Q-teach Plant CO_2 Package Operation Manual

Manufactured and Distributed by Qubit Systems Inc.

613-384-1977, info@qubitsystems.com

www.qubitsystems.com

Nov 2020

Table of Contents

Overview of Q-teach Plant CO_2 Package

The Q-teach Plant CO_2 package has been designed for measurements and teaching of photosynthesis and plant respiration in attached or detached leaves placed in a flow-through leaf chamber. The package contains all the components required, including this operational manual. An additional manual is included with the description and instructions of laboratory experiments for this package (Q-teach Plant CO2 Laboratory Experiments). The laboratory experiments manual is provided in a word format so instructors may edit it as they see fit for distribution to students. Before using this package, ensure that all the components are included and familiarize yourself with their function as described in this manual. If any part of the package is missing, contact QUBIT SYSTEMS INC. immediately by email at info@qubitsystems.com or by phone (613-384-1977). Purchase of the **Q-teach Plant CO_2 Package** entitles the user to copy the software provided, or any part of the manuals, for use only within the educational institution where the purchase has been made. The user may not give, sell, or loan any part of the written or software components of the package to any other institution or person.

The Laboratory Experiments manual provides detailed notes to the instructor with step-by-step instructions for performing several experiments. At the end of each experiment, the students are assigned questions to direct them in the interpretation of their data, and the instructor's notes provide the answers to these questions. Instructors may wish to modify, add to, or delete these questions. The laboratory manual is provided on a disk in a Word format for convenient editing.

Students can use the **Q-teach Plant CO_2 Package** to compare the photosynthetic rates of different plant species under different environmental growth conditions. Students may investigate differences between C3 and C4 plants under different light regimes and different CO_2 concentrations. The software allows calculations of CO_2 assimilation rate (A) over a range of CO_2 concentrations or over the range of light intensities. Further, the software allows a photosynthetic CO_2 response and/or light response curves to be plotted. From these, the students can derive such physiologically important parameters as: carboxylation efficiency, CO_2 and light compensation points, CO_2 and light saturation points, leaf respiration rate in the absence of light, and photorespiration rate at zero CO_2 levels while in the presence of light. From the ratio of transpiration rate and photosynthesis students can calculate the water use efficiency (WUE) of the plant.

Several experimental investigations are fully described in the Laboratory Experiments manual. These can be used as the basis for many other studies that students can pursue under supervision or as independent research projects.

Photosynthesis requires both light and CO_2. Light is provided by a warm white LED light source (**A113**) that has been calibrated in the software for use with the flow through leaf chamber (**G112-t**). This light source sits directly on top of the leaf chamber and its intensity may be varied between 0-2000 μmol quanta/m^2/s. CO_2 is supplied from a gas bag (**G122**) filled with either outside air (400ppm) or with the mixtures of different CO_2 concentrations. The gas from the gas

bag is delivered via **Q-teach 201** Pump/Flow Monitor to the leaf chamber, or in case of reference gas measurements it bypasses the leaf chamber (via two 3-way valves) on its way to the analyzers. The gas first enters the **S161** RH/Temp Sensor, then **Q-teach101** CO_2 Analyzer and finally vents to the atmosphere via the gas "Out" port.

The other components of the Q-teach Plant CO_2 Package not mentioned above are the **Q-A101** Lab Stand that holds the leaf chamber up, **Q-teach Accessory Kit** (accessory kit with tubing, connectors, filters, valves, screwdriver), **C610** LabQuest Mini data interface x2 (6 analog channels), **C901** Logger Pro software, **C404** USB disk with the experimental setup file and manuals for this package.

This manual contains detailed information about the components of this package and instructions on how to set up the system for teaching experiments. **Please note that this package is designed for teaching purposes only.** Each of the sensors has been calibrated in factory and no further calibration is required.

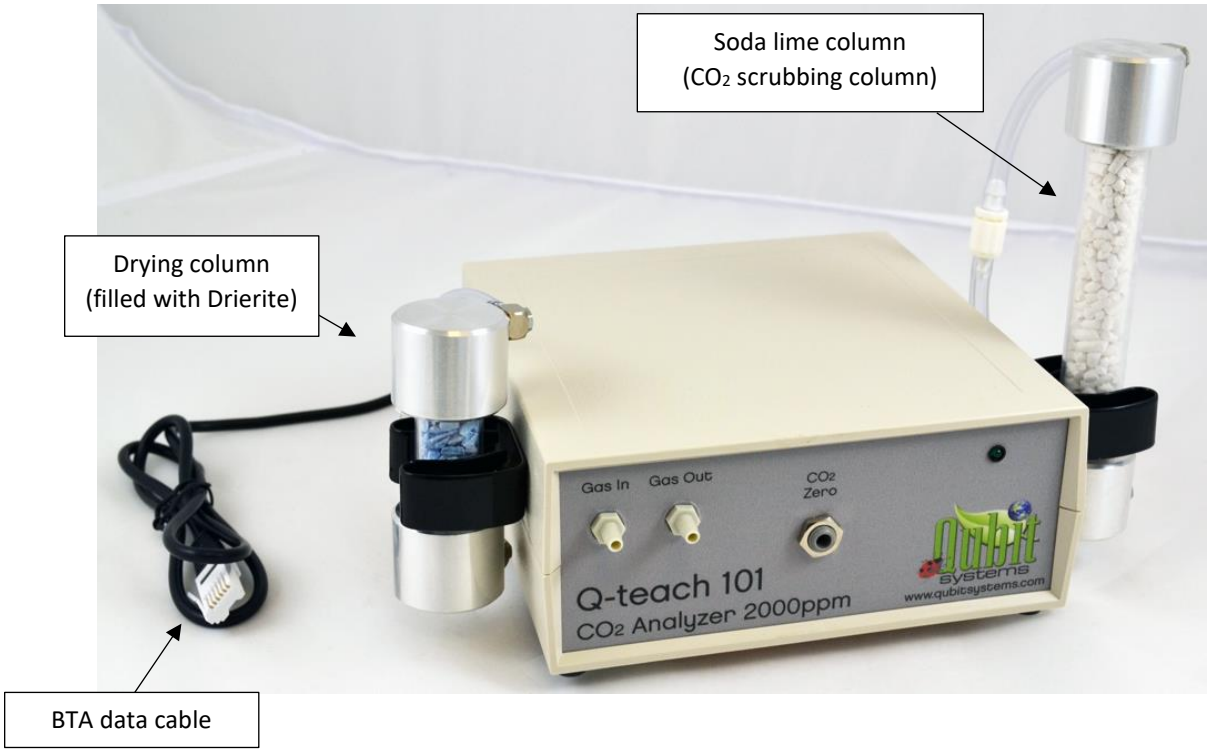
Components of Q-teach Plant CO_2 Package

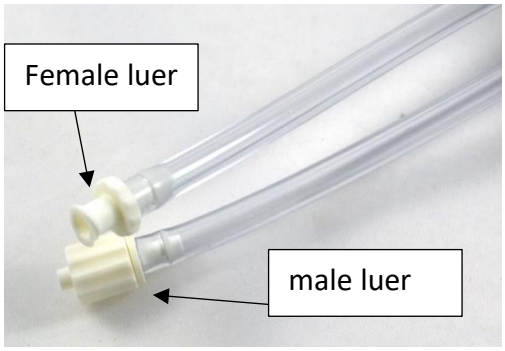
- **Q-teach 101** CO_2 Analyzer 0-2000ppm (drying and soda lime columns included)
- **Q-teach 201** Pump/Flow Monitor 1LPM
- **S161** RH/Temp Sensor
- **Q-A101** Lab Stand (holds the leaf chamber in place)
- **G112-t** Flow Through Leaf Chamber (9cm^2 area)
- **Q-teach Accessory Kit** (tubing, connectors, blue particulate filters x3, screwdriver, 3-way valves x2)
- **G122** Gas Bags (2 x 30L) x 3 for total of 6 bags
- **C610** LabQuest Mini (3 analog channels) x2 (total 6 channels)
- **C901** Logger Pro Software
- **C404** USB Disk with operation and laboratory experiments manuals plus Logger Pro **Q-teach Plant CO2 Setup** experimental file.

Q-teach 101 CO_2 Analyzer 2000ppm

The **Q-teach 101** CO_2 Analyzer is a non-dispersive infrared gas analyzer (IRGA). It has a "Gas In" port and a "Gas Out" port on the front of the analyzer. Two short piece of vinyl tubing with a luer-lock connector at one end are provided to connect the analyzer to the rest of the system. Please note that "Gas In" port should be connected with a female luer connector tubing and "Gas Out" port may be left with no tubing (as gas vents to atmosphere) or with male luer connector tubing.

The gas supplied to the IRGA passes through a sealed waveguide and vents from the "Gas Out" port. The analyzer has two column holders on either side for a drying column and a CO_2 scrubbing column. The columns should be placed in upright position when in use and may be placed inside these holders.





On the back of the **Q-teach 101** CO_2 Analyzer the user will find the BTA data cable for connection to the LabQuest Mini data interface (Mini 1: CH 1) and a power supply connection. A standard 12V power supply with a 120/220 AC power adaptor is included with the analyzer.

The gas entering the CO_2 analyzer "Gas In" port is delivered by the **Q-teach 201** Pump/Flow Monitor 1LPM. The maximum flow rate of gas into the CO_2 analyzer should not exceed 650 ml/min**.** Flow rates of about 50-150 ml/min for measurements of leaf photosynthesis are recommended, depending on the activity of the leaf. Leaves grown in high light and exposed to high light will be consuming more CO_2 than leaves grown in low light and exposed to low light. The flow rate should be adjusted accordingly to maintain a differential in CO_2 from reference levels around 20-50ppm. The flow rate at factory was set around 100ml/min.

