42 Aero Camino, Goleta, CA 93117
Tel (805) 685-0066 | Fax (805) 685-0067
info@biopac.com | **www.biopac.com**

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BSL *PRO* Lesson H29: Basal Metabolic Rate

This BSL *PRO* lesson describes the hardware and software setup of the BSL System in order to measure Oxygen Consumption ($V\dot{O}_2$) using an open circuit indirect calorimetry technique. Metabolic Rate can then be calculated using the $V\dot{O}_2$ measurement.

Objectives:

1. To obtain Basal Metabolic Rate (BMR) values from a subject
2. To compare this rate to standardized rate.
3. To measure post-exercise* metabolic rate and compare it to BMR.

*The GASSYS2 module is intended for $V\dot{O}_2$ studies ranging from resting to moderate exercise. For prolonged or $V\dot{O}_2$ max exercise studies where CO_2 levels may exceed 5%, BIOPAC recommends the Acq*Knowledge* Research system with O2100C and CO2100C gas sensing modules.

Equipment:

- Biopac Student Lab System:
  - MP36 or MP35 hardware
  - BSL 4.0.1 or greater software
- BSL *PRO* template file: ñ**h29_bsl4.gtl"**
- Airflow transducer (SS11LA)
- Gas Analysis System (GASSYS2-EA)
- Calibration Syringe: AFT26 (2 Liter), AFT27 (3 Liter), or AFT6 (.6 L)
- If using AFT26: Coupler, (AFT11D)
- 2 x Tubing, 35 mm ID (AFT7-L, 3m or AFT7, 1m)
- Coupler, 25 mm OD, 28.6 mm ID (AFT11H)

T-Valve option 1:

- T-Valve, 35 mm OD (AFT21)
- Mouthpiece (AFT9)
- Disposable Nose Clip (AFT 3)

T-Valve option 2:

Facemask with T-valve (AFT25)

T-Valve option 3:

- T-valve AFT22
- 2 x Rigid coupler (2 x AFT11C)
- 2 x Flexible coupler (2 x AFT11E)
- Disposable Bacterial Filter (AFT1)
- Disposable Mouth Piece (AFT2)
- Disposable Nose Clip (AFT3)

OPTIONAL:

- Head support for AFT21 T-Valve (AFT24)
- Tripod

Calibration Gas setup:

- Cal. Gas, 4% CO_2, 16% O_2 (GASCAL)
- Gas Regulator (GASREG)
- Gas cylinder cart
- PVC Tubing, 1/8òID (M537)
- Luer Lock Male to 3/32òbarb (CN192)

Background:

Blood transports gases to and from the bodyôs cells. The respiratory system supplies O_2 to the blood, and removes carbon dioxide (CO_2) from the blood with each respiratory cycle. Most of the gas exchange occurs at the level of the alveoli in the lungs, and the process is completely dependent on the maintenance of gas partial pressures favorable for adequate diffusion of O_2 and CO_2. Blood that has absorbed O_2 during inhalation (oxygenated blood) is transported by the cardiovascular system to systemic tissues throughout the body. Once in the tissues, the O_2 moves from the bloodstream into cells by diffusion, where it is used for ATP production. Although the majority of ATP is produced by aerobic metabolism, some ATP is produced via anerobic (without O_2) metabolism. Anaerobic metabolism can produce ATP much more quickly than aerobic metabolism, but can only sustain production for a short amount of time.

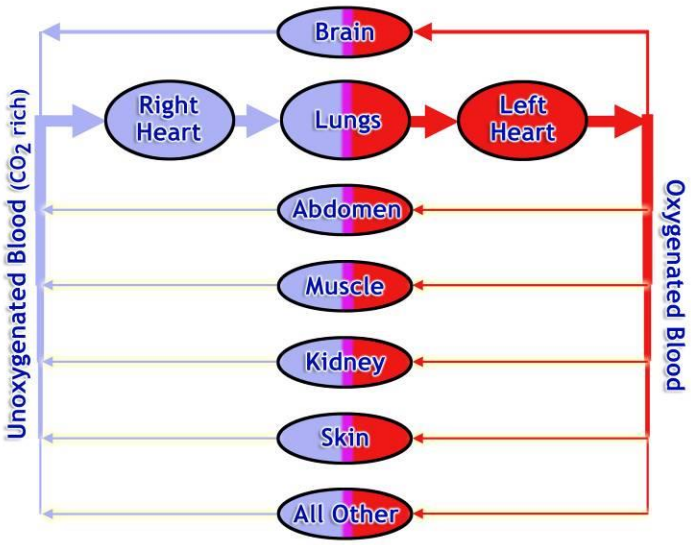


Figure 1

Oxygen consumption ($\dot{V}O_2$) is the amount of oxygen taken in and used by the body per minute. The ñdotò above the V signifies the extraction of a **rate** measurement rather than a **volume** measurement. $\dot{V}O_2$ is dependent on the amount of air that can be moved in and out of the lungs during ventilation, the amount of O_2 extracted from air in the alveoli, the volume of blood that the heart can pump, and the tissuesô capacity for extracting O_2 from the blood. $\dot{V}O_2$ can yield useful information and is one of the most common studied variables in exercise physiology.

$\dot{V}O_2$ can be reported in absolute terms (liters/min) or it can be reported relative to body mass (milliliters of O_2 per kilogram of body weight per minute).

The human bodyôs oxidation of organic food such as carbohydrate, fat, or protein, produces carbon dioxide and water, and releases chemical and thermal energy:

Food + O_2 ® CO_2 + H_2O + Energy (chemical & thermal)

The chemical energy is used by the bodyôs cells to generate adenosine triphosphate (ATP), a compound containing high-energy bonds which the cell may later break to release energy and perform work, such as secretion, contraction, or membrane transport. The thermal energy (heat) is used to maintain a relatively stable, optimum internal body temperature.

Metabolic rate is the amount of energy released per unit of time. It can be determined by using a whole-body calorimeter to measure the amount of heat given off by the body (direct calorimetry), or it can be determined by measuring the volume of oxygen consumed by the body during a brief time period (indirect calorimetry).

The amount of heat (measured in kilocalories) released during the oxidation of a food is directly proportional to the energy content of the food and directly proportional to the volume of oxygen required for complete oxidation. For example, the complete oxidation of one mole of glucose (in a calorimeter) requires 134.4 liters of O_2 (6 moles x 22.4 liters/mole = 134.4 liters of O_2) and yields 673 kcal of energy:

C6H12O6 + 6O2 ® 6CO2 + 6H2O + 673 kcal

Thus, the complete oxidation of one mole of glucose yields 5.01 kcal per liter of O_2 consumed. This value is called the *caloric equivalent* of glucose. The caloric equivalent of other foods are 5.06 kcal/liter O_2 for starches, 4.70 kcal/liter O2 for fats, and 4.6 kcal/liter O_2 for protein.

