Q-Box HR1LP Human Respirometry Package

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Overview of Q-Box HR1LP Human Respirometry Package:

The Q-Box HR1LP Human Respirometry Package provides the user with all the materials required to measure both the metabolic rate (**Respiration**) of humans as well as lung volumes and capacities (**Spirometry**). See the appendix for a discussion of respiration and lung parameters.

During respiration measurements, the subject breathes through a face mask or mouth piece connected via a disposable bacterial filter to a three-way non-rebreathing valve. On inhale, breath by breath inflow is measured by a pneumotach spirometer with a time response of ~5ms. Exhaled breath is directed to a mixing bag by the non-rebreathing valve. Exhaled air is sub-sampled from the mixing bag and pumped through the gas analysis system at a known flow rate (measured by the Q-G266 Flow Monitor; manually controlled by the Q-G266 valve). The concentration of CO_2 and O_2 in the mixed expired breath is measured using a Q-S153 infrared CO_2 gas analyzer (IRGA) and a fuel cell Q-S102 O_2 Analyzer with response times of ~15 sec. Heart rate is also measured with a chest belt monitor.

During lung volume measurements, the subject breathes directly through a spirometer via a disposable mouthpiece and bacterial filter. The spirometer measures breath flow, the only parameter needed for lung volume calculations.

Analog signals from all of the sensors are converted to digital signals via two LabQuest Mini interfaces (6 available channels). Data are displayed, recorded and manipulated on a PC or Macintosh computer using Logger Pro software. Changes in breath flow as well as the concentrations of CO_2 and O_2 in the mixed expired breath are monitored in real time for respirometry studies. The flow and gas concentration data can be used to determine O_2 consumption ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$) and respiratory exchange ratio, (RER=$\dot{V}$CO2/$\dot{V}O_2$). In spirometry investigations, flow data alone can provide respiration rate (RR), tidal volume (VT) and minute ventillation (VE). In addition, lung parameters such as vital capacity (VC), forced expiratory volume after 1 sec (FEV1), and peak expiratory flow (PEF) can be calculated from breath flow data alone.

The Q-Box HR1LP Human Respirometry Package can be used to investigate human metabolic responses to exercise, to different diets and to various concentrations of O_2 and CO_2 in the gas supplied to the subject. Gas mixtures can be supplied via two large gas bags (supplied with the system. Using spirometry, studies of differences in lung volume between individuals of different sizes, sex and race may be performed. In addition, lung obstructive disease may be simulated to observe the effects of this breathing disorder on lung parameters.

Components of Q-Box HR1LP:

Q-S153 CO_2 Analyzer (Range: 0-10%)

Q-S102 O_2 Analyzer with atmospheric pressure sensor for O2 signal correction (Range: 0-100%)

Drying columns for Q-S153 and Q-S102 with DRIERITE (blue) (3 x Q11784)

CO_2 scrubbing column with soda lime (white) (Q13025)

Q-G266 Flow Monitor (Range: 0 -1 LPM)

Q-P103 Gas Pump (1 LPM no load)

G122 Two Large Gas Bag (30 Litres)

C610 Integrated Data Acquisition Interface (2x)

C901 Logger Pro Data Acquisition Software

C404 Customized Setup Files

S182 Wireless Exercise Heart Rate Monitor

G129 Breath Mixing Bags (2x)

A505 Face Mask (2 Large, 2 Medium Sizes)

A506-neo Neoprene Holder for Face Mask

A508 Non-rebreathing Valve; with bacterial filter adapter, spirometer adapter, mixing bag adapter and 2 valve leaflets (plus 2 extra leaflets) and valve leaflet insertion tool)

S184 Spirometer with nose clip and disposable bacterial filter and mouthpieces

Q-Box Accessory Kit (includes tubing, filters, connectors, wrench for needle valve adjustment, screwdriver for CO2 and O2 analyzer calibration)

Rugged Weather Proof Case

Manual

Individual power supplies for all the sensors (for use in stand-alone mode outside of the Q-Box)

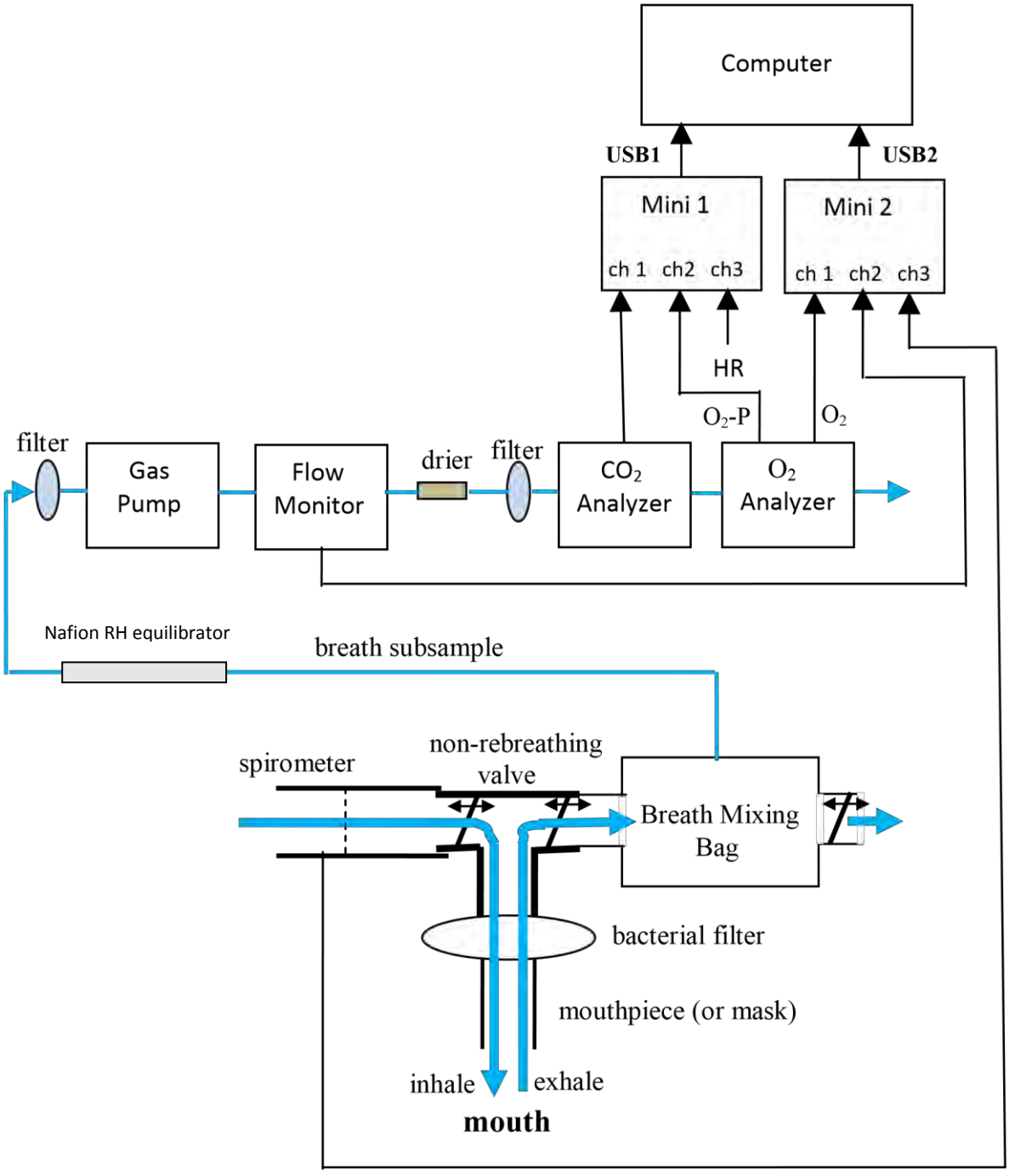
A103 Spirometer Stand (**Optional**)

A550 Clean-Bor disposable tubing (2x72") (**Optional**)

Respirometry

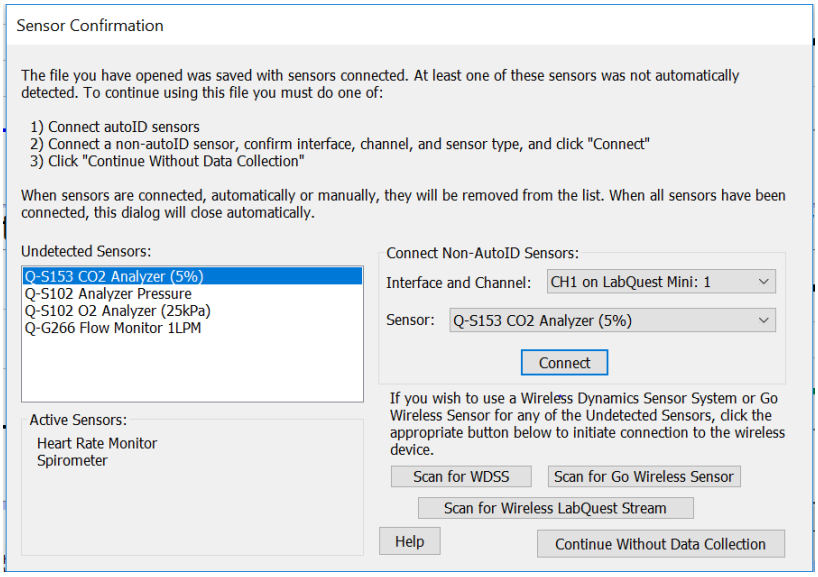
Setup Diagram for Respirometry

Note: thin black lines indicate electrical connections, thick blue lines indicate breath flow, thin blue lines indicate breath subsample



Quick Start Up Steps for Respirometry:

1. Load Logger Pro software onto the computer (follow instructions on pg. 29).
2. Load C404 customized files onto the computer (follow instructions from pg. 31)
3. Plug the Q-Box into a power supply
4. Turn on the pump Q-P103, flow monitor Q-G266, CO_2 analyzer Q-S153 and O_2 analyzer QS102
5. Allow the Q-S153 CO_2 analyzer to warm up for at least 15 min
6. Connect two USB cables from the Q-Box frame to the computer via the USB hub provided plug USB1 first and USB2 second (should hear two audible sounds as the two interfaces are recognized and drivers are loaded).
7. Open the "**Q-Box HR1LP(Resp) Setup**" file to start Logger Pro software for Respirometry measurements. For lung volume (Spirometry) measurements see pg. 43 for instructions. The following screen will appear.



8. Assign the sensors to appropriate channels on the 2 interfaces as follows:
    a. Ch. 1 LabQuest Mini 1 = Q-S153 CO_2 Analyzer
    b. Ch. 2 LabQuest Mini 1 - Q-S102 Pressure (total gas pressure KPa)
    c. Ch. 3 LabQuest Mini 1 = Heart Rate Monitor **(auto detected)**
    d. Ch. 1 LabQuest Mini 2 = Q-S102 O_2 Sensor (O2 KPa)
    e. Ch. 2 LabQuest Mini 2 = Q-G266 Flow Monitor 1LPM
    f. Ch. 3 LabQuest Mini 2 = Spirometer **(auto detected)**

Note: Ch. 3 LabQuest Mini 1 automatically recognizes the S182 Heart Rate Monitor and Ch. 3 LabQuest Mini 2 automatically recognizes the S184 Spirometer. This configuration of the sensor connections is shown in a text box at the bottom of Page 1 in the software.

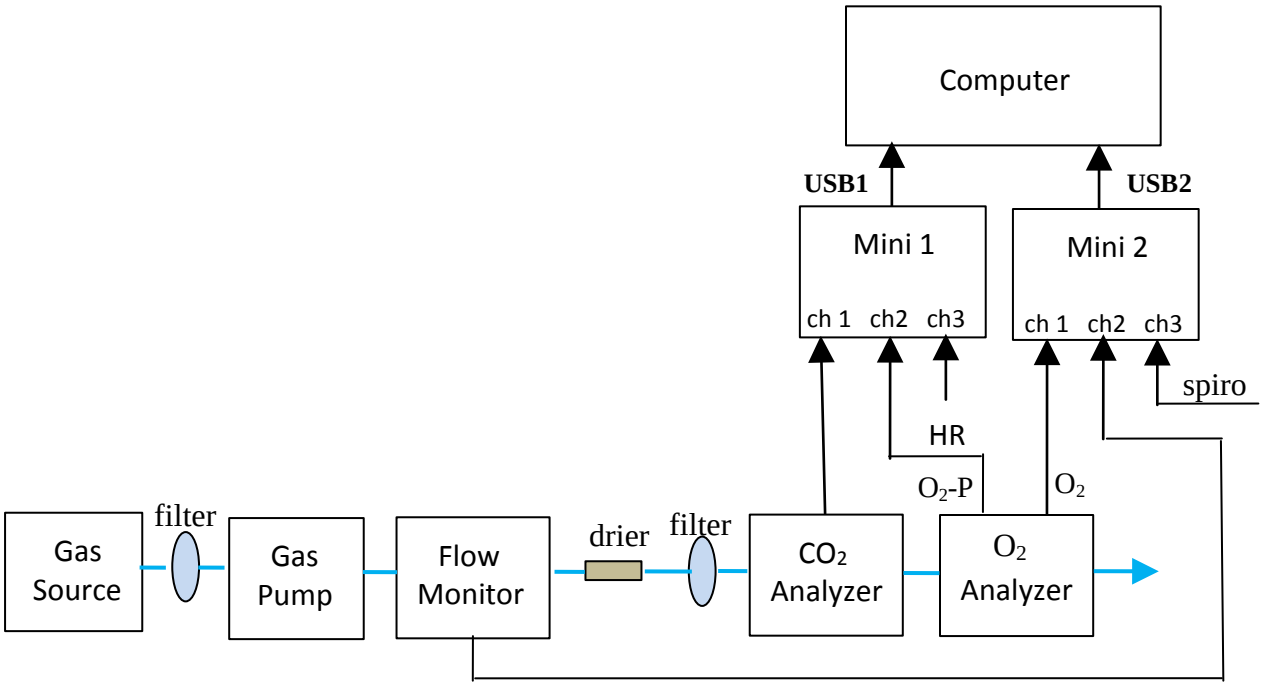
Sensor Connections:

Mini 1: Ch1 - Q-S153 (CO2)
Ch2 - Q-S102 P (Pressure kPa)
Ch3 - S182 (HR monitor - autodetect)

Mini 2: Ch1 - Q-S102 O2 (kPa)
Ch2 - Q-G266 (flow; Volt)
Ch3 - S184 (spirometer - autodetect)

Check the plumbing of the system by gently removing the tray with all the sensors from the Q-Box and placing it outside of the box with the back of the sensors facing up. The system should be configured for calibration before it is used in experiments.

Component Set-Up for Calibration



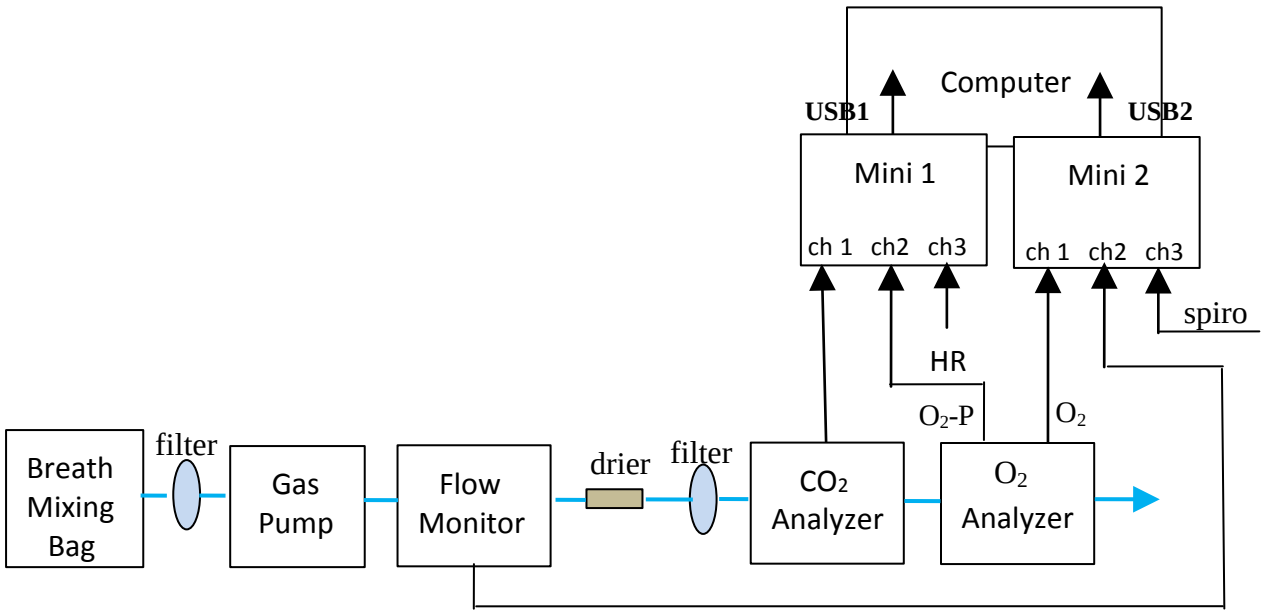
g. The gas supply tubing from the gas source (gas bag filled with known CO2 or other constant source of CO_2) is attached to "in" port on the Q-P103 Gas Pump via a blue particulate filter.
h. The "out" port of the Gas Pump connects to the "in" port of the Q-G266 Flow Monitor.
i. The "out" port of the Flow Monitor initially (in the calibration mode) connects to the "in" port of the Q-S153 CO_2 Analyzer via the Drying Column (blue DRIERITE) and a blue filter.

Note that only one drying column needs to be used when the Q-S151 and Q-S102 are used in series unless the gas sample is high in moisture. To equilibrate the RH of the sample gas to the ambient RH levels and reduce the moisture in the gas stream before it enters the system attach the Nafion RH equilibrator tubing to the output of the breath mixing bag before it enters the Gas pump.

j. The "out" port of the Q-S153 CO_2 Analyzer connects to the "in" port of the Q-S102 O_2 Analyzer.
k. Gas vents from the O_2 analyzer via the "out" port.
l. Two blue filters should be placed in the gas line, one before the pump and one before the CO_2 analyzer, to prevent particulate matter from entering the analyzers.

9. After initial calibration and check, configure the components for measurements of respiration in an open-flow system:

Component Set-Up for Breath Measurements in Open-Flow System with Flow rates of < 650ml/min



Replace the Gas Source bag in the above calibration setup with the breath mixing bag and attach it via the Nafion RH equilibrator tubing and the blue filter to the

gas pump. The analyzers then measure a sample of the mixed expired breath from the breath mixing bag that has been equilibrated to the ambient RH before it is dried further by the drying column.

10. Set the flow rate through the system. It is recommended that the system be calibrated at the same flow rate that is used through the CO_2 and O_2 analyzers during experiments. The flow through the Q-S153 CO_2 and Q-S102 analyzers **should not exceed 650 mL/min**, or damage to the analyzers may result. A flow of about 200ml/min is recommended for both calibration and breath analysis and the system was set at factory to a flow rate around 200ml/min.
11. If changes to the flow rate need to be made use the single valve on Q-G266 Flow Monitor to make these changes. The needle valves of the gas pump are set during manufacture (restricted about 1/3 of the way from fully open) and should not be adjusted when the pump is used with the Q-Box system. Turn the Flow Monitor valve counter clockwise to increase flow or clockwise to reduce flow. Observe the flow in software Page 1 (lower left; Flow meter). Once the flow is adjusted, use the small 8mm wrench provided in the accessory pack to lock the valve to avoid accidental changes in flow during experiments. Note that flow is recorded in software. The tray holding all the sensors can then be placed back in the Q-Box.

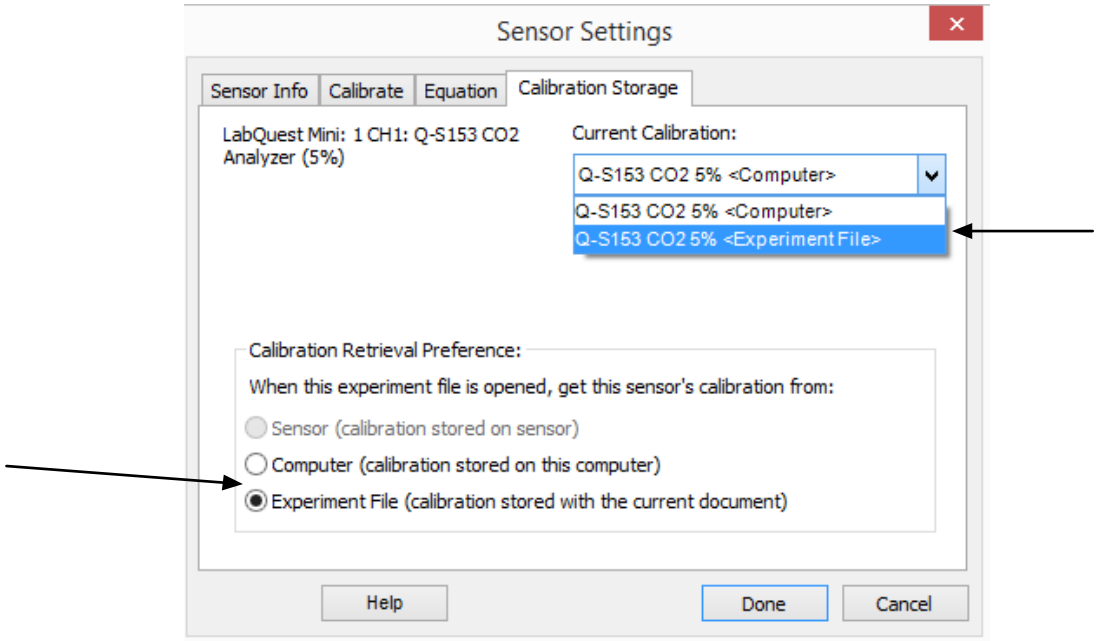
12. The Q-G266 Flow Monitor, S182 Heart Rate Monitor and S184 Spirometer are factory calibrated and no additional calibrations are required. The Q-S153 CO_2 Analyzer and Q-S102 O_2 Analyzer are also factory calibrated. The calibration equation is stored in the software when supplied with the analyzers. However, both analyzers should be checked at the start of each day of experiments, and if required recalibrated. Both Analyzers have linear responses and hence require only 2 point calibrations. The first point should be zero and the second point should be a standard CO_2 and O_2 concentration near the upper range at which the analyzer will be used. A gas mixture with **~ 5% CO_2 and ~16% O_2 with a balance of N_2 (similar to expired breath)** is recommended. Such a gas mixture can be supplied by local gas distributors.

