# Black Carbon Photometer


## OPERATION MANUAL

## Black Carbon Photometer



Technical Support:
https://2btech.io/support/
techsupport@2btech.io
+1(303)273-0559

# Contents

## *IDENTIFICATION RECORDS*

Record the following information for future reference:

Unit serial number: ________________________________________

Warranty start date: ________________________________________
(date of receipt)

## *PRINTING HISTORY*

This manual describes the 2B Technologies Black Carbon Photometer (BCP™). New editions of this manual are complete revisions that reflect updates to the instrument itself, as well as clarifications, additions and other modifications of the text.

Revision A-1 ........................................................................................June 2019
Revision A-2 ....................................................................................September 2019

*Improvements to the zeroing function, addition to the screen to show the new zero values, and additional explanation (Sections 3.6 and 4.2.2); additions and corrections to the serial data line in Section 3.6; corrected date format; other small corrections.*

Revision A-3 .....................................................................................December 2023

*Updated hyperlinks.*

## TRADEMARKS & PATENTS

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### Warranty Period

The warranty period is one (1) year from date of receipt by the purchaser, but in no event more than thirteen (13) months from original invoice date from 2B Technologies.

### Warranty Service

Warranty Service is provided to customers via web ticket, email and phone support, Monday - Friday, from 9:00 a.m. to 5:00 p.m., Mountain Time USA. The preferred method of contacting us is through our web ticketing software at:

https://2btech.io/support/

This way all technical staff at 2B Tech will be alerted of your problem and be able to respond. When you receive an email reply, please click on the Ticket link provided to continue to communicate with us directly over the internet. The web ticket approach to customer service allows us to better track your problem and be certain that you get a timely response. We at 2B Tech pride ourselves on the excellent customer service we provide.

You may also contact us by email at techsupport@2btech.io or by phone at +1(303)273-0559. In either case, a web ticket will be created, and future communications with you will be through that ticket.

Initial support involves troubleshooting and determination of parts to be shipped from 2B Technologies to the customer in order to return the product to operation within stated specifications. If such support is not efficient and effective, the product may be returned to 2B Technologies for repair or replacement. Prior to returning the product, a Repair Authorization Number (RA) must be obtained from the 2B Technologies Service Department. We will provide you with a simple Repair Authorization Form to fill out to return with the instrument.

### Shipping

2B Technologies will pay freight charges for replacement or repaired products shipped to the customer site. Customers shall pay freight charges for all products returning to 2B Technologies.

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The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance, adjustment, calibration or operation by the customer. Maintenance, adjustment, calibration or operation must be performed in accordance with instructions stated in this manual. Use of maintenance materials purchased from suppliers other than 2B Technologies will void this warranty.

## Limitation of Remedies and Liability

The remedies provided herein are the customer's sole and exclusive remedies. In no event shall 2B Technologies be liable for direct, indirect, special, incidental or consequential damages (including loss of profits) whether based on contract, tort or any other legal theory. This manual is believed to be accurate at the time of publication and no responsibility is taken for any errors that may be present. In no event shall 2B Technologies be liable for incidental or consequential damages in connection with or arising from the use of this manual and its accompanying related materials. Warranty is valid only for the country designated on the 2B Technologies quote or invoice.

# *WARNINGS*

## ENGLISH

***WARNING*:**
Any operation requiring access to the inside of the equipment, could result in injury. To avoid potentially dangerous shock, disconnect from power supply before opening the equipment.

***WARNING:***
This symbol, ⚠ on the instrument indicates that the user should refer to the manual for operating instructions.

***WARNING:***
If this instrument is used in a manner not specified by 2B Technologies, USA, the protection provided by the instrument may be impaired.

## ESPAÑOL

***ATENCION:***
Cualquier operación que requiera acceso al interior del equipo, puede causar una lesión. Para evitar peligros potenciales, desconectarlo de la alimentación a red antes de abrir el equipo.

***ATENCION**:*
Este símbolo, ⚠ en el instrumento indica que el usuario debería referirse al manual para instrucciones de funcionamiento.

***ATENCION:***
Si este instrumento se usa de una forma no especificada por 2B Technologies, USA, puede desactivarse la protección suministrada por el instrumento.

## FRANÇAIS

***ATTENTION:***
Chaque opération à l'intérieur de l'appareil, peut causer du préjudice. Afin d'éviter un shock qui pourrait être dangereux, disconnectez l'appareil du réseau avant de l'ouvrir.

***ATTENTION:***
Le symbol, ⚠ indique que l'utilisateur doit consulter le manuel d'instructions.

***ATTENTION:***
Si l'instrument n'est pas utilisé suivant les instructions de 2B Technologies, USA, les dispositions de sécurité de l'appareil ne sont plus valables.

## DEUTSCH

***WARNHINWEIS:***
Vor dem Öffnen des Gerätes Netzstecker ziehen!

***WARNHINWEIS:***
Dieses, ⚠ auf dem Gerät weist darauf hin, dab der Anwender zuerst das entsprechende Kapitel in der Bedienungsanleitung lesen sollte.

***WARNHINWEIS:***
Wenn das Gerät nicht wie durch die Firma 2B Technologies, USA, vorgeschrieben und im Handbuch beschrieben betrieben wird, können die im Gerät eingebauten Schutzvorrichtungen beeinträchtigt werden.