The human body is continually oxidizing a mixture of carbohydrate, protein, and fat rather than using any single food as the sole source of energy. Based on an average utilization of all three foods, the average release of energy (in terms of oxygen consumed) is 4.825 kcal per liter of O_2 consumed. Metabolic rates under varying conditions may, therefore, be measured by determining oxygen consumption in liters per hour and multiplying by the caloric equivalent of 4.825 kcal per liter of oxygen consumed.

Basal metabolic rate (**BMR**) refers to body metabolism as measured under a set of standard basal conditions designed to minimize the effects of as many influencing factors as possible. Basal conditions are as follows:

1. The subject must ingest no food for at least 12 hours prior to the test.
2. The subject must be mentally and physically relaxed.
3. The subject's core body temperature must be normal.

Room temperature must be comfortable (65°F - 80°F).

This lesson demonstrates how to obtain $V\dot{O}_2$ using an open circuit indirect calorimetry technique. Once $V\dot{O}_2$ is determined, Metabolic Rate can be calculated as follows:

$$\text{Metabolic Rate} = \frac{(VO_2)(60)(4.825\ \text{kcal/l})}{\text{Body Surface Area } (m^2)} \quad (\text{kcal/m}^2\text{/hr})$$

In the setup, a Subject is connected to a gas analyzer (GASSYS2) by way of plastic tubing and a non-rebreathing T-valve. The T-valve allows the subject to inspire from the atmosphere but diverts all of the expired air through the GASSYS2. The GASSYS2 consists of an air mixing chamber and O_2 and CO_2 sensors.

The sensors output voltages that are proportional to the $\%O_2$ and $\%CO_2$ in the chamber. The tubing and air mixing chamber act to average respiratory outflows. This averaging effect causes the CO_2 and O_2 concentrations to vary in accordance with the mean values resident over multiple expired breaths.

An airflow transducer (SS11LA) is used to measure inspired air flow. It is placed on the inspired side rather than the expired side to minimize errors due to condensation (expired air is saturated with water vapor). Placing it on the inspired side also eliminates the need for a temperature transducer in order to make STPD corrections (explained below). Because the airflow transducer is such a critical part of the system, it may be helpful to review Appendix 4 (at bottom of document) to get a better understanding of how it works and how to properly use it.

Note: Changes occurring in expired air gas concentrations will not be immediately apparent in the recorded data. This is due to the time required for air to travel through the tubing, mix with the 5 liters of air in the mixing chamber and flow past the sensors. In addition, each sensor requires varying amounts of processing time. The delays are not important when taking steady state measurements, but will affect the accuracy of non-steady state $V\dot{O}_2$. To improve accuracy, assume a delay of 15 seconds for O_2e, CO_2e, $V\dot{O}_2$ with respect to the airflow signal and any manually entered event markers.

The system inputs three signals:

- **Airflow**: inspired air flow (Liters/sec)
- **O_2e**: % CO_2 in expired air
- **CO_2e**: % CO_2 in expired air

To determine $V\dot{O}_2$, the following calculations are performed in software:

- **Vi (ATP):** Volume of inspired air in liters/min at temperature and pressure (ambient conditions). This is calculated by integrating the airflow data using a 60 second (6000 samples@100 samples/second) box car average.
- **Vi (STPD):** Vi (ATP), is converted to Vi at standard temperature and pressure dry (STPD) to allow accurate comparisons between Subjects tested under different ambient air conditions. This conversion scales the volume to what it would be at a temperature of 0° C, pressure of 760 mmHg and with water vapor pressure removed. To make the conversion, the observed barometric reading (mmHg), and temperature of the ambient air (in lab) must be determined. A scaling (or normalization) factor is found using the table in Appendix 1 (at bottom of document) Fand manually entered into the software.
- **Ves (STPD):** Applies the **Haldane Transformation** to find the volume of expired air per minute using Vi (STPD), O_2e and CO_2e. The following assumptions are made:
  a) Air is made up of only N_2, O_2 and CO_2.
  b) The composition of ambient (inspired) air is constant at 79.03% N_2, 20.93 % O_2 and 0.04 % CO_2.
  c) Nitrogen is inert in terms of metabolism, so any changes in its concentration between inspired and expired air must be due to an imbalance between the number of oxygen molecules removed and carbon dioxide molecules produced during metabolism.

Haldane Transformation formula:

$$Ve(STPD) = Vi(STPD) \times \frac{\%N2i}{\%N2e} = Vi(STPD) \times \frac{79.03\%}{(100\% - \%O2e - \%CO2e)}$$

Note: Additional trace elements are present in the atmosphere such as Ar, Ne, He, but their percentage by volume are very small and assumed negligible. The assumption that ambient air is made up of 0.04% CO_2 is accurate for well mixed outside air, but for air in a confined room, with multiple bodies expiring CO_2, it can be much higher (> 0.1%) and can vary over short periods of time. This variation does not greatly affect the $\dot{V}O_2$, and RER calculations because the amount of CO_2 in ambient air is small compared to the amount of O_2 and to N_2 and because the amount of CO_2 in expired air is much larger than that in ambient air. It is important to note, however, that ambient air calibration assumes 0.04% CO_2. Therefore, when returning the system to ambient conditions (flushing with ambient air) following expired air recordings, the $\%CO_2$ reading may not return to 0.04% and can even read slightly negative.

- **$\dot{V}O_2$ (STPD):** Calculates the volume of O_2 consumed per minute by taking the volume of O_2 inspired per minute and subtracting the volume of O_2 expired per minute.

$$\dot{V}O_2(STPD) = [Vis(STPD) \times \frac{20.93\%}{100\%}] - [Ves(STPD) \times \frac{O2e}{100\%}]$$

Note: Additional calculations not included in this section are shown in Appendix 2 at bottom of document. Although the channel designations and formula arrangement used in the actual calculation channel expressions shown in Appendix 2 may differ from that shown above, they are still equivalent.

Setup:

General Connections

The MP36/35 should be connected to its power source but turned OFF. It is assumed that the MP36/35 is connected to the host computer (via USB cable) and that BSL *PRO* software has been installed and is known to work with the MP unit.