13. **Check and Calibration of the Q-S153 CO_2 analyzer**

    a. Set the CO_2 analyzer in the 0 – 5% range which is the default for Q-Box HR1LP Package.

b. Supply CO_2 free-air to the analyzer by attaching the soda lime column (white) to the outlet of the Flow Monitor. Attach the outlet of the soda lime column to the inlet of the drying column. Both the soda lime and drying columns should be in a vertical position. The outlet of the drying column should already be attached to the inlet of the CO_2 analyzer. Soda lime will scrub the CO_2 from the gas before it enters the CO_2 analyzer and provide the zero reading (the first point of the calibration).

c. From the main menu in LoggerPro Software select ***Experiment>Calibrate>LabQuest Mini 1> QS153 CO2 Analyzer>Calibration Storage***. A dialog box will appear as shown below. Select the calibration storage as "Experiment File". This will ensure that the calibration coefficients that have been saved for the specific analyzer purchased are used and this way the CO2 values displayed on the CO2 analyzer and in the software should match.



d. When the reading on the CO_2 analyzer is stable, use the small screwdriver provided to adjust the "CO_2 Zero" control on the analyzer to set the analyzer digital display to 0.00 CO_2. Clockwise turns increase the value and anticlockwise turns decrease the value. The reading on the CO_2 analyzer display should match the reading in the software on the Q-S153 meter.

e. If the zero reading is highly out of range (by more than 0.06%), or if the maximum or minimum position of the "CO_2 Zero" has been reached (i.e. turning the control has no effect), use the "Coarse Zero" on the back of the instrument to bring zero within range. Use the "Coarse Zero" with **caution since very small adjustments result in large changes, and there is a delay in response to changes in "Coarse Zero".** Use the Coarse Zero to bring the reading close to Zero. Then use the "CO_2 Zero" on the front of the analyzer to make the final zero adjustment. If the Coarse Zero adjustment is required, first adjust the fine zero to the middle of its range. Do this by turning the "CO_2 Zero" potentiometer on the front of the analyzer clockwise or counter-clockwise to the end of its range (it will click when this is reached). Next turn the potentiometer twelve complete turns in the opposite direction. The CO_2 Zero control is then centered.

f. Remove the soda lime column (white) from the gas lines and attach the "in" port of the Q-P103 Gas Pump to a known CO_2 concentration (i.e. gas bag with known CO_2 concentration).

g. Wait until the CO_2 analyzer shows a steady reading. If the Q-S153 display does not show the concentration of CO_2 in the calibration gas, adjust the display using "CO_2 Span" control. Turning the potentiometer clockwise will increase the reading and anticlockwise will reduce the value displayed.

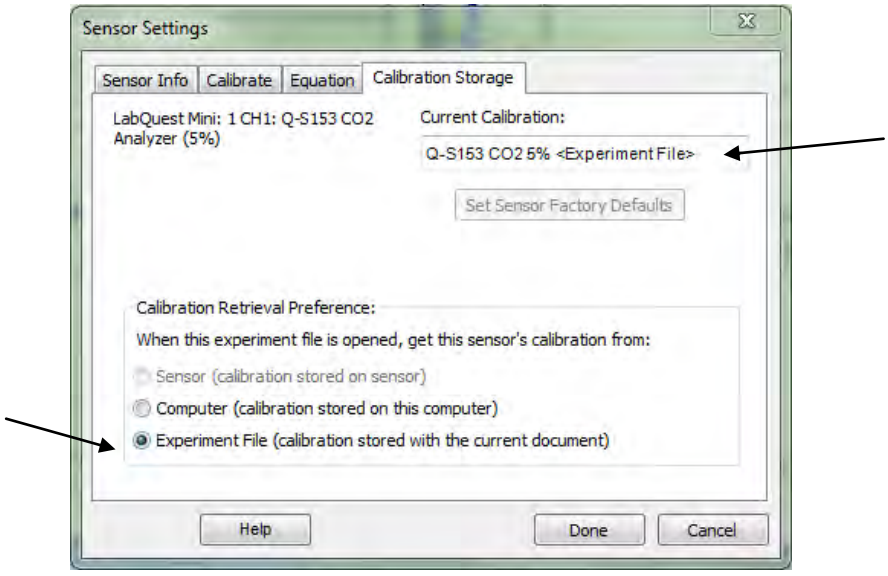
h. If a significant adjustment had to be made to "CO_2 Span", go back to the zero check and ensure the zero reading on the analyzer has not shifted.

i. If the readings on the Q-S153 digital display are significantly different from those on the Q-S153 CO_2 meter in the software, first check that the correct range (5%) is still selected on the CO_2 analyzer and the correct CO_2 analyzer (Q-S153 CO_2 Analyzer 5%) has been selected in the experimental file. If these are correct and the readings are mismatched then proceed to calibration of the CO_2 analyzer in the software as described below.

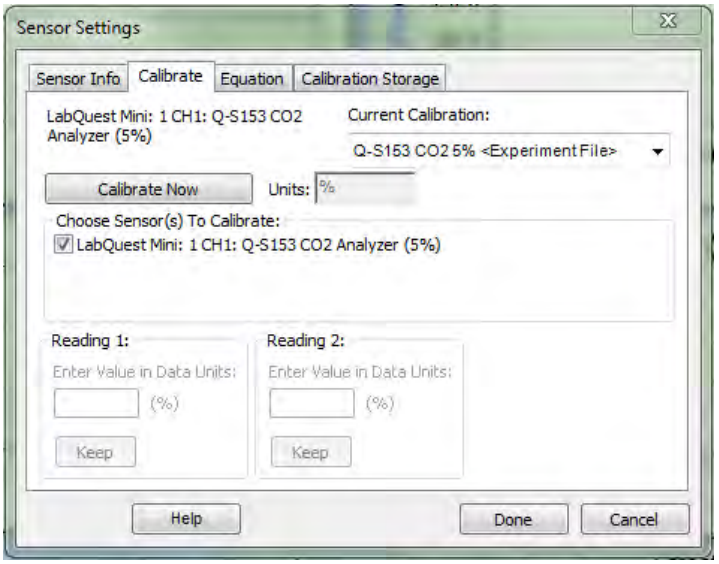
Calibration of the CO_2 analyzer in the software (to be used only if display readings on the analyzer and software readings are significantly different)

a. Supply CO_2-free air to the analyzer by attaching the soda lime column to the outlet of the flow monitor. Attach the outlet of the soda lime column to the inlet of the drying column. Both the soda lime and drying columns should be in a vertical position to ensure maximal contact of the gas with the particles. The outlet of the drying column should already be attached to the inlet of the CO_2 analyzer. Soda lime will scrub CO_2 from air and provide the zero reading (the first point of the calibration).

b. From the menu in Logger Pro Software, select ***Experiment>Calibrate>LabQuest Mini 1>Q-S153 CO2 Analyzer (5%)***. A dialog box will appear as shown below. Select the calibration storage as "Experiment File" so the new calibration is saved with the current file.



c. Proceed to "Calibrate" in the same window (see below). Ensure the Current Calibration is selected as ***Q-S153 CO_2 Analyzer 5%<Experiment>***.



d. When the reading on the CO_2 analyzer is stable, use the small green screwdriver provided to adjust the "CO_2 Zero" control on the analyzer (if needed) to set the digital display to read 0.00 CO_2. In software, enter "Reading 1" as 0 and click "Keep"

e. Remove the soda lime column from the gas line. Attach the "in" port of the Q-P103 Gas Pump to a gas bag with known CO_2 concentration.

f. If the Q-S153 display does not show the correct concentration of CO_2 in the calibration gas, adjust the display using the "CO_2 Span" control. When the Q-S153 CO_2 display shows the correct CO_2 concentration, enter that concentration as "Reading 2" in software and click "Keep" then "Done". **Save the experimental file under a new name so the new calibration is saved with the current file.** The CO_2 readings in Logger Pro software should now be the same as those on the digital display of the CO_2 analyzer.

2. Check and Calibration of the Q-S102 O_2 Analyzer

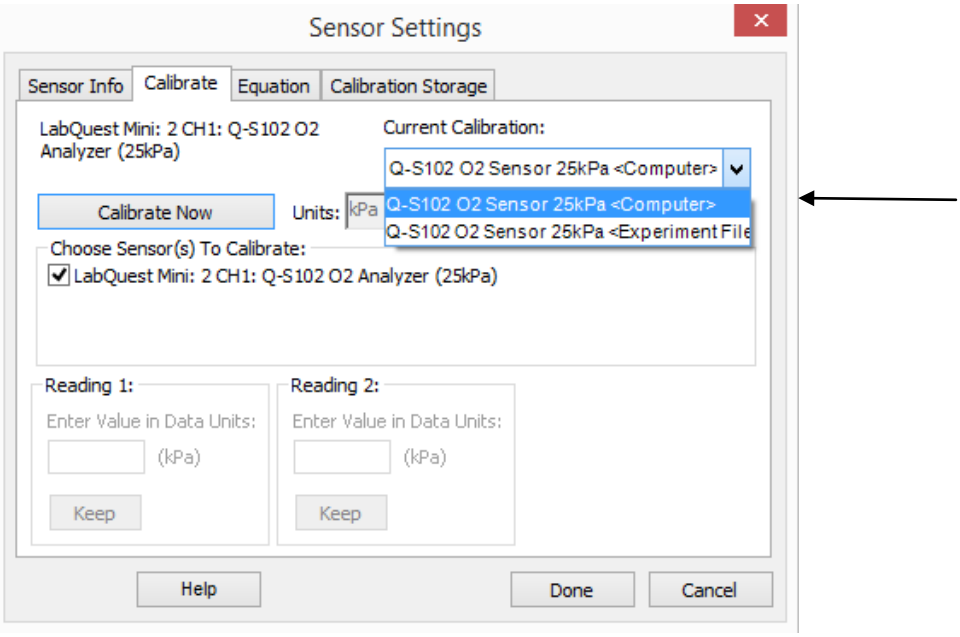
Note the Q-S102 analyzer measures partial pressure (kPa) of O_2 in a gas and total gas pressure in the system. The partial pressure of O_2 will follow atmospheric pressure changes whereas the concentration is constant and independent of pressure variation. The analyzer O_2 partial pressure reading has been corrected in software for changes in total gas pressure to produce O_2 (Pcor) reading in % units. These corrected readings (see calculation below) are displayed in the software in a meter and in the graph as shown below.

$$O2\ (Pcor) = ((Q\text{-}S102\ O2\ )/(Q\text{-}S102\ P))*100$$

Q-S102 O2 is the O_2 partial pressure, and *Q-S102 P* is the (total) gas pressure measured in the QS102 O_2 analyzer.

To check and adjust the calibration of the Q-S102 follow these steps:

a. Set the O_2 analyzer in the 0-25 kPa range this is the default range for measurements of respiratory O_2 consumption. Ensure the current calibration is selected as Q-S102 O2 Sensor 25KPa< Computer> then click Done.

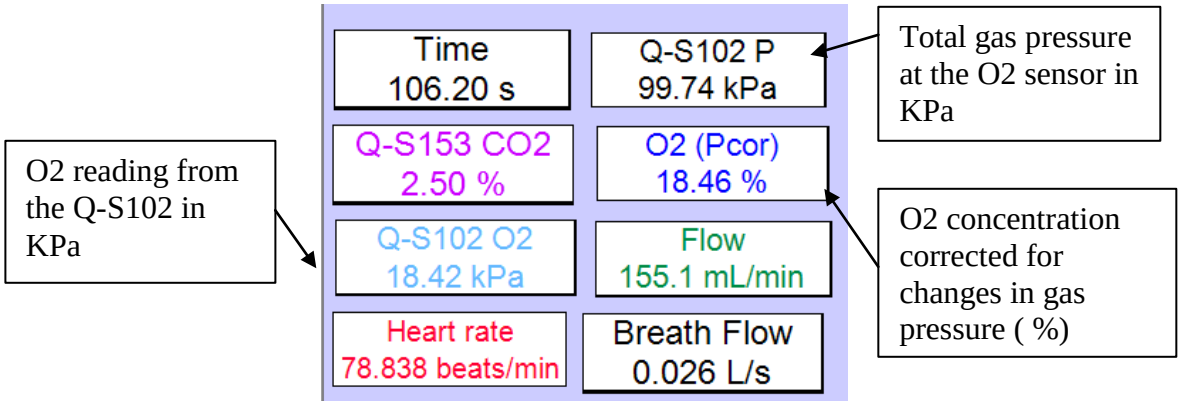


b. Supply O_2 free-gas (e.g. N_2) to the analyzer by attaching the O_2-free gas source (i.e. gas bag) to the "in" port of the Q-P103 gas pump. As the O_2-free gas enters the Q-S102 O_2 Analyzer, the reading in the software on page 1 - (**O2(Pcor)**) will decrease towards zero (the first point of the calibration).

c. When the reading in the software (in O2(Pcor) window) is stable, use the small green screwdriver provided to adjust the "O_2 Zero" control on the analyzer until this meter display in the software reads 0.00 O_2.

d. Attach the "In" port of the Q-P103 Gas Pump to a source of gas with known O_2 concentration (i.e. gas bag with a known concentration of O_2). Alternatively, dried room air contains 20.95% O_2.

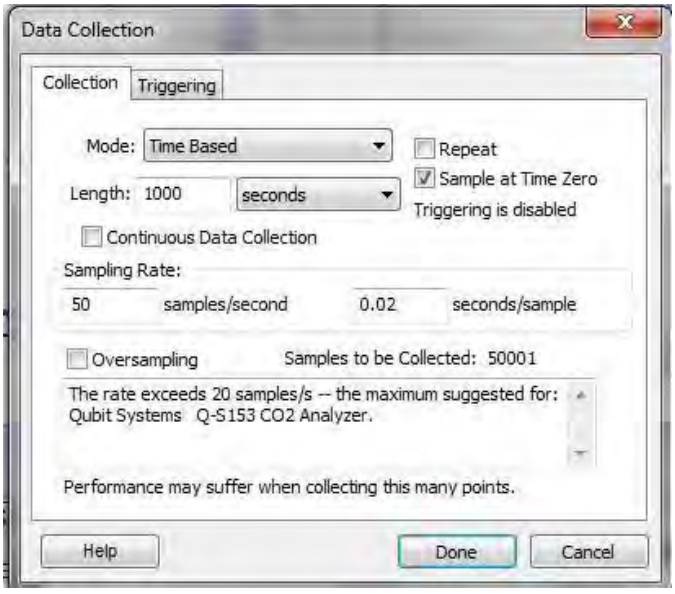
e. When the **O2 (Pcor)** reading in software becomes stable, adjust the "O_2 Span" control on the analyzer until this reading corresponds to the O_2 concentration supplied to the analyzer.



f. If a significant adjustment had to be made to "O_2 Span", return to the zero check and ensure that the zero reading on the analyzer has not shifted. It is not necessary to do the zero check while in the calibration mode of the software.

14. The Q-Box HR1LP system is now ready for use in respirometry measurements.

15. Before collecting data with Logger Pro, select ***Experiment > Data Collection*** in the main menu. The following dialog box will appear:

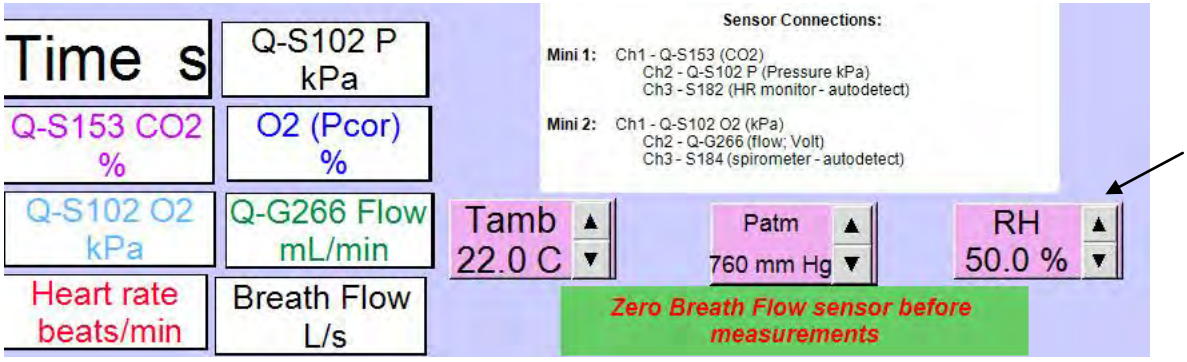


Input experiment length as required. The default sampling rate is 50 samples/sec and note that the rate should not drop below 40 for accurate heart rate data collection. Note this sampling rate

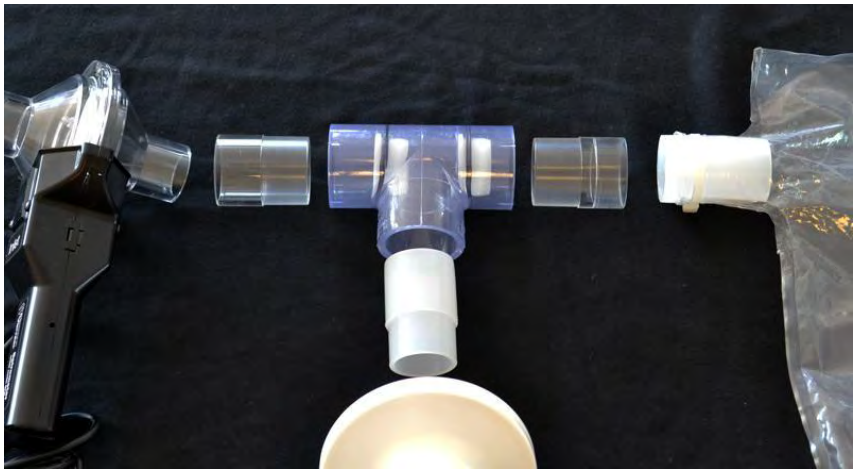
is greater than necessary for some of the sensors such as the Q-S153 CO_2 Analyzer and Q-S102 O_2 Analyzers which have response times that are much longer than this sample time. However this fast sampling rate is necessary for the spirometer and the heart rate monitor. Note that with longer experiments, the message "Performance may suffer" will appear as the data collection and data display may not be well synchronized for "on the fly" visualization. However, even if the display of the data lags collection, the logging of the data proceeds as normal. Click "Done".

Select: ***File> Save As*** to save the experiment settings under the file name selected during calibrations of Q-S153, so that the original set up file (**Q-Box HR1LP(Resp) Setup**) is not overwritten.

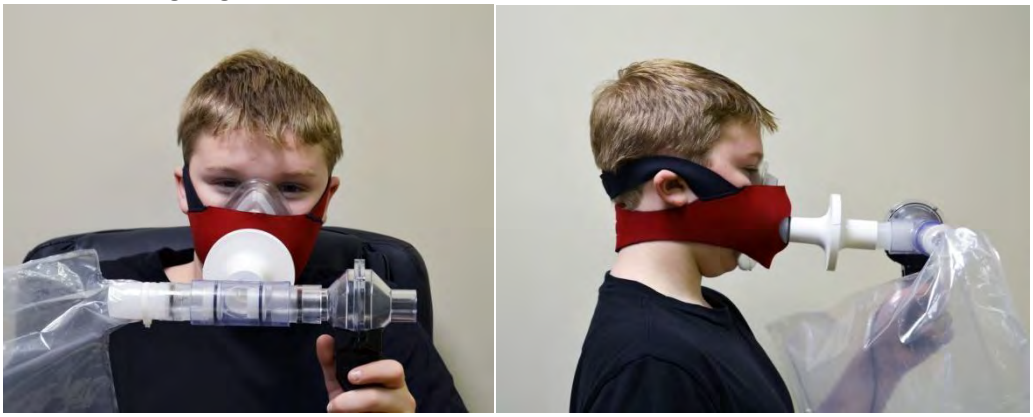
16. Before starting data collection, three User Parameters must be entered in the software on Page 1 Raw Data (lower left). These parameters are ambient temperature in °C (Tamb), atmospheric pressure in mmHg (Patm) and ambient relative humidity in % (RH). These parameters are used in converting $\dot{V}O_2$ and $\dot{V}CO2$ to STPD (standard temperature, pressure and dry gas). The default values may be altered if local values are known. These parameters can also be obtained from **optional** sensors (not included in this package).



