analyser IRGA cell. Take care not to allow any debris to get inside the analysis IRGA cell.





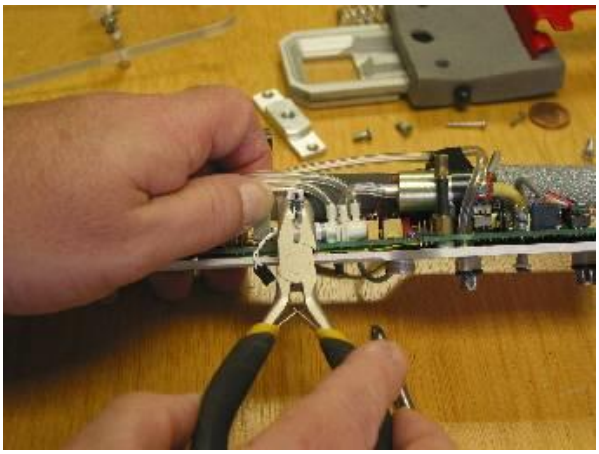
Disconnect the sources electrical connection from the circuit board.

Then remove the old source.



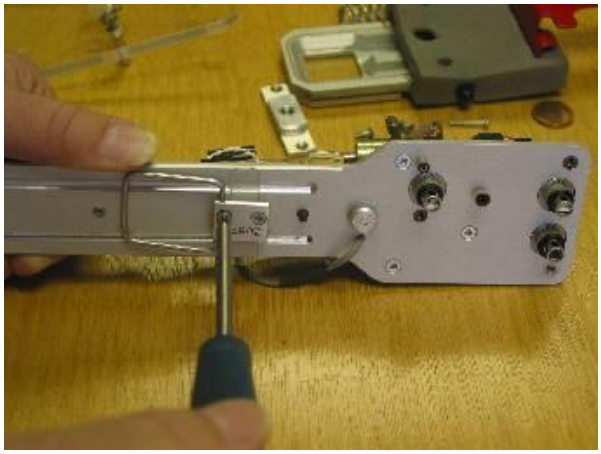
A thermal isolation gasket should have come off with the old source.

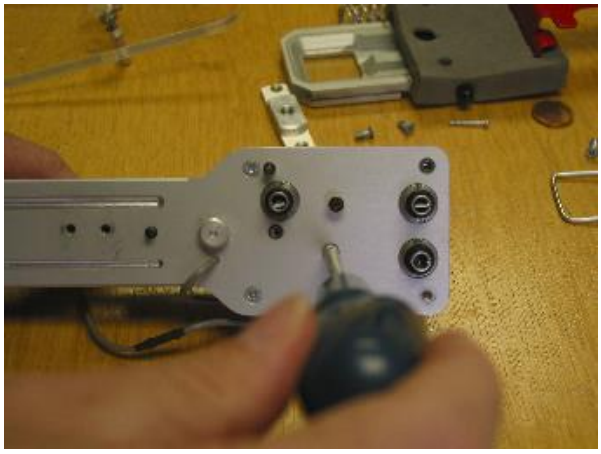
Remove the thermal isolation gasket from the old source and fit it onto the new replacement source.