1. The GASSYS2 should be plugged into its power adapter and turned ñON.ò
2. Connect the equipment as shown in the Figure 2 example. There are two alternatives for T-valves as shown in Figure 4 and Figure 5. The Airflow transducer must be on the inspired side of the T-Valve and the ñInletò label must facing the tubing. If using the optional Head Support (AFT24), refer to Figure 3. The connections to the MP36/35 must be as follows:

CH 1: Airflow transducer (SS11LA) CH 2: ñO_2ò from GASSYS2 CH 3: ñCO_2ò from GASSYS2

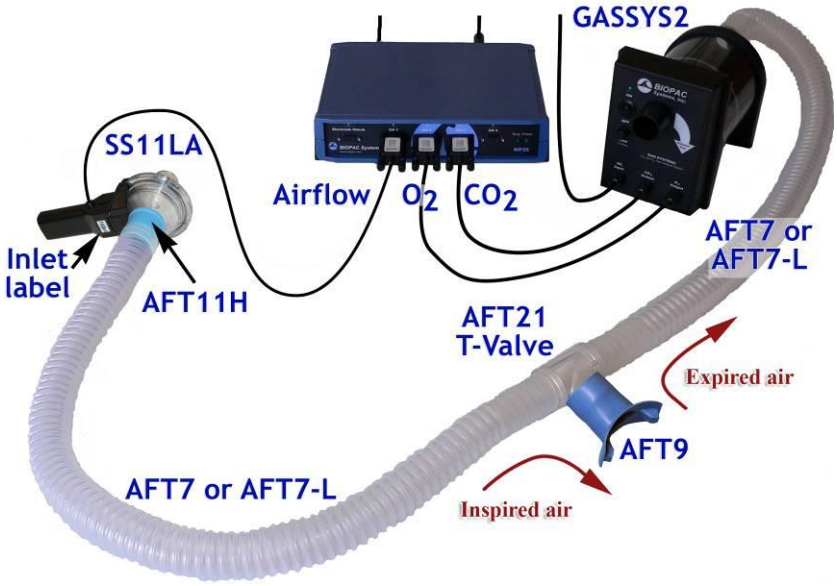


Figure 2

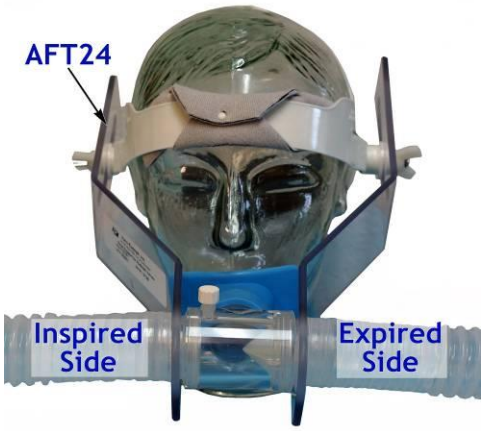


Figure 3

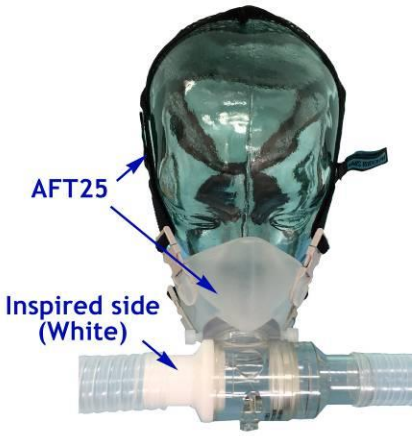


Figure 4

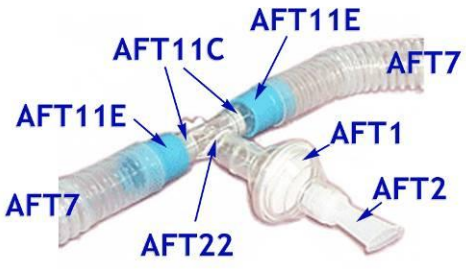


Figure 5

Important: The majority of the calibration need only be performed once each semester, but in order for this to work, the hardware must be matched to the software. It is recommended to label each computer, MP device, Airflow Transducer (SS11LA/L) and the GASSYS2 with a station number and make sure they are always matched.

Turn ON the hardware

After all cables are connected, the MP36/35 may be turned ON. Allow the system to warm up for at least fifteen minutes prior to calibration.

Secure the Airflow transducer and inlet tubing

The SS11LA Airflow transducer should be held stationary and vibration must be minimized. One method is to secure the transducer on a tripod as shown in the picture at the top of the lesson.

Software Setup

Launch BSL 4, and from the Startup dialog choose the **Create/Record a new experiment** option. Choose **Open Graph template from disk** and then click **OK**. Navigate to the correct template file*, select it and click **Open**.

*The default BIOPAC template file is not normally used by students, as it does not include the last calibration settings. Check with your instructor to make sure the correct file is opened.

NOTE: In BSL 4.1.2 and higher, this Lesson Procedure PDF is also embedded in the graph templateôs Journal but is best viewed with the Journal set to ñFloating display.òSee Appendix 5 for details.

Calibration Procedure:

Notes:

- The GASSYS2 and SS11LA Airflow transducer must be warmed up at least 15 minutes prior to calibration.
- Prior to each lesson recording, it is important to zero the airflow baseline and apply the STPD Normalization factor. The remaining calibration steps are normally performed by a lab technician once each semester.

Zero airflow baseline

1. Navigate to the ñCH1, Airflowò**Scaling dialog** (reference Appendix 3 at bottom of document).
2. With no air flowing through the SS11LA, click **Cal 2**.
3. Add ñ3000òto the Cal 2 Input value and manually enter this as the new Input value for Cal 1. In the Figure 6 example, after clicking Cal 2, the Input reading is 172 microvolts (rounded). This value is added to 3000 microvolts and then entered as the new value (3172) for Cal 1 Input.
4. Close both CH1 Setup dialogs by clicking **OK**.

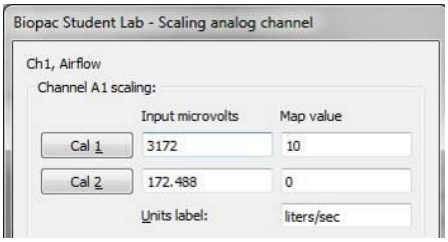


Figure 6

Check polarity and verify calibration

5. Display Channel ñ1ò(Airflow) by holding down the ñAltòkey (Windows) or ñoptionòkey (Mac) and clicking the Channel Box.
6. Click **Start** and record for a few seconds with no air flowing through the system, then have the subject inhale into the mouthpiece and click **Stop**.
7. Verify that the airflow waveform is positive when air is inhaled into the mouthpiece. If it is not, then the tubing is connected to the wrong port of the airflow transducer (SS11LA) and must be reversed before proceeding.
8. Using the ñ1òcursor, select an area of baseline (no flow) data as shown in Figure 7 and verify that the ñMeanòmeasurement is close to zero (ideally less than 0.01 Liters/sec). If there is excessive offset, repeat steps 1 through 8.
9. Hide Channel 1 by toggling the Channel Box.