17. Attach the mask to the bacterial filter and the 3 way non-rebreathing valve as shown in the photos below. The "In" and "Out" ends of the non-rebreathing valve can be determined by briefly blowing into one of the ends and checking for resistance which is present at the "out" end. Connect the spirometer via its "Inlet" end to the "In" end of the 3-way non-rebreathing valve using the adapter provided. Attach the Breath Mixing Bag to the "Out" end of the 3-way valve via the provided adapter. The bacterial filter also requires an adapter for attachment to the non-rebreathing valve.

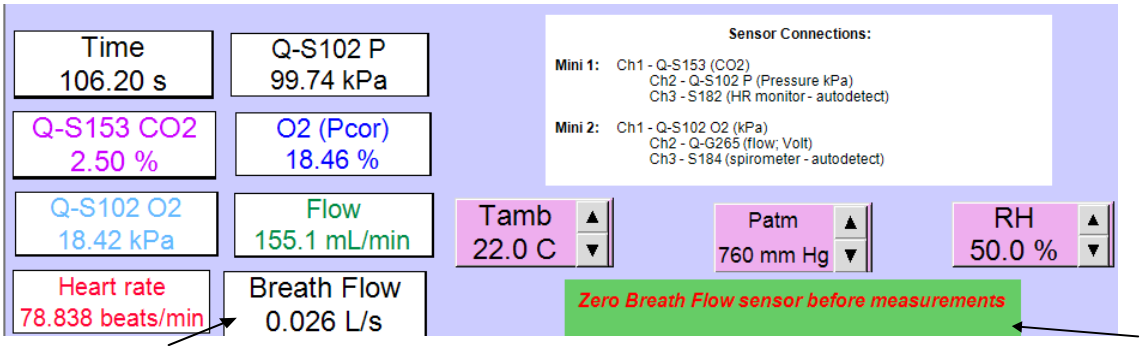


18. Put on the mask with the 3 way valve assembly, spirometer and breath mixing bag and secure it with the head strap as shown in the photos below. Breathe normally to inflate the mixing bag. During Inhale air will be breathed through the spirometer and during exhale air will enter the breath mixing bag.

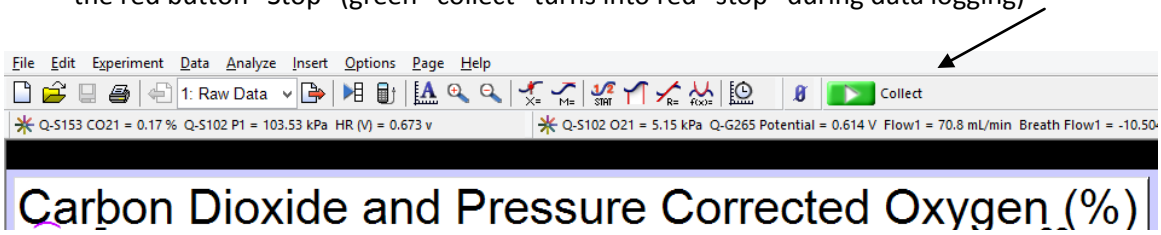


19. Ensure the spirometer is held **upright and still** throughout the experiment since tilting may affect the readings. When using the system during exercise an optional spirometer stand (A103) and 2 x 72" of Clean-Bor disposable tubing (A550) can be purchased to maintain the spirometer at a distance from the subject being measured, and allow the freedom of exercise (i.e. during riding a stationary bike). See photo below for the setup.

20. While holding the breath, the spirometer should be zeroed to obtain the base line. Select from the top menu ***Experiment<Zero*** and watch the values in the Breath Flow meter (lower right of page 1) drop to zero. A reminder message to zero the Breath Flow (Spirometer) is shown on the first page of the software (see below).



21. Start data collection by clicking the green button "Collect" and stop data collection by clicking the red button "Stop" (green "collect" turns into red "stop" during data logging)



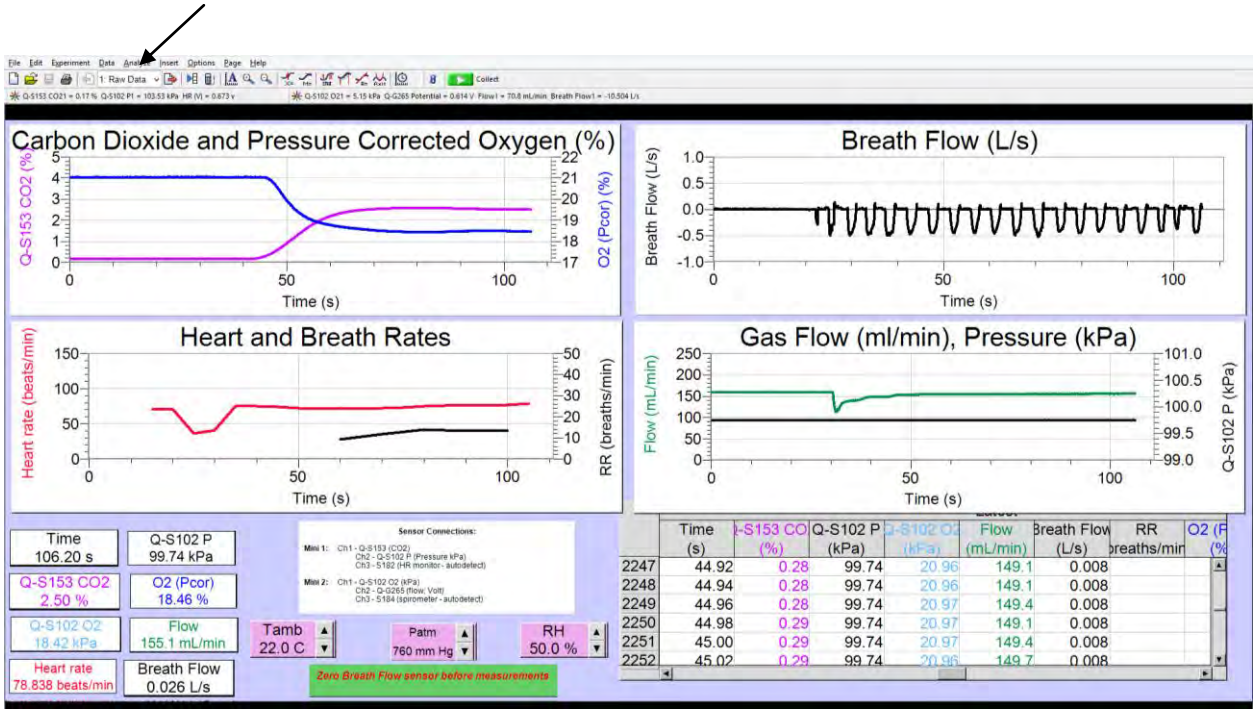
22. At the beginning of an experiment, obtain ~ 30 sec of reference readings for the Q-S153 CO_2 and Q-S102 O_2 analyzers before connecting the subsample tube to the Breath Mixing Bag for measurements of CO_2 and O_2 in the expired breath. To do this, subsample background room air through the system while collecting data. These values will be approximately 0.05% CO_2 and 20.95% O_2.

23. While collecting the CO_2 and O_2 reference data, hold the breath for a few seconds to check for baseline shift in the breath flow, then resume normal breathing.

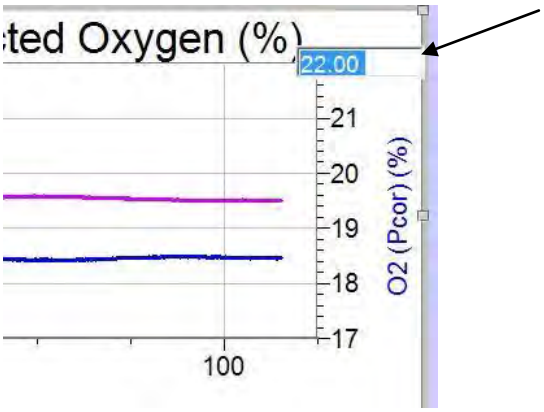
24. Attach the subsample tube between the breath mixing bag and the Q-P103 Gas Pump as shown in the Setup Diagram for Respirometry on pg. 6, as well as in the photo below.

25. Collect the CO_2, O_2 and breath flow data from the mixing bag and spirometer for few minutes until stable readings are obtained. The duration of the experiment to obtain all relevant data should be 5-10 minutes.

26. Logger Pro software displays data on Page 1 (Raw Data) as they are collected in graphs, meters and table columns. Sample respiration data is shown below. Note the inverse relationship between the O_2 and CO_2 readings. The heart rate, as recorded by the heart rate monitor is displayed in a separate graph together with the respiration rate (breaths/min) which is calculated from the breath flow.



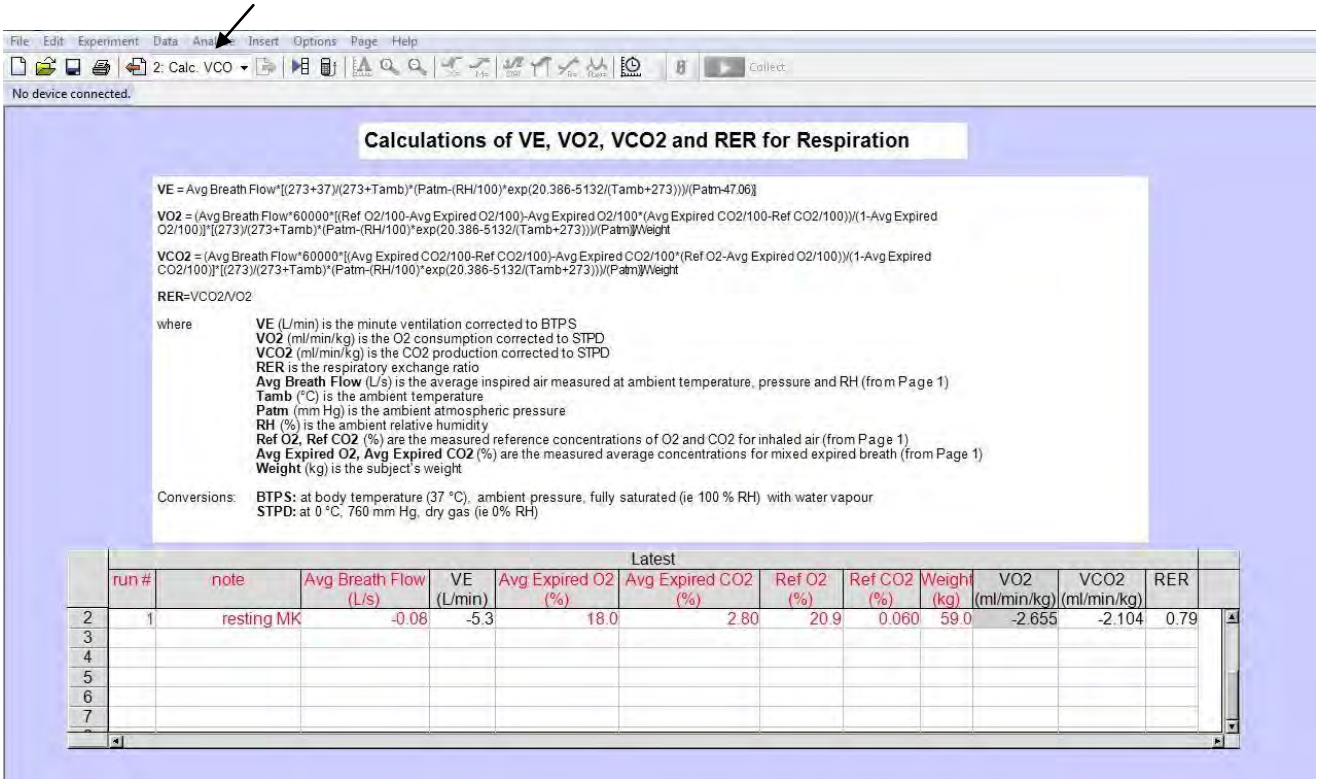
27. During the experiment, the x and y axis ranges can be adjusted by clicking on the lowest or highest number and typing in the desired new value.



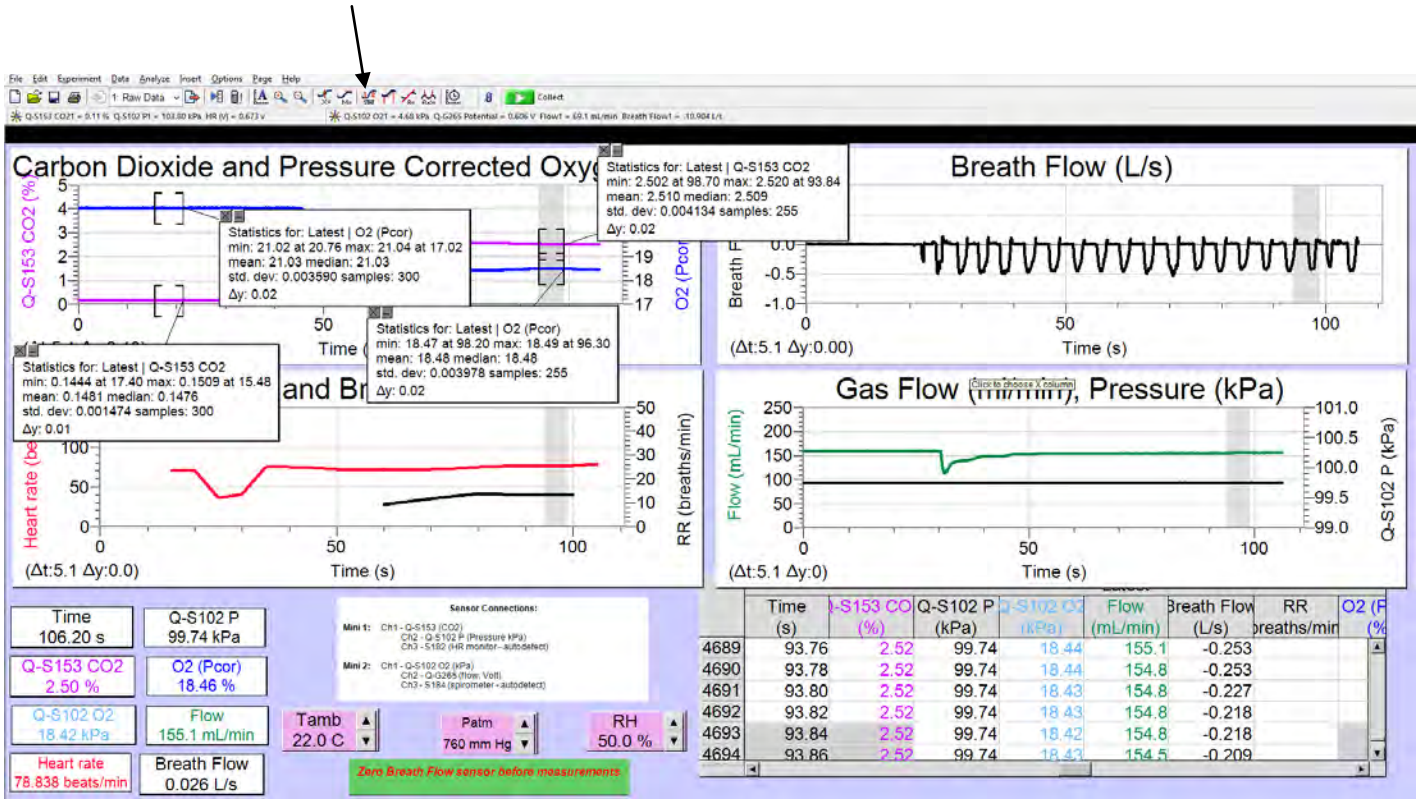
28. Upon completion of the experiment, the data can be analyzed directly in Logger Pro using the various analysis tools in the ***Analyze*** menu, or using icons selected in the top menu bar. Further calculations can be done directly in software on Page 2. The data can also be directly exported as a CSV file (***File > Export As > CSC***), which can then be opened in any spreadsheet program for further analysis and calculations.

Calculations of $\dot{V}O_2$ and $\dot{V}CO2$

Calculations of O_2 consumption ($\dot{V}O_2$) and CO_2 production ($\dot{V}$ CO2) and Respiratory Exchange Ratio (RER =$\dot{V}$CO2/$\dot{V}$ O_2) are done on page 2 of the software.



The user must enter the values in the red columns of the table on Page 2. These are Avg expired O2 (%), Avg expired CO2 (%), Ref O2 (%), Ref CO2 (%) and average breath flow. These values are obtained from the raw data on Page 1 using the statistics analysis tool. These average data can be obtained by left clicking the mouse and dragging the cursor to highlight a portion of the data when the reference or expired measurements are stable. Once highlighted, select ***Analyze<Statistics*** in the menu or the stats icon tool from the icon bar, to obtain the mean values for the parameters of interest. See the software screen below.



The mean values from the statistics windows can be copied into the red columns on page 2. The weight of the person also needs to be entered and the calculations of the $\dot{V}O_2$ and $\dot{V}CO2$ **(converted to STPD)** will be done automatically according to the formulas below:

$\dot{V}O_2$ = (Avg Breath Flow*60000*[(Ref O2/100-Avg Expired O2/100)-Avg Expired O2/100*(Avg Expired CO2/100-Ref CO2/100))/(1-Avg Expired O2/100)]*[(273)/(273+Tamb)*(Patm-(RH/100)*exp(20.3865132/(Tamb+273)))/(Patm)]/Weight

$\dot{V}CO2$ = (Avg Breath Flow*60000*[(Avg Expired CO2/100-Ref CO2/100)-Avg Expired CO2/100*(Ref O2-Avg Expired O2/100))/(1-Avg Expired CO2/100)]*[(273)/(273+Tamb)*(Patm-(RH/100)*exp(20.3865132/(Tamb+273)))/(Patm)]/Weight

Where Tamb is ambient temperature in °C, Patm is atmospheric pressure in mmHg and RH is relative humidity. For most accurate measurements of $\dot{V}O_2$, $\dot{V}CO2$ and RER, a Haldane correction must be made, because, unless the subject is respiring pure carbohydrate (in which the amount of carbon is exactly equal to the amount of oxygen), the subject will inhale more gas than is exhaled. This is due to the fact that fat and protein are highly reduced compared to carbohydrate, and therefore more O_2 is consumed during their metabolism than CO_2 is produced. As a result, the volume of inhaled breath is typically greater than the volume of exhaled breath. Since the respiration package measures only inhaled breath, a correction has to be applied for this imbalance as shown in the equations above. $\dot{V}O_2$ and $\dot{V}CO2$ calculated this way will be expressed in units of mL/min.

The above equations are only valid if breath flow rate is measured from inhaled breath. Other equations must be used if breath flow rate is measured from the exhaled breath.

Both $\dot{V}O_2$ and $\dot{V}CO2$ are corrected to standard temperature, pressure and dry gas (STPD; 0 °C, 760 mm Hg, 0% RH). For these conversions to be correct, the user parameters (Tamb, Patm, RH) on Page 1 need to be entered if different from the default values. The software also calculates the

ratio of $\dot{V}$CO2 to $\dot{V}O_2$, which is the respiratory exchange rate RER. The average breath flow as measured by the spirometer, is used in calculation of the minute ventilation (VE) in L/min and is corrected to BTPS (body temperature, ambient pressure and saturated with water vapour) as per equation below:

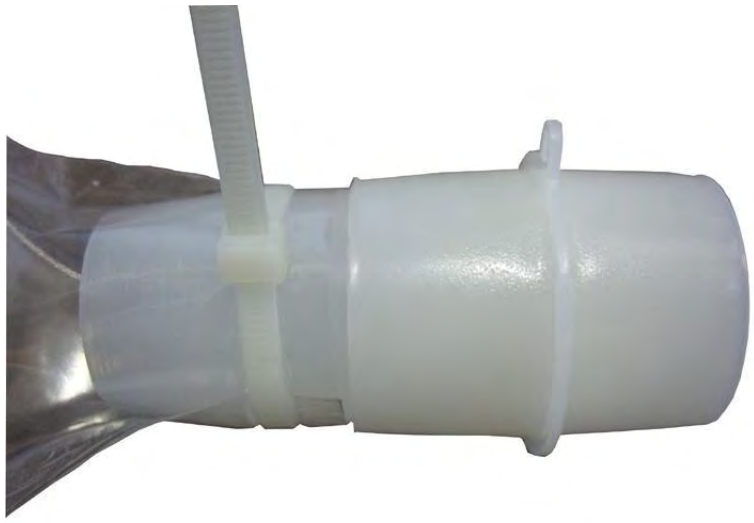
VE = Avg Breath Flow*[(273+37)/(273+Tamb)*(Patm-(RH/100)*exp(20.386-5132/(Tamb+273)))/(Patm47.06)]

See the appendix at the end of the manual for more information on the respirometry measurements.

G129 Breath Mixing Bags

The breath mixing bags have an approximate capacity of 15L and are designed to be reused many times. They are made from a gas-impermeable, nylon-polyethylene laminate and are heat-sealed. The openings in each bag are large enough to accommodate a tapered connector secured to the bag with a NYLON TIE positioned in the groove on the fitting. Connect the outlet of the non-rebreathing valve to the connector in the Breath Mixing Bag. Ensure that the bag does not become twisted during an experiment, at the point where the fitting is inserted. This may cause restriction to breath flow.

The other end of the Breath Mixing Volume Bag, has the second tapered fitting. A 1-way valve fits over this connector. This overflow 1-way valve ensures that the bag does not overinflate. Excess breath is released but no outside air can enter the bag. Breathe into the valve to ensure it is installed correctly.