## ITALIANO

***ATTENZIONE:***
Qualsiasi intervento debba essere effettuato sullo strumento può essere potenzialmente pericoloso a causa della corrente elettrica.
Il cavo di alimentazione deve essere staccato dallo strumento prima della sua apertura.

***ATTENZIONE:***
Il simbolo, ⚠ sullo strumento avverte l'utilizzatore di consultare il Manuale di Istruzioni alla sezione specifica.

***ATTENZIONE:***
Se questo strumento viene utilizzato in maniera non conforme alle specifiche di 2B Technologies, USA, le protezioni di cui esso è dotato potrebbero essere alterate.

## DUTCH

***OPGELET:***
Iedere handeling binnenin het toestel kan beschadiging veroorzaken. Om iedere mogelijk gevaarlijke shock te vermijden moet de aansluiting met het net verbroken worden, vóór het openen van het toestel.

***OPGELET:***
Het symbool, ⚠ geeft aan dat de gebruiker de instructies in de handleiding moet raadplegen.

***OPGELET:***
Indien het toestel niet gebruikt wordt volgens de richtlijnen van 2B Technologies, USA gelden de veiligheidsvoorzieningen niet meer.

## CHINESE

**警告**：
任何需要接触设备内部的操作均可能造成人身伤害。为避免可能的触电危险，请在打开设备前切断电源。

**警告**：
这个符号 ⚠ 在仪器上表示用户应参考说明书上的操作指南。

**警告：**
如果仪器没有按照美国2B科技公司指定方式操作，仪器的保护性能会减弱。

## JAPANESE

**警告**：
機器の内部で操作する時、怪我できます。危険な衝撃を回避するために、機器を開ける前に、電源を切断してください。

**警告**：
機器でこの記号⚠を見れば、マニュアルを読んでください。

**警告**：
この機器は2B テクノロジー会社、
USAの指定でしなければ、機器の保護が損なえます。

# 1. BLACK CARBON PHOTOMETER INTRODUCTION

## 1.1. Overview

The 2B Technologies Black Carbon Photometer™ is designed to enable accurate measurements of particulate extinction at the wavelengths of 405 and 880 nm over a dynamic range extending from less than one inverse megameter (referred to herein as simply $Mm^{-1}$) up to 10,000 $Mm^{-1}$. The Black Carbon Photometer enables direct measurement of black carbon at 880 nm without filter preconcentration.

The Black Carbon Photometer provides an absolute method for measuring particulate extinction based on the Beer-Lambert Law and thus requires only infrequent calibration. The extinction measurement is analogous to the measurement of ozone ($O_3$) in conventional absorbance-based ozone monitors; the two main differences are the use of longer wavelengths (405 and 880 nm) of light in place of the 254 nm light for $O_3$, and a much longer path length of ~2 meters (vs. 15-30 cm for ozone) to compensate for the much lower extinction cross sections. The long path length is achieved by use of a cell with a tubular design that provides low volume and rapid gas exchange. This folded tubular photometer is described in a paper published by 2B Technologies in the peer-reviewed literature (Birks et al., *Atmospheric Measurement Techniques*, **11**, 2821-2835, 2018).

Particulate mass density is computed using the appropriate wavelength-dependent mass extinction coefficient (with units of $m^2$/g of particulate).

The Black Carbon Photometer is provided with a NIST-traceable calibration. Because detection is based on the absolute method of absorbance, frequent calibration of the span (sensitivity) is not required.

## 1.2. Theory of Operation

Figure 1.1 is a simplified schematic diagram of the Black Carbon Photometer.