Gases entering the **Q-teach 101** CO_2 Analyzer must be clean and dry, since particulate matter may absorb infrared light and cause erroneous readings. Water vapour will not interfere with the IR absorption measurement of CO_2, but water vapour will dilute the CO_2 concentration. The CO_2 analyzer is supplied with a short drying column containing blue DRIERITE. This drying agent removes moisture from the analysis gas before it enters the CO_2 analyzer. Wool plugs at the base and top of the column prevent particulate matter from leaving the column. The drying column should be attached to the CO_2 analyzer "Gas In" port via a blue tubular particulate filter (25µm). This filter will prevent any particulate matter from getting inside the analyzer. Three of these filters are included with the **Q-teach Accessory Kit**. Over time these filters may get plugged up with particulates, but they can be cleaned by washing them in water and blow drying them with compressed air.

The **Q-teach 101** CO_2 Analyzer requires a 15 to 30-minute warm-up period with air running through the analyzer. When used over a period of a few days or weeks it is recommended to keep the analyzer powered continuously (with the gas pump turned off) for better stability of the signal. When running a teaching laboratory session, it is recommended that the instructor or teaching assistant set up the analyzers <u>before</u> the session begins so that the analyzers are fully warmed up. Once the analyzer has warmed up it may be connected to the LabQuest Mini data interface (Mini 1: CH 1) for data collection.

The **Q-teach 101** CO_2 Analyzer has a linear response to changes in CO_2 levels. The linear response is delivered with the analyzer's factory calibration. No further calibration by the user is required. Calibration constants have been entered in the experimental setup file (**Q-teach Plant CO2 Setup**) and the voltage reading is converted into ppm of CO_2 in Logger Pro software. However, before the start of an experiment, it is recommended to check the zero CO_2 reading and adjust if required. This is done by connecting the CO_2 scrubbing column (long white column filled with soda lime) to the "Gas In" port on the analyzer (maintaining the drying column and the blue filter connection as described above). The soda lime will be attached before the drying column in-line to the analyzer as per the diagram below. Note that the blue lines represent gas connections and

black lines represent data cable connections. The black arrows represent the direction of gas flow.

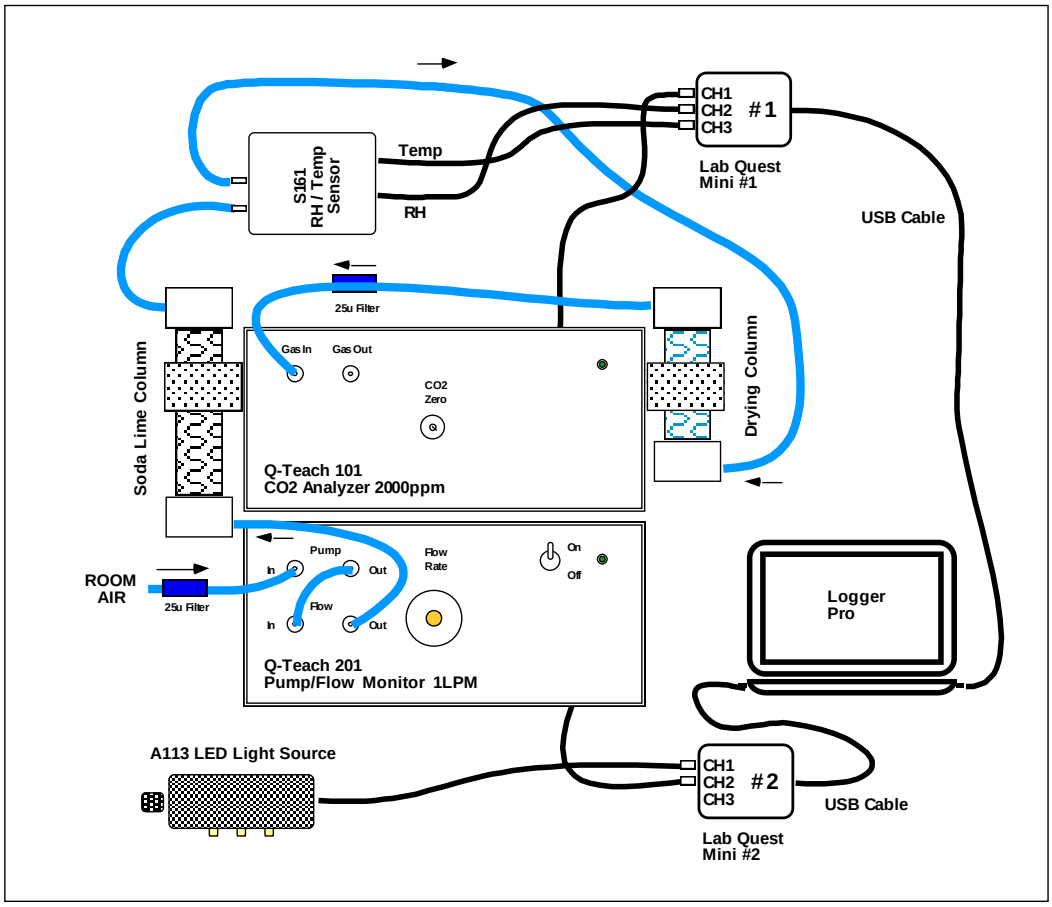
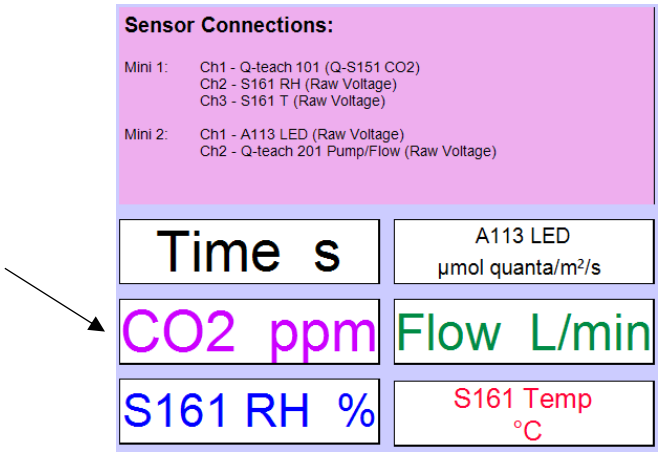


Figure 1: Setup of Q-teach Plant CO_2 Package for zero CO2 check

Soda lime will scrub CO_2 from the air delivered to the analyzer and a reading of zero CO_2 should be observed in the CO_2 meter of the experimental file (page 1, Raw data, bottom left-hand side).



To open the Logger Pro software and visualize the CO_2 readings it is necessary to follow the instructions below on how to load the software, connect the sensors and use the experimental setup file (pg. 15).

When the CO_2 reading in Logger Pro (CO_2 meter on page 1 of the experimental file) stabilizes but is not zero, the user can adjust the "CO_2 Zero" screw on the front panel of the analyzer using the small flat screwdriver provided with the Q-teach Accessory Kit. Turning the screw clockwise will increase the reading and turning it anticlockwise will reduce the reading. Once the zero CO_2 has been set, the user can start an experiment. It is recommended to check the zero CO_2 level at the beginning of each experiment and at the end. The **Q-teach 101** CO_2 Analyzer is sensitive to big temperature and pressure changes; therefore, we recommend using it in a temperature-controlled laboratory. Remove the soda lime scrubbing column before starting the experiments unless background air needs to be CO_2 free.

Soda Lime and Drying Columns

The **Q-teach 101** CO_2 Analyzer is designed to analyze dry gas samples and has been calibrated in factory with dry gases. A short drying column filled with DRIERITE is provided to dry the gas before analysis. The column has a wool plug at both ends to prevent particulates from being carried through the system. The column is supplied ready for use and should be mounted **vertically** on the side of the CO_2 analyzer with the in-port (female luer) at the bottom and out-port (male luer) at the top.

DRIERITE contains an indicator that is blue when the column is functional and pink when the DRIERITE is saturated with absorbed water vapour. When spent (pink), the DRIERITE should be replaced or reconditioned. To **recondition**, remove the **DRIERITE** from the column and place it in a drying oven at **210 ˚C for 1 hour**, or until the blue coloration reappears. Note that it will be paler blue color after regeneration. The replacement DRIERITE is #8 mesh, order #23005 from DRIERITE.com.

The soda lime column is used to scrub CO_2 from air. It is the long column filled with white soda lime. A small amount of wool is placed at each end of the column to prevent particulates from getting into the gas stream. The soda lime column should be used in a **vertical** position to ensure the gas has maximal contact with the crystals when flowing through the column**.** This is achieved by placing the column in one of the holders on the side of the **Q-teach 101** CO_2 Analyzer. Again, the in-port (female luer) should be at the bottom and out-port (male luer) should be at the top.

The soda lime provided with the CO_2 analyzer has a coloured indicator to show when it is saturated with absorbed CO_2. The soda lime should be replaced when most of it has changed from its original white colour to a pale purple. This colour change is subtle, and the purple coloration often does not persist, but appears as a band in the column at the junction between active and inactive soda lime. Replacement supplies may be obtained from Fisher Scientific (product #S200I-3) or other chemical supply company.

Warning: Soda lime can cause burns and should be handled with gloves. Users should read and comply with the Material Safety Data Sheet supplied with the soda lime.

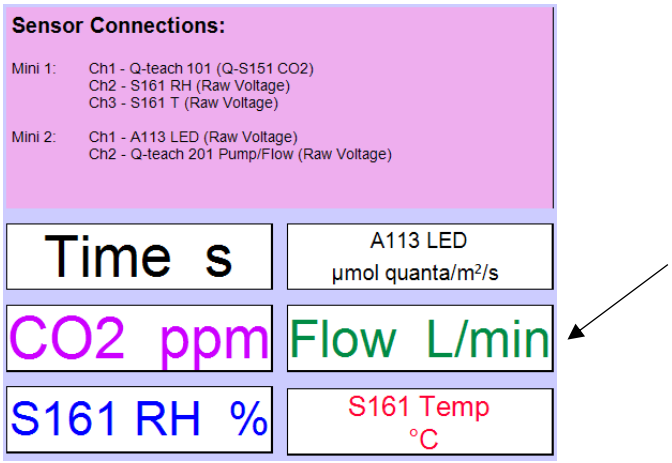
Q-teach 201 Pump/Flow Monitor 1LPM

The Q-teach Plant CO_2 Package comes with the **Q-teach 201**, which is a gas pump and flow monitor combination. The gas pump can generate flow rates of up to 1LPM and the mass flow monitor can measure flow rate as voltage changes. The voltage output from the flow monitor is delivered via the data cable on the back of the unit with a BTA connector to the LabQuest Mini data interface (Mini 2: CH 2) and is read in Logger Pro software. The voltage output is linear, and the flow monitor has been calibrated in factory. No further calibration is required. Calibration coefficients used to convert voltage into flow rate (L/min) are incorporated in the experimental Setup file (**Q-teach Plant CO2 Setup**) provided. To use the **Q-teach 201**, ensure that the power supply provided with the device is plugged in and the power switch on the front of the unit is in the "On" position.