The breath mixing bags also contain a valve with a luer lock connector for the sub-sampling tubing that is attached to the Q-P103 gas pump which delivers a subsample of mixed expired breath to the CO_2 and O_2 analyzers.

Using the Drying Column and Soda Lime Column

The Q-S153 and Q-S102 are designed to analyze dry gas samples. Three desiccant columns (short blue column) are provided with the package. These are filled with DRIERITE to dry the gas before analysis.

The column is supplied ready for use. One column should be mounted **vertically** on the back of the QS153. For very wet samples a second column can be installed in a series with the first one.

DRIERITE contains an indicator that is blue when the column is functional and pink when the DRIERITE is spent. When spent, the DRIERITE should be replaced or reconditioned. To recondition, remove the DRIERITE from the column and place it in a drying oven at 210^{o}C for 1 hour, or until the pink coloration disappears. The replacement DRIERITE is #8 mesh, order #23005 from drierite.com.

During calibration of the Q-S153 CO2 Analyzer, CO_2 free gas is provided by pumping air through a column containing soda lime (Long column with white chemical). A small amount of poly-wool should be placed towards the outlet of the column, and the column should then be filled with soda lime using a spatula. When the column is full, it should be tapped on the desk to settle the soda lime, and then topped off with another wool plug. The soda lime column should be used in a **VERTICAL** position**.**

The soda lime provided with the Q-S153 has a coloured indicator to show when it is spent. 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).

Note: remove the soda lime column from the system once calibration has been completed.

Warning: Soda lime can cause severe burns. Users should read and comply with the Material Safety Data Sheet on soda lime.

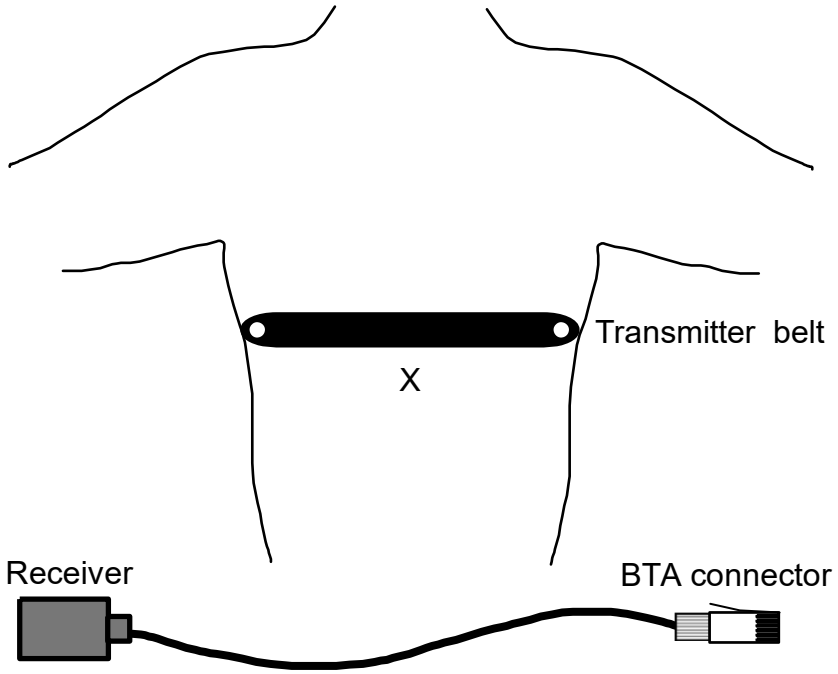
S182 Wireless Exercise Heart Rate Monitor

The wireless heart rate monitor is designed for use with a strap and a receiver module that plugs into the Labquest Mini data interface. The heart rate monitor does not require any calibration, and when plugged into the data interface, will be auto-detected. The heart rate monitor provides heart rate data that is complementary to the respiratory data. To use the wireless heart rate monitor, attach the elastic strap to one end of the transmitter belt. Apply the saline solution to the rubber portion of the monitor that comes in contact with the chest and Place the belt against the subject's chest, in the position shown in the diagram below. Secure the other end of the elastic strap to the transmitter belt. Adjust the elastic strap so that the belt lies snugly against the chest.

Ensure that the receiver is kept at least 40 cm away from other electrical sources (especially a computer!). Interference from other electrical sources will cause readings from the HR Monitor to be invalid and sporadic.

The 2 oval grooved areas on the back of the transmitter belt are electrodes. For best contact, wet each electrode with 3 drops of saline solution. Plug the BTA connector of the receiver into the Labquest Mini data interface and ensure that the subject remains within 90 cm (3 feet) of the receiver. Taking the length of the receiver cable into consideration, the subject can be up to 5 feet from the interface. This should allow for heart rate monitoring during most types of exercise.

Note that the sampling rate during data collection **MUST BE AT LEAST 40 samples/second** to achieve accurate results. At this sample rate, updating of the tables and graphs will slow down as the experiment progresses, however data will still be collected. It is recommended to limit the collection time to less than 15 minutes.



S184 Spirometer

The S184 Spirometer can be used to perform a variety of tests related to breath flow and lung volume. The sensor includes a removable flow head (22 mm ID / 30 mm OD) for easy cleaning and sterilization, and a differential pressure transducer. The Spirometer is designed to make human respiratory

measurements at rest and during moderate activity. The spirometer is factory calibrated and does not need to be re-calibrated. It provides accurate measurements at low flow rates.

The Spirometer package includes 1 sensor handle, 1 flow head, 5 disposable mouthpieces, 1 disposable bacterial filter, and 1 nose clip.

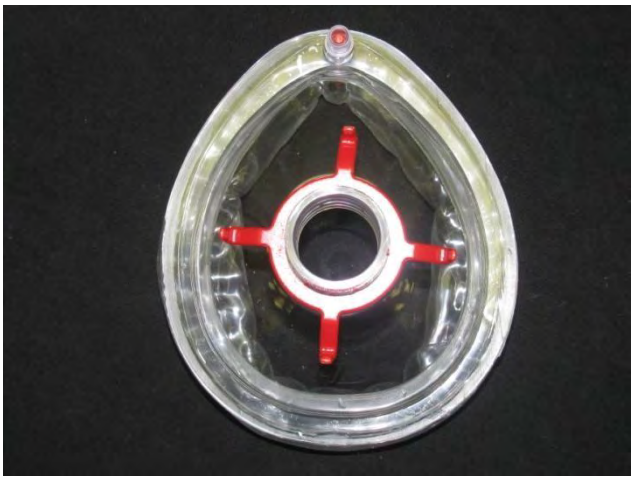
It is important to keep the spirometer in an **UPRIGHT** position and **still** during measurements to reduce noise measured by the internal differential pressure sensor. An optional spirometer stand can be purchased (A103). The bottom of the spirometer handle has a threaded hole which may be used to fix the spirometer to the stand. When plugged into the data interface, the spirometer is auto-detected by the software. Attach the "In" end of the 3-way non-rebreathing valve to the “inlet” port of the spirometer for respiratory measurements. For spirometry measurements, attach the face mask or the mouth piece to the "inlet" of the spirometer via the bacterial filter.

When making respiration or spirometry measurements, first zero the base line of the spirometer without breath flowing through it. This can be done in the top menu ***Experiment<Zero***. The Breath

Flow meter will then display values close to zero. Start collecting the data and after a few seconds of zero flow (i.e. holding breath), start breathing into the system.

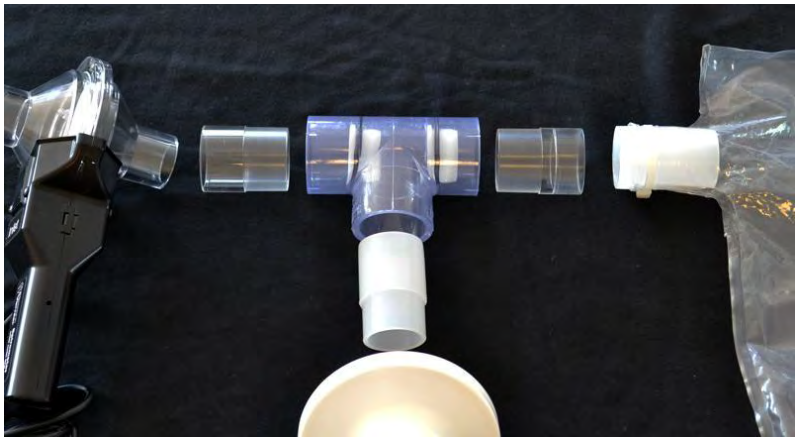
A505 Face Masks

Four Face masks are provided with the Q-Box HR1LP Human Respiration Package. Two large and two medium masks are included. The masks are fitted with an air-cushion for a more comfortable fit. The valve at the top can be depressed with a standard medical syringe tip to adjust the air pressure in the cushion. This will permit a custom fit to the face to provide an airtight seal. The neoprene holder (A506neo) secures the mask to the face. The mask attaches to the A508 non-rebreathing valve via a disposable bacterial filter. The bacterial filter connects to the non-rebreathing valve with an adapter. To reduce dead volume, the mask may be replaced by a disposable mouth piece and a noseclip. Face masks can be sterilized between measurements with 95% alcohol.



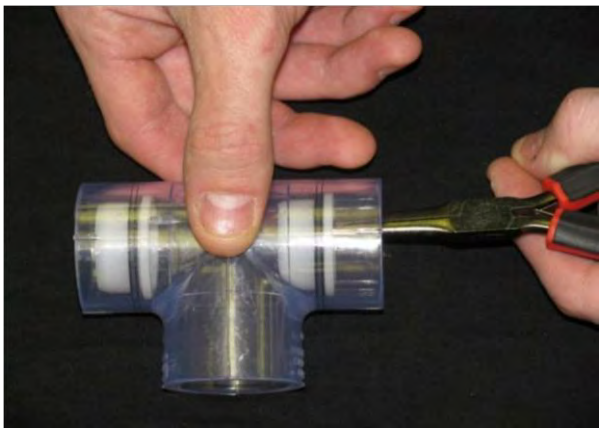
A508 Non-Rebreathing Valve

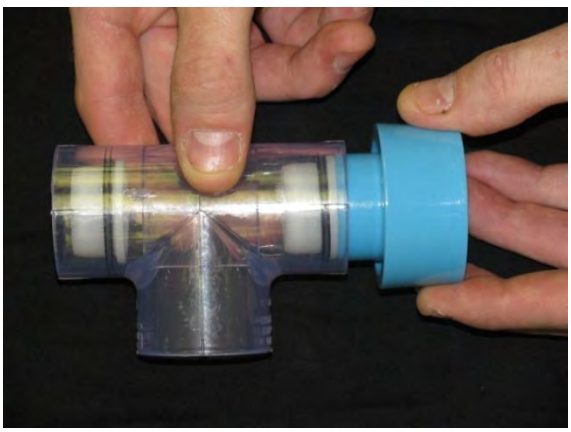
The non-rebreathing valve is shown below. The assembly attaches to the bacterial filter with the white plastic adapter, whereas the spirometer and mixing bag attach to the T-piece with the clear plastic adapters. The inlet of the valve connects to the spirometer (Inlet side) to measure inhaled breath flow, whereas the outlet of the valve is attached to the breath mixing bag to collect exhaled breath. The valve leaflets are visible inside the housing. The "In" and "Out" ends of the 3 way non-rebreathing valve, can be determined by blowing into one side of the valve T. Since the leaflets act as one-way valves the outlet end will be met with resistance to flow from the outside.



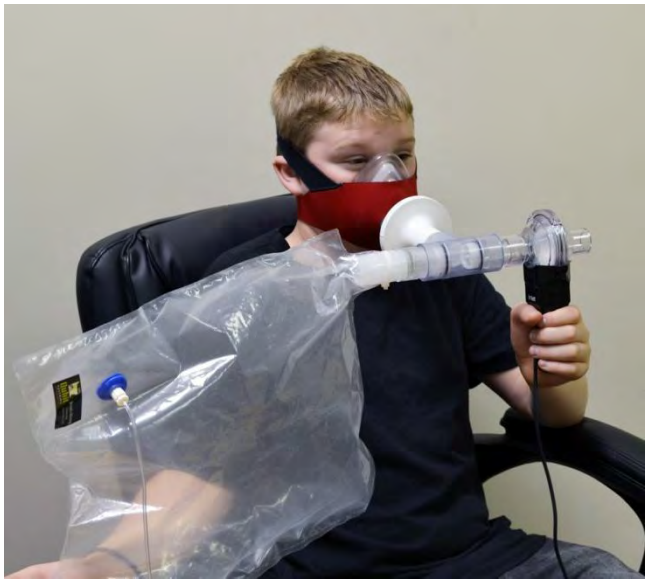
A507 Valve Leaflet and A509 Valve Leaflet Insertion Tool

The valve leaflets are inserted into the inlet and outlet ports of the valve T-piece housing. As shown below, they can be removed with pliers and reinserted with either a clear adapter or the A509 valve leaflet insertion tool. Ensure the inlet and outlet valves are inserted in the correct orientation to permit inhaling through the inlet and exhaling through the outlet. This can be checked by breathing through the white mask adapter.





A subject is shown wearing the face mask with the non-rebreathing valve, spirometer and Breath Mixing Bag attached.



LabQuest Mini Interfaces

The LabQuest Mini interface has 5 independent channels: 3 analog and 2 digital. The digital channels can be used with digital control units and other monitors. The analog channels are used to connect the Q-Box HR1LP sensors. LabQuest Minis can be used with a PC or Macintosh computer (running Logger Pro 3 software). Vernier Software of Portland, Oregon, manufactures both the LabQuest Mini and Logger Pro software.

Installing and Running Logger Pro 3

PC Users:

(1) To start, 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 or other interfaces 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.

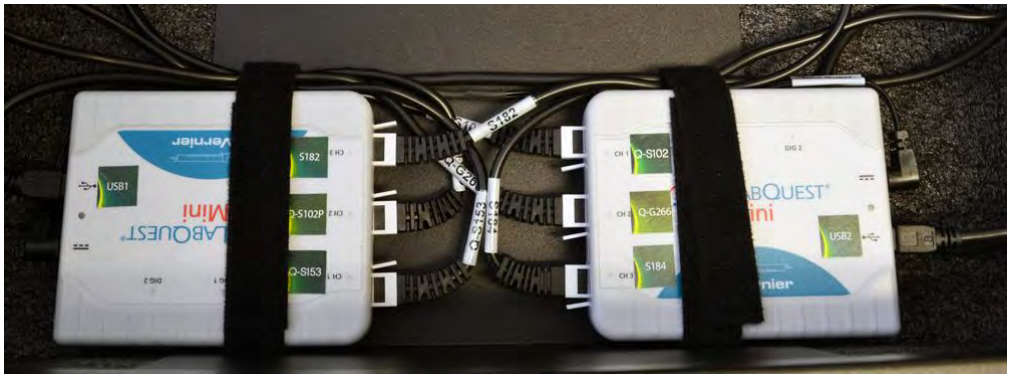
(5) You will be prompted to connect the LabQuest Mini or other interfaces to the computer via the USB connection. The LabQuest Minis can be connected to the computer by connecting the USB1 and USB2 cables **(in that order)** from the Q-Box frame into the computer.

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

(7) Proceed to C404 installation (below) before opening the Logger Pro with the "**Q-Box HR1LP (Resp**) Setup" file.

(8) Double click the "**Q-Box HR1LP (Resp) Setup**" file (shortcut copied to the desktop from the C404 disk) to start Logger Pro and data collection. If Logger Pro detects the two LabQuest Mini interfaces, the Logger Pro screen will appear with two stars (icons for LabQuest Minis) in the top left corner.

(9) If Logger Pro cannot detect the LabQuest Mini Interfaces, a message will appear "no device connected". Or if only one mini is connected then only one star will be shown in the top menu. Check that the LabQuest Minis are connected to the computer directly via USB plugs 1 and 2 on the frame of the Q-Box. Check if the USB cables are connected to the minis. The LED power lights on the Minis should be green. No LED light indicates that power is not supplied to the Minis - check power connections. A red LED indicates that power is on but there is no communication between the interfaces and the computer. In this case, exit the "Q-Box HR1LP (resp) Setup" file and unplug the USB cables from the computer. Reconnect the USB cables with **USB1 connected first and USB2 second**. This order is important as **the computer will assign the LabQuest Minis as 1 or 2 according to the order in which they were connected**. Allow the computer to recognize the Minis (bell tone) and then re-open the "Q-Box HR1LP (Resp) Setup" file.



Macintosh Users:

(1) To start, a complete copy of Logger Pro 3 must be installed on the computer (You must be using at least OS 9.2). Run the "Complete Installation" and ensure all TI GRAPH_LINK and USB cables are disconnected . The most recent version of Logger Pro (3) is included with this package. The following instructions are the same as those for PC users.

C404 Custom Setup Files Installation:

Qubit Systems' C404 Custom Setup Files disk contains Experiment files (designed by Qubit Systems) for this package these are "**Q-Box HR1LP (Resp) Setup**" and "**Q-Box HR1LP (Spiro) Setup"** files plus two image files ("F-V Loop" and "V-t plot") that need to be copied to the same folder as the setup files as they are used on page 3 of "**Q-Box HR1LP (Spiro) Setup"** file to define and illustrate some of the lung parameters**.** The C404 disk also contains the manual for this package and the manual for the LabQuest mini data interface. These files can be copied to user specified location on the computer and the experimental file of interest. "**Q-Box HR1LP (Resp) Setup**" and "**Q-Box HR1LP (Spiro) Setup"** should be placed in an accessible location or have a shortcut created on the desktop to the file. We highly recommend for 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.

Using the Q-S153 CO_2 Analyzer

The Q-S153 CO_2 Analyzer is a non-dispersive infrared gas analyzer (NDIR IRGA). It has a gas "in" port with a female luer-lock connector and a gas "out" port with a male luer-lock connector. A length of tygon tubing with a luer-lock connector is provided to join the Q-S153 to the rest of the gas exchange system. The gas supplied to the IRGA passes through a sealed wave guide and vents from the "out" port. The Q-S153 can be used as a stand-alone analyzer in an open or closed-circuit gas exchange system. It can be used with other gas analyzers downstream. However, ensure that the placement of an analyzer or instrument downstream from the Q-S153 does not cause a significant increase in backpressure. Increasing pressure significantly beyond that at which the IRGA was calibrated, produces erroneously high readings.

The maximum flow rate of gas into the Q-S153 should not exceed 650 mL/min. This, or lower flow rates, should be provided by the Q-P103 Gas pump and monitored by the Q-G266 Flow Monitor. It is recommended that the user calibrate the Q-S153 at the flow rate intended to be used during the experiments.

Gases entering the Q-S153 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 Q-S153 CO_2 analyzer is supplied with a drying column containing 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 Q-S153 CO_2 Analyzer requires 12 Volts DC power to operate. A 120/220 AC power adaptor (included) provides 12 Volts DC. For continuous use, leave the Q-S153 CO_2 analyzer powered all the time. Keeping the Q-S153 powered up will maintain the calibration longer.

Caution: Use only a 12 VDC adapter with the correct AC line voltages. A 120/220 VAC 50/60 Hz to 12 VDC adapter is supplied by QUBIT SYSTEMS.

The Q-S153 requires a 2 to 3 minute warm-up period before the CO_2 level will be displayed. During warm-up, the LCD will flash numbers briefly and display the number 1. After the unit has warmed up, the LCD will display a very high reading, which will slowly decline to the CO_2 level in the supplied gas stream.
For most accurate and stable readings, it is recommended that the Q-S153 be warmed up for minimum of 15 min to 1 hour before use. If the Q-S153 is to be used on a regular basis, it should be powered continuously.

Altitude and Barometric Pressure Correction

The Q-S153 is factory calibrated at sea level. When using the IRGA at elevations other than sea level, calibrate at the elevation at which the analyzer will be used. If this is not possible, correct the CO_2 reading of the analyzer according to the table below. For example, when using a factory-calibrated unit at an altitude of 2,500 feet, multiply the displayed CO_2 reading by 89% (1,000 ppm x 0.89 = 890 ppm actual).

Altitude (feet)	**Pressure (inches Hg)**	**Pressure (mm Hg)**	**Pressure (psia)**	**% Display Reading**
0 sea level	29.92	759.78	14.70	100
500	29.38	746.04	14.43	97.97
1000	28.86	732.84	14.18	95.94
1500	28.34	719.64	13.92	93.91
2000	27.82	706.43	13.66	91.88
2500	27.32	693.73	13.42	89.84
3000	26.82	681.04	13.17	87.81
3500	26.32	668.34	12.93	85.78
4000	25.82	655.65	12.68	83.75
4500	25.36	643.96	12.46	81.72
5000	24.90	632.28	12.23	79.69

For other altitudes, use the following equation:

Percentage of measured CO_2 = [1- (4.06234 x 10^{-5} x Altitude in feet)] x 100

Troubleshooting the Q-S153:

The LCD display will not stabilize during operation:

This may indicate that the unit is not getting power. Unplug the power cord from the unit and measure the DC voltage at the plug; it should be 12 Volts DC. If using an alternate DC power source, the unit will operate with 12 to 19 Volts DC. If the provided power supply is not supplying 12 Volts DC, contact QUBIT SYSTEMS.

Insufficient power may cause a "1" to appear on the display:

Check that the power supply is properly connected and is delivering +12 Volts (Centre Positive). Check that the unit has been sufficiently warmed up.