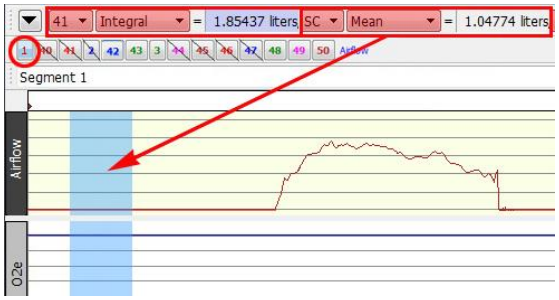


Figure 7

Apply STPD Normalization factor

10. Obtain the temperature and observed barometric reading (OBR in mmHg) for conditions in the lab.
11. Find the Normalization factor using the table in Appendix 1 at bottom of document. Record this information in the Data Report section and/or the journal.
12. Navigate to the C7 **(Vis STPD)** Expression dialog (see Appendix 3 at bottom of document for details).
13. Replace the scaling factor in the expression dialog with the normalization factor found in the table. In the Figure 8 example, for a lab OBR of 728 mmHg and a temperature of 72º F, the normalization factor from the table is .ð859.ò
14. Click **OK** to close the Expression dialog.

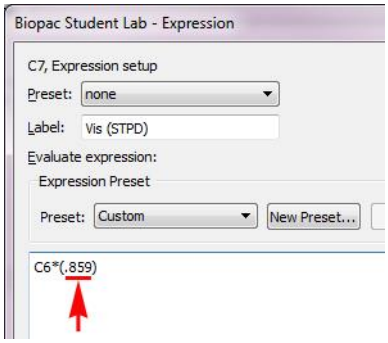


Figure 8

Note: The remaining calibration steps are normally performed by a lab technician once prior to the start of each semester. Students should proceed to the **Recording Procedure** section.

Connect calibration syringe

15. Connect the Calibration Syringe to the T-valve (in place of the mouthpiece) as shown in Figure 9.
16. Cycle the syringe for several cycles (2 to 3 minutes) at a moderate rate to completely flush GASSYS2 with ambient air.

Figure 9

Calibrate airflow amplitude

17. Click **Start** to begin a recording.
18. Cycle the Syringe all the way in and out at a moderate rate and then click **Stop**.
19. Select an area of data that encompasses the airflow pulse as shown in Figure 10. Note the value of the ñIntegralò measurement. If this value does not closely match the volume of the calibration syringe, then a scaling factor must be used.

    Scaling factor = Syringe volume / Integral value.

    For example, if a 2 Liter syringe is used and the integral measures 1.85 Liters, then a scaling factor of 2.0/1.85 = 1.08 must be applied.
20. *Apply the Scaling factor*. Navigate to the Calculation channel **C3** (Airflow Scaled) Expression dialog.
21. Enter the calculated scaling factor into the C2 expression. For the Figure 11 example, the previous value was replaced with ñ1.08.ò
22. Click **OK** to close the Expression dialog.
23. Check the airflow calibration by recording another syringe cycle and verify that the Integral measurement more closely matches the Syringe volume.

Figure 10

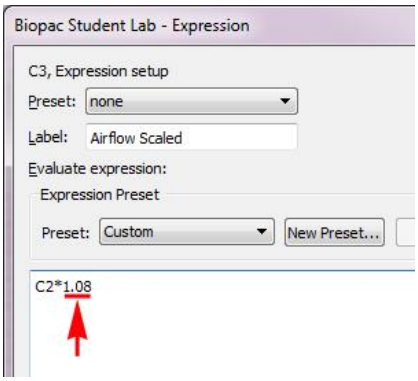


Figure 11

Gas calibration part 1 ï using ambient air

Note: If the lesson objective only examines relative changes in a Subjectõs VO_2 and RER, then only ambient air calibration is necessary. If, however absolute measurements are required, it will be necessary to perform the additional ñGas calibration part 2òusing a calibration gas.

O_2 Sensor

1. Flush the GASSYS2 with ambient air by cycling the calibration syringe at a moderate rate for 1 minute.
2. Wait 2 minutes.
3. Navigate to the **CH2** (O_2e) **Scaling** dialog (see Appendix 3 at bottom of document).
4. Record the initial Input values of Cal 1 and Cal 2.
5. Click **Cal 1** to obtain the actual Input voltage value.

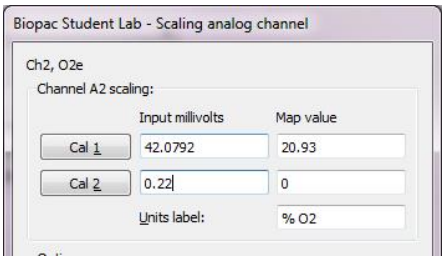


Figure 12

Note: If you will be performing Gas Calibration part 2 (with calibration gas), skip the next step.

6. Manually calculate a new Cal 2 Input value as follows:

   Cal 2 New = Cal 2 initial + (Cal 1 actual – Cal 1 initial)

   Enter this new value for Cal 2 Input.

   In the Figure 12 example, the Cal 1 initial Input value was 41.86 millivolts and the Cal 2 initial value was 0 millivolts. After clicking Cal 1, the Input changed to 42.08 millivolts (rounded). Cal 2 New was calculated as: 0 + (42.08 - 41.86) = 0.22 and this was then manually entered as the new Cal 2 Input value.

CO_2 Sensor

7. Navigate to the **CH3** (CO_2e) **Scaling** dialog.
8. Record the initial Input values of Cal 1 and Cal 2.
9. Click **Cal 2** to obtain the actual Input voltage value.

Note: If you will be performing Gas Calibration part 2 (with calibration gas), proceed to Step 12.

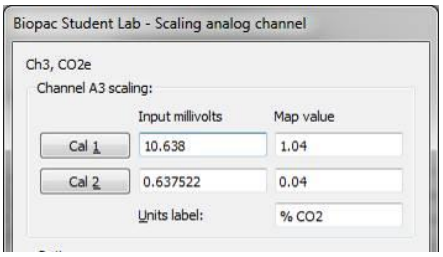


Figure 13

10. Manually calculate a new Cal 1 Input value as follows:

    Cal 1 New = Cal 1 initial + (Cal 2 actual – Cal 2 initial)

    Enter this new value for Cal 1 Input.

In the Figure 13 example, the Cal 1 initial Input value was 10 millivolts and the Cal 2 initial value was 0 millivolts. After clicking Cal 2, the Input changed to 0.638 millivolts (rounded). Cal 1 New was calculated as: 10 + (0.638 - 0) = 10.638 and this was then manually entered as the new Cal 1 Input value.

11. Skip the Gas Calibration part 2 steps and save the calibration settings.

Gas Calibration part 2 ï Using calibration gas

12. Connect the calibration gas to the ñCalibration Portòon the GASSYS2 and turn on the flow. It can take several minutes for the gas to saturate the chamber and sensors.
13. Click **Start** to begin a recording and monitor the CO_2e and O_2e channels. Wait until both have completely stabilized and then Click **Stop**.