The **Q-teach 201** Pump/Flow Monitor has one set of "In" and "Out" ports associated with the gas pump (top) and a second set associated with the flow monitor (bottom). Four pieces of tubing with luer connectors are delivered with the unit. It is important to connect the tubing with female luer connector to the "Gas In" ports and the male luer connector tubing to the "Gas Out" ports. The gas from the source (gas bag) should be connected to the Pump "In" port via a blue tubular particulate filter (to keep the gas entering the system free of debris). The Pump "Out" port is connected with the Flow "In" port. The Flow "Out" port delivers the gas either directly to the **S161** RH/temp sensor first and **Q-teach 101** CO_2 Analyzer second (during reference gas measurement). During the analysis measurements the gas is first delivered to the leaf chamber, and the output from the leaf chamber is carried to the **S161** RH/Temp sensor first and CO_2 analyzer next. This is achieved by changing the 3-way valve settings as described below on pg. 14. The flow rate of the **Q-teach 201** Pump/Flow Monitor is controlled by the needle valve on the front of the instrument.

The flow rate of the **Q-teach 201** Pump/Flow Monitor has been set in factory to around 100 ml/min. Flow rate may need to be adjusted depending on how active the leaf is. If the leaf has been grown in bright light, or is light-adapted, and higher rates of CO_2 consumption are observed, then higher flow rates of gas through the chamber will be required. If the leaf has been grown in low light, or is not light-adapted, and lower rates of CO_2 consumption are observed, then lower flow rates may be required to increase the sensitivity of the system.

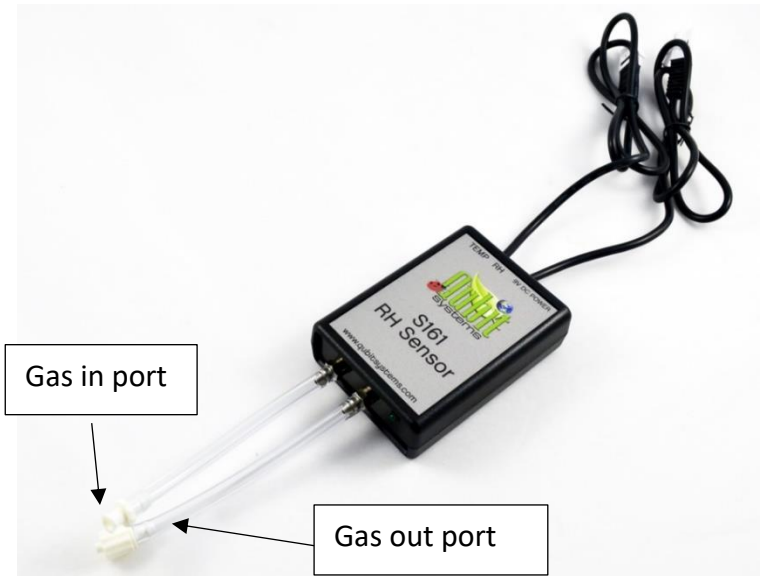
Increasing the flow rate will reduce the CO_2 signal and decreasing the flow rate will increase the signal size and sensitivity. Before changing the flow rate ensure that the **Q-teach 201** is connected to the LabQuest Mini data interface, is recognized by the Logger Pro software, and the experimental file (**Q-teach Plant CO2 Setup**) is open (see pg. 16 for instructions on setting up Logger Pro and C404 disk files). This file is found on the C404 disk supplied with the package. Flow rate may be observed in the meter labelled "Flow" on page 1 of the experimental setup file as shown below:



To increase the flow rate of gas, turn the needle valve *anticlockwise* and to decrease the flow, turn it clockwise.

S161 RH/Temp Sensor

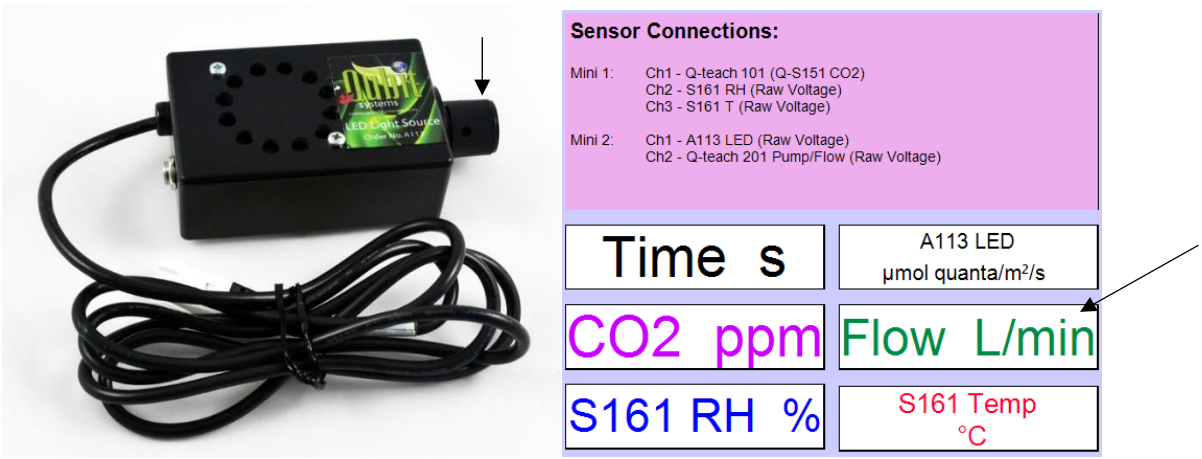
The **S161** RH/Temp Sensor included with this package is a flow-through sensor that measures relative humidity (RH) and temperature of the gas flowing past the RH sensor at the temperature of the RH sensor. The temperature measurement is needed for the calculation of water vapour concentrations and subsequently transpiration rate. The RH sensor is a thermoset polymer-based capacitive sensor with a fast response, high linearity, and excellent long-term stability. It measures RH in 0-100% range with ± 2% accuracy. The temperature sensor is the NTC thermistor chip that measures temperature of the gas at the sensor in the range of 3-70°C with 0.2°C accuracy. Two analog outputs of 0-5V for both RH and temperature sensors are provided with the **S161**. These should be plugged into the LabQuest Mini data acquisition interface as outlined in the Logger Pro setup file sensor connection window (RH in Mini 1: CH 2, Temp in Mini 1: CH 3). Both the RH and temperature sensors are factory calibrated and no further calibration is necessary. The RH and temperature data are both displayed in Logger Pro in the meters on page 1 (Raw Data). When data collection is started, both S161 RH and S161 Temp are also populated in the table and graphs on page 1.



A113 LED Light Source

This package includes a warm white LED light source that is composed of 9 LEDs. This light source should be placed directly on top of the leaf chamber and attached via the Velcro straps provided. The **A113** LED Light Source is calibrated in Logger Pro for use with the **G112-t** Flow Through Leaf Chamber only and should be connected via the BTA data cable to LabQuest Mini 2: CH 1. The irradiance of the **A113** can be set between 0 and 2000 μmol quanta/m^2/sec by monitoring the

A113 meter in Logger Pro on page 1 while setting the dial on the side of the **A113** LED Light Source.

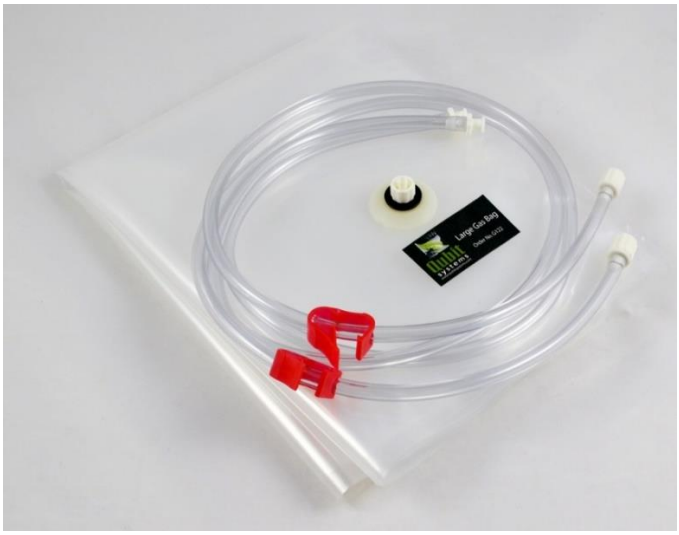


Ensure that the power cable of the A113 LED light source is connected and plugged in to AC outlet before use.