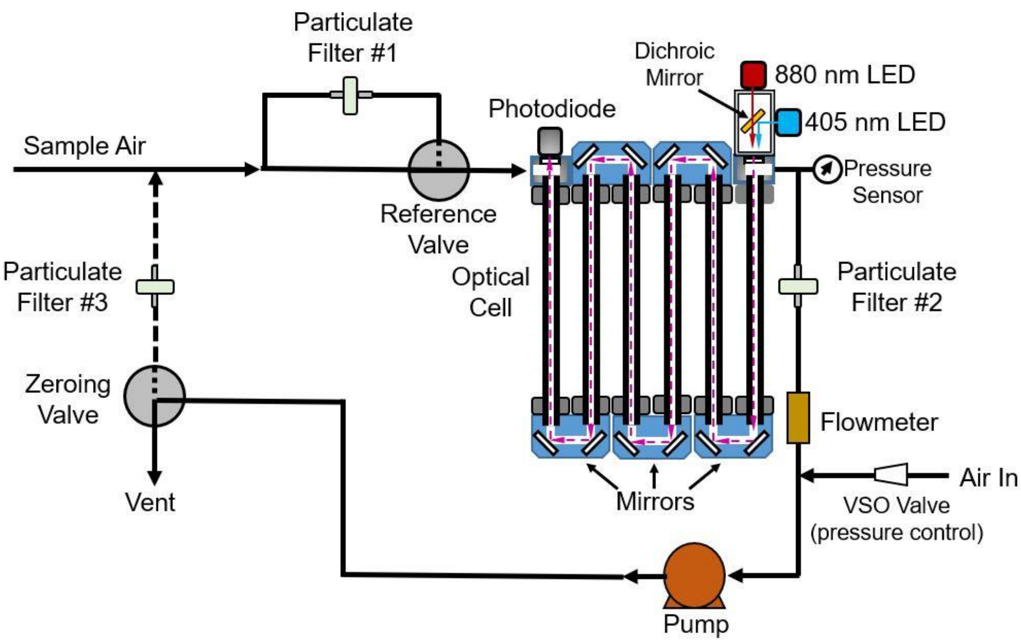



**Figure 1.1.** ***Schematic Diagram of the 2B Technologies Black Carbon Photometer.***

Sample air is continuously drawn through the instrument by the Air Pump at a flow rate of ~1.0-1.5 L/min. The Reference Valve alternately sends the sample air through a PTFE particulate filter (labeled Particulate Filter #1 in Figure 1.1) to remove all particulates or pass directly into the Optical Cell. Particulate-scrubbed or unscrubbed air passes through the Optical Cell and through the Cell Flowmeter. Alternate switching of the Reference Valve once every 10 seconds allows the measurement of a light intensity in the absence ($I_o$) of particulates and presence ($I$) of particulates. The Beer-Lambert Law is then used to calculate the particulate extinction ($B_{ext}$) from $I$ and $I_o$:

$$B_{ext} = \frac{1}{L} ln\left(\frac{I_o}{I}\right) \qquad (1)$$

Here, L is the path length (2.1 m). The measurement provides a direct measure of total particulate extinction ($B_{ext}$). The 2B Technologies Black Carbon Photometer measures the cell temperature and pressure in addition to $B_{ext}$ at 405 and 880 nm. The cell pressure is displayed and logged in units of mbar, and the cell temperature in units of °C. $B_{ext}$ can be displayed/output either directly or corrected to standard conditions ($P_o$ = 1 atm, $T_o$ = 298 K) using the measured pressure and temperature:

$$B_{ext} = \frac{1}{L} ln\left(\frac{I_o}{I}\right)\left(\frac{P_o}{P}\right)\left(\frac{T}{T_o}\right) \qquad (2)$$

Particulate extinction is the sum of two factors: aerosol absorption ($B_{abs}$) and scattering ($B_{sct}$):

$$B_{ext} = B_{abs} + B_{sct} \qquad (3)$$

Absorption causes the loss of a light photon (thus reducing the light intensity measured) whereas scattering from a particle merely redirects the photon within the optical cells. In theory, a scattered photon could reflect from the optical cell walls and still be detected by the photodiode detector – thus not contributing to a loss of light intensity. However, apertures in the Black Carbon Photometer create a small detector acceptance angle that effectively prevents any light that is scattered off the main beam axis by aerosols from reaching the detector. Thus, to a good approximation, the BCP provides a measurement of total extinction.

Extinction can be related to mass concentration ($\mu g\ m^{-3}$) of the aerosol by the mass extinction coefficient denoted as $\sigma_{ext}$ and has units of square meters per gram ($m^2\ g^{-1}$):

$$Concentration\ (\mu g\ m^{-3}) = \frac{B_{ext}}{\sigma_{ext}} \qquad (4)$$

Analogous to equation (3), $\sigma_{ext}$ can be defined via its scattering and absorption contributions:

$$\sigma_{ext} = \sigma_{abs} + \sigma_{sct} \qquad (5)$$

Furthermore, the fraction of light that is scattered by aerosols relative to total extinction is known as the single-scattering albedo (SSA):

$$SSA = \frac{\sigma_{sct}}{\sigma_{abs}+\sigma_{sct}} = \frac{B_{sct}}{B_{abs}+B_{sct}} \qquad (6)$$

For most atmospheric particle distributions, scattering dominates at shorter wavelengths (SSA > 0.5, λ < 600 nm). However, in polluted urban areas absorption by black carbon (BC) aerosols is a significant fraction of extinction, particularly in the near-IR (880 nm).

The 2B Technologies Black Carbon Photometer measures extinction at 2 wavelengths – one in the UV (405 nm) and one in the near-IR (880 nm). In polluted urban air that is dominated by black carbon aerosols, the 880 nm channel can be used to approximate aerosol absorption ($B_{ext} \cong B_{abs}$) and BC concentration can be determined by use of the appropriate $\sigma_{abs}$.

$$[BC]\ \mu g\ m^{-3} = \frac{B_{ext}}{\sigma_{ext}} \cong \frac{B_{abs}}{\sigma_{abs}} \qquad (7)$$

A default value of $\sigma_{abs}$(880 nm) = 7.77 $m^2\ g^{-1}$ (derived from aethalometers, Drinovec et al., *Atmos. Meas. Tech*., **8**, 1965-1979, 2015) is used to compute BC mass concentration in the 2B Black Carbon Photometer; however, this value can be changed by the user since values of $\sigma_{abs}$ for black carbon have been shown to vary over a range of ~ 5 to 15 $m^2$ $g^{-1}$. The same approximation ($B_{ext} \cong B_{abs}$) cannot typically be made at 405 nm where $B_{sct}$ is always a significant fraction of extinction. In fact, the extinction at the shorter 405 nm wavelength can typically be related empirically to PM2.5 in a given location. Therefore, this value can also be changed by the user to an appropriate value for their location. The default value of 6.2 $m^2$ $g^{-1}$ is based on initial roadside studies in Denver, Colorado. For consistencies with other aerosol instrumentation, we use the nomenclature of BC (i.e., Black carbon) = $B_{ext}$ at 880 nm and PM (i.e., PM2.5) = $B_{ext}$ at 405 nm.