Fit the new source in to the analyser IRGA 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 analyser 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 CO_2 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 holding down the power 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 IRGA cell.	Recalibrate CO_2 zero. Check soda lime Remove and clean IRGA 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>sysinfo>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 (normal when jaws open). Or a jaw screw has been over-tightened, which can break a wire attached to the jaw. No jaw pressure, caused by a 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	Log	An o/p	Screen	Units	Range	Type
#free	Estimated free space in records on SD card	-	-	Log	-	-	-
[c]z	Raw CO_2 zero reading	-	y	Diagnose Hidden	adc counts	-	-
[cab]a	Infra-red absorption due to analysis CO_2	-	-	Diagnose Hidden	%	0-40	-
[cab]r	Infra-red absorption due to ref CO_2	-	-	Diagnose Hidden	%	0-40	-
[w]a	Raw H_2O analysis reading	-	-	Hidden	adc counts	-	-
[w]r	Raw H_2O reference reading	-	-	Hidden	adc counts	-	-
A	Photosynthetic assimilation rate	26		2	µmol m^{-2} s^{-1}	0-100	Ca
Alt	Altitude	31	-	GPS	DMM	-	-
Area	Projected leaf surface area	27	-	3, Config	cm^2	0.1-100	G
C_{an}	CO_2 analysis (corrected for dilution)	-	y	1	vpm	0-2000	M,Co
C*e*	Soil Respiration	23 SOIL	-	2, SOIL only	µmol s^{-1}		Ca
Chcfg	Chamber type/ configuration	-	-	3, Config	-	-	-
C_I	Sub-stomatal CO_2	23	y	2	vpm	0-2000	Ca
CO_2 bot	CO_2 estimated bottle, pre-mix concentration.	-	y	An.Output	ppm	0-3500	Ca
Cref	CO_2 reference	7	y	1	ppm	0-3000	M,Co
Cset	CO_2 set by user	9	-	1, Clim.	ppm	0-2000	G
ΔCO_2	Delta CO_2 (Cref - C'an)	8	y	1	ppm	+/-3000	Ca
Δe	Delta H_2O (e'_{an}-e_{ref}), partial p.	5	y	1	mBar	+/-75	Ca
Dt	Date (text)	2	-	Diagnose	-	-	-
Δw	Delta H_2O (w'an-Wref), as%RH	-	y	-	%RH	+/-100	Ca
E	Transpiration rate	24	y	2	mmol m^{-2} s^{-1}		Ca
e'an	H_2O analysis, dilution corrected	-	y	1	mBar	0-75	Ca,Co
e ref	H_2O reference, as partial pressure	4	y	1	mBar	0-75	Ca,Co
e set	H_2O set by user	6	-	1, Clim.	mBar	0-75	G
GPS fix	GPS Fix	32	-	GPS	-	0-2	-
Gs	Stomatal conductance of H_2O	25	y	2	mmol m^{-2} s^{-1}	0-100	Ca
Hfac	H factor - energy conversion factor	-	-	3, Config	-	0.1-1	F,G
Lat	Latitude	29	-	GPS	ddmm.mmmm	-	-
Log	Name of log file	-	-	3 Config, Log	-	--	G

Long	Longitude	30	-	GPS	dddmm.mmmm	-	-
Symbol	**Description**	**Log**	**An o/p**	**Screen**	**Units**	**Range**	**Type**
Mem	Free space on SD card	-	-	Log	Kb	-	-
NCER	Net CO_2 Exchange Rate	26 SOIL	-	2 SOIL only	µmol m^{-2} s^{-1}	0-100	Ca
P	Atmospheric Pressure	22	-	1, Hidden	mBar	600-1100	M
P_{adj}	Atmos. pressure correction	-	-	Hidden	mBar	+/- 4	Co
Phase	CO_2 rectifier phase shift	-	-	Hidden	°	-	-
Power	Bar graph showing battery state	-	-	2	-	10.5-14.3	M
Q	P.A.R. at window corrected for Trw	-	-	Hidden	µmol m^{-2} s^{-1}	0-3000	M
Qblu	Blue LED light unit output corrected for Trw	14	-	Climate	µmol m^{-2} s^{-1}	0-800	M,Co
Qgrn	Green LED light unit output corrected for Trw	13	-	Climate	µmol m^{-2} s^{-1}	0-800	M,Co
Qleaf	P.A.R. incident on leaf surface corrected for Trw	10	y	1	µmol m^{-2} s^{-1}	0-3000	Ca
Qmode	Light measurement method	28	-	-	-	-	-
Qred	Red LED light unit output corrected for Trw	12	-	Climate	µmol m^{-2} s^{-1}	0-800	M,Co
Qw	White LED light unit output corrected for Trw	11	-	Climate	µmol m^{-2} s^{-1}	0-2500	M,Co
R_b	Boundary resistance to H_2O	27	-	3	m^2 s mol^{-1}	0.1-9	G
R_b set	Boundary resistance at full flow	-	-	Config.	m^2 s mol^{-1}	0.1-9	G
Record	Measurement number	1	-	2, Log	-	-	-
Rs	Stomatal resistance to H_2O	-	-	-	m^2 s mol^{-1}	0-100	Ca
RunT	Run time counter	-	-	Hidden	days/hrs	455 days	M
S/No	Serial number	-	-	Hidden	-	-	G
Taux	Temperature calculated from Auxillary input	-	y	Diagnose	°C	-5 to +50	Ca
Tch	Leaf chamber temperature	15	y	1	°C	-5 to +50	M
Tl mtd	Leaf temperature determination method	18	-	3, Config	-	Meas. or Calc.	-
Tleaf	Leaf surface temperature	17	y	2	°C	-5 to +50	M,G
tm	Time of day	3	-	Diagnose	-	-	-
Trw	Chamber window transmission factor	-	-	3, Config	-	0.25-1	F,G
Tset	Leaf chamber temperature set by user	16	-	Climate	°C	1-40	M, Co
U	ASU mass flow (measured)	17	y	2	µmol s^{-1}	68-341	M
U_a	Last value of “an.flo” from flowcheck	-	-	Diagnose	µmol s^{-1}	-	Ca
U_s	Flow per unit leaf area	-	-	-	mol m^{-2} s^{-1}	-	Ca
Uset	Desired flow rate as set by user	20	-	2,3, Config.	µmol s^{-1}	68-341	G
Va (± 20%)	Measured analyser flow	-	-	-	µmol s^{-1}	-	-