G122 Gas Bags

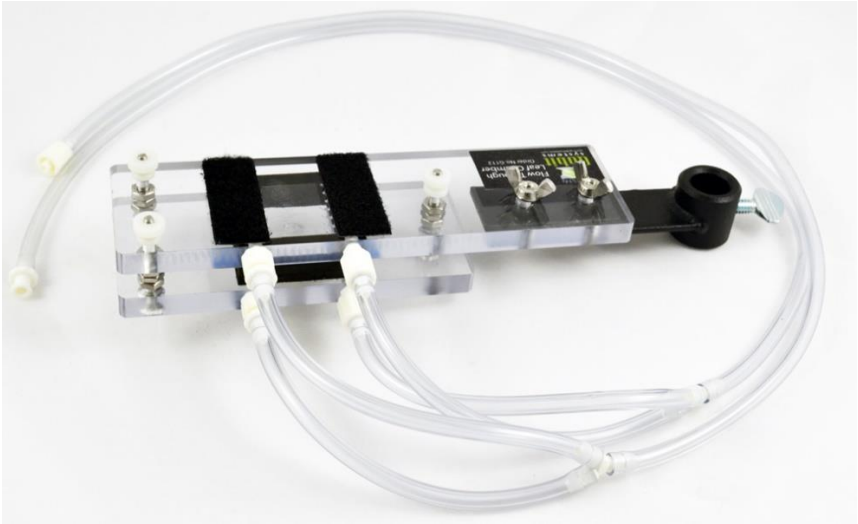
This package is delivered with 3 sets of **G122** Gas Bags (30 L x2) for a total of 6 gas bags. These are heat-sealed gas bags. They are made from a gas-impermeable nylon-polyethylene laminate. Vinyl tubing with a locking valve is attached to each bag by a luer-lock fitting. The fitting on the other end of the tubing attaches directly to the fittings on the **Q-teach 201** Pump Gas "In" port. The gas bags can be filled with air from a compressor (or another gas mixture from a commercial tank and prepared by the instructor) to provide a **constant source of CO_2**. When measuring photosynthesis or respiration activity from a leaf, it is crucial that the background level of CO_2 (reference) is constant. This is achieved by using gas bags to deliver background gas to the leaf. Outside air has a constant level of CO_2 (close to 400 ppm) and may be used directly with a long piece of tubing connected to the Pump "In" port and the other end hanging out a window. If this is not possible then gas bags should be filled with outside air and used as the background gas in experiments. **Inside air in the lab can vary several hundred ppm in CO_2 due to human activity and should not be used in experiments directly unless higher CO_2 levels are required for the experiments.**

To fill the gas bag with air, connect the Pump "Out" port from the **Q-teach 201** Pump to the bag inlet. The gas pump will pump air into the bag at about 1LPM so a 30L gas bag will take about 30 min to fill. Bags may also be filed with compressed air from a compressor or a gas tank if available. Ensure that the flow of gas into the bag from a compressed source is reduced to avoid bursting of the bag. Bags should not be overinflated, as this can cause weakening of the seams and eventual leakage. After use, the bags should be fully deflated, preferably by attachment to a vacuum-line or to the Pump gas "In" port.



G112-t Flow Through Leaf Chamber

The Q-teach Plant CO_2 Package includes **G112-t** Flow Through Leaf Chamber with removable pieces of vinyl tubing with luer connectors at either end. The male connectors are used on the gas out ports and the female connectors are used on the gas in ports. There are two connectors in the upper half of the leaf chamber and two in the bottom half. Gas is delivered to the chamber from both upper and lower halves of the leaf chamber and is distributed evenly via the manifold holes inside the chamber. The two halves of the leaf chamber are held together with easily removable thumb screws. The thumb screws can be loosened to separate the two halves of the chamber, and the leaf may be placed inside. The thumb screws should be tightened when the leaf is in the chamber to create a good seal around the leaf.



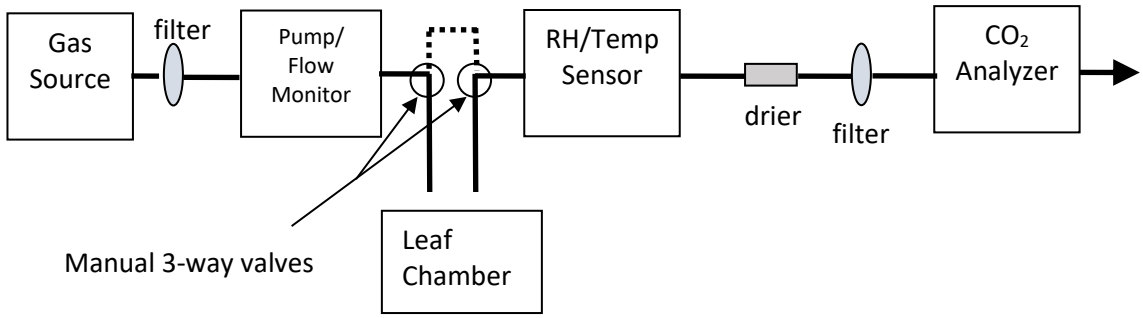
Two Velcro strips are attached to the top of the leaf chamber, this is where the **A113** LED Light Source attaches for illumination of the leaf (see images below).

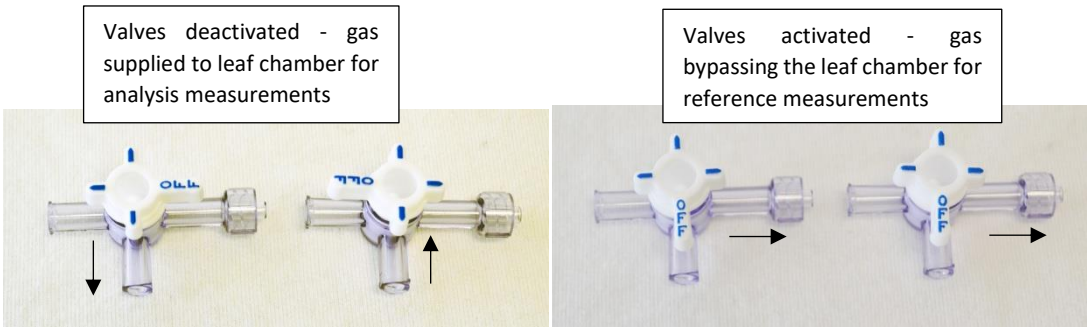
Q-A101 Lab Stand

The Q-teach Plant CO_2 Package includes the **Q-A101** Lab Stand that should be assembled by connecting the two pieces of the rod with the base. The stand is used to hold the leaf chamber and the LED light source in place.

3-way Valves

The Q-teach Plant CO_2 Package includes two 3-way valves in the accessory kit. They provide a manual way of obtaining reference measurements of RH and CO_2 during a bypass of the leaf chamber. One of these valves should be placed between the **Q-teach 201** Pump/Flow Monitor and the gas line going into the leaf chamber. The other valve should be placed between the gas line coming out of the chamber and into the **S161** RH/Temp Sensor as per diagram below.





When these are in deactivated position the gas will flow through the leaf chamber. When the valves are in activated position the gas will bypass the leaf chamber for the reference measurements.

LabQuest Mini Interfaces

The Q-teach Plant CO_2 Package comes with two LabQuest Mini data interfaces. These interfaces have 3 analog and 2 digital channels each, for a total of 6 analog channels. The interfaces are connected to the computer (PC or Mac) by USB cables. The USB cable is used to transfer data to the software and to power the LabQuest Mini**.** The interface converts the analog voltages (12-bit A to D) from the sensor to digital signals which are transmitted to the computer via USB and processed by the Logger Pro software. The digital channels can be used and programmed in Logger Pro with a Digital Control Unit (not part of this package), for instrument control based on input data crossing a threshold. This package only uses the analog channels. The complete guide to the use of LabQuest Mini is included with the package on the C404 disk. This manual only provides a general outline of the use and capabilities of LabQuest Mini data interface within the scope of this package. The 3 analog channels on the two LabQuest Minis are used to connect the sensors of this package as outlined in the sensor connection window on page 1 of the experimental file and shown below.

.

Sensor Connections:

Mini 1:	Ch1 - Q-teach 101 (Q-S151 CO2) Ch2 - S161 RH (Raw Voltage) Ch3 - S161 T (Raw Voltage)
Mini 2:	Ch1 - A113 LED (Raw Voltage) Ch2 - Q-teach 201 Pump/Flow (Raw Voltage)

All the sensors in this package must be selected manually in Logger Pro for connection in the software as described below on pg. 19.

Logger Pro 3 Installation

Logger Pro software is delivered with the package on a CD and requires a CD drive to load onto a computer. If a CD drive is not available, please contact Qubit Systems for an alternative solution. This software can run on both PC and Mac computers and the licence allows use on as many computers per institution as required. Therefore, all students that are using this package may obtain copies of the software on their personal computers. Free updates of this software are regularly released and may be accessed directly from the manufacturer website at the following link:

https://www.vernier.com/downloads/logger-pro-updates/

PC Users:

(1) To use this package, a complete copy of Logger Pro 3 must be installed on the computer. Before starting the installation, make sure all USB cables are disconnected from the computer. Failure to do so may cause an error in the installation of the USB drivers.

(2) Run the installation and do not change the default destination directory. Logger Pro 3 will be installed in C:/Program Files/Vernier Software/Logger Pro 3.

(3) The setup process will automatically load the USB drivers for connecting the LabQuest Mini to the computer.

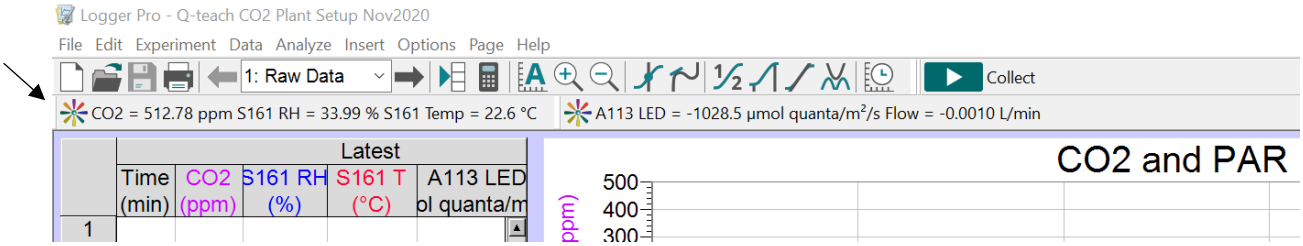
(4) If QuickTime 6 (or greater) is not installed on the computer, install it when prompted. QuickTime will allow use of the picture and movie features of Logger Pro 3.

(5) You will be prompted to connect the LabQuest Mini or other interfaces to the computer via the USB connection.

(6) Click 'Finish' to complete the installation process.

(7) Proceed to C404 disk installation (below) before opening the Logger Pro.