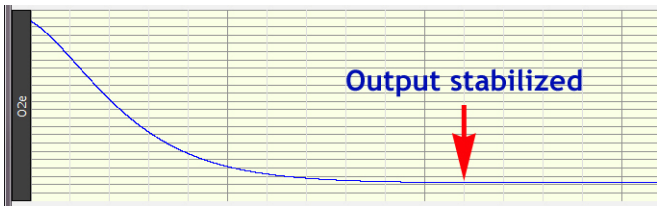


Figure 14

O_2 Sensor

14. Navigate to the **CH2** (O_2e) **Scaling** dialog.
15. Enter the calibration gas O_2 % value into the Cal 2 Map value.
16. Click **Cal 2** to update the Input voltage value.
17. Click **OK** to close the Scaling dialog.

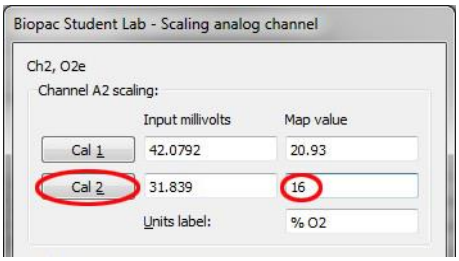


Figure 15

CO2 Sensor

18. Navigate to the **CH3** (CO_2e) Scaling dialog.
19. Enter the calibration gas CO_2 % value into the Cal 1 Map value.
20. Click **Cal 1** to update the Input voltage value.
21. Click **OK** to close the Scaling dialog.

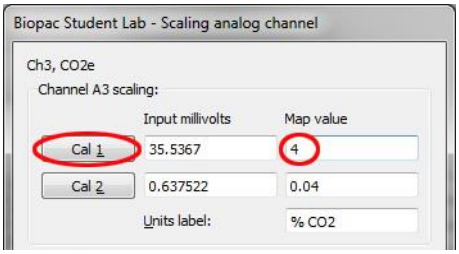


Figure 16

22. Erase all calibration data by holding down the ñCtrlò key (Windows) or ñoptionò key (Mac) and clicking the Rewind toolbar button.

Save the calibration settings

23. Choose **Save As** from the File menu.
24. Navigate to the location where the lesson files (templates) are stored.
25. Make sure ñ**Graph Template (*.gtl)**ò is selected as the ñSave as type.ò
26. Enter a file name. Include the station number in the name if the files are not stored on the local computer.
27. Click **Save**.

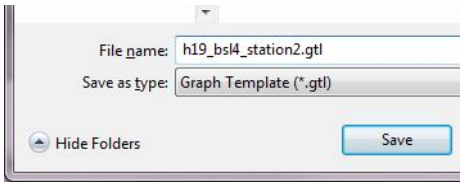


Figure 17

Recording Procedure:

Note: The Subject must be healthy and have no history of respiratory or cardiovascular problems.

Resting state:

The Subject should be in a seated and relaxed position.

Note: For true ñBaselòconditions to be met, the Subject must:

- Ingest no food for at least 12 hours prior to the test.
- Be mentally and physically relaxed.
- Have a normal core body temperature.
- Be at room temperature (65°F - 80°F).

Figure 18

1. Subject puts on facemask or inserts the mouthpiece. If using a mouthpiece, place the nose clip over nose.
2. Subject breathes normally for at least 6 minutes to allow expired air to saturate the tubing and 5 Liter mixing chamber (GASSYS2).
3. Click **Start** to begin recording.
4. After 5 minutes of recording, examine the trend of the VO2 data. Continue the recording, if necessary, until the data has reached a somewhat steady state for approximately 2 minutes.
5. Click **Stop** to end the recording.
6. If this is the only recording performed, have Subject remove the mouthpiece and nose clip and skip to the ñSave the dataòsection.

Optional Post-exercise recording

7. Flush the Gas System Chamber with ambient air using calibration syringe.
8. Subject should perform five minutes of moderate exercise. The chosen exercise must allow the Subject to remain in close proximity to the GASSYS2. Both the cardio step (Figure 19) and stationary bicycle are exercises work well.
9. After the exercise period, allow subject to rest in a comfortable position for 7-8 minutes.
10. Repeat steps 2 through 5 of the Resting state recording.

Figure 19

Troubleshooting

If $V\dot{O}_2$ seems incorrect, check that the airflow baseline is zero and that the airflow amplitude is scaled properly (calibration steps 5 ï 9 and 17 ï 19). Recalibrate if necessary.

Save the Data

1. Select **Autoscale Horizontal** from the Display menu followed by Display > **Autoscale Waveforms** so that all of the data can be seen.
2. Save the data by selecting: **File** menu > **Save As**é Enter a file name and then click **Save**.

Data Analysis:

Take measurements of VO_2 (STPD) at the end of each recording period and then calculate BMR for each.

Notes:

- Data Analysis requires familiarization with the measurement tools (see Appendix 3 for basic details).
- V$\dot{O}_2$ data is not valid until at least 1 minute after the start of a recording as the airflow to volume integrator is averaging over 1 minute.
- Measurements of V$\dot{O}$2 should use a selection interval of 60 seconds.

Measurement example:

Figure 20 shows an example of a ñResting Stateò measurement.

a. The zoom tool is used to zoom in on the Resting State recording.

b. A 60 second data interval is selected (utilizing the **Delta T** measurement) near the end of the recording period.

c. The CH 48 ñMeanòmeasurement is obtained. This value is the mean V$\dot{O}$2 (Liters of O_2 consumed per minute).

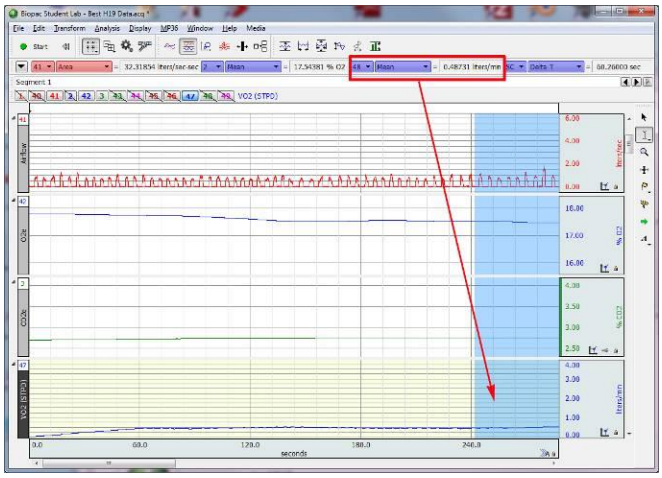


Figure 20

1. In order to calculate BMR, you will also need to know Body Surface Area in square meters. Use the following formula to calculate Body Surface Area:

Body Surface Area (m2) = ([Height (cm) x Weight (kg)]/ 3600)½

Click here to review the BSA Adult Nomograph (based on the formula of DuBois and DuBpois, 1916)

2. Use VO_2 and Body Surface Area in the following equation to calculate metabolic rate, or click here to use the **BMR Calculator** (requires Microsoft Excel; if your browser does not open the calculator, click here to download the BMR Calculator file for Windows or Mac).

$$\text{Metabolic Rate} = \frac{(VO_2)(60)(4.825\ \text{kcal/l})}{\text{Body Surface Area } (m^2)}$$

(kcal/m²/hr)

3. Use the BMR Calculator to establish predicted BMR and calculate % deviation from predicted rate.
4. If doing post-exercise metabolic rate, use the BMR Calculator to calculate % increase over BMR.