Vaux	Aux input, scaled as volts	-	-	Diagnose	Volts	-	-
Vbatt	Battery voltage	-	-	Diagnose	Volts	10.5-14.3	-
W'_{an}	H_2O analysis, corrected as%RH	-	y	Diagnose	%RH	0-100	M,Co
W_{flux}	Net H_2O Exchange Rate	24 SOIL	y	2 SOIL only	mmol m^{-2} s^{-1}	-	Ca
W_{ref}	H_2O reference, as %RH	-	y	Diagnose	%RH	0-100	M,Co

Column key:

"Screen" gives the location of displayed parameters. There are three main screens (1, 2, & 3) and four sub-screens: Diag. = diagnostics screen
Config. = configuration set up screen
Log = log set up screen
Hidden = hidden screen for ADC use only

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

"An o/p" indicates whether the parameter can be monitored from the analogue output port.

"Type" indicates the method of derivation:

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

Appendix 2 Analogue Output Scaling

Parameter & Symbol		Units	Reading @ 0V	Reading @ 5V	Units/V
Atmospheric pressure	(p)	mBar	600	1100	100
Analysis CO_2	(c'an)	vpm	0	2000	400
Delta CO_2	(Δc)	vpm	-200	+200	80
Reference CO_2	(cref)	vpm	0	2000	400
Analysis H_2O	(e'an)	mBar	0	100	20
Delta H_2O	(Δe)	mBar	-5	+5	2
Reference H_2O	(eref)	mbar	0	100	20
Analysis humidity	(w'an)	%RH	0	100	20
Delta humidity	(Δw)	%RH	-5	+5	2
Reference humidity	(wref)	%RH	0	100	20
Leaf chamber temperature	(Tch)	°C	-5	+50	11
Flow	(u)	μmol s^{-1}	0	342	68.4
Leaf temperature (meas/calc'd)	(Tl)	°C	-5	+50	11
Qleaf (PAR @ leaf surface)	(qleaf)	μmol m^{-2} s^{-1}	0	3000	600
Sub-stomatal CO_2	(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 CO_2 zero at TP20 [*2]	([c]z)	Volts	4.05	5	0.19
Raw CO_2 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 CO_2 zero calibration
[*3] A-D count optimally 52500 for "perfect" CO_2 zero calibration.

Appendix 3 Calculated Parameters and Constants

CO_2 Concentration

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

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

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

The 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 T 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*** (mmol m^{-2} s^{-1})

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

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

APPENDIX 3 (Continued)

Leaf surface temperature

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

symbol: T_{leaf} (°C)

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

where

T_{ch}	leaf chamber temperature, °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 Stefan-Boltzmann's constant, $Wm^{-2}K^{-4}$

Stomatal resistance to water vapour

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

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

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

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

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

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

APPENDIX 3 (Continued)

Sub-stomatal cavity CO_2 concentration

symbol: c_i (μmol mol^{-1})

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

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

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

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

where T_{leaf} leaf surface temperature, °C

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

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

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

P.A.R. incident on leaf surface

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

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

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

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

symbol: C_e (μ mol s^{-1})

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

where u molar air flow in mol s^{-1}
Δc difference in CO_2 concentration through soil pot, dilution corrected, μmol mol^{-1}.