(8) Double click the "**Q-teach Plant CO2 Setup**" file (create a shortcut on the desktop once moved from the C404 disk for easy access) to start Logger Pro and data collection. When Logger Pro detects the LabQuest Mini interface, the Logger Pro screen will appear with a star icon in the top left corner.



(9) If Logger Pro cannot detect the LabQuest Mini interfaces, a message will appear reading, "no device connected". Check that the LabQuest Minis are attached to the computer directly via USB cable. The LED power lights on the Minis should be green. No LED light indicates that power is not supplied to the Mini – check the USB cable connection as the power is supplied via this cable directly from the computer. A red LED indicates that power is on but there is no communication between the interface and the software. In this case, exit the experimental file and disconnect the USB cables from the computer. Reconnect the USB cable and reopen the "**Q-teach Plant CO2 Setup**" file. You may try different USB port in case the problem is with the computer.

C404 Custom Setup Files Installation

Qubit Systems' C404 Custom Setup Files disk contains experimental Setup file built in Logger Pro software (designed by Qubit Systems) for this package (**Q-teach Plant CO2 Setup**). The C404 disk also contains the operational manual and laboratory experiments manual for this package. Also included is the manual for the LabQuest Mini data interface. These files can be copied to user specified location on a computer and the experimental setup file should be placed in an accessible location or have a shortcut created on the desktop to the file. We highly recommend that the user to make a copy of the original file and keep it in a safe place on the computer in case the original is accidentally altered.

Quick Start-up

1. Read the operational manual of this package ("**Q-teach Plant CO2 Package Operation Manual**" PDF file on the C404 USB disk) to become familiar with all the components before setting it up.

2. Load Logger Pro software onto the computer (follow instructions on pg. 16).

3. Copy the experimental setup file "**Q-teach Plant CO2 Setup**" and the manuals from the C404 disk to the computer.

4. Set up all the components of the package as shown in the diagram below and connect the sensors to the correct analog channels on the two LabQuest Mini as indicated by the window below:

Sensor Connections:

Mini 1: Ch1 - Q-teach 101 (Q-S151 CO2)
Ch2 - S161 RH (Raw Voltage)
Ch3 - S161 T (Raw Voltage)

Mini 2: Ch1 - A113 LED (Raw Voltage)
Ch2 - Q-teach 201 Pump/Flow (Raw Voltage)

Please note that the gas bag and the leaf chamber do not need to be connected to the system while the system is warming up.

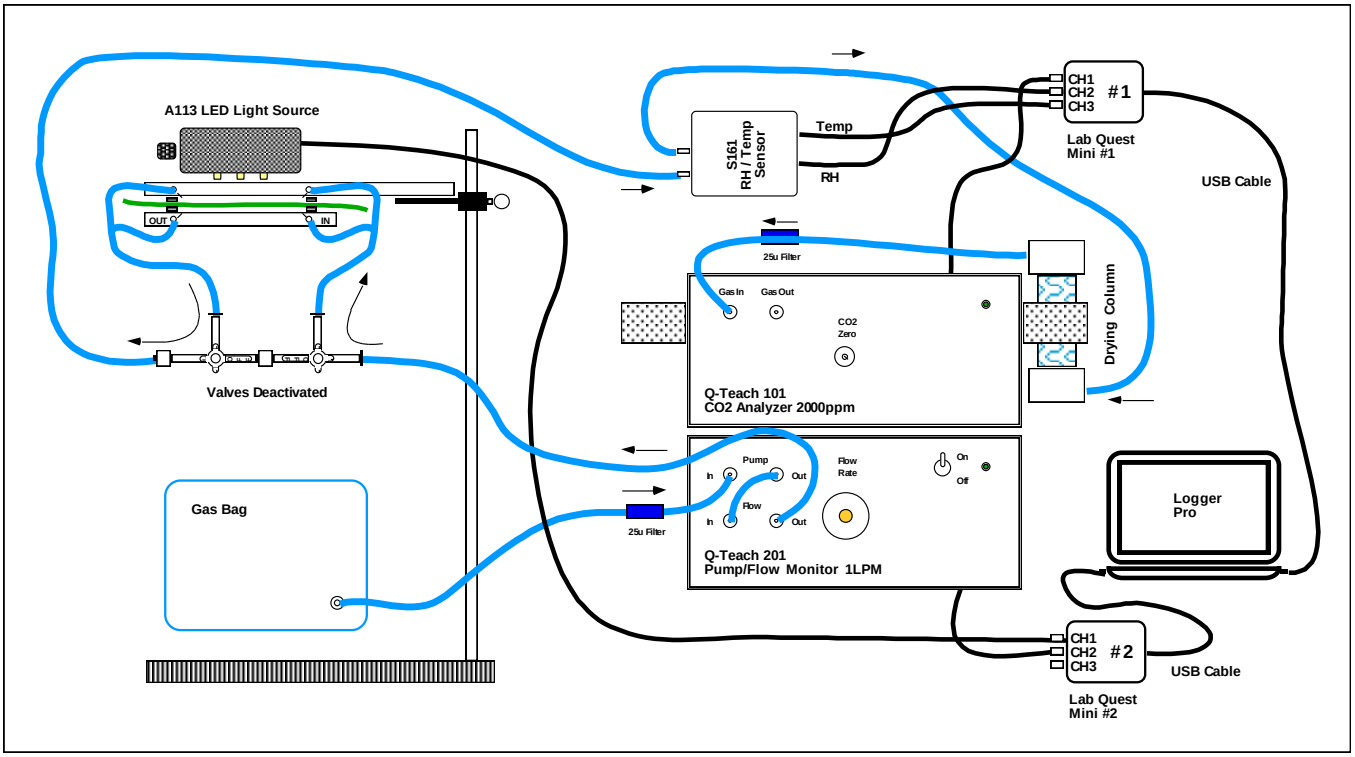
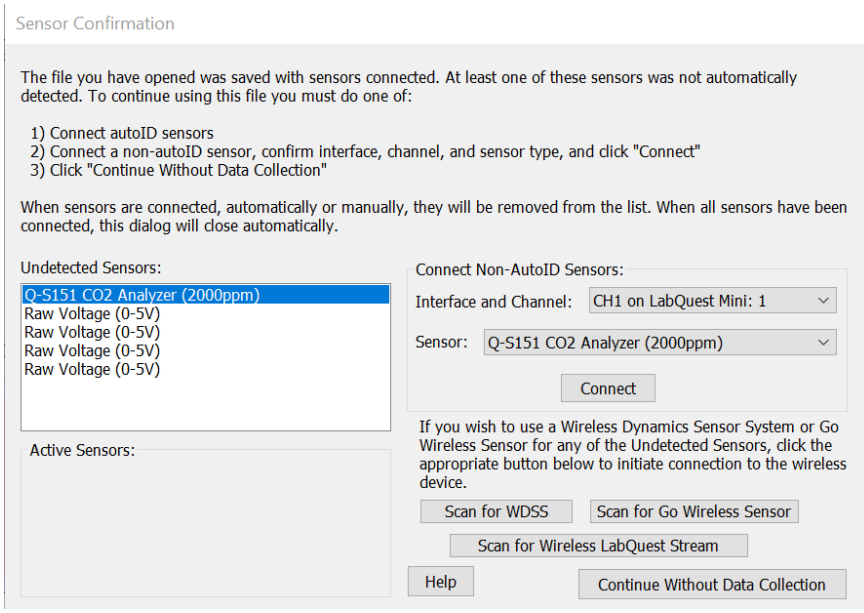


Figure 2: Q-teach Plant CO_2 Package experiment setup

5. Provide power to and turn on the **Q-teach 101** CO_2 Analyzer and the **Q-teach 201** Pump/Flow Monitor. Allow the CO_2 analyzer to warm up for at least 15-20 min while running room air through the system.