Span or zero out of range may cause "1" to appear on the display:

Turn the "CO_2 Span" all the way down (counter clockwise) and use the "Coarse Zero" on the back of the CO_2 analyzer to display 0 with zero CO_2 gas flowing through the system. Once the zero display is read, attach a known CO_2 concentration to the system and use "CO_2 Span" to adjust the display on the CO_2 analyzer to the correct CO_2 concentration. Return to the zero CO_2 check with zero CO_2 gas running through the system, and if necessary, make small adjustments with the "CO_2 Zero".

Ensure no material (liquid or dust) has entered the analyzer:

If material has entered the analyzer, it will block the internal light path and "1" will be shown on the display. The unit will need to be returned to QUBIT Systems for repair.

Ensure the Gas Flow Path in the Analyzer is Open:

Check that there are no internal leaks in the analyzer. Connect a 10mL syringe to a tube on the 'OUT Port' of the CO_2 analyzer and plug the 'IN Port'. Pull a slight vacuum with the syringe. If there is no leak, the plunger should not move. If there is an internal leak, contact QUBIT Systems for further instructions. If the analyzer is exposed to extreme pressures, a leak can result.

Ensure the Pump is not Leaking.

A faulty pump can leak room air (possible high ppm CO_2) and increase the CO_2 reading. To test the pump, turn it on and plug the inlet. Connect a tube to its outlet and place the tube in a glass of water. There should be no bubbles. If there are bubbles, the pump is leaking internally and should be repaired or replaced.

Ensure the Soda Lime CO_2 Scrubbing Column is used to provide Zero CO_2 gas to the analyzer:

Do not confuse the soda lime column with the drying column filled with DRIERITE. Soda Lime is white, whereas DRIERITE is blue. If the drying column is mistaken as the CO_2 scrubbing column, CO_2 may enter the analyzer since **DRIERITE absorbs some CO_2, and can release it slowly thereby slowing response** time. If unsure of the condition of the Soda Lime in the column, replace it with new Soda Lime or use an alternate Zero CO_2 source such as pure N_2 gas.

Check Calibration

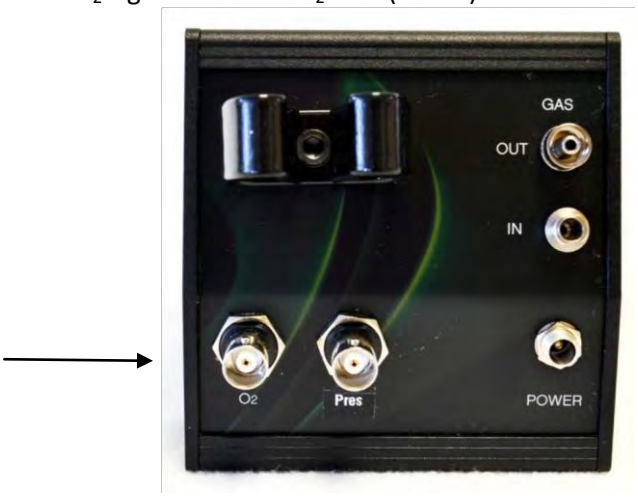
If the CO_2 Span control has been adjusted without following a full calibration procedure, the analyzer must be recalibrated using a zero gas mixture and a gas mixture with a known CO_2 level. See the CO_2 analyzer calibration section of this manual for the correct procedure.

The CO_2 readings on the display of Q-S153 are different from those in Logger Pro

If the CO_2 values displayed on the Q-S153 CO_2 Analyzer are very different from those displayed in the Logger Pro file check the following: first check that the calibration selected in Logger Pro (***Experiment>calibrate>LabQuest Mini1>CH1 Q-S153 CO2 Analyzer (5%)***) matches the range selected on the CO_2 analyzer (0-5%). If the ranges are selected correctly, check that the LabQuest Mini interfaces have not been reversed (check that values displayed in Logger Pro software for other sensors are correct). If the LabQuest Minis have not been reversed then the CO_2 Analyzer requires new calibration. Proceed with calibration instructions outlined above on page 13. If the LabQuest Minis have been reversed, follow the instructions below on pg. 37 on how to fix the problem.

Using the Q-S102 O_2 Analyzer

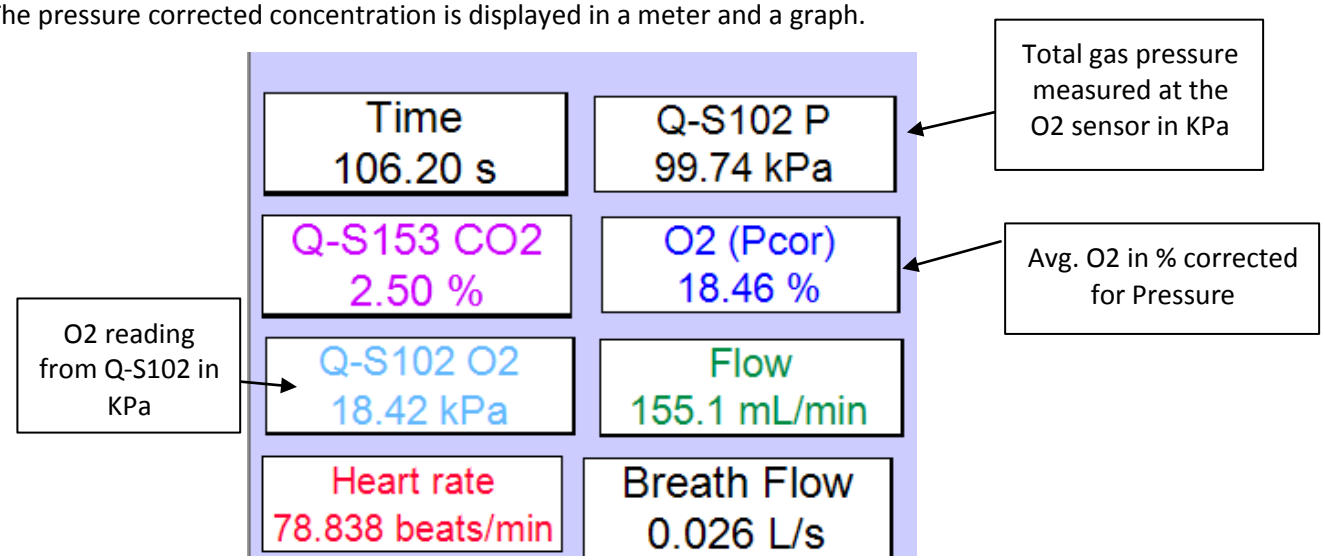
The Q-S102 O_2 Analyzer contains an O_2 sensor which is a galvanic cell (a lead-oxygen battery) consisting of a lead anode, an O_2 cathode, and an acid electrolyte. It also incorporates an O_2-permeable Teflon FEP membrane with a gold electrode bonded to its surface. Oxygen diffusing through this membrane is reduced electrochemically at the gold electrode. A resistor and a thermistor (for temperature compensating diffusion across the Teflon membrane) are connected between the anode and the cathode. The output of the instrument is proportional to the current flowing through the resistor and thermistor. This current is proportional to the partial pressure of O_2 in contact with the Teflon FEP membrane. The signal from the oxygen sensor is transmitted to the computer via the LabQuest Mini (i.e. Q-S102 O2). The Q-S102 O_2 Analyzer has two analog signal outputs, one for O_2 and one for total gas pressure at the O_2 sensor. The pressure readings from Q-S102 can only be observed in software and are used in correction of the O_2 signal in KPa to O_2 in % (O2cor).



The galvanic cell is housed in a brass cylinder for greater temperature stability and more stable O_2 signal. Pressure (Q-S102 P) is measured at the O_2 cell and is displayed on page 1 in a meter and a graph. This pressure value is then used in software to convert the partial pressure of O_2 (Q-S102 O2) to a concentration O2 (Pcor) which is independent of pressure.

O2 (Pcor)=((Q-S102 O2)/(Q-S102 P))*100

The pressure corrected concentration is displayed in a meter and a graph.



The maximum **flow** through the Q-S102 O_2 analyzer **should not exceed 650 ml/min**. The minimum **flow** through the O_2 analyzer **should not decrease below 5mL/min** to avoid local depletion of O_2 at the membrane of the sensor. The analyzer should not be exposed to pressures that are above 20 PSIG or below 10 PSIG, or the damage to the sensor can result. The expected **life** of the O_2 Analyzer's galvanic cell is **3 – 5 years**. If it is impossible to adjust the O_2 signal amplitude by adjusting the span, a new sensor is necessary. Contact Qubit Systems to obtain the replacement galvanic cell.

The Q-S102 is supplied with its own drying column filled with DRIERITE. When used in series with the QS153 CO_2 Analyzer, only one drying column is necessary (in front of the Q-S153) unless the sample gas is very wet. When using the Q-S102 in a stand-alone mode, gas should be dried before entering the O_2 Analyzer to avoid dilution by the water vapour. Place the drying column in the bracket mounted on the analyzer and connect it to the "in" port via the blue particulate filter (25um). Please check the filter frequently to ensure that it is not plugged. Plugged filters will result in reduced gas flow to the analyzer and should be replaced.

Troubleshooting Q-S102 O_2 Analyzer

If the O_2 **signal can no longer be adjusted** with the "O_2 Span" and the Analyzer has been used for 3-5 years, the galvanic cell should be replaced. Contact Qubit Systems for instructions on ordering the new cell and on the replacement procedure.

If **significant periodic jumps** (0.5-1%) in the O_2 readings are observed, this may indicate pressure damage to the Teflon membrane inside the sensor cell. If the signal shows unexpected drift, check for other damage to the membrane by removing the Q-S102 O_2 Analyzer from the Q-Box tray by unscrewing the two bolts on the back that hold the analyzer in place. While monitoring the O_2 readings, tilt the analyzer 90 degrees. If there is a large change in the signal following the tilt, the Teflon membrane is

likely damaged. In case of damage to the membrane, the galvanic cell should be replaced. Contact Qubit Systems for replacement instructions.

If **small pulses in the O_2 readings** are observed when passing a stable O_2 gas through the analyzer, this may indicate pressure changes in the system resulting from unstable gas delivery. First, check the system for obstructions or restriction in the gas lines. Second, check the O_2 analyzer by unplugging the gas supply line from it. The reading should become stable after detaching the gas supply line. A stable reading when no gas is flowing through the analyzer, indicates that gas delivery to the analyzer is the problem.

Unstable gas delivery may be due to the Q-P103 Gas Pump. In an open-flow system, both needle valves on the Q-P103 Gas Pump should be partially restricted (as set at the time of manufacture, about 1/3 closed from the fully open position) and the flow should be adjusted via the needle valve of the Q-G266 Flow Monitor.

Using G122 Gas Bags

The heat-sealed, 30 L gas bags are made from a gas-impermeable nylon-polyethylene laminate. Tygon tubing 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-P103 Gas pump. These bags can be filled with air from a compressor (or another gas mixture) to provide a **constant source of CO_2 or O_2** for calibration. 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 pump.

Troubleshooting LabQuest Minis

LabQuest Mini 1 and 2 are switched

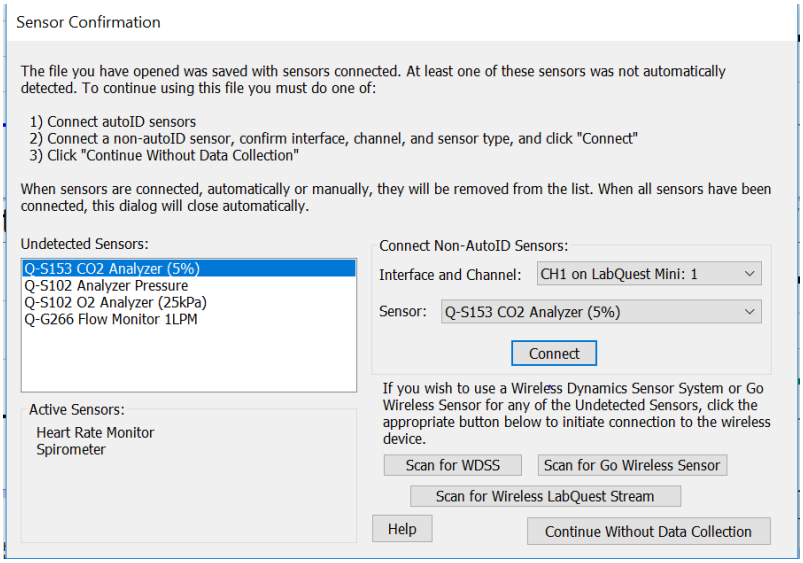
If the sensors show unusual values, Logger Pro software may have confused LabQuest Mini 1 with LabQuest Mini 2. To rectify this situation follow these steps:

Close the “Q-Box HR1LP (Resp) Setup” file. Unplug the two USB cables from the frame of the Q-Box.

First, reconnect one cable into the USB 1 outlet on the frame, then plug the second cable into the USB 2 outlet. As each LabQuest Mini is recognized by the drivers, there will be an audible beep and the indicator LED light on the LabQuest Minis will change from red to orange. Reopen the "Q-Box HR1LP (Resp) Setup" file and proceed to assigning the sensors to appropriate channels on the two LabQuest Mini interfaces as follows:

a. Ch. 1 LabQuest Mini 1 = Q-S153 CO_2 Analyzer
b. Ch. 2 LabQuest Mini 1 - Q-S102 Pressure (total gas pressure)
c. Ch. 3 LabQuest Mini 1 = Heart Rate Monitor **(auto detected)**
d. Ch. 1 LabQuest Mini 2 = Q-S102 O_2 Sensor
e. Ch. 2 LabQuest Mini 2 = Q-G266 Flow Monitor
f. Ch. 3 LabQuest Mini 2 = Spirometer **(auto detected)**

Note: Ch. 3 LabQuest Mini 1 automatically recognizes the S182 Heart Rate Monitor and Ch. 3 LabQuest Mini 2 automatically recognizes the S184 Spirometer. This configuration of the sensor connections is shown in a text box at the bottom of Logger Pro Page 1.



Using Q-G266 Flow Monitor

The Q-G266 Flow Monitor has been factory calibrated and should not require further calibration. However, if after extended use the flow values appear erroneous, the zero may have drifted. To reset zero, adjust "Flow Zero" on the front of the instrument using the small green screwdriver provided with the package. Make this adjustment with no gas running through the system, until a zero flow value is displayed in Logger Pro. **Do not accidentally adjust the "Flow Span". If "Flow Span" needs adjusting, a calibrated flow standard must be used.**

It is recommended to adjust the flow rate through the Q-Box using the needle valve on the back of the flow monitor. The flow is increased by turning the valve counter clockwise, and decreased by turning it clockwise. Once the flow is set, lock the ring on the needle valve with the small wrench. The data cable from the analog output labeled "Flow" is plugged into the data interface and the flow data is displayed in the software.

Using Q-P103 Gas Pump

The Q-P103 Gas Pump is a 1L/min (no load) pump. It is used in this Package to carry gas through the system. The Q-P103 Gas Pump is delivered with pre-set pump speed of 0.8L/min as part of the Q-Box system, and together with the Flow Monitor it delivers the gas at a flow of about 200mL/min. The two needle valves on the back of the pump are locked in position to maintain this flow of air through the system. The flow rate through the system should be adjusted with the needle valve of the Flow Monitor Q-G266.

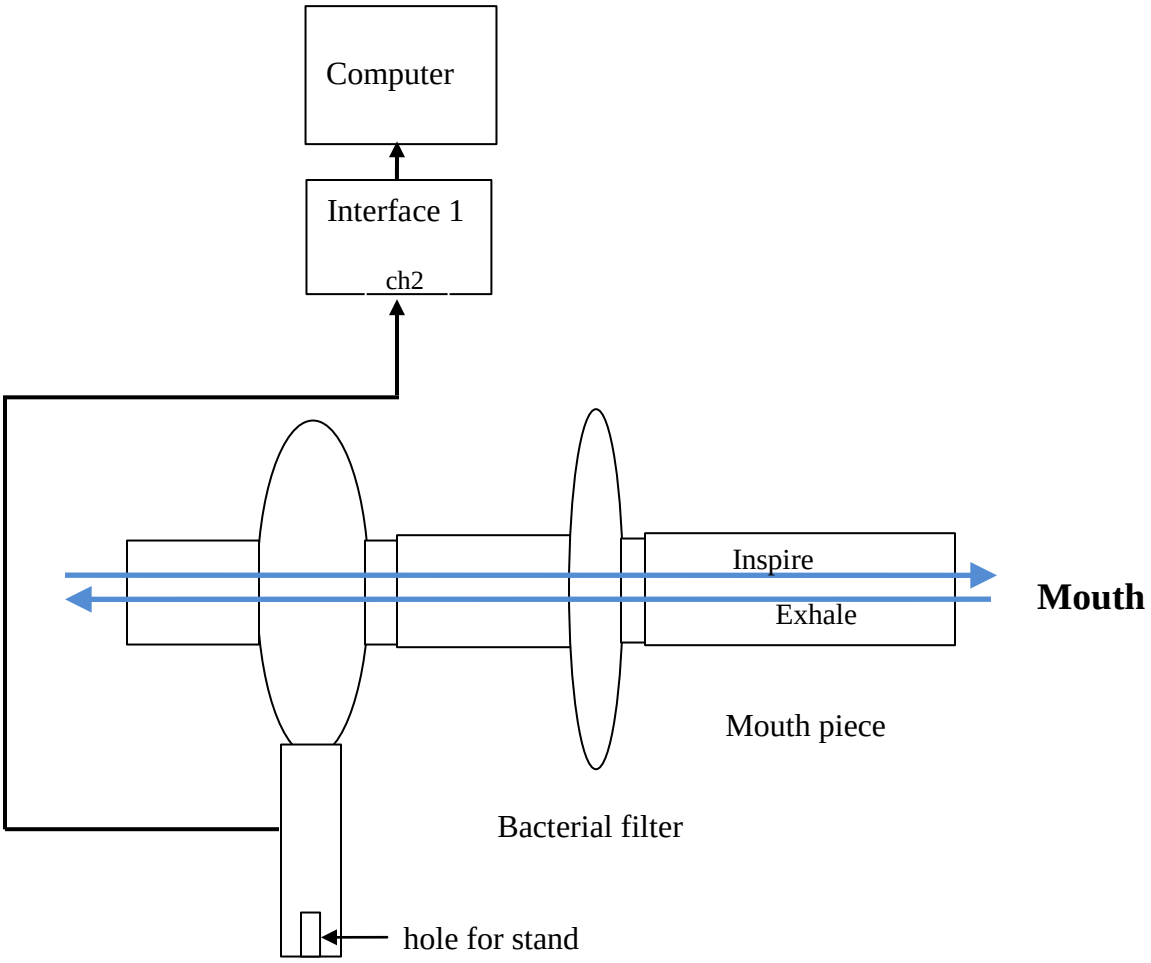
If the pump is used in a stand-alone mode and the pump speed needs to be adjusted, it can be done with the two needle valves on the back. To set the flow rate with the gas pump, initially fully open both needle valves on the back of the Q-P103 Gas Pump (turn counter-clockwise). Adjust the flow rate down to about twice the required rate using the valve beside the pump outlet ("out"). Second, reduce the flow further to the required rate with the needle valve on the Gas Pump across from the "in" gas port (see photo below).

Turn the valves on the gas pump clockwise to reduce the flow or counter-clockwise to increase the flow. Once the flow is adjusted to the desired rate, use the small wrench provided in the accessory pack to lock both valves of the gas pump with the outside nut in place to avoid accidental changes in the flow rate during experiments.

Spirometry

This section of the Q-Box HR1LP Human Respirometry package can be used as a stand-alone section when only breath flow is measured. By performing the vital capacity maneuver various lung volume and capacity parameters can be calculated from the breath flow data. The set up of the system for Spirometry alone is shown in the diagram below.