Net CO_2 Exchange Rate (C_e per unit area)

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

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

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

Note: *This is equivalent to -A*

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*

Appendix 4 Constants

Volume of 1 micro-mole of air at 20˚C and 1 Bar (Vm_{20C})
Value used is $2.4387x10^{-2}$ m^3.

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

Stefan-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 5 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.

$$H = Q \times Hfactor$$

A value for Hfactor is given by the following equation:

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

Where;

H = energy absorbed by the leaf in W/m^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 T]

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

d = the fraction of infrared absorbed by the leaf

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

f = the fraction of visible absorbed by the leaf

Typical values for the above factors are;

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

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

c = 0.6

d = 0.2 (for typical leaves)

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

f = 0.8 (for typical leaves)

These values give Hfactor = 0.168 (Broad & Narrow chambers) – for sunlight

= 0.177 (Conifer chamber)

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 6 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 7 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.
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 the SD card.

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

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 T will attempt to interpret invalid fields, but the result may be unexpected.

NOTE: The step number (as shown on the LCpro T 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.
Note:
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 - a parameter with this indicator is not 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 (as they are presented from left to right):

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.

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.

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.

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.

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.

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 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.)

3. 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 T to recognise it. If you are using transfer to send the file to the LCpro T, 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™Climate sdoes 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 T will result in the file being truncated.

End-Of-Line
The LCpro T 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 T, 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 T.