6. Open the "**Q-teach Plant CO2 Setup**" file. The following screen will appear:

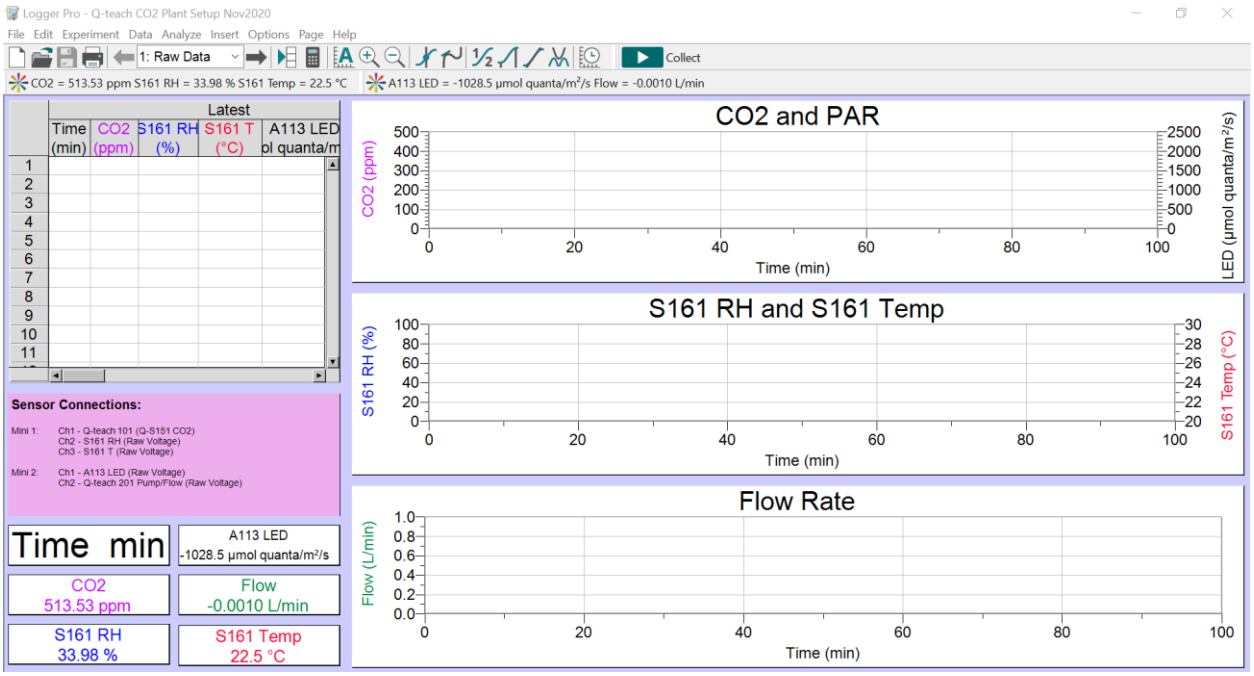


7. Connect the sensors as follows:

   a. If the list of available sensors reads as the following, make the following assignments in this **exact** order:
      i. **Q-S151 CO2 Analyzer** > CH1 on LabQuest Mini: 1
      ii. Raw Voltage (0-5V) > CH2 on LabQuest Mini: 1
      iii. Raw Voltage (0-5V) > CH3 on LabQuest Mini: 1
      iv. Raw Voltage (0-5V) > CH1 on LabQuest Mini: 2
      v. Raw Voltage (0-5V) > CH2 on LabQuest Mini: 2
   b. However, if the sensor list appears as the following, make the below assignments in this **exact** order:
      i. Raw Voltage (0-5V) > CH1 on LabQuest Mini :2
      ii. Raw Voltage (0-5V) > CH2 on LabQuest Mini: 2
      iii. **Q-S151 CO2 Analyzer** > CH1 on LabQuest Mini: 1
      iv. Raw Voltage (0-5V) > CH2 on LabQuest Mini: 1
      v. Raw Voltage (0-5V) > CH3 on LabQuest Mini: 1

8. The following screen will be shown in the software once the sensors are connected. This is page 1 of the software where all the raw data will be displayed:

The sensor data will be shown in the top menu and in the meters at the bottom of the page. to start data collection click green button "Collect" . The table and graphs will also populate with the logged data.



9. While the CO_2 analyzer is warming up, the flow rate through the system should be set up as described above on pg. 9 by turning the valve on the **Q-teach 201** Pump/Flow Monitor clockwise to reduce the flow rate and *anticlockwise* to increase the flow rate through the system. The default flow rate is set at factory around 100 ml/min.

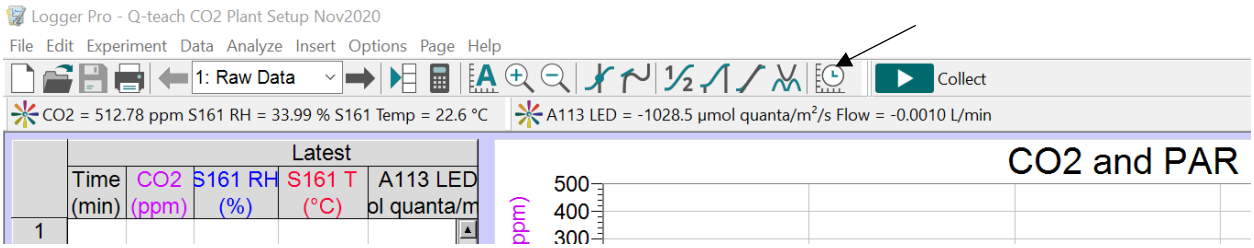
10. After the CO_2 analyzer has warmed up and the flow rate has been set, check the zero by connecting the soda lime column (long white column) to the Flow "Out" port of the **Q-teach 201** Pump/Flow Monitor and the other end to the S161 RH/Temp sensor (as shown on Figure 1 on pg. 7). This will deliver the scrubbed room air to the CO_2 analyzer after it passes through the **S161** sensor. Observe the CO_2 signal in the software drop to zero. When the reading stabilizes, if it is not at zero adjust the "CO_2 Zero" screw on the analyzer with the screwdriver provided in the kit as described above in the manual on pg. 7). Briefly turn the "CO_2 Zero" screw clockwise to increase the reading and anticlockwise to reduce the reading.

11. Once CO_2 zero has been established and adjusted, disconnect the soda lime from the system and connect the gas bag filled with outside air to the Pump "In" port on the **Q-teach 201** and observe the CO_2 signal in the software rise to approximately 400ppm. Once this signal stabilizes the system is ready to use for experiments.

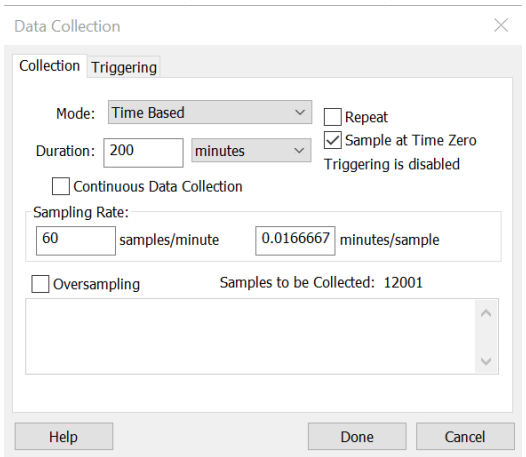
12. Always measure background levels of CO_2 (reference, or incurrent CO_2) for few minutes before starting measurements with the leaf and again when the experiment is finished. The

reference measurements will be used in calculations of assimilation rate and/or respiration rate later on.

13. Before starting data collection in each experiment, select the time icon to set up experiment duration and data collection frequency.



14. The following window will appear. Input experiment length and data sampling rate as required. The default is 60 samples/min or 1 sample/sec.



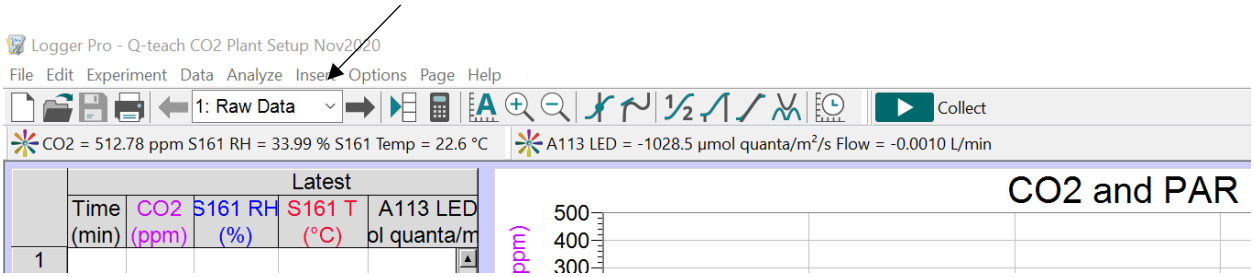
15. To start data collection, click the “Collect” green button in the top menu. To stop data collection, click the red “Stop” button (collect button will turn red during data collection).

16. Once the data has been collected, the experimental file should be saved under a new name by selecting **File>Save As** from the top menu or clicking on the disk icon.

17. Save the experimental file under a new name following each experiment so the original setup file is not accidently overridden.

18. Saved data may be analyzed later with the various analysis tools available in Logger Pro or it may be exported into a spreadsheet program by selecting **File>Export As>CSV**.

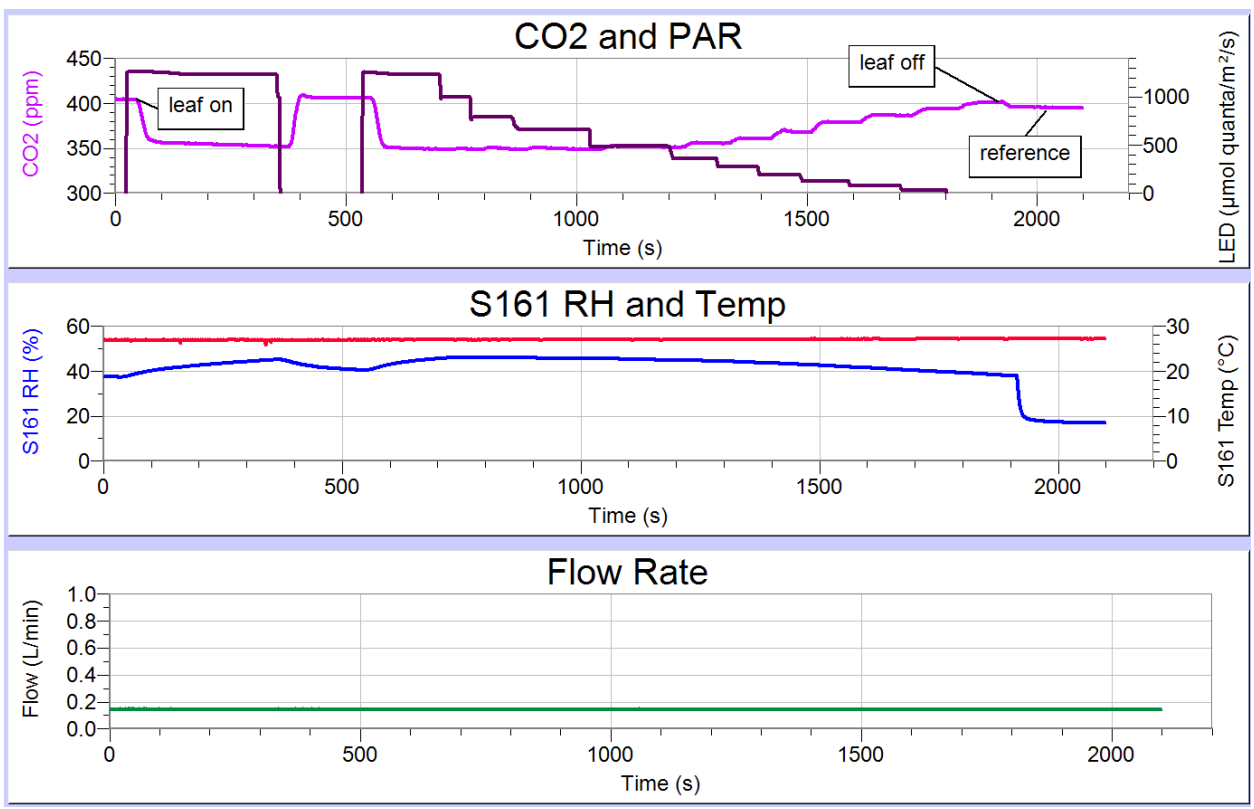
19. Calculations of the assimilation rates from the collected data are described below and may be done on page 2 and 3 of the setup file. Page number may be selected in the top menu.