In principle, the extinction measurement requires no external calibration; it is an absolute method. However, factors such as variability in the LED peak emission wavelength and band width, and non-linearity of the photodiode and amplifier response, can result in a small measurement error. Therefore, each instrument is calibrated against a NIST-traceable standard of $NO_2$ at 405 nm by replacing Particulate Filter #1 with an $NO_2$ scrubber (as used in the 2B Tech Model 405 $NO_2$/NO/$NO_x$ analyzer). These results are used to calibrate the Black Carbon Photometer with respect to its gain (or sensitivity) at 405 nm. Then, monodisperse polystyrene latex aerosols (PSLs, 500 or 750 nm in diameter) are introduced to the photometer and extinction is measured at both wavelengths. PSL aerosols are known to only scatter light ($B_{ext}$ = $B_{sct}$) and are well-characterized by the Mie scattering theory. Mie theory calculations can then be used to calibrate the gain at 880 nm relative to that at 405 nm. Furthermore, offsets at both wavelengths are measured by introducing air scrubbed of particulates. The corrections for offset (Zero) and gain (Slope) are recorded in the instrument Birth Certificate and on a calibration sticker that can be viewed by removing the top cover of the instrument. These calibration parameters are entered into the microprocessor memory prior to shipment. The user may change these calibration parameters from the front panel by entering the Menu if desired. It is recommended that the instrument be recalibrated at least once annually and preferably more frequently.

The offset may drift on time scales of hours to days due to temperature change or chemical contamination of the absorption cell. It is recommended to periodically zero the instrument during use by sampling particulate-free air. The Black Carbon Photometer is equipped with an automatic zeroing valve that directs the effluent of the analyzer pump through Particulate Filter #3 (Figure 1.1) to the instrument inlet – providing a source of particle-free air for this purpose. Furthermore, it is also recommended to operate the instrument with an appropriate user-supplied particulate cut-off filter (typically a cyclone impactor) on the inlet line. Recommended total particulate and cut-off filters and their suppliers are given Section 12.

## 2. SPECIFICATIONS: BLACK CARBON PHOTOMETER

| | |
|---|---|
| **Principle of Measurement** | Direct extinction at 405 and 880 nm |
| **Measurement Outputs** | Extinction ($Mm^{-1}$) at 405 and 880 nm<br>Mass concentration ($\mu g\ m^{-3}$) at 880 nm |
| **Linear Dynamic Range** | 0-10,000 $Mm^{-1}$ (~0-1300 $\mu g\ m^{-3}$ at 880 nm) |
| **Resolution** | 0.1 $Mm^{-1}$ (0.1 $\mu g\ m^{-3}$) |
| **Precision (10-s measurement, 1σ rms noise)** | 405 nm: 4.1 $Mm^{-1}$; 0.7 $Mm^{-1}$ with adaptive filter[1]<br>880 nm: 2.8 $Mm^{-1}$; 0.5 $Mm^{-1}$ with adaptive filter[1]<br>0.35 $\mu g\ m^{-3}$; 0.07 $\mu g\ m^{-3}$ with adaptive filter[1,2]<br>880 nm, 1–hr average: 0.018 $\mu g\ m^{-3}$ |
| **Accuracy** | Greater of 2 $Mm^{-1}$ or 2% of reading |
| **Limit of Detection (2σ)** | < 1.1 $Mm^{-1}$ at 880 nm (with adaptive filter[1])<br>< 1.6 $Mm^{-1}$ at 405 nm (with adaptive filter[1])<br>880 nm, 1–hr average: 0.036 $\mu g\ m^{-3}$ |
| **Flow Rate (nominal)** | 1.3 Liter/min |
| **Flow Rate Requirement** | Minimum: 1.0 Liter/min; Maximum: 1.6 Liter/min |
| **Response Time, 100% of Step Change** | 20 s for 10-s averaging<br>30 s with adaptive filter[1] |
| **Measurement Frequency** | 0.1 Hz (once every 10 s) |
| **Averaging Times** | 10 s, 1 min, 5 min, 1 hr |
| **Internal Logger Capacity** | 10 Gbytes, > 3.2 years of 10-sec data |
| **Pressure Units** | mbar |
| **Temperature Units** | °C |
| **T and P Corrected** | User-Selected |
| **Operating Temperature Range** | 5 to 45°C |
| **Operating Pressure** | 600 - 1000 mbar |
| **Power Requirement; 5-amp 110/220 VAC Power Pack (provided) or Battery** | 11-14 V dc or 120/240 V ac, 1.3 A at 12 V, 16 watt |

| | |
|---|---|
| **Size** | Rackmount: 17" w × 14.5" d × 5.5" h (43 × 37 × 14 cm) |
| **Weight** | 19.2 lb (8.7 kg) |
| **User Interface** | Touchscreen or Serial |
| **Data Outputs** | RS232, 0-2.5 V Analog Outputs for 405 and 880 nm extinctions, USB drive |
| **Data Transfer Baud Rate** | 2400 |
| **Output Ranges** | User-defined scaling factor in menu |
| **Long Life Pump** | Yes: 15,000 hr |
| **Flow Meter** | Yes |
| **Built-In Auto-Zeroing Capability** | Yes |

[1] An adaptive filter may be selected from the serial menu. Specifications above are for default parameters: Minimum absolute difference = 15 $Mm^{-1}$, Percent difference = 5%, Short Average Filter = 4 pts (40 s), Long Average Filter = 18 pts (3 min). Adaptive filter parameters may be adjusted by the user. See Sections 4 and 5 of this manual.