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

Example File

```
# ADC BioScientific  LCpro T  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 8 Saturated Vapour Pressure

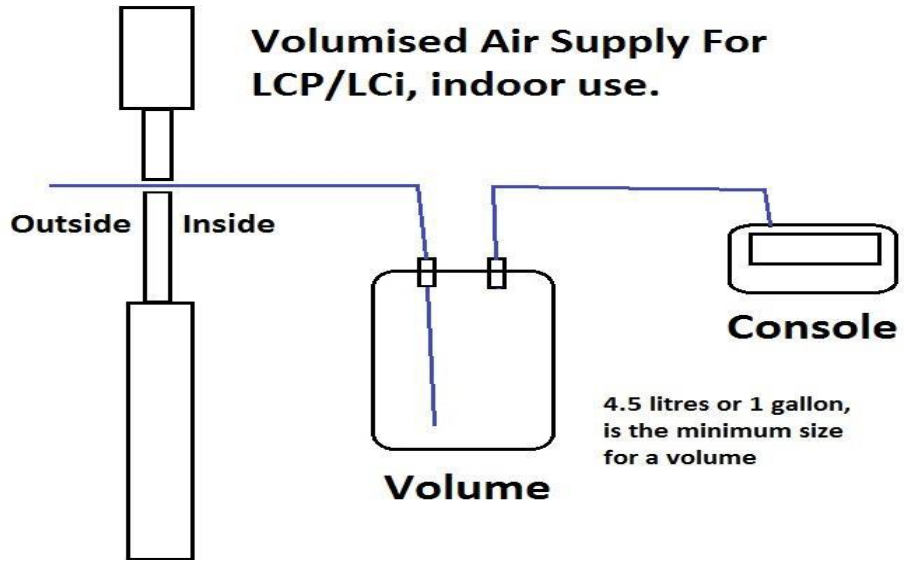
SATURATION VAPOUR PRESSURE OVER WATER (SVP)

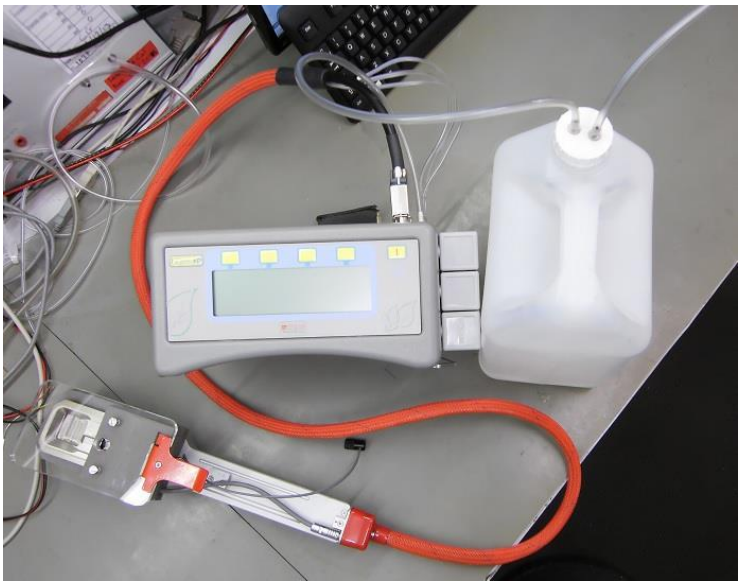
Values obtained using the LCpro T software based on the Arden Buck 1981

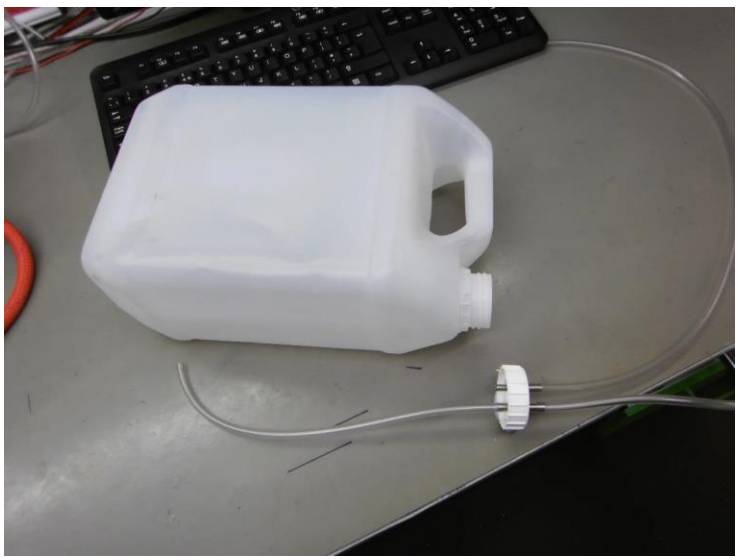
Metric Units (millibars)

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

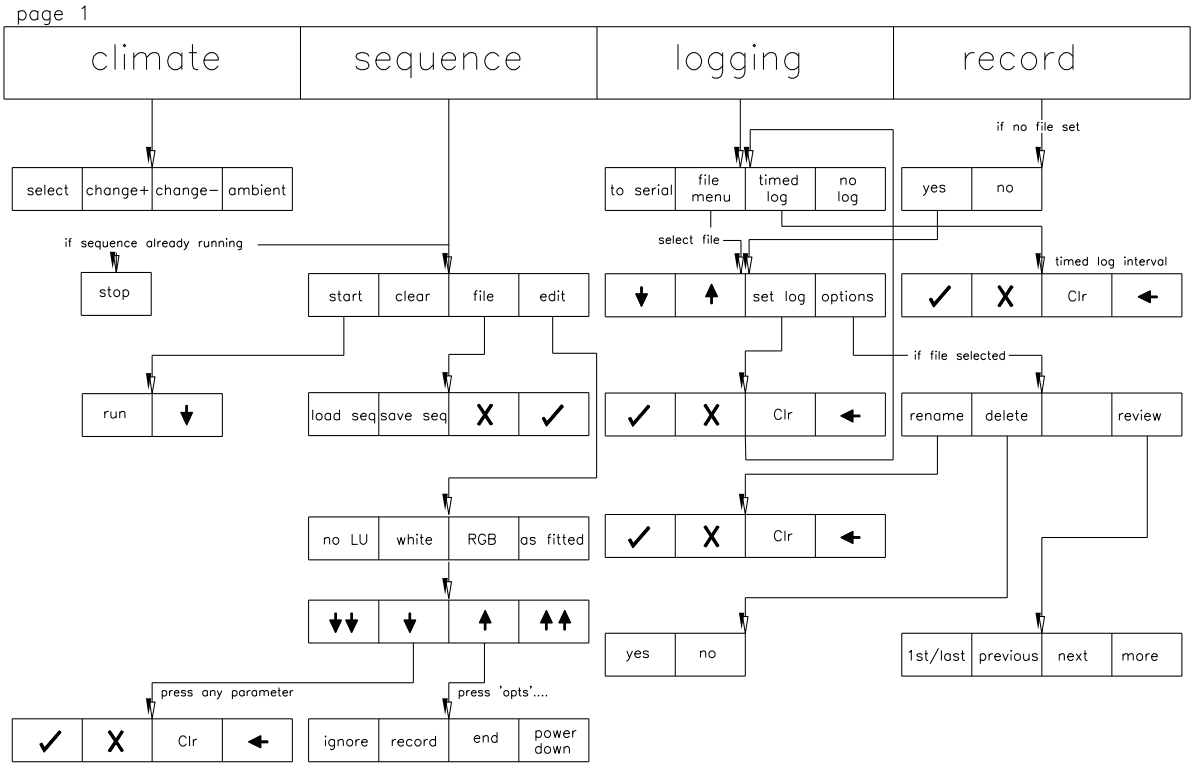
Appendix 9 Volumised Air Supply for Indoor Use.

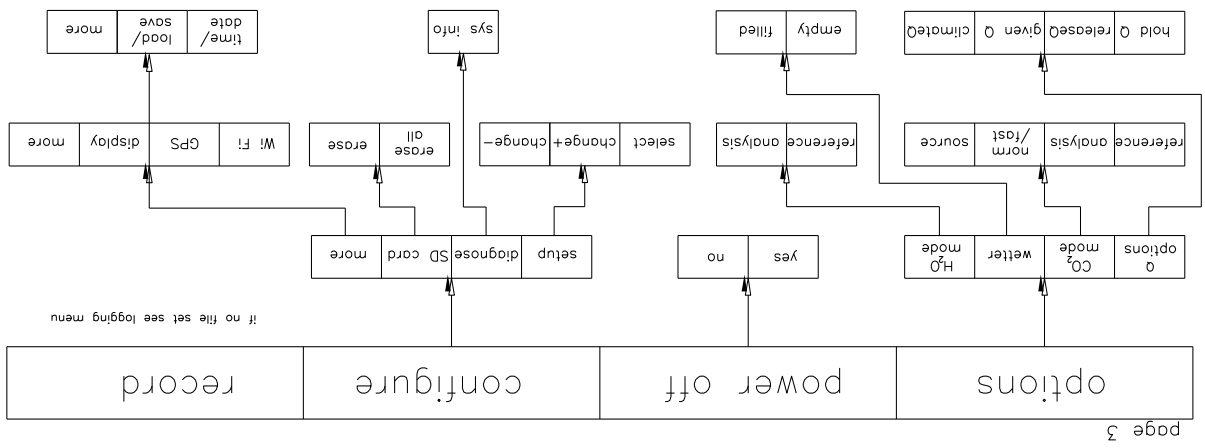


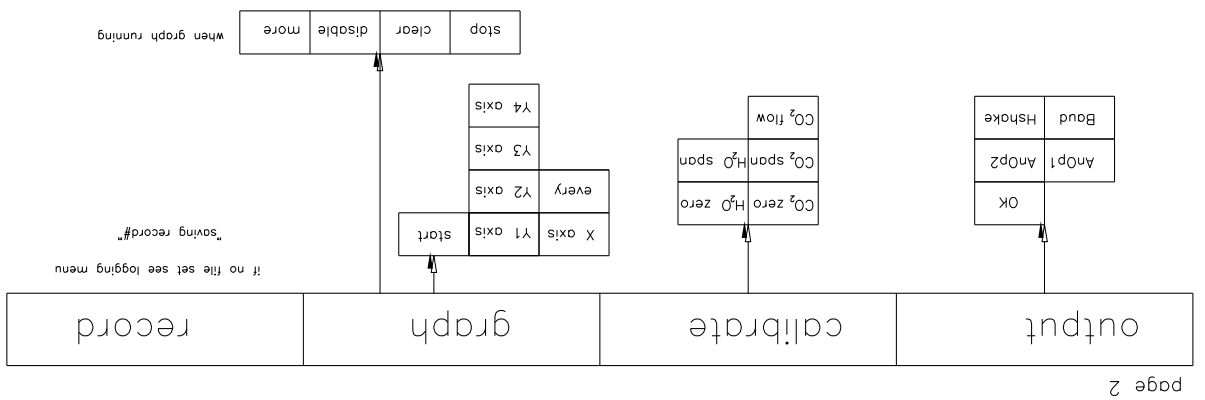




Appendix 10 LCpro T Menu Structure







11 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 2400 μmol m^{-2} sec^{-1} by red/green/blue LED array or 2500 μmol m^{-2} sec^{-1} by white LED array.
Display:	Colour WQVGA touch sensitive LCD
Warm up time:	5 minutes at 20°C
Recorded data:	Secure Digital 8Gb SD card.
Battery:	7.5 Li-ion 12V to give 16 hours max
Battery charger:	90 to 260V, 50/60 Hz
Analogue output:	0 to 5V on user selected parameter

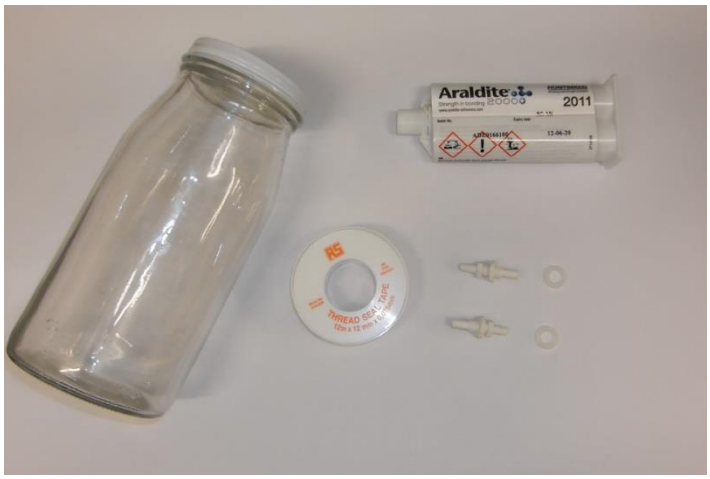