Setup Diagram for Spirometry



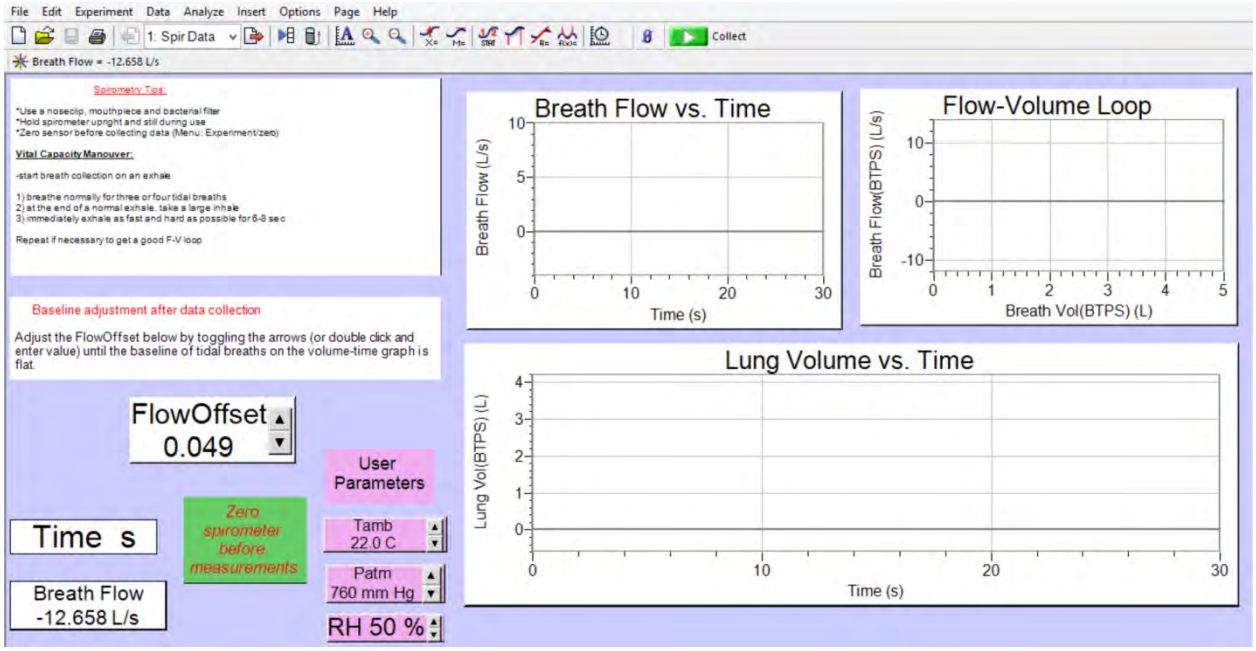
Spirometer

Quick Start Up Steps for Spirometry:

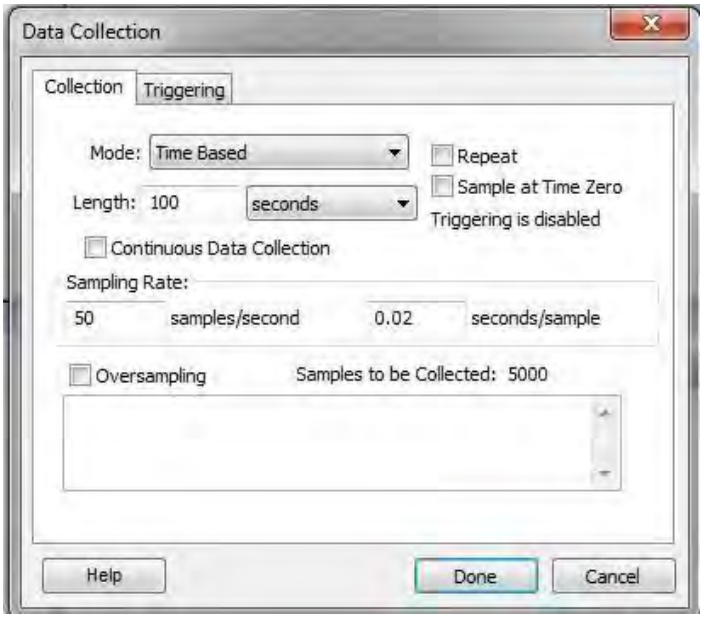
1. Load Logger Pro software onto the computer (follow instructions on pg. 30).
2. Load C404 customized setup files (follow instructions from pg. 32)
3. Plug the Q-BOX into a power supply
4. Connect USB 1 cable from the Q-Box frame to the computer via the USB hub provided; may hear an audible sound as the Labquest Mini interface 1 is recognized and drivers are loaded. Note only LabQuest Mini 1 interface is used with Spirometry stand-alone setup.
5. Open the "**Q-Box HR1LP(Spiro) Setup**" file to start Logger Pro software.

Note : Ch. 2 LabQuest Mini 1 automatically recognizes the S184 Spirometer. The Spirometer is factory calibrated and no additional calibration is required

The following screen (page 1 – Spir Data) will appear. This page contains instructions on the left side as well as Breath flow-time, flow-volume and Lung volume-time plots on the right side.



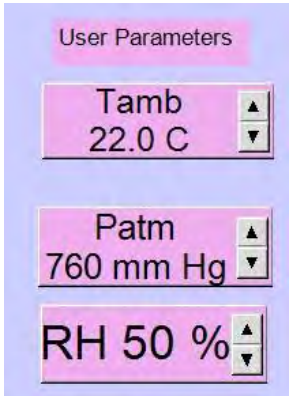
6. Before starting to collect data with Logger Pro software, select ***Experiment > Data Collection*** in the main menu. The following dialog box will appear:



Input experiment length as required. The default sampling rate is 50 samples/sec. Note that with longer experiments, the message "Performance may suffer" will appear as the data collection and data display may not be well synchronized for on the fly visualization. However, even if the display of the data lags collection, the logging of the data proceeds as normal. Click "Done".

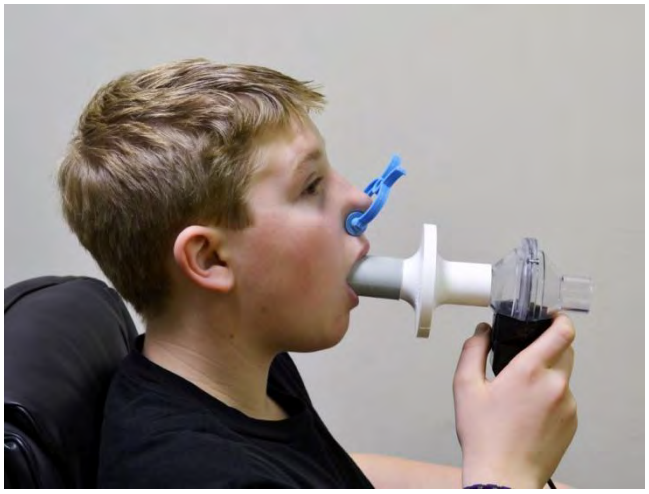
Select: ***File> Save As*** to save the experiment settings under a new file name, so that the original set up file (**Q-Box HR1LP(Spiro) Setup**) is not over-written.

7. Before starting data collection, three User Parameters need to be entered in the software on Page- 1 Spir Data (bottom left side). These parameters are ambient temperature in °C (Tamb), atmospheric pressure in mmHg (Patm) and ambient relative humidity in % (RH). These parameters are used in converting volume to BTPS (body temperature, ambient pressure, fully saturated with water vapor). The default values may be altered if local values are known. These parameters can also be obtained from external sensors (not included in this package).



8. Assemble the Spirometer, bacterial filter and mouthpiece as shown in the photo below.

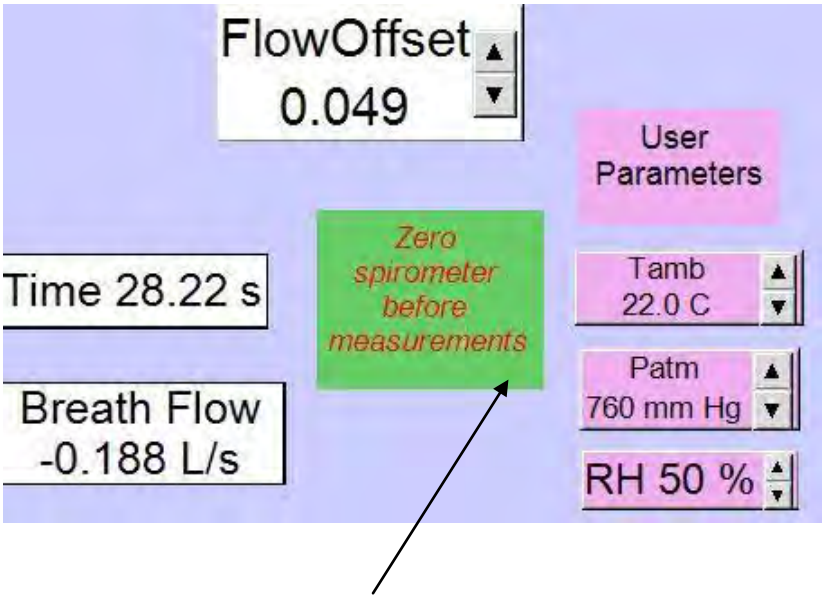
9. Have subject insert mouthpiece into mouth as shown in the photo below. Use a nose clip to force mouth breathing.



10. Start data collection by clicking the green button “Collect” and stop data collection by clicking the red button “Stop” (green “collect” turns into red “stop” during data logging).

11. Ensure that the spirometer is held **upright and still** throughout the experiment since tilting may affect the readings. While **holding the breath,** the spirometer should be **zeroed** to obtain the base line. Select from the top menu ***Experiment<Zero*** and watch the values in the Breath Flow meter (right hand side bottom of page 1) drop to zero. A reminder message to zero the Breath Flow (Spirometer) is shown on the first page of the software (see below).

12.



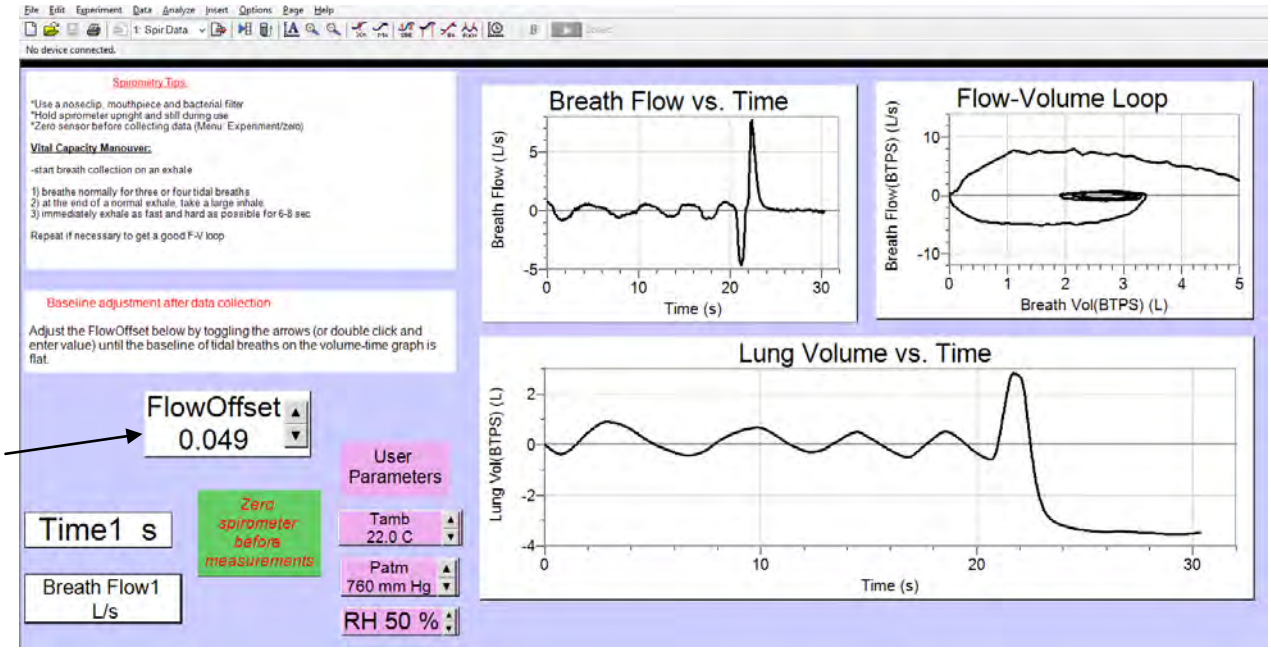
Vital Capacity Maneuver

Many lung and breath parameters can be obtained from breath flow measured by a spirometer. See Figures 1, 2 and Table 2 in the Appendix for a full discussion of lung parameters. These parameters can be obtained from the volume-time and flow-volume plots produced by a vital capacity (VC) maneuver. The maneuver consists of normal tidal breathing followed by a large inhale and immediate forceful expiration (for 6-8 sec) until the lungs are completely empty.

To perform a VC Maneuver:

- start breath collection on an exhale
- breathe normally for three or four tidal breaths
- at the end of a normal exhale, take a large inhale
- immediately exhale as fast and hard as possible for 6-8 sec

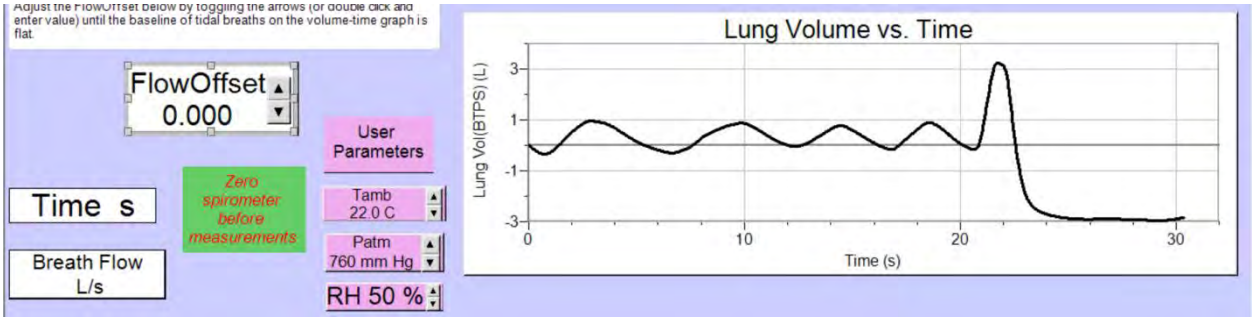
Typical Spirometry data (page 1) for a VC maneuver is shown below.



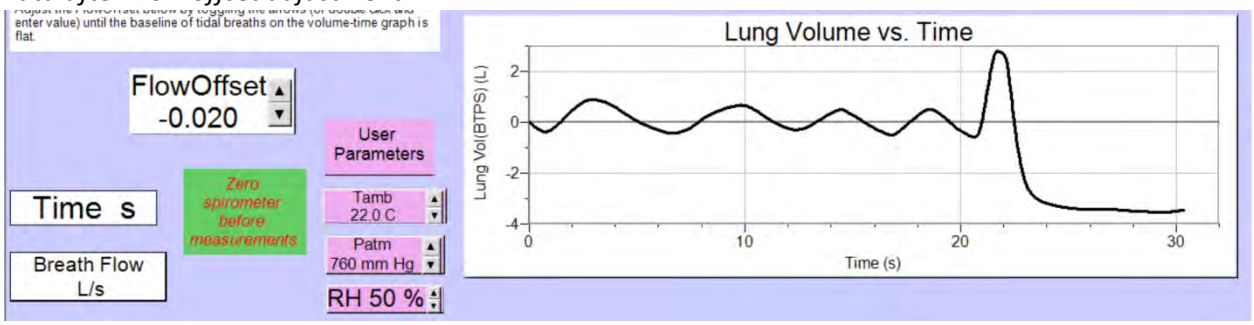
Baseline adjustment after data collection

Adjust the **FlowOffset** by toggling the arrows (or double click and enter value) until the baseline of tidal breaths on the volume-time graph is flat.

Data with no Flow offset:



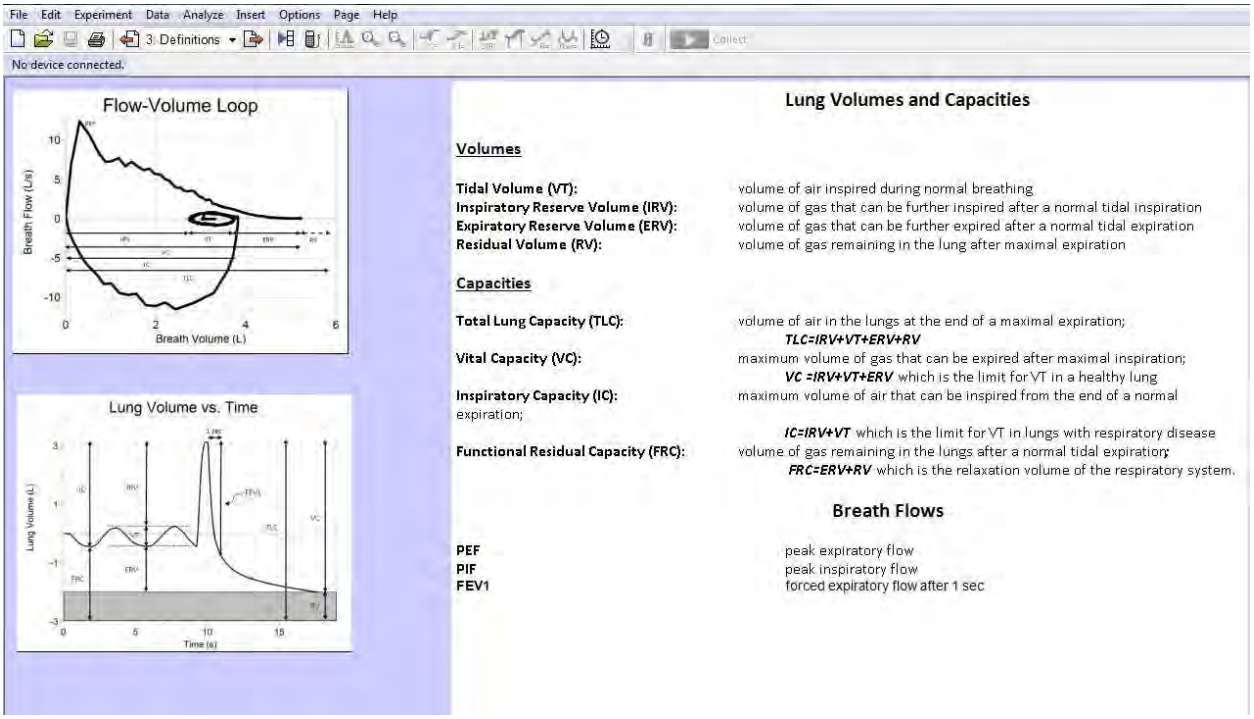
Data after Flow offset adjustment:



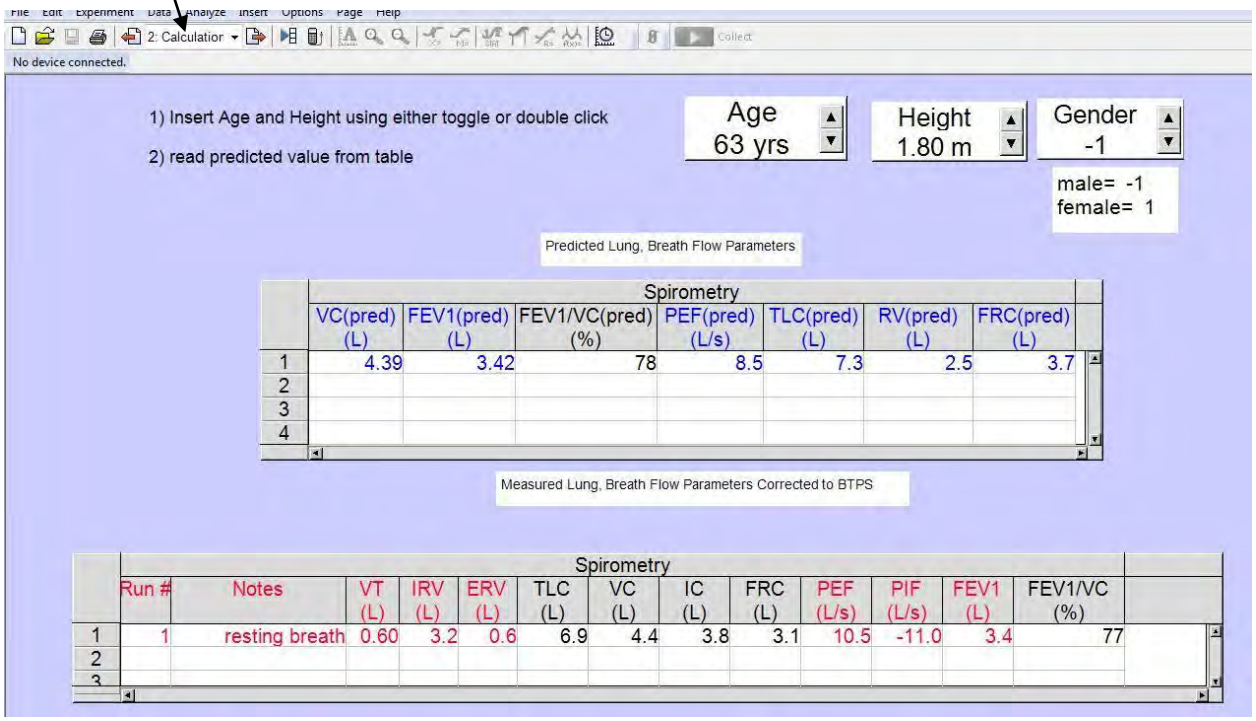
Reading Differential Volumes and Flows from V-t and F-V Plots

Obtain VT, IRV, ERV, PEF, PIF and FEV1 values from the V-t and F-V plots on the Raw data (page 1). **Note:** (Δx, Δy) can be obtained by holding left tab and dragging cursor across region of interest, keeping crosshairs on the data

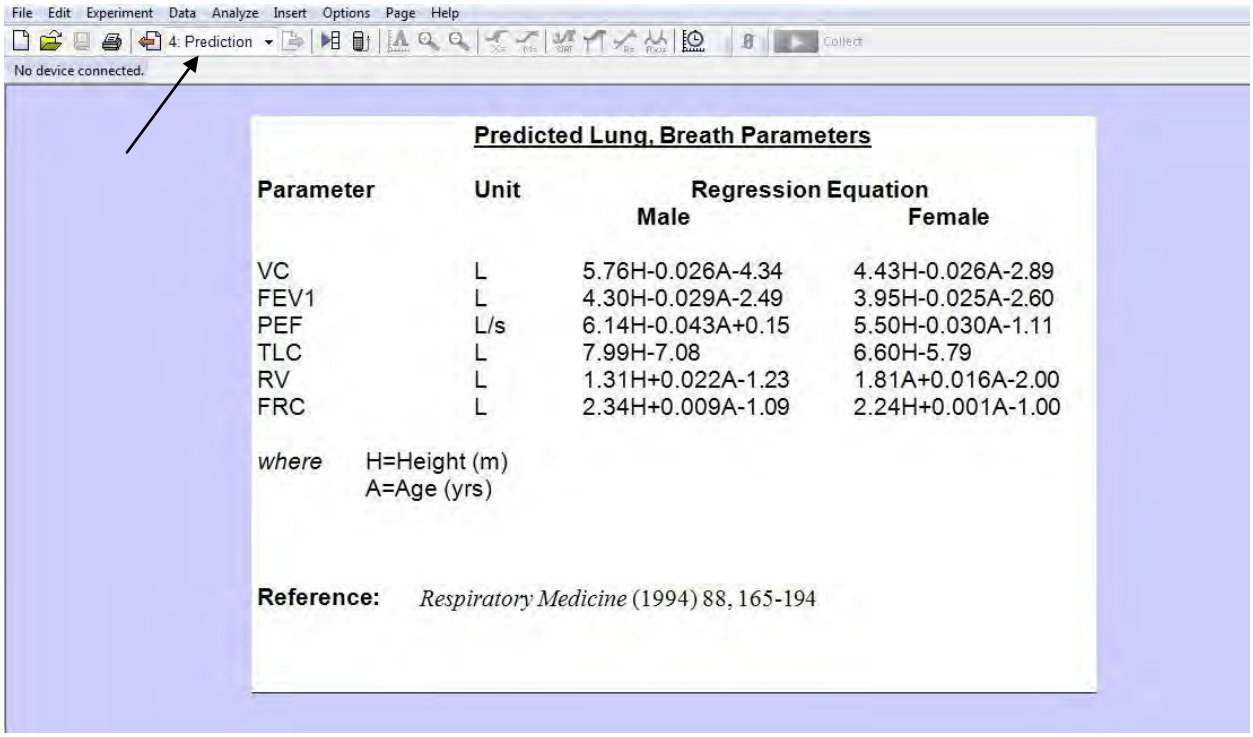
To assist with identifying VT, IRV etc, definitions of lung parameters and typical V-t and F-V plots are presented on Page 3 – Definitions as shown below. Please note that for the FlowVolume loop and Lung Volume vs. Time plots to be visible the data file has to reside on the same computer where the **Q-Box HR1LP(Sprir) Setup** file resides together with the two image files (F-V Loop.jpg and V-t plot.jpg). these were transferred from the C404 disk at the time of software installation.