[2] Using the default values of the mass extinction coefficient of $\sigma$(880 nm) = 7.77 $m^2\ g^{-1}$. This value can be adjusted by the user.

## 3. OPERATION: OVERVIEW

Please read all the following information before attempting to install the Black Carbon Photometer. For assistance, please call 2B Technologies at (303)273-0559.

> ***NOTE:***
>
> **Save the shipping carton and packing materials that came with the Monitor. If the Black Carbon Photometer must be returned to the factory, pack it in the original carton. Any repairs as a result of damage incurred during shipping will be charged.**

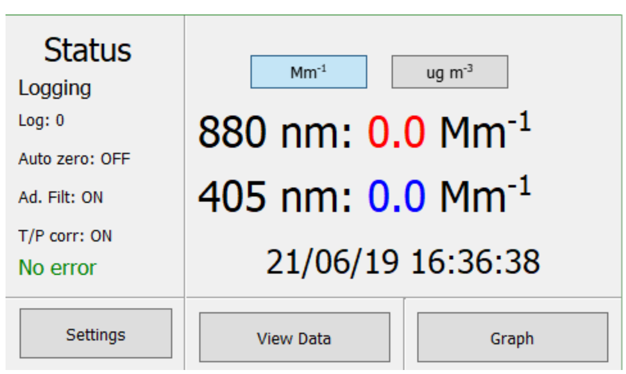
### 3.1. Shipping Box Contents

Open the shipping box and verify that it contains all of the items on the shipping list. If anything is missing or obviously damaged, contact 2B Technologies immediately.

### 3.2. Power Source and Initial Startup

To operate the Black Carbon Photometer, connect it to an external power source and power the instrument on using the front panel power switch. The instrument requires a 12 V DC source, which can be supplied by the provided 110-220 V AC power adapter or an external battery. The power source should be capable of supplying at least 1.3 amperes of current at 12 V (16 watts). The source can be in the range 11-14 V DC without any detrimental effects on the measurement. Note that the instrument cannot be powered via USB connection to a computer because the minimum power requirements cannot be achieved via this method. (Connection to the computer may only be used for data transmission; see Section 5.)

Once turned on, the instrument will briefly show an introductory screen after about 20 seconds. A few seconds later, the instrument should display the **Home** screen below.



For the first 2.5 minutes, the clock on the **Home** screen will display the current date and time, but will continue to show only zeros during this instrument startup period (also note that the number of logged points remains at 0). After the first minute, diagnostic data (cell temperature, pressure, etc.) can be viewed under the **View Data** menu (see Section 4.3). After the 2.5-minute startup period, extinction measurements at 880 and 405 nm will begin to appear and the Log number will increase with each new measurement. If the No error message is displayed, the instrument is now ready for measurements. Full stabilization of the LED, photodiode, and internal temperature of the extinction cell requires about 15-20 minutes.

## 3.3. Connections and Setup

### *3.3.1. Inlet Line and Exhaust*

Attach a user-provided sample inlet line to the SAMPLE inlet port (see Section 10, Figure 10.5).

**Note:** Do not attach a pressurized sample inlet line. If the sample inlet line is above ambient pressure, an overflow Y-fitting (preferable to a tee to reduce particulate losses) should be included and vented to ambient just prior to the attaching to the SAMPLE inlet port.

The inlet tubing should be made of conductive material such as metals (stainless steel, copper) or conductive plastics (conductive silicone, conductive polyurethane). In order to reduce particle loss, the inlet tubing should be connected to an electrical ground to reduce static charging on the tubing walls. The SAMPLE inlet port is equipped with a ¼" stainless steel Swagelok™ fitting, and tubing with an outer diameter (o.d.) of at least ¼" and internal diameter (i.d.) of 3/16" is recommended to increase conductance and reduce wall losses of particulates. The length of tubing should be kept as short as possible to minimize loss of particulates to the internal surface. Stainless steel as well as conductive polyurethane and silicone tubing are used inside the instrument.

The instrument can be exhausted to the room.

### *3.3.2. Flow Rate Adjustment*

The instrument flow rate is adjusted to be in the ranges specified above at the factory. However, due to changes in altitude and thus pressure, the flow rate needs to be verified (via the instrument's touchscreen display or serial menu) and adjusted before operating the instrument. To do this, follow the flow rates on the touchscreen (Section 4.3) or serial output (see Section 3.6). The Cell Flow is shown under the **View Data** screen (Section 4.3), and should be in the range **1100-1600 cm$^3$/min**. This flow can be adjusted by the needle valve located on the back panel labeled CELL FLOW (Figure 10.5). Once the flow has been verified and adjusted it should not need to be re-adjusted as long as the Cell Flow is ≥ 1100 cm$^3$/min.

**After adjusting the flow rate, it is advisable to restart to the instrument to allow the pressure control to re-initiate at the new flow rate.**

### *3.3.3. Thermal Insulation*

Although the instrument compensates for temperature drift, if strong temperature fluctuations are expected the instrument should be placed in a thermally insulated box in order to slow the rate of temperature change.