Appendix 11. Technical Specification (Continued)

RS232 output: USB Slave Peripheral	User selected from 300 to 230400 baud	
Electrical connections	Power:	5 pin DIN
	Analogue out:	5 pin DIN
	RS232:	9 pin D type. “AT” pin configuration.
	Chamber:	15 pin high density D type
	USB:	USB Mini B
Gas connections:	3mm barbed	
Power requirements:	2A @ 12V DC	
Operating temperature:	5°C to 45°C	
Dimensions: L x W x H overall incl. clips and columns.	Console:	306 x 190 x 162 mm
	Chamber:	300 x 75 x 80 mm
Weight	Console:	4.1 kg
	Chamber:	0.8 kg

Appendix 12 Small Buffer Volume Construction

A useful accessory is a **buffer volume** to average out or stabilize the CO_2 level going into a console. It is made from a clean glass jar which glass has very little gas "hangup".
When water is added to the jar it can be used as a water bubbler for making 100% RH air if two are connected in series, useful if a H_2O recalibration needs to be done.

The volume consists of a glass jar with two air entries (also known as 1/8" bulkhead connectors) mounted through the lid. The assembly must be air tight, which is achieved usingf two part epoxy resin and PTFE tape.

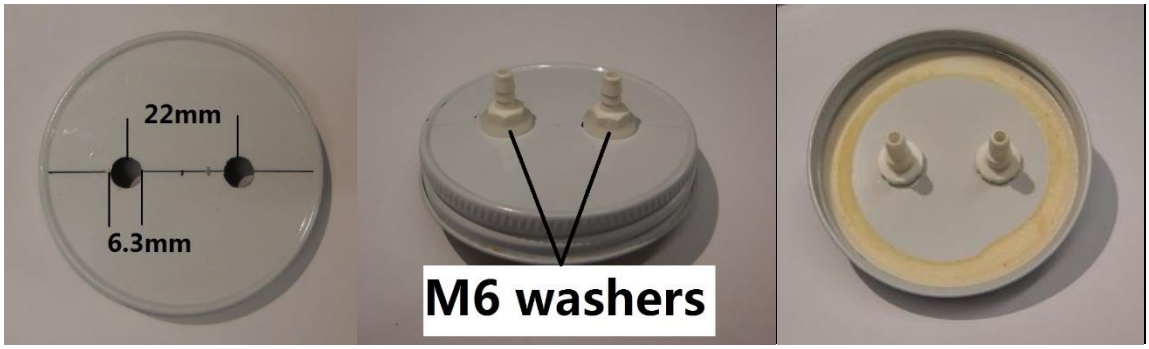