20. To proceed with specific laboratory experiments please refer to the **Laboratory Experiments for Plant CO_2 Package** Manual included on the C404 disk.

Calculations of photosynthesis or respiration rate

All the raw data collected in Logger Pro is shown on page 1 of the "**Q-teach Plant CO2 Setup**" file. Data is displayed in the table and graphs. The print screen below shows an example of the graph with raw data obtained with a Zinia leaf at ambient levels of CO_2. Photosynthetically Active Radiation (PAR) levels were changed by changing the **A113** LED Light Source irradiance.



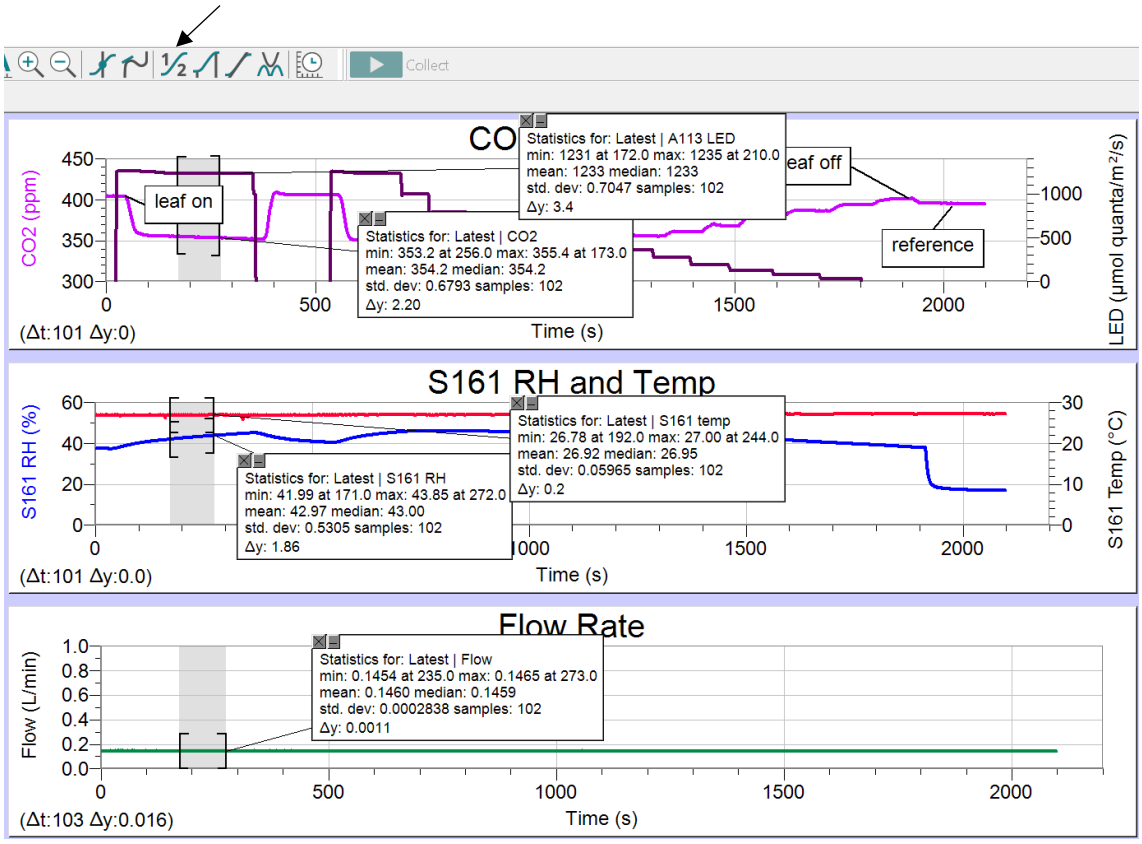
To calculate the rates of photosynthesis and transpiration at different light levels, average CO_2 and RH levels from raw data must be obtained and entered on page 2 in the experimental setup file. All the calculations of assimilation and transpiration rates at specific times during the

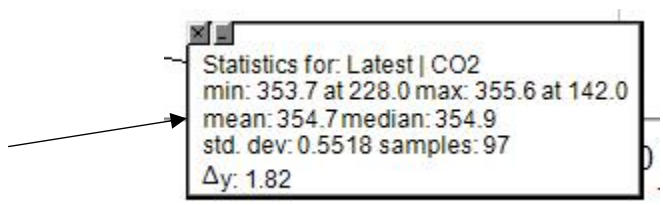
experiment are done on either page 2 (calculations at different PAR levels) or page 3 (calculations at different CO_2 levels).

It is important to understand how to run a successful experiment, so all the parameters required for the calculations are recorded. Initially, the reference levels of CO_2 and RH need to be recorded before the leaf inside the chamber is connected to the system. Two 3-way valves are provided in the accessory kit so switching between the reference measurements and sample measurements is easy and quick (see pg. 14 for instructions on how to use the valves). Once stable reference readings are obtained, the leaf chamber is connected to the system (via a change in 3-way valve position).

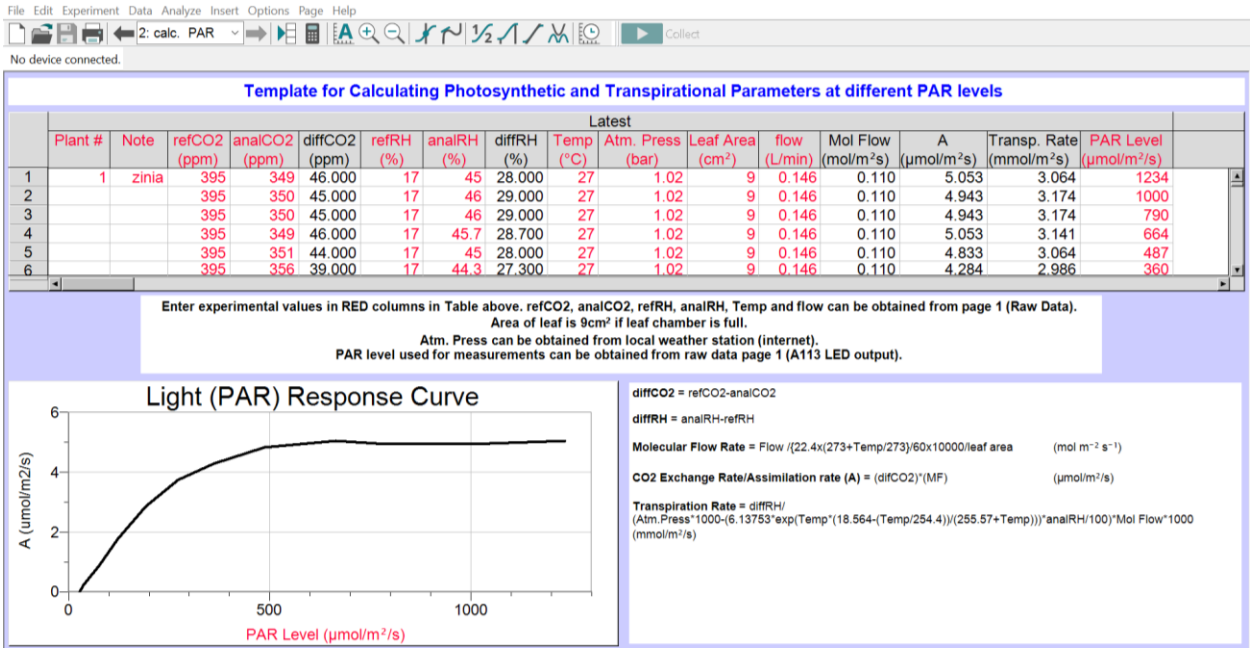
When the LED light is turned on and photosynthesis is activated, the CO_2 readings will decrease (as CO_2 is fixed in the light during photosynthesis) and RH readings will increase (due to water vapour release during transpiration). These are the "analysis" readings for CO_2 and RH. The user can then modify the light conditions and watch how the CO_2 and RH readings are affected. Reference levels of CO2 and RH should be checked again at the end of the experiment to ensure no drift in the signal occurred. Mean "reference" (at the beginning of the run) and mean "analysis" CO_2 and RH during a specific portion of the experiment can then be determined from the raw data as shown below. These mean values are then manually entered in the calculation pages (page 2 and 3).

The mean raw data is obtained by first clicking to highlight all the graphs (hold shift key and click on each graph) and then dragging the mouse over the data to select it (see print screen below). Various analysis icons may then be selected from the top menu to obtain the data required. In this case, selecting the “Statistics” icon in the top menu will result in popup windows with all the statistics for the selected data including the mean values that need to be manually entered on calculation pages 2 and 3 .





The mean values of refCO2, analCO2, refRH, analRH, Flow, and Temperature need to be manually entered on calculation pages 2 or 3 of the setup file in the red columns. The atmospheric pressure in units of bar can be obtained from an external pressure sensor or from a local weather station (i.e. internet). The leaf area, if the whole leaf chamber is filled, will be 9 cm^2. Leaf area also needs to be entered in the calculation table. If the leaf does not fill the chamber, then the area must be determined manually (placing the leaf on the graph paper and counting the squares covered by the leaf is one option). The assimilation rate and transpiration rates will automatically be calculated in the black columns when measurements are done at different light intensities and the values of PAR levels are entered in the red column of the table on page 2 of the experimental file. The light response graph will also be automatically populated and displayed with the calculated data as shown below:



File Edit Experiment Data Analyze Insert Options Page Help

2: calc. PAR

No device connected.