## 3.4. Data Averaging and Logging

When first turned on, the instrument will start making measurements at a rate of once every 10 s. Data will be saved to a file at a frequency dependent upon the averaging time selected (see Section 4.2.1 and Section 5). Internal logging will begin immediately upon instrument startup, generating a comma-delimited text file with a name based on the startup date and time (example: a start time of May 29, 2019, 13:51:05 gives, 05_29_19_13_51_05.txt). A line of data includes: log number (since startup), Extinction at 880 nm ($Mm^{-1}$), Extinction at 405 nm ($Mm^{-1}$), Black Carbon ($\mu g\ m^{-3}$), PM ($\mu g\ m^{-3}$), Cell Temperature (°C), Cell Pressure (mbar), Cell Volumetric Flow Rate ($cm^3$/min), Cell Relative Humidity (%), Flow Temperature (°C), Sample Photodiode Voltage (V) at 880 nm, Sample Photodiode Voltage at 405 nm, Date, Time, and a status indicator. Averaging times of 10 s, 1 min, 5 min and 1 hr can be selected from the menu (Section 4.2.1, Section 5). There are ~10 Gbytes of storage space on the Black Carbon Photometer, which allows for storage of > $10^7$ lines of data.

Internally logged data files can also be transferred to a user-supplied memory stick. The USB stick is inserted in the front USB port and then an option to either transfer internal files to the USB or to delete old internal files can be selected using the **Settings** menu of the touchscreen display (see Section 4.2.8). A new data file is begun each time the instrument is powered on.

## 3.5. Collecting Data from the Analog Outputs

The data may be logged in real time using a data logger attached to the BNC analog outputs. There are two analog outputs: one for 880 nm extinction, and one for the 405 nm extinction. The range of each analog output is 0-2.5 V. A user-selectable scaling factor can be input for each wavelength under the respective **Calibration** screens on the touchscreen display (see Section 4.2.5). The output voltage is then scaled according to this scaling factor. For example, you may define 2.5 V = 250 $Mm^{-1}$. In that case, the maximum output is 250 $Mm^{-1}$, and 10 mV is equal to 1 $Mm^{-1}$. There is a small positive offset, typically 2 mV in the analog output, but this offset varies from instrument to instrument. The offset can be measured by simultaneously observing the touchscreen display and measuring the analog output with a voltmeter.

## 3.6. Collecting Data over the Serial Port in Real Time

To transmit data to a computer over the serial port in real time, connect the instrument to the computer using the 9-pin cable provided (and a serial-to-USB adapter cable if necessary). Note that the 9-pin cable provided is a "straight-through" female-female serial cable. A "cross-over" cable will not work. Start your data acquisition software, preferably using the 2B Technologies Display and Graphing Software. Other terminal emulation software such as HyperTerminal (a program provided with earlier versions of Windows) or Tera Term may be used as well. Be sure to specify the baud rate setting of your data acquisition software to match the baud rate setting of your instrument. Note that the baud rate of the instrument is 2400.

Log number (since startup), Extinction at 880 nm ($Mm^{-1}$), Extinction at 405 nm ($Mm^{-1}$), Black Carbon ($\mu g\ m^{-3}$), PM ($\mu g\ m^{-3}$), Cell Temperature (°C), Cell Pressure (mbar), Cell Volumetric Flow Rate (mL/min), Cell Relative Humidity (%), Flow temperature (°C), Sample Photodiode Voltage (V) at 880 nm, Sample Photodiode Voltage at 405 nm, Date, Time, Current 880 nm Zero Offset ($Mm^{-1}$), Current 405 nm Zero Offset ($Mm^{-1}$), and status are sent as comma-delimited ASCII text to the serial port (2400 baud; 8 bits; no parity; 1 stop bit) every 10 seconds, 1 minute, 5 minutes, or 1 hour, depending on the averaging time selected (Section 4.2.1). Time is provided in 24-hour (military) format, and the date is given in European style (day/month/year). The user should separately make note of the instrument settings and averaging time.

A typical data line might read:

25,44.2,87.4,5.7,14.1,26.5,980.6,1343,25.4,26.4,0.9816,1.3151,12/06/19,18:31:27,1.0,-0.8,0

where:

Log Number = 25
Extinction at 880 nm = 44.2 $Mm^{-1}$
Extinction at 405 nm = 87.4 $Mm^{-1}$
BC (880 nm) = 5.7 $\mu g/m^3$
PM (405 nm) = 14.1 $\mu g/m^3$
Cell temperature = 26.5°C
Cell pressure = 980.6 mbar
Cell volumetric flow rate = 1343 cc/min
Relative Humidity = 25.4%
Flow temperature = 26.4°C
Sample photodiode voltage at 880 nm = 0.9816 volts
Sample photodiode voltage at 405 nm = 1.3151 volts
Date = June 12, 2019
Time = 6:31:27 PM
Current 880 nm zero = 1.0 $Mm^{-1}$
Current 405 nm zero = -0.8 $Mm^{-1}$
Status = 0 *(Measuring sample) (see Section 5 for status codes)*

In addition to data lines, messages are written to the serial port when logging is interrupted (e.g., due to a power failure) or when the settings are changed on the touchscreen display. Section 5 of this manual describes the serial menu and how to access it.

## 3.7. Calibration

It is recommended that a full calibration be performed annually at the factory, or any time major disassembly occurs or new parts installed. Please see Section 7 of this manual for a description of 2B Tech's calibration service and information about how to return your instrument for calibration.

## 3.8. Periodic Measurement of the Zero Offset

The electronic zeros for $B_{ext}$ at both 880 and 405 nm may be periodically measured by providing particle-free air to the sample inlet for a period of 5-10 minutes. This can done manually by the user by sampling through an external particle filter attached to the instrument inlet. The Black Carbon Photometer also has a built-in automatic zeroing capability to provide an offset measurement on a periodic (user-defined) basis. Section 8 gives procedural recommendations for proper measurement of the instrumental zero offset. When making multi-day continuous measurements, it is recommended to check the zero offset daily.