The small buffer volume is shown above left, the parts required to make one are shown above right.

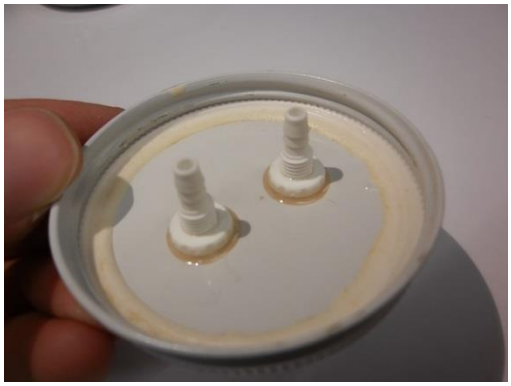
Parts used (above right): A glass jar at least 500 ml in volume, some PTFE tape, two plastic M6 washers, two 1/8" barbed bulkhead connectors (ADC part number 614-802). Some slow setting araldite 2011 glue, (quick setting epoxy resins may be used but they are not suitable for use with water) and a short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

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

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

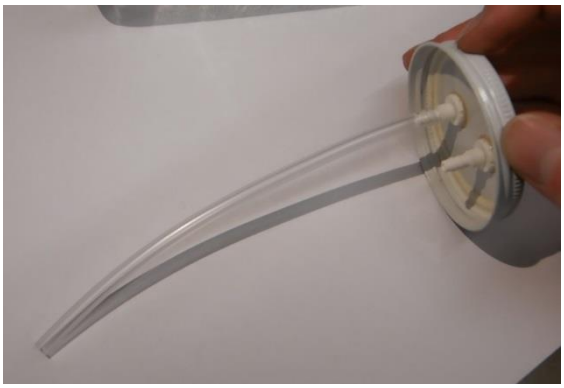


3. Apply some two part glue using a cocktail stick to make a seal around the bulkhead connectors on both sides of the lid as shown below.



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

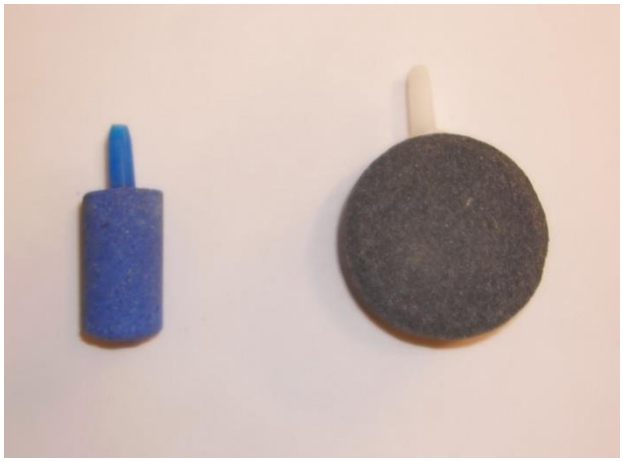
6. Connect this length of tubing to one of the bulkhead connectors on the inside of the lid (see left). If this buffer is connected to a console then the console “air in” entry connects to the buffer entry without the long tube on it, the “short” air entry.



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

Note on Water Bubblers.

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



Appendix 13 Spares and Accessories

Part No.	Description
022-658	3.15A fuse glass time delay
077-725	Figure “8” AC power “mains” lead (UK)
077-735	Figure “8” AC power “mains” lead (Euro
077-745	Figure “8” AC power “mains” lead (USA)
192-160	Li-ion battery, 7.5Ah, 12V
197-720	SD card 8G
LCM-025	Lead acid charger, 12V
612-354	Tee, plastic
631-180	Aluminium bodied filter
630-964	Hydrophobic filter (25mm diameter 2µm 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
802-151	Calcium Sulphate (drier), 10-20 mesh
LCM-065	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
LCI-020/AL	Gasket set Small
LCI-020/B	Gasket set Broad
LCI-020/N	Gasket set Narrow
LCI-020/C	Gasket set Conifer
LCI-023A	Source assembly
LCI-056	Car power supply lead
LCI-059	Lead assy. power/chart
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	RH sensor spacer
LCM-140	jaw fixing spacer
LCM-146	CO_2 regulator “key”
LCM-189	Handle air out (out from jaws, brass)
LCM-165	Handle air in (in to jaws, brass)
PLC-011	Leaf temperature thermistor assembly
MAN-LCpro T	this manual.