Appendix 1: Normalization Factors

The following table lists the factors required to reduce volume of moist gas to volume occupied by dry gas at 0° C, 760 mmHg. **OBR** is observed barometric reading (mmHg), uncorrected for temperature.

Important! All factors are **0.x**, with x being the value from the table. Be sure to include the **leading decimal** when completing the calculation.

° C	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
° F	59	61	63	64	66	68	69	72	73	75	77	79	81	82	84	86	88	90
OBR																		
700	855	851	847	842	838	834	829	825	821	816	812	807	802	797	793	788	783	778
702	857	853	849	845	840	836	832	827	823	818	814	809	805	800	795	790	785	780
704	860	856	852	847	843	839	834	830	825	821	816	812	807	802	797	792	787	783
706	862	858	854	840	845	841	837	832	828	823	819	814	810	804	800	795	790	785
708	865	861	856	852	848	843	839	834	830	825	821	816	812	807	802	797	792	787
710	867	863	859	855	850	846	842	837	833	828	824	819	814	809	804	799	795	790
712	870	866	861	857	853	848	844	839	836	830	826	821	817	812	807	802	797	793
714	872	868	864	859	855	851	846	842	837	833	828	824	819	814	809	804	799	794
716	875	871	866	862	858	853	849	844	840	835	831	826	822	816	812	807	802	797
718	877	873	869	864	860	856	851	847	842	838	833	828	824	819	814	809	804	799
720	880	876	871	867	863	858	854	849	845	840	836	831	826	821	816	812	807	802
722	882	878	874	869	865	861	856	852	847	843	838	833	829	824	819	814	809	804
724	885	880	866	872	867	863	858	854	849	845	840	835	831	826	821	816	811	806
726	887	883	879	874	870	866	861	856	852	847	843	838	833	829	824	818	813	808
728	890	886	881	877	872	868	863	859	854	850	845	840	836	831	826	821	816	811
730	892	888	884	879	875	871	866	861	857	852	847	843	838	833	828	823	818	813
732	895	890	886	882	877	873	868	864	859	854	850	845	840	836	831	825	820	815
734	897	893	889	884	880	875	871	866	862	857	852	847	843	838	833	828	823	818
736	900	895	891	887	882	878	873	869	864	859	855	850	845	840	835	830	825	820
738	902	898	894	889	885	880	876	871	866	862	857	852	848	843	838	833	828	822
740	905	900	896	892	887	883	878	874	869	864	860	855	850	845	840	835	830	825
742	907	903	898	894	890	885	881	876	871	867	862	857	852	847	842	837	832	827
744	910	906	901	897	892	888	883	878	874	869	864	859	855	850	845	840	834	829
746	912	908	903	899	895	890	886	881	876	872	867	862	857	852	847	842	837	832
748	915	910	906	901	897	892	888	883	879	874	869	864	860	854	850	845	839	834
750	917	913	908	904	900	895	890	886	881	876	872	867	862	857	852	847	842	837
752	920	915	911	906	902	897	893	888	883	879	874	869	864	859	854	849	844	839
754	922	918	913	909	904	900	895	891	886	881	876	872	867	862	857	852	846	841
756	925	920	916	911	907	902	898	893	888	883	879	874	869	864	859	854	849	844
758	927	923	918	914	909	905	900	896	891	886	881	876	872	866	861	856	851	846
760	930	925	921	916	912	907	902	898	893	888	883	879	874	869	864	859	854	848

762	932	928	923	919	914	910	905	900	896	891	886	881	876	871	866	861	856	851
764	936	930	926	921	916	912	907	903	898	893	888	884	879	874	869	864	858	853
766	937	933	928	924	919	915	910	905	900	896	891	886	881	876	871	866	861	855
768	940	935	931	926	922	917	912	908	903	898	893	888	883	878	873	868	863	858
770	942	938	933	928	924	919	915	910	905	901	896	891	886	881	876	871	865	860
772	945	940	936	931	926	922	917	912	908	903	898	893	888	883	878	873	868	862
774	947	943	938	933	929	924	920	915	910	905	901	896	891	886	880	875	870	865
776	950	945	941	936	931	927	922	917	912	908	903	898	893	888	883	878	872	867
778	952	948	943	938	934	929	924	920	915	910	905	900	895	890	885	880	875	869
780	955	950	945	941	936	932	927	922	917	912	908	903	898	892	887	882	877	872
° F	**59**	**61**	**63**	**64**	**66**	**68**	**69**	**72**	**73**	**75**	**77**	**79**	**81**	**82**	**84**	**86**	**88**	**90**
° C	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**

From Peters and Van Slyke, *Quantitative Clinical Chemistry*, vol. 11. (Methods) Baltimore: Williams and Wilkins, 1932, reprinted 1956.

Appendix 2: Channel Processing Summary:

Channel	Label	Description/Processing
Ch1	Airflow	Airflow from SS11LA
		3 IIR Filters: Low Pass, 66.5 Hz, Q=.5, Low Pass, 38.5 Hz, Q=1, Band Stop, Line Freq, Q=1
Ch2	O_2e	O_2 Expired from GASSYS2
		3 IIR Filters: Low Pass, 66.5 Hz, Q=.5, Low Pass, 38.5 Hz, Q=1, Band Stop, Line Freq, Q=1
Ch3	CO_2e	CO_2 Expired from GASSYS2
		3 IIR Filters: Low Pass, 66.5 Hz, Q=.5, Low Pass, 38.5 Hz, Q=1, Band Stop, Line Freq, Q=1
C1 [40]	Airflow Threshold	Applies zero to any airflow signal that is less than 0.02 Liters/sec. This reduces noise artifact caused by mechanical vibration and also prevents the signal from going negative which can occur briefly when valves inside the T-valve slam shut.
		IF (LESS(0.02, ABS(Ch1)), Ch1, 0)
C2 [41]	Airflow corrected	Polynomial correction that extends the linear range of the SS11LA from 5 Liters/sec. to 10 Liters/sec.
		(2.0*C1)/((0.247951736452952*C1)+(-0.0928767685027268*C1^2)+(0.0224986269987362*C1^3)+(-0.00222581575367371*C1^4)+(7.53176506967997E-005*C1^5)+1.71749281362047)
C3 [42]	Airflow Scaled	Applies a scale factor to the airflow signal for amplitude calibration (using syringe) ï see Figure 11.
		C2*1.0
C4 [43]	O_2e	Acts as a delay on O_2 data to more closely align the response time of the O2 sensor with the slower responding CO_2 sensor.
		Low Pass Filter on Ch2 data (O_2e), 0.01Hz, Q = .5
C5 [44]	N_2e	Calculates percentage of Nitrogen in expired air by subtracting out percentages of O_2 and CO_2.
		100-(Ch2+Ch3)
C6 [45]	Vi (ATP)	Integrates the corrected airflow data (C3) to produce volume of air Inspired per minute. This volume is At Temperature and Pressure which is to say it is not yet corrected for Standard Temperature and Pressure Dry (STPD).
		INTEGRATE <C3 Data!> 6000 samples, Average over samples, no parameters - do not rectify
C7 [46]	Vis (STPD)	Applies STPD Normalization Factor to volume of inspired air per minute
		C6*(.874)
C8 [47]	Ves (STPD)	Applies the Haldane Transformation to find volume of expired air per minute (Ves) from volume of inspired air per minute (Vis)
		(C7*79.03)/C5
C9 [48]	VO_2 (STPD)	Calculates volume of O_2 consumed per minute (difference between Vis and Ves).
		(1/100)*((C7*20.93)-(C8*Ch2))

Note: ñ*Channel" displays both the calculation channel reference (i.e. "C1") and channel graph reference (i.e "40").*

Appendix 3:

This section offers a quick overview of software essentials. For a full explanation of features, see the BSL *PRO* Tutorial or BSL *PRO* Manual.

Show/Hide channels:

Channel visibility can be toggled on and off by holding down the ñAltòkey (Windows) or ñoptionòkey (Mac) and clicking on the Channel Box.

Navigating to channel Scaling dialog:

Select **Set Up Channels** or **Set Up Data Acquisition** (depending on software version) from the MP3x menu to bring up the Input channels setup dialog and then select the **Analog** tab. Click on the desired channel (i.e. CH 1, Airflow) and then click **Setup.** From the setup dialog, click **Scaling**.

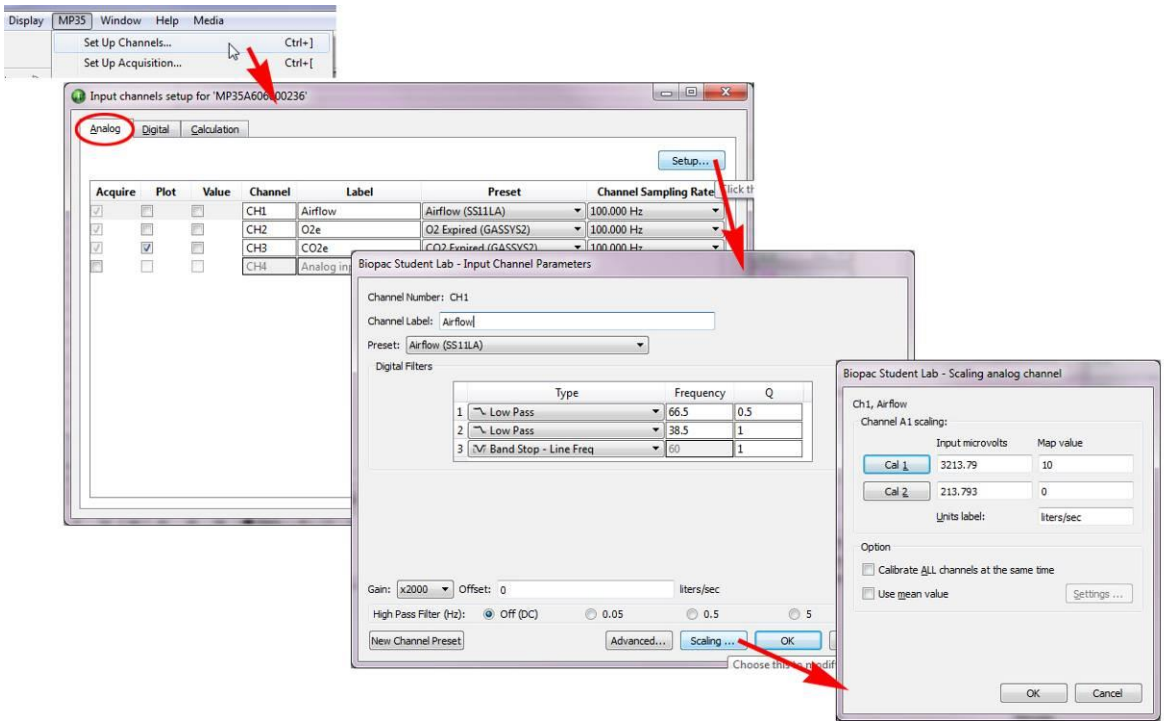


Figure 21

Navigating to calculation channel Expression dialog:

Select **Set Up Channels** or **Set Up Data Acquisition** (depending on software version) from the MP3x menu to bring up the Input channels setup dialog and then select the **Calculation** tab. Click on the desired calculation channel (i.e. C3 (Airflow Scaled)) and then click **Setup.**

Autoscaling data:

Graph data can be autoscaled vertically and horizontally for enhanced viewing.

- Autoscale vertically by using the  toolbar button or Display > Autoscale Waveforms to optimize the vertical display and allow closer examination of the waveform.
- Autoscale horizontally by using the  toolbar button or Display > Autoscale Horizontal to display the entire horizontal time scale in a single graph window.

Zooming in and out of data:

Use the Zoom tool to magnify portions of the waveform for a closer look.

- Zoom in by selecting the  toolbar icon and click/drag over the area of interest.
- To zoom back, use Ctrl ï (minus) or ñDisplay > Zoom Back.ò

Measurements used in this lesson:

Graph data measurements are taken by using the I-beam tool  to select an area of interest. The following basic measurements are used in this experiment:

Delta-T	Shows the difference in time between the last and first sample of the selected area.
Max (Maximum)	Shows the maximum amplitude value in the selected area.
Mean	Shows the mean amplitude value of data samples within the selected area.
Min (Minimum)	Shows the minimum amplitude value in the selected area.
P-P (Peak-to-Peak)	Shows the difference between the maximum amplitude value and the minimum amplitude value in the selected area.
Value	Shows the data value at the cursor position, or if an area is selected, the data value at the end of the selection.