## 3.9. Adaptive Filter

The Black Carbon Photometer firmware can output averaged sample extinction data through a built-in adaptive filter. This can be used to maximize precision (i.e., sensitivity) while still maintaining the ability to observe relatively rapidly changing measurements. When activated, the firmware will automatically switch between two averaging filters of different time lengths based on the conditions at hand. During the measurement of stable extinctions, the firmware, by default, computes and outputs a user-selectable "long" running average (**Long Avg**., typically 2 - 4 minutes). This provides smooth and stable readings by averaging out a considerable amount of random noise to improve the precision. If the filter detects rapid changes in extinction, the firmware outputs the results of a "short" averaging filter (**Short Avg**, typically only 3 - 4 samples or 20 - 40 seconds) that allows the analyzer to respond more rapidly. As extinctions are typically much larger and more variable at 405 nm, this wavelength is used to determine which averaging filter is output for both 405 and 880 nm. Two conditions must be simultaneously met to switch to the short filter. First, the instantaneous PM (405 nm) must differ from the average in the long filter by a user-selectable minimum absolute difference (**Min Diff**). Secondly, at higher extinction values the instantaneous extinction must also differ from the average in the long filter by at least a user-designated percentage **(% Diff**) of the long filter. The lengths of the long and short filter can be changed as well as the minimum absolute difference and percent difference. This can be done either in the instrument touchscreen (Section 4.2.3) or via the serial connection (Section 5).

Default values of the adaptive filter are: **Long Avg** = 18 samples (3 minutes), **Short Avg** = 4 samples (40 seconds), **Min Diff** = 15 $Mm^{-1}$, **% Diff** = 5%. To disable the adaptive filter and measure discrete 10-second sample outputs, set the **Short Avg** length to 1, the **MinDiff** to 0, and the **%Diff** to 0.

## 3.10. Summary of Operating Recommendations

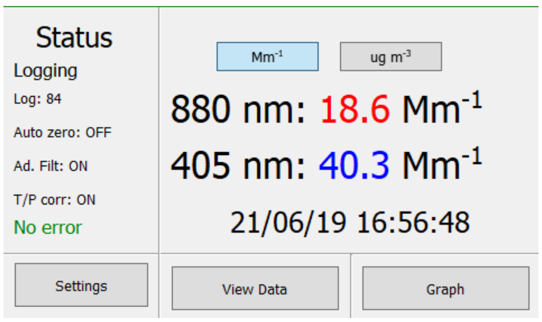
The following table summarizes operating recommendations mentioned in this manual.

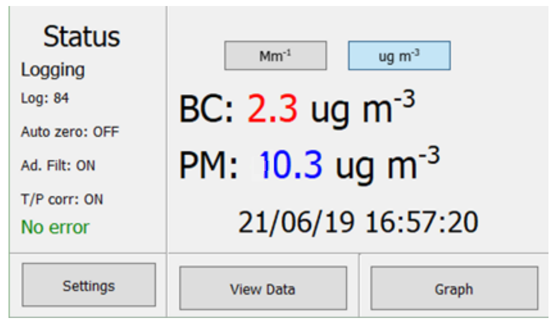
| Operating Recommendation | Frequency | Section Reference |
|---|---|---|
| Check and adjust cell flow rate before operating instrument (restart instrument after adjustment of flows) | Upon initial setup | 3.3.2 |
| Allow ~20 minutes for instrument warmup before taking data | Each startup | 3.2 |
| Inlet tubing should be made of conductive materials, such as metals (copper, stainless steel) or conductive polymers (silicone or polyurethane). Connect to electrical ground. | Each use | 3.3.1 |
| Check the zero offset | Periodically. Daily for long-term continuous measurements | 3.7, 8 |
| Check the span (full calibration) | • Annually (return instrument to factory)<br>• Any time major disassembly of components is performed | 3.7, 4.2.5, 7 |
| If strong temperature fluctuations are expected, place the instrument in a thermally insulated box | User-defined | 3.3.3 |

# 4. INSTRUMENT SETUP USING THE TOUCHSCREEN

## 4.1. Home Screen

Most of the instrument operations can be configured either via the serial connection (remotely, see Section 5) or through the touchscreen. The following section describes the use of the touchscreen for configuring and operating the 2B Technologies Black Carbon Photometer. Once the instrument is powered up and has completed its startup period, it automatically displays the current extinction measurements for both the 880 nm (in red, units of $Mm^{-1}$) and 405 nm (in blue, units of $Mm^{-1}$) channels (below left).




The buttons above the current measurements can be used to change the output display units between **$Mm^{-1}$** (default) and **$\mu g\ m^{-3}$**. The labels then change to **BC** (corresponding to 880 nm) and **PM** (corresponding to 405 nm) – (above right). Below these measurements are the current time and date (dd/mm/yy hr:mm:ss).

**Note:** The Black Carbon Photometer is calibrated for extinction – the $\mu g\ m^{-3}$ output units rely on the Mass Extinction Coefficient (MEC) at each wavelength which are input in the **Settings** screen (Section 4.2). See also Section 1.2.

When the analyzer is set to output longer averages (1, 5, or 60 minutes; see Section 4.2.1), the Home screen will continue to be updated with the most current 10-sec measurement even though only the longer averages are saved to the output data file.