Template for Calculating Photosynthetic and Transpirational Parameters at different PAR levels

	Latest															
	Plant #	Note	refCO2 (ppm)	analCO2 (ppm)	diffCO2 (ppm)	refRH (%)	analRH (%)	diffRH (%)	Temp (°C)	Atm. Press (bar)	Leaf Area (cm²)	flow (L/min)	Mol Flow (mol/m²s)	A (µmol/m²s)	Transp. Rate (mmol/m²s)	PAR Level (µmol/m²/s)
1	1	zinia	395	349	46.000	17	45	28.000	27	1.02	9	0.146	0.110	5.053	3.064	1234
2			395	350	45.000	17	46	29.000	27	1.02	9	0.146	0.110	4.943	3.174	1000
3			395	350	45.000	17	46	29.000	27	1.02	9	0.146	0.110	4.943	3.174	790
4			395	349	46.000	17	45.7	28.700	27	1.02	9	0.146	0.110	5.053	3.141	664
5			395	351	44.000	17	45	28.000	27	1.02	9	0.146	0.110	4.833	3.064	487
6			395	356	39.000	17	44.3	27.300	27	1.02	9	0.146	0.110	4.284	2.986	360

Enter experimental values in RED columns in Table above. refCO2, analCO2, refRH, analRH, Temp and flow can be obtained from page 1 (Raw Data).
Area of leaf is 9cm² if leaf chamber is full.
Atm. Press can be obtained from local weather station (internet).
PAR level used for measurements can be obtained from raw data page 1 (A113 LED output).

diffCO2 = refCO2-analCO2

diffRH = analRH-refRH

Molecular Flow Rate = Flow /(22.4x(273+Temp/273)/60x10000/leaf area (mol m⁻² s⁻¹)

CO2 Exchange Rate/Assimilation rate (A) = (difCO2)*(MF) (µmol/m²/s)

Transpiration Rate = diffRH/(Atm.Press*1000-(6.13753*exp(Temp*(18.564-(Temp/254.4))/(255.57+Temp)))*analRH/100)*Mol Flow*1000 (mmol/m²/s)

The formulas used in the calculations of CO_2 exchange rate/assimilation rate and transpiration rate are explained in a text box on page 2 of the experimental file (shown above). These calculations are also explained further below.

Measurements of photosynthetic, photorespiratory, and respiratory rates in leaves are usually expressed as rates of CO_2 exchange per unit time per unit leaf area. The units most commonly used are µmol $CO_2/m^2/s$. To express data in these units, the following calculations were used:

1. The difference between the CO_2 concentration in the reference and analysis gases (leaf chamber input CO_2 minus leaf chamber output CO_2) is calculated as **diffCO2**. For example, if an experiment was conducted in air at an input of 400 ppm CO_2, at a flow rate of 200 ml/min, the depletion of CO_2 due to leaf uptake in photosynthesis at bright light may result in a concentration of 360 ppm in analysis CO_2 gas. In this case, the difference between the reference and sample gas streams ($diffCO_2 = refCO_2 - analCO_2$) would be 40 ppm.

2. The differential CO_2 value is converted from ppm (µl/L) into µmol CO_2/L knowing that 1 mole of gas at STP occupies 22.415L. The pressure correction is only necessary if measurements are done at pressures significantly different from1 atm. Temperature correction should be applied since measurements are not done at 0°C (273K):

$$\boxed{\frac{\Delta CO_2}{22.415 \times \left(\frac{T + C}{T}\right)}}$$

- Where C is the temperature in °C and T is the absolute temperature (273 K)

- At a temperature of 20°C, and a differential CO_2 of 40 ppm, the differential CO_2 would be equivalent to 1.66 µmol CO_2/L.

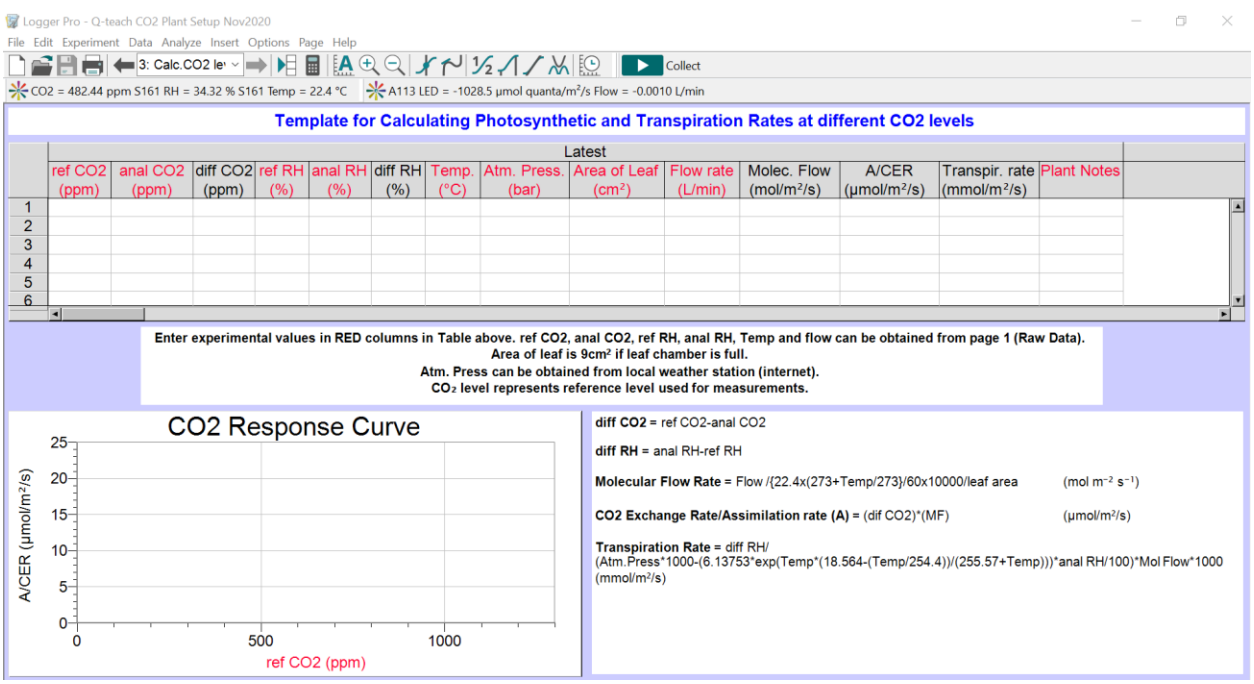
3. The differential CO_2 value is then multiplied by the flow rate (in L/s) used in the experiment to obtain a CO_2 exchange rate per second. A flow rate of 200 ml/min is equivalent to 0.0033 L/s, so the CO_2 exchange rate would be 0.0055 µmol CO_2/s.

4. The CO_2 exchange rate/assimilation rate is expressed on a leaf area basis by dividing the CO_2 exchange rate by the leaf area in m^2. If the leaf completely fills the **G112-t** Flow Through Leaf Chamber, the area used in the calculation would be 9 cm^2 = 0.0009 m^2. The photosynthetic rate would therefore be 6.1 µmol $CO_2/m^2/s$.

The transpiration rate is calculated from the differential in water vapor concentrations that are determined from differential in relative humidity (RH) taking the temperature and atmospheric pressure into account. The following formula is used for this calculation:

diffRH/(Atm.Press*1000-(6.13753*exp(Temp*(18.564Temp/254.4))/(255.57+Temp)))*analRH/100)*Mol Flow*1000

The experimental file for this package has two calculation pages. Page 2 provides calculations of Assimilation/Carbon exchange rate at different levels of PAR and page 3 provides the same calculations at different levels of CO_2. The mean refCO2, analCO2, refRH, analRH, Flow rate, Temp, leaf area and Atm. Pressure must be entered from the raw data obtained on page 1 as described above. The black columns will populate with calculated data and the CO_2 response curve graph will automatically be graphed. The print screen of page 3 is shown below.



Qubit Systems Warranty Information

QUBIT warrants all its instruments to be free from defects in materials or workmanship for a period of **one year** from the date of invoice/shipment from QUBIT.

If at any time within this warranty period the instrument does not function as warranted, return it and QUBIT will repair or replace it at no charge. The customer is responsible for shipping and insurance charges (for the full product value) to QUBIT. QUBIT is responsible for shipping and insurance on return of the instrument to the customer.

No warranty will apply to any instrument that has been (i) modified, altered, or repaired by persons unauthorized by QUBIT; (ii) subjected to misuse, negligence, or accident; (iii) connected, installed, adjusted, or used otherwise than in accordance with the instructions supplied by QUBIT.

The warranty is return-to-base only and does not include on-site repair charges such as labour, travel, or other expenses associated with the repair or installation of replacement parts at the customer's site.

QUBIT repairs or replaces the faulty instruments as quickly as possible; maximum time is one month.

QUBIT will keep spare parts or their adequate substitutes for a period of at least five years.

Returned instruments must be packaged sufficiently so as not to assume any transit damage. If damage is caused due to insufficient packaging, the instrument will be treated as an out-of-warranty repair and charged as such.

QUBIT also offers out-of-warranty repairs. These are usually returned to the customer on a cash-on delivery basis.

Wear & Tear Items are excluded from this warranty. The term Wear & Tear denotes the damage that naturally and inevitably occurs as a result of normal use or aging even when an item is used competently and with care and proper maintenance.

Qubit Systems also offer a service package for all the Q-teach Package components, whereby once a year all of the components may be returned to Qubit for calibrations, service and minor repairs. Contact Qubit Systems for details.

Return Procedure

Before returning any instrument to QUBIT:

Consult the operating manual or contact Qubit to ensure that the instrument(s) is in fact faulty and has not just been set up improperly.

Contact QUBIT before sending anything back. We will issue an RMA number and provide shipping instructions. QUBIT will refuse any goods that are returned without an RMA number, or which are sent in a manner outside of QUBIT'S stipulations.

If you have encountered a program failure, we need a printed copy of any faults you have seen, including how to reproduce them. Include these in the return package along with your mailing address.

Include a copy of the Invoice on which the product was shipped to you.

All returns must be shipped prepaid. Unpaid packages will not be accepted.

In case of questions contact QUBIT by E-mail: info@qubitsystems.com, by phone: (01)-613 384 1977, or by fax: (01)-613 384- 9118.