Appendix 4:

Airflow transducer operation

The BIOPAC SS11LA airflow transducer works by funneling air through a sealed head which is divided in half by a fine mesh screen (Figure 22). The screen creates a slight resistance to air flow resulting in a higher pressure on one side than the other. This pressure differential is closely proportional* to the air flow rate (liters/second). A differential pressure sensor outputs a voltage that is proportional to the difference in pressure across its two inlet ports.

In software, air volume is determined by integrating air flow. This integration technique is simple and accurate as long as the air flow signal is precise. Small errors in the air flow signal, such as a non-zero baseline offset, can cause larger errors in the calculated volume. For this reason, it is important to note the following:

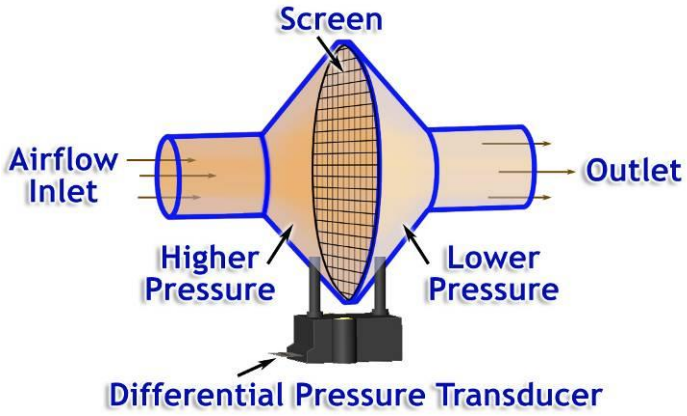


Figure 22

- Baseline offset will vary slightly during the transducer warm-up period. For this reason it is important to perform calibration at least 15 minutes after the transducer has been turned ON.
- The differential pressure sensor is a micro-electromechanical system (MEMS) that is subject to the effects of gravity. This means orientation changes can cause slight shifts in baseline offset. To prevent this, the airflow transducer must be held stationary during Subject recordings.
- Vibration can cause noise artifact in the airflow signal. It is recommended that the airflow transducer and its tubing be held in a fixed, secure position.
- The SS11LA works best for this lesson when it is placed on the inspired side of the T-valve. This is because condensation can clog the screen and change relationship between air flow and differential pressure. Condensation occurs because expired air exits the body at 37°C and is saturated with water vapor. As the air travels through the exhaust tubing and into the GASSYS2, the air is cooled and condensation forms.
- To obtain the best accuracy, the airflow transducer should be calibrated using a calibration syringe at least once a semester. This calibration is described in the ñCalibrate airflow amplitudeòsection above. A scaling factor is determined and applied to the airflow signal. Because air volume is calculated by integrating the air flow, the scaling factor is directly applied to the volume.

*The relationship between the air flow and differential pressure is not perfectly proportional. Non-linearities can arise due to air turbulence hitting the screen. The SS11LA maintains good linearity over its rated flow range of 0 to 5 liters/second, but becomes increasing non-linear for flow rates from 5 to 10 liter/second. Flow rates in the 5 to 10 liter/second range can be produced by some subjects during exercise. This problem is resolved by modeling the airflow response and creating a polynomial expression to correct (linearize) the response. For this lesson, calculation channel expression C2 performs this airflow correction (see Appendix 2).

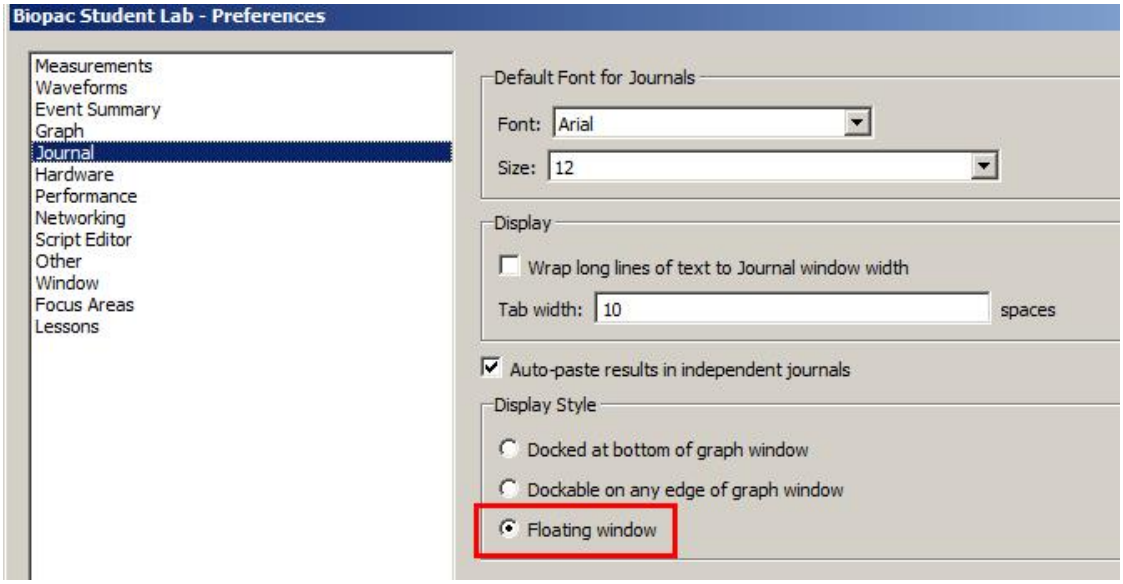
Appendix 5:

Enabling the ñFloating windowòJournal Display

BSL 4.1.2 and higher: In addition to the Help menu, lesson-specific *PRO* Lesson PDFs are also available in the lessonôs Journal and viewable by clicking the Journalôs ñlesson procedureòtab. To enhance viewing of lesson PDFs from within the Journal, BIOPAC recommends changing the Journal display preference from the default ñDocked at bottom of graph windowòsetting to ñ**Floating window**.òThis option allows for easy resizing and repositioning of the onscreen lesson Journal while allowing full access to the graph. ñFloating windowòalso provides a higher resolution PDF display and positions any Output Control panels directly below the graph for easier viewing.

To change the Journal display to ñFloating windowò

1. In BSL *PRO*, choose ñDisplay > Preferencesò(or click the Preferences toolbar button. ).
2. Highlight the ñJournalòoption in the Preferences window.
3. Under ñDisplay Style,òselect ñFloating windowòand click OK.



4. The Journal will now appear in a separate window from the BSL graph. (It may appear behind the graph display. Drag the graph sideways and click the Journal window to bring it to the front.
5. Click the ñlesson procedureòtab to view the PDF. Reposition and resize the Journal window as necessary. Toggle between Journal text (notes youôve entered) and the lesson procedure PDF by clicking the ñJournalòand ñlesson procedureòtabs.