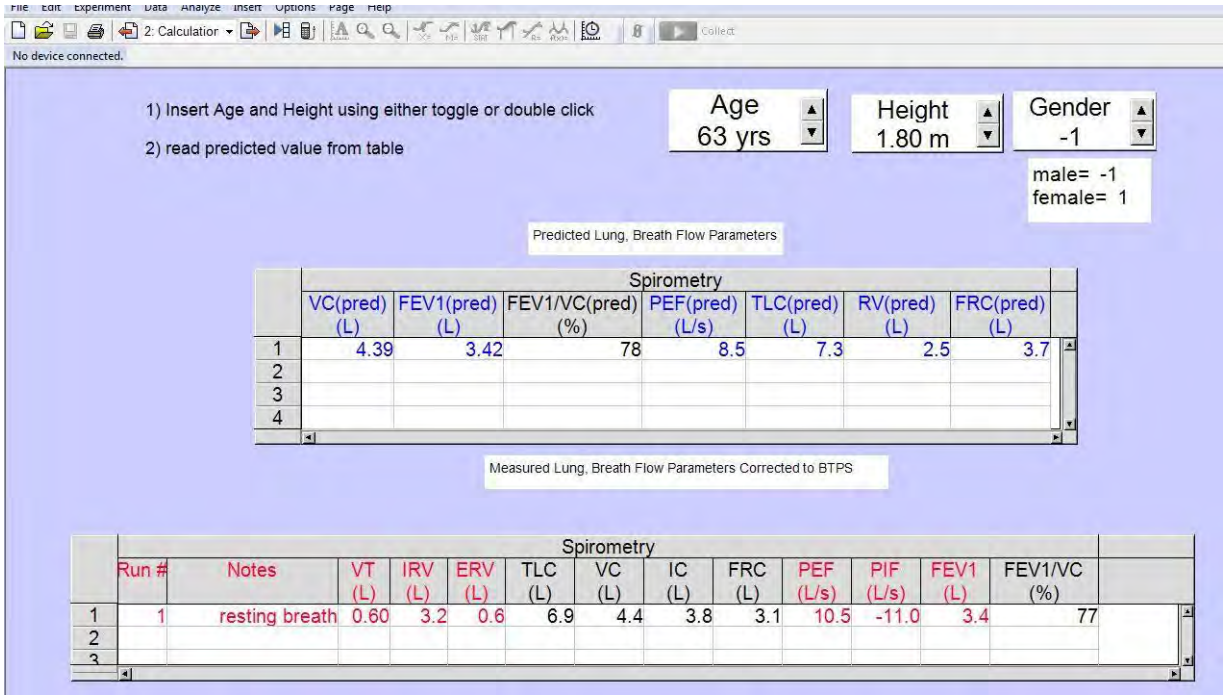
On page 2, the user parameters “Age”, “Height” and “Gender” must be entered to obtain the correct predicted values for the subject. These predicted values are presented in the upper table on page 2 Calculations.



The prediction equations used in calculations of predicted lung breath flow parameters based on age, height and gender are shown on page 4 Predictions.



12. The values for VT, IRV etc obtained from page 1 should be entered in the red columns of the bottom table on the calculations page (page 2) shown below. Calculations are automatic in the black columns when all input data has been entered.



Specifications of Q-S153 CO2 Analyzer

Operating principle	Non-dispersive infrared
Gas sampling mode	Flowing gas stream, sealed chamber
Maximum gas flow rate	650 mL/min
Measurement range (LCD display)	0-10 %
Analog output, low sensitivity	0-10 %
Analog output, high sensitivity	0 -5 %
Accuracy (assumes accurate recent calibration)	0.3% of FS
Resolution	0.01%
Repeatability (assumes stable atm press and temp)	Better than ±1%
Maximum drift (per year)	±0.5%
Response time (@ 250 mL/min; to 95% of final value)	ca. 20 sec
Warm up time (@ 22^{o}C)	ca. 5 min
Output (linear) for Low Sensitivity setting	0-5 VDC for 0-10 %
Output (linear) for High Sensitivity setting	0 -5 VDC for 0-5 %
Calibration adjustments	Zero and Span
Operating temperature range	0 to 50^{o}C
Storage temperature range	-40 to 70^{o}C
Operating pressure range	±1.5% local mean pressure
Humidity range	5 to 95% RH, non-condensing (Recommend drying gas stream)
Pressure dependence	+0.19% reading per mm Hg
Power requirements	12 VDC via 120 VAC/60 Hz adapter
Current requirements	175 mA average, 450 mA peak
Dimensions (cm)	(H x W x D: 5.5 to 9.5 x 9.5 x 17cm)
Weight	1kg
Warranty	1 year limited

Specifications of Q-S102 O_2 Analyzer:

- Operating principle - Acid Electrolyte, Teflon Diffusion Membrane
- Detection Range - 0-25% and 0-100 %O2 (Linear)
- Resolution - ±60 ppm
- Accuracy ± 0.21% of Full Scale
- Response Time (90%) - 12 Seconds
- Life Expectancy of sensor - 3-5 years
- Easy sensor replacement
- Influence by Other Gases - Ammonia and Ozone
- min flow - 5 mL/min
- max flow - 650 mL/min
- Built in total gas pressure reading at the sensor (for pressure correction in the software)
- Pressure Range - 0.5 atm to 1.5 atm

- Pressure Effect - Output voltage changes proportionally
- Shock Resistant - to 2.7 G
- Avoid strong vibration
- Operating Temperature - 5 to 40^{o}C (Effective range)
- Weight – 1.35 kg
- Dimensions (cm) – (H x W x D: 5.5 to 9.5 x 9.5 x 17)
- Output - 0 to 5 volt
- Power Supply - 12 Volts

Specifications of S184 Spirometer

Flow Rate	+/-10 L/s
Dead Space	93 mL
Nominal Output	60 µV/(L/s)
Detachable Flow Head	
Dimensions	80.5 mm (diameter) x 101.5 mm (length)
Weight	80 g
Construction	clear acrylic plastic
Handle	
Dimensions	127 mm x 23 mm x 35 mm
Mass	85 g
Construction	black ABS plastic
Cable Length	1.5 meters
Default Sampling Rate	100 samples/s
Stored calibration	
Slope	7.1869 (L/s)/V
Intercept	-17.9672 L/s

Appendix

Respirometry:

Basic Respiratory Physiology

In biochemistry, respiration is considered to be the O_2-requiring chemical processes in tissues and cells. In physiology, the term respiration is used to mean "breathing". The human respiratory system functions to supply O_2 to blood, and to eliminate CO_2 from the blood. O_2 and CO_2 diffuse between the air in the alveoli and the capillaries, which supply the alveoli. During inspiration, the volume of the thoracic cavity increases and air is drawn into the lungs. The increase in volume is caused by the diaphragm, which moves downward as it contracts, and by the intercostal muscles, which raise the ribs as they contract, thereby increasing the cross-sectional area of the thorax. During expiration, the diaphragm and intercostal muscles relax, forcing air out of the lungs. At rest, especially in the supine position, the increase in the volume of the plural cavity is largely due to the action of the diaphragm. During exercise,

the contraction of the intercostals plays a disproportionately large role in the expansion of the plural cavity.

Respiratory Exchange Ratio and Respiratory Quotient

The difference in inhaled and exhaled O_2 and CO_2 concentrations can be used to calculate the *respiratory exchange ratio*, RER:

$$\textbf{RER} = (\textbf{CO}_2 \textbf{ Production})/(\textbf{O}_2 \textbf{ Consumption}) = \dot{V}\textbf{CO2}/\dot{V}\ \textbf{O}_2$$

In steady state at rest, this is equivalent to the *respiratory quotient* (RQ). At rest, the RQ is usually between 0.7 and 1.0. It is defined as the number of CO_2 molecules produced relative to the number of O_2 molecules consumed by intermediary metabolism. The body obtains chemical energy and heat from carbohydrates, fats and proteins through glycolysis and oxidative phosphorylation in order to do muscle work and maintain body temperature. The ratio of these three macromolecules used depends on the type of exercise as well as the reserves of carbohydrates in the body. At rest ~40% of the energy comes from carbohydrates and 60% from fats. With increased work the energy production shifts to oxidation of carbohydrates, a much faster reaction. Protein is used as an energy source only when the reserves of carbohydrates are low such as during starvation or after extreme, prolonged exercise. This can cause tissue damage.

Carbohydrate: The oxidation of glucose, a typical carbohydrate, is shown by

$$6O_2+C_6H_{12}O_6 \longrightarrow 6CO_2+6H_2O \qquad (1)$$

Equation (1) predicts an $RQ=6CO_2/6O_2=1$.

Fatty Acid: The oxidation of palmitic acid, a typical fatty acid, is shown by

$$23O_2+C_{16}H_{32}O_2 \longrightarrow 16CO_2+16H_2O \qquad (2)$$

Equation (2) provides an RQ=16/23=0.7

Thus RQ is directly related to a subject's diet. As indicated by the above equations, in metabolizing carbohydrate alone, the body produces 1 CO_2 molecule for every O_2 molecule consumed, for an RQ of 1.0. In metabolizing fat alone, the body produces 0.7 of a CO_2 molecule for every O_2 molecule consumed, for an RQ of 0.7. At rest, the RQ is usually about 0.85, which reflects a balance between fat and glucose oxidation. During exercise, the RER increases with the level of exercise intensity. This is due to a progressive shift from fat to carbohydrate metabolism. The increase in blood lactate concentration at higher levels of exercise leads to an increase in RER that is not related to the type of substrate utilized. RER increases because of the CO_2 that is produced when the lactate is buffered by sodium bicarbonate. In exercise above the lactate threshold, the RER is often greater than one.

The Q-Box HR1LP package measures air volume breathed as well as CO_2 and O_2 concentrations in the mixed expired breath. This provides a measure of oxygen consumption, $\dot{V}O_2$, and carbon dioxide produced, $\dot{V}$CO2, and hence **RER=$\dot{V}$CO2/$\dot{V}$ O_2**. Consequently, RER provides a measure of the food

metabolized (carbohydrate/fat ratio) and in turn the energy produced per liter of O_2 consumed as shown by Table 1. RER has been used to monitor metabolic response in diabetics to pulsatile insulin treatments (Hall et al, 1979).

Table 1: Relation Between RER, Energy and Food Source

RER	Energy ($kCal/LO_2$)	% Energy from Carbohydrate	% Energy from Fat
0.7	4.69	0	100
0.75	4.74	15.6	84.4
0.80	4.80	33.4	66.6
0.85	4.86	50.7	49.3
0.90	4.92	67.5	32.5
0.96	4.99	84.0	16.0
1.00	5.05	100	0

The amount of energy released during food oxidation can be measured with **indirect calorimetry** by using breath measurements to measure O_2 consumption. The amount of heat released during food oxidation is directly proportional to the amount of O_2 consumed, as well as to the type of macromolecule being used. The amount of heat produced for each litre of oxygen consumed in the metabolism of carbohydrate, fat or protein is slightly different. The values are 5.0 kCal/L O_2, 4.7 kCal/L O_2, and 4.5 kCal/L O_2 for carbohydrate, fat, and protein respectively. The average value of 4.8 kCal/L O_2 is generally used in calculating metabolic rate; however, it is important that the composition of the subject's diet be taken into consideration.

Cellular Respiration

At lower work levels, most of the energy used for muscle contraction comes from aerobic sources. Aerobic respiration involves the oxidation of glucose to pyruvate through a set of chemical reactions called *aerobic glycolysis*. During aerobic glycolysis, energy released from each glucose molecule is stored in the conversion of 2 adenosine diphosphate (ADP) molecules into 2 adenosine triphosphate (ATP) molecules:

$$C_6H_{12}O_6 + 2NAD + 2ADP + 2pi \longrightarrow 2Pyruvate + 2NADH_2 + 2ATP$$

The subsequent phosphorylation of the 2 NADH2 yields another 4 – 6 ATP. Pyruvate is oxidized to CO_2 via the chemical reactions of the Tricarboxylic Acid Cycle. The energy released is stored in electron carriers such as NAD (nicotinamide adenine dinucleotide) and FAD (flavine adenine dinucleotide). Energy is stored through the addition of high-energy electrons to NAD and FAD. This process is called reduction. $NADH_2$ and $FADH_2$ later transfer their high-energy electrons to a series of compounds, which comprise the electron transport chain. In the electron transport chain, the energy stored in $NADH_2$ and $FADH_2$ is used to form 30 more ATP. O_2 is the final electron acceptor in the electron transport chain.

The Ventilatory and Lactate Thresholds

Even at rest and during moderate exercise, there is some lactic acid production through *anaerobic glycolysis*. Anaerobic glycolysis does not involve the Tricarboxylic Acid Cycle or the electron transport chain. It produces only 2 ATP per glucose molecule, whereas aerobic respiration produces 36 ATP per

glucose molecule in muscle cells. As exercise intensity increases, blood lactate levels start to rise exponentially. The point at which this occurs is called the ***lactate threshold*** or the "onset of blood lactate accumulation" (OBLA). This happens in untrained subjects at about 50 - 60% of maximal $\dot{V}O_2$. In trained subjects, it occurs at about 65 – 80% of maximal $\dot{V}O_2$.

The lactate threshold is the point at which lactate production exceeds lactate removal from the blood. The sudden increase in blood lactate at the threshold does not necessarily indicate O_2 deficiency in the working muscle. Several other processes contribute to the exponential rise in blood lactate beyond the lactate threshold. Increased release of norepinephrine causes the constriction of blood vessels in the arterioles of non-working muscles and in the liver, kidneys and adipose tissue. There is a concurrent increase in blood flow to the working muscle, and an overall redistribution of blood flow from lactateconsuming (gluconeogenic) tissues to lactate-producing tissues. Contraction of the working muscles results in the release of Ca^{2+} from the sarcoplasmic reticulum. This increases the rate of *glycogenolysis* (glycogen breakdown) through the activation of phosphorylase kinase. The release of epinephrine and glucagon at high levels of exercise also greatly accelerates glycogenolysis and glycolysis. Pyruvate is therefore produced at a rate that exceeds the rate of mitochondrial respiration, so the excess pyruvate is converted to lactate. In addition, the recruitment of a larger proportion of fast glycolytic muscle fibres at higher levels of exercise, leads to greater anaerobic glycolysis and lactate production. (These fibres produce lactic acid when they are recruited to contract, whether O_2 is present or not.)

There is also an exponential rise in VE at about 50 – 75% of maximal $\dot{V}O_2$. This is known as the ***ventilatory threshold***. The accumulation of lactate in the blood after the lactate threshold was once thought to be the primary cause of the exponential increase in VE, but it has been shown that VE increases exponentially even in subjects who are genetically incapable of producing lactate. Also, there can be as much as an 8% difference in the relative work rates at the lactate threshold and at the ventilatory threshold in the same subject. The ventilatory threshold is now considered to be an indicator of the onset of metabolic acidosis. This acidosis is accompanied by a small increase in $PaCO_2$, which results in increased neural output to the respiratory centre as well as increased ventilation.

Basic Cardiovascular Physiology

Heart Rate Response to Exercise

The normal resting heart rate for a non-athlete is about 70 beats per minute (bpm). Athletes can have much lower resting heart rates.

Just prior to exercise, there is some anticipatory increase in heart rate. Within seconds of the onset of exercise there is a further increase in heart rate due to the withdrawal of parasympathetic stimulation (vagal outflow) to the heart followed by increased sympathetic stimulation of the heart. Sympathetic nerve fibres reach the heart by means of the cardioaccelerator nerves, which enervate both the sinoatrial node and the ventricles. The hormone norepinephrine is released at the ends of these fibres. Sympathetic stimulation causes an increase in both heart rate and the force of myocardial contraction. The parasympathetic fibres that supply the heart, arise from neurons in the cardiovascular control centre in the medulla oblongata. These fibres make up a portion of the vagus nerve. When stimulated, these nerve endings release acetylcholine, which causes a decrease in the activity of both the sino-atrial and atrioventricular nodes, thus reducing the heart rate. Withdrawal of parasympathetic stimulation raises heart rate. The initial, rapid response of heart rate to exercise is thought to be due to central command from the cerebral cortex.

As the exercise level is raised, there is an increase in sympathetic stimulation to the heart and systemic blood vessels, which is proportional to the relative work rate. This causes an increase in heart rate, constriction of capacitance vessels in the splanchnic bed and constriction of resistance vessels in the kidneys and splanchnic bed. The increased sympathetic stimulation with exercise is caused by central command from the cerebral cortex, and by feedback from muscle chemoreceptors, mechano-receptors and arterial baroreceptors (pressure sensors).

Change in Blood Distribution with Exercise

During exercise, there is a decrease in systemic vascular resistance that is proportional to the amount of exercising muscle mass. The resistance vessels in the exercising muscle dilate rapidly due to the increased local concentration of metabolites, which releases the vessels from the influence of the sympathetic nerves. Arterial blood pressure is maintained because of the constriction of the resistance vessels in the splanchnic bed and the kidneys. Arterial and cardiopulmonary mechanoreceptors prevent marked fluctuations in arterial pressure. The active mobilization of blood from the constriction of the capacitance vessels and the resistance vessels, together with the passive mobilization of blood from arteriolar constriction in non-working areas, ensures the maintenance of an adequate filling pressure for the heart, and allows for the maintenance or increase of stroke volume.

Response of Stroke Volume to Exercise

Stroke volume (mL/min) is the amount of blood ejected from the ventricles with each beat of the heart. The stroke volume of an exercising subject is proportional to the relative work rate until about 40% of the subject's maximal $\dot{V}O_2$, when maximum stroke volume is reached. Stroke volume increases if venous return is enhanced , and decreases if average aortic pressure rises.

Response of Cardiac Output to Exercise

Cardiac output (L/min), is the product of heart rate and stroke volume. In exercise, cardiac output is increased through greater cardiac activity and augmented return of venous blood from the contracting muscles. At work rates higher than 40% of maximal $\dot{V}O_2$, increases in heart rate are responsible for all of the subsequent changes in cardiac output.

Blood Pressure

Systolic pressure is the maximal pumping pressure generated by the left ventricle during the contraction of the heart; ***diastolic pressure*** is the lowest pressure existing in the main arteries of the systemic circuit during the resting phase of a cardiac cycle. Blood pressure is reported as systolic pressure / diastolic pressure in millimetres of mercury (mmHg). In a normal subject, blood pressure would be approximately 120/80 mmHg at rest.

Control of Blood Pressure in Exercise

During exercise, there is a dramatic increase in systolic pressure, but little change in diastolic pressure. Pressure should return to resting levels within 4 minutes of the end of exercise. Blood pressure rises in response to increased blood volume, heart rate, stroke volume, viscosity, and peripheral resistance.

Short-term regulation of blood pressure is achieved by the sympathetic nervous system. Increases in blood pressure are detected by the aortic and carotid body baroreceptors. These receptors send impulses to the cardiovascular control centre, which responds by decreasing sympathetic activity. A decrease in sympathetic activity reduces cardiac output and vascular resistance, which lowers blood pressure. An increase in sympathetic activity has the opposite effect.

The Effects of Training

Cardiovascular training causes a significant increase in stroke volume at rest and during exercise. Therefore, in order to attain a given level of cardiac output, a trained subject requires a lower heart rate than an untrained subject. An average subject's cardiac output in the resting state is 5.6 L/min. For an average stroke volume of 80 mL, this corresponds to a heart rate of 70 bpm. In contrast, a heart rate of only 60 bpm is required to achieve the same cardiac output with a "trained" resting stroke volume of 93 mL. Heart rate is also lower in trained subjects because there is an increase in parasympathetic activity and a decrease in sympathetic discharge with training. In mild exercise, the heart rate of a trained subject may rise to 90 bpm, whereas the heart rate of an untrained subject could reach 120 bpm. For an individual subject, there is a linear relationship between heart rate and relative work rate. Other adaptations to training include lower systolic and diastolic blood pressure and increased glycogen stores, blood volume, total haemoglobin, myocardial contractility, and O_2 extraction, as well as more effective distribution of blood flow.

At a given level of exercise, a trained subject ventilates less than an untrained subject. This reduces the total O_2 cost of breathing (The O_2 uptake required by the muscles used for breathing). Generally, in trained subjects, tidal volume is larger and breathing frequency is reduced. Air remains in the lungs for a longer period of time between breaths, so O_2 extraction from the air is increased. As a result, the exhaled air of trained subjects often contains only 14 – 15% O_2 during sub-maximal exercise, whereas the exhaled air of untrained subjects may contain 18% O_2 at the same work rate.

In examining the differences in exercise response between trained and untrained subjects working at the same absolute level of exercise, one must consider that the untrained subjects will be working at a higher relative level of exercise than the trained subjects. (They will be working at higher percentages of their maximal O_2 uptakes.) The response levels of many physiological variables, such as heart rate and breathing frequency, depend on the relative rather than the absolute level of exercise. Lower heart rates should be observed in the trained subject at any given absolute level of work. In part, this is due to the training-induced increase in stroke volume; however, the difference in response can also be attributed to the trained subject working at a lower percentage of his or her maximal $\dot{V}O_2$ than the untrained subject. Heart rate and ventilation recovery times for a given absolute level of work tend to be much faster in trained subjects than in untrained subjects because the trained subjects are recovering from a lower relative level of work.

Spirometry:

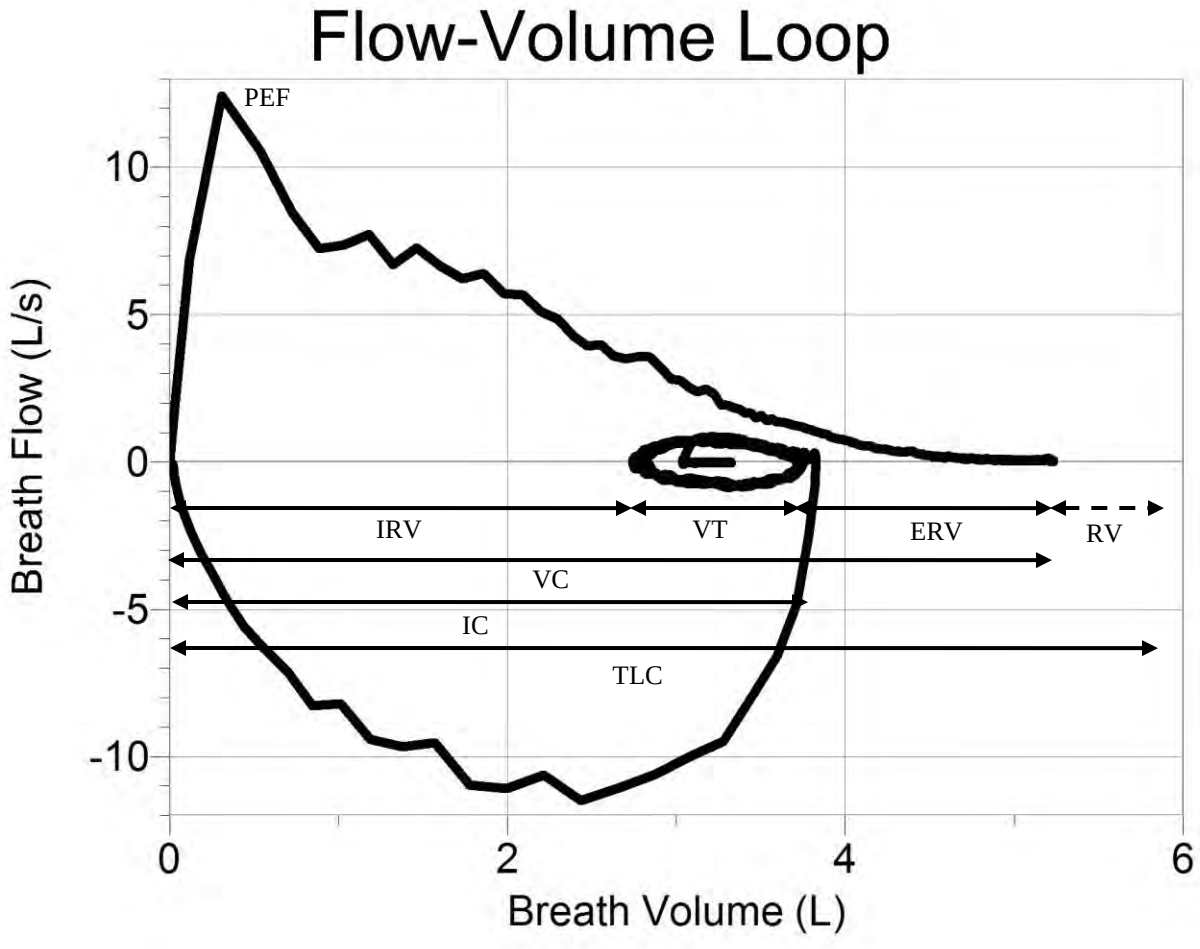
Breathing Frequency and Tidal Volume

At rest, about 300 – 500 mL of air enter the lungs with each inspiration. For the average healthy person, the breathing frequency at rest is 12 – 15 breaths per minute.

Tidal volume, **VT**, is the volume of air inspired or expired during a breath. Additional air, called the inspiratory reserve volume, **IRV**, may be inhaled after a resting inspiration. Likewise, after a tidal expiration, further volume called the expiratory reserve volume, **ERV**, can be expelled from the lungs. Even when the ERV is forcefully exhaled, there remains a volume of gas in the lungs, the residual volume, **RV**, which cannot be exhaled. This gas has a high CO_2 concentration which has diffused across the alveolar membranes in the lung from the blood capillaries. This CO_2 is removed by exhaling when fresh air is inhaled and mixed with the residual gas. The residual volume cannot be measured by the QBox HR1LP package and requires other methods such as whole body plethysmography or tracer gas washout. During exercise when O_2 demand and CO_2 production is higher, tidal volumes are increased by using the reserve volumes to match the gas exchange at the alveoli to the metabolic demands in the muscles.

Figure 1 presents an ideal Flow-Volume loop whereas Figure 2 shows a Volume-Time plot. From these graphs, several lung volume parameters and lung capacities can be extracted. The various lung volumes and capacities which are defined in Table 2 can be used to diagnose lung diseases (M.R. Miller et al, 2005). Typical values for healthy lungs are shown in Table 3.

Figure 1: Ideal Flow-Volume Loop for a Healthy Lung



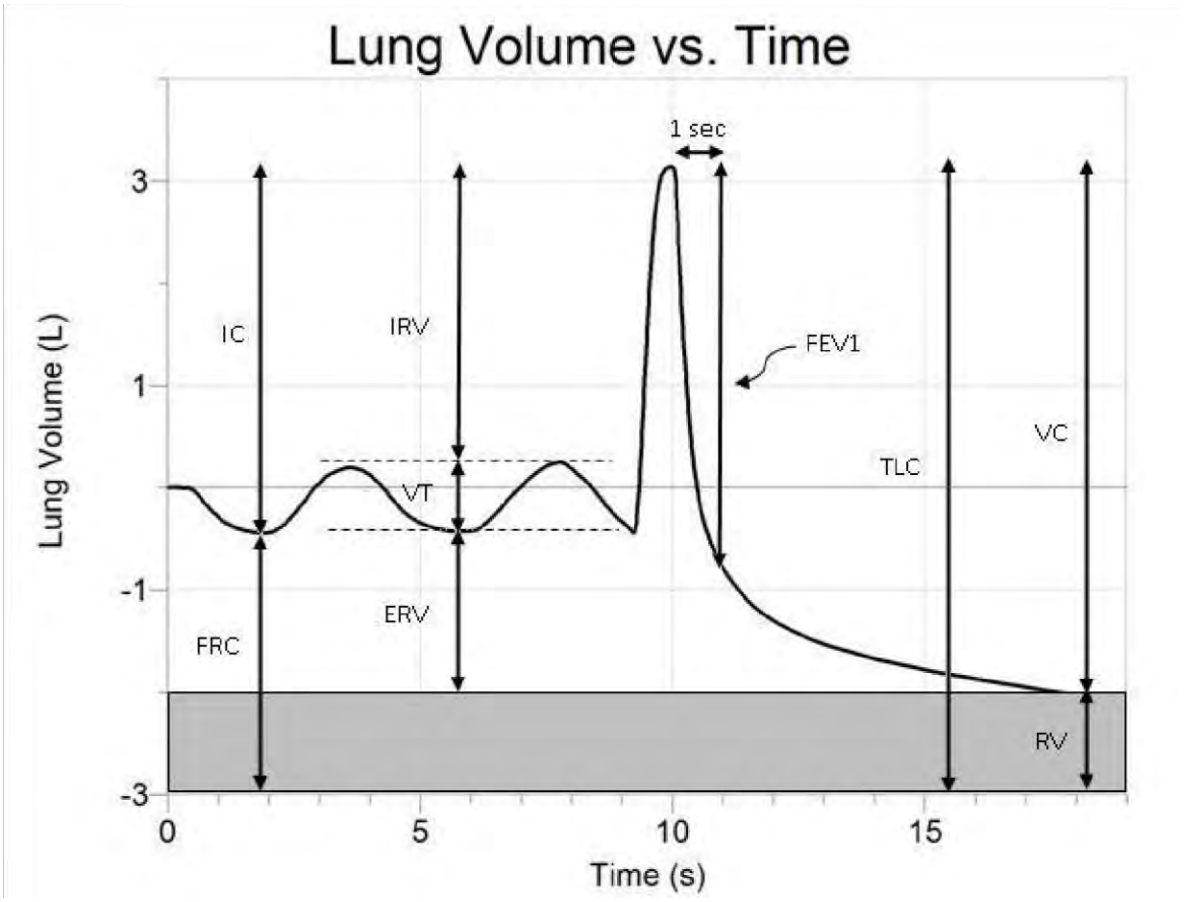


Figure 2: Ideal Volume-Time Plot for Lung

Table 2: Lung Volumes and Capacities

<u>Volumes</u>

Tidal Volume (VT):
volume of air inspired during normal breathing

Inspiratory Reserve Volume (IRV):
volume of gas that can be further inspired after a normal tidal inspiration

Expiratory Reserve Volume (ERV):
volume of gas that can be further expired after a normal tidal expiration

Residual Volume (RV):
volume of gas remaining in the lung after maximal expiration

End-Inspiratory Lung Volume (EILV):
volume of air at the end of a normal inspiration

End-Expiratory Lung Volume (EELV):
volume of air at the end of a normal expiration

Capacities

Total Lung Capacity (TLC):

volume of air in the lungs at the end of a maximal expiration; ***TLC=IRV+VT+ERV+RV***

Vital Capacity (VC):

maximum volume of gas that can be expired after maximal inspiration; ***VC =IRV+VT+ERV*** which is the limit for VT in a healthy lung

Inspiratory Capacity (IC):

maximum volume of air that can be inspired from the end of a normal expiration; ***IC=IRV+VT*** which is the limit for VT in lungs with respiratory disease

Functional Residual Capacity (FRC):

volume of gas remaining in the lungs after a normal tidal expiration***; FRC=ERV+RV*** which is the relaxation volume of the respiratory system.

Table 3: Typical Healthy Lung Volumes and Breath Parameters

Lung Parameters

Parameter	Definition	25 yr old 6' male	55 yr old 5' female	units
VC	Vital Capacity	5.4	2.4	L
FRC	Functional Residual Capacity	4.0	2.2	L
RV	Residual Volume	1.9	1.4	L
TLC	Total Lung Capacity	7.3	3.8	L
FEV1	Forced Expired Volume in one sec	4.4	2.0	L
FEV1/VC	FEV1/Vital Capacity Ratio	80	75	%

Resting Ventilation and Gas Transport Parameters

Parameter	Definition	Value	units
RR	Respiratory frequency	12-16	bpm
VE	Minute Ventilation	6-8	L/min
VT	Tidal Volume	0.5	L
VDanat	Anatomic Dead Space	150-200	mL
VDanat/VT	Ratio of Dead to Tidal Volume	<0.4	
$\dot{V}O_2$	Oxygen Consumption	250-300	mL/min
$\dot{V}$CO2	Carbon Dioxide Production	200-250	mL/min
RER	Respiratory Exchange Ratio	0.8	

(http://courses.washington.edu/hubio541/secure/syllabus/EApp1_RespParameters.pdf)

The following table presents linear regression equations for predicting several lung and breath parameters based on gender, age and height.

Predicted Lung, Breath Parameters

Parameter	Unit	Regression Equation	
		Male	Female
VC	L	5.76H-0.026A-4.34	4.43H-0.026A-2.89
FEV1	L	4.30H-0.029A-2.49	3.95H-0.025A-2.60
PEF	L/s	6.14H-0.043A+0.15	5.50H-0.030A-1.11
TLC	L	7.99H-7.08	6.60H-5.79
RV	L	1.31H+0.022A-1.23	1.81A+0.016A-2.00
FRC	L	2.34H+0.009A-1.09	2.24H+0.001A-1.00

where H=Height (m)
A=Age (yrs)

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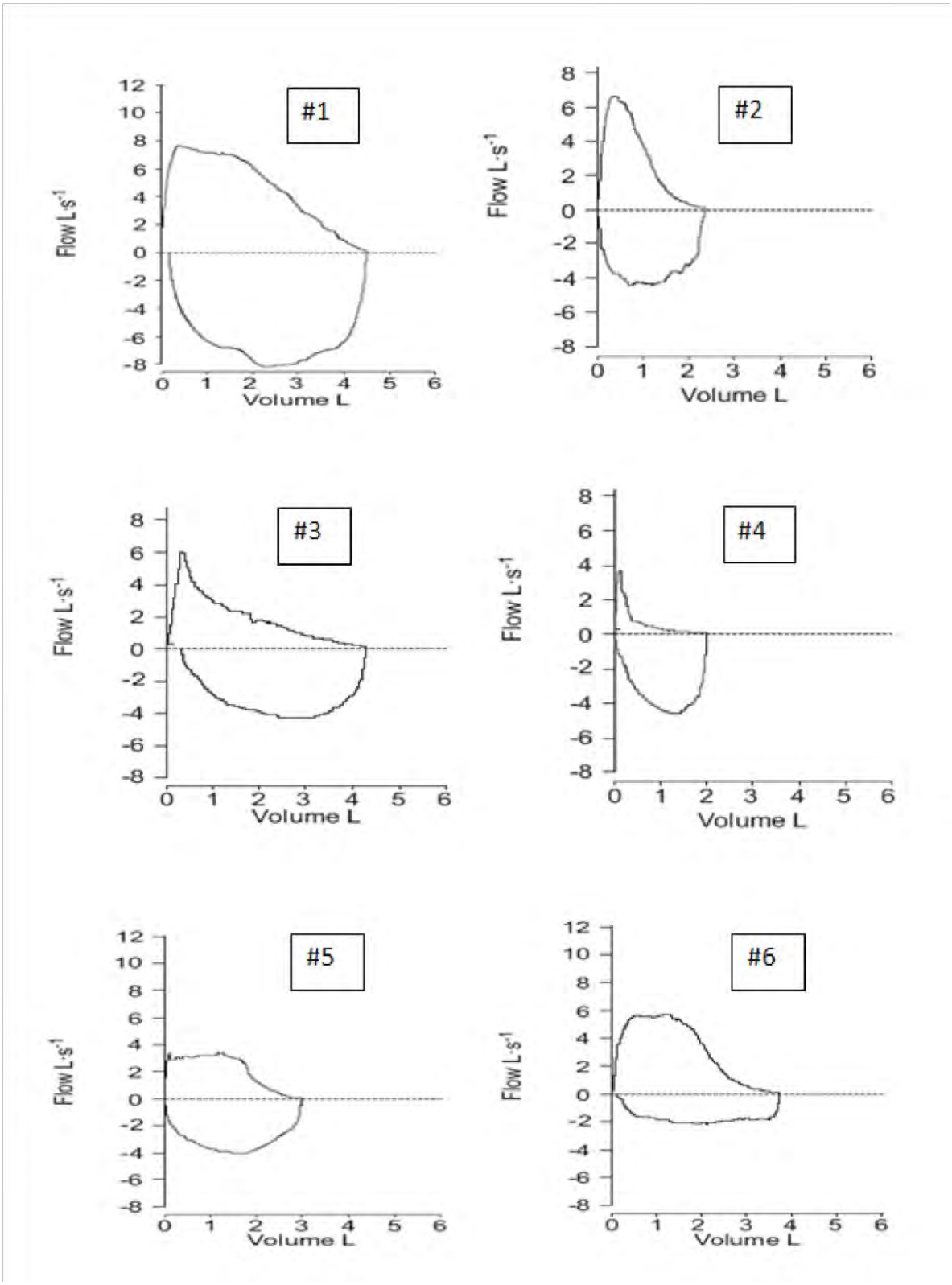
The following panel of graphs shows the expected deviation from a normal Flow-Volume loop for several breathing disorders. Panel 1 is for normal healthy lungs. Panel 2 is for a normal subject with end expiratory curve linearity, which can be seen with ageing. Panel 3 shows moderate airflow limitation in a subject with asthma. Panel 4 shows severe airflow limitation in a subject with chronic obstructive pulmonary disease. Panel 5 shows variable intra-thoracic upper airway obstruction. Panel 6 shows variable extra-thoracic upper airway obstruction.



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REFERENCES

ATS/ACCP Statement on Cardiopulmonary Exercise Testing (2003): Am J Respir Crit Care Med, **667**, 211277.

Bird, S.R. (1992). Exercise Physiology for Health Professionals. Singular Publishing Group, Inc. San Diego, California.

Brooks, G.A., T.D. Fahey and Timothy P. White (1996). Exercise Physiology: Human Bioenergetics and its Applications. Mayfield Publishing Company, Mountain View, California.

Ellestad, M.H. (1996). Stress Testing: Principles and Practice. F.A. Davis Co., Philadelphia, Pennsylvania.

Froelicher, V.F. (1983). Exercise Testing and Training. Le Jacq Publishing Inc., New York, New York.

Grinnell, A. and A.A. Barber (1976). Laboratory Experiments in Physiology. C.V. Mosby Co., St. Louis, Missouri.

Hall, S.E.H., J. Saunders and P.H. Sonksen (1979): "Glucose and Fatty Acid Turnover in Normal Subjects and in Diabetic Patients Before and After Insulin Treatment", Diabetologia, **16**, 297-306.

Jones, N.L. (1997). Clinical Exercise Testing. W.B. Saunders Co., Toronto, Ontario.

Leff, A. R. and P.T. Schumacker (1993). Respiratory Physiology: Basics and Applications. W.B. Saunders Co., Toronto, Ontario.

Marieb, E.N. (1989). Human Anatomy and Physiology Laboratory Manual. The Benjamin/Cummings Publishing Co. Inc., New York, New York.

McArdle. W.D., F.I. Katch and V.L. Katch (1996). Energy Nutrition and Human Performance. Williams and Wilkins, Baltimore, Maryland.

Miller M.R. et al(2005): "ATS/ETS Standardization of Lung Function Testing – Standardization of Spirometry", Eur Respir J, **26**, 319-338.

Miller, W.F., R. Scacci, and L.R. Yast (1987). Laboratory Evaluation of Pulmonary Function. Lippin Colt Co., Philadelphia, Pennsylvania.

Morehouse, L.E. (1972). Laboratory Manual for the Physiology of Exercise. C.V. Mosby Co., St. Louis, Missouri.

Nunn, J.F. (1987). Applied Respiratory Physiology. Butterworths, Toronto, Ontario.

Powers, S.K. and E.T. Howley (1996). Exercise Physiology: Theory and Application to Fitness and Performance. McGraw-Hill, Boston, Massachusetts.

Robergs, R.A. and S.O. Roberts (1997). Exercise Physiology: Exercise, Performance, and Clinical Applications. Mosby, New York, New York.

Rowell, L.B. and J.T. Shepherd (eds.) (1996). Handbook of Physiology. Exercise: Regulation and Integration of Multiple Systems. Oxford University Press, New York, New York.

Russell, G.K. (1978). Laboratory Investigations in Human Physiology. MacMillan, New York, New York. West, J.B. (1990). Respiratory Physiology, the Essentials. Williams and Wilkins, Baltimore, Maryland.

Wasserman, K., J.E. Hansen, D.Y. Sue, W.W. Stringer and B.J. Whipp (2005): "Principles of Exercise Testing and Interpretation" 4th Ed., App. C; Lippincott Williams & Wilkins Publ.

Widdicombe, J. and A. Davis (1983). Respiratory Physiology. University Park Press, Baltimore, Maryland.

Wilmore, J.H. and D.L. Costill (1994). Physiology of Sport and Exercise. Human Kinetics, Champaign, Illinois.

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-ondelivery 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.

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 would 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.

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E-mail: info@qubitsystems.com,

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