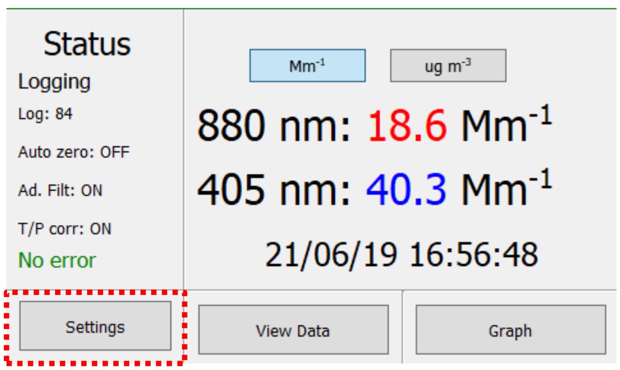
The left side of the **Home** screen shows the current operational status. The top line will display **Logging** if the instrument is running normally and logging data. This line will be followed by a **Log** number showing the current number of saved measurements since startup. Below this, the current status (on or off) of the **Auto Zero**, the **Ad. Filter** (Adaptive Filter), and **T/P corr** (Temperature and Pressure corrections) are displayed. Selecting one of these will take you to their respective configuration screens under the **Settings** menu (Section 4.2). These configuration screens can also be accessed by selecting the **Settings** button (Section 4.2) at the bottom of the **Home** screen. Finally, a message showing current errors is given. The example above shows normal operation with the message No error. When an error occurs, a message in red text will be shown and selecting the error will give a brief description of the error in a pop-up box. The error is cleared by selecting the OK button.

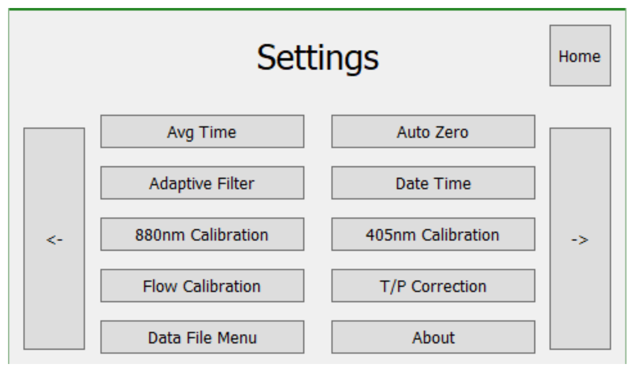
At the bottom of the **Home** screen are buttons that will take the user to other screens. The **Settings** button allows the user to see and change calibration coefficients and Mass Extinction Coefficients (MECs), change averaging times, set the current time and date, configure logging and manipulate saved data files, and set parameters for Auto zeroing and the adaptive filter. The **View Data** button lists all the current measurements made by the instrument – this is the same list of data that is saved in the logged data files and output via the serial data stream. The **Graph** button allows the user to plot up to all 11 variables measured by the 2B Black Carbon Photometer on a time series graph to visually inspect data.

From the **Settings**, **View Data,** or **Graph** pages, one can return to the **Home** screen by selecting the **Home** button.

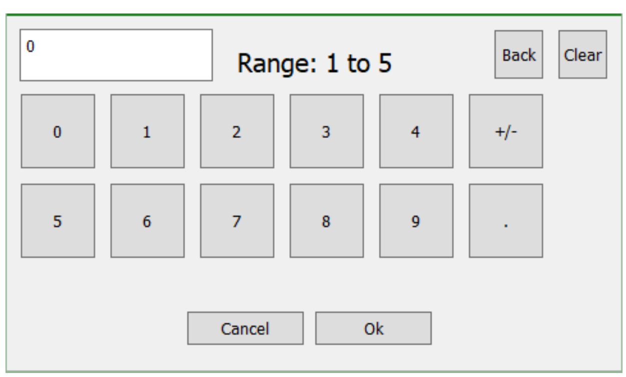
## 4.2. Settings Screen

The instrument can be configured either through the serial menu (Section 5) or via the **Settings** screen on the touchscreen display. After selecting the **Settings** button from the **Home** screen, the menu below will be displayed showing buttons for the various instrument operating parameters that can be changed by the user.



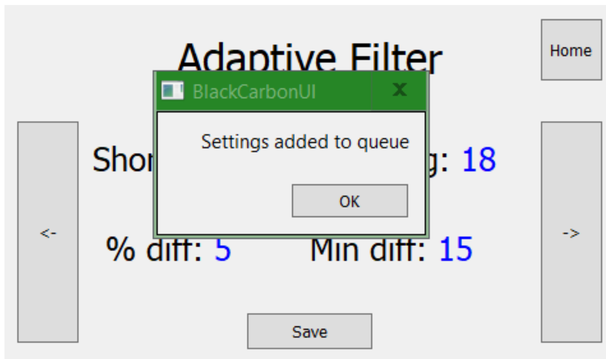




Selecting any of the buttons takes you to that setup screen. You can also scroll through the various settings by using the arrow buttons on each side of the **Settings** screen. Below is a description of these different settings that can be configured by the user from this menu. Whenever numerical inputs are needed to change set points, a numerical keypad will appear such as the one shown below.



Use the keypad to insert the desired value (which will be shown in the upper left box) and the **Clear** and **Back** buttons to delete input values. The input value must be within the range given on the keypad otherwise the font will turn red and you will not be able to save the value. Hit **OK** to select the values and return to the original setup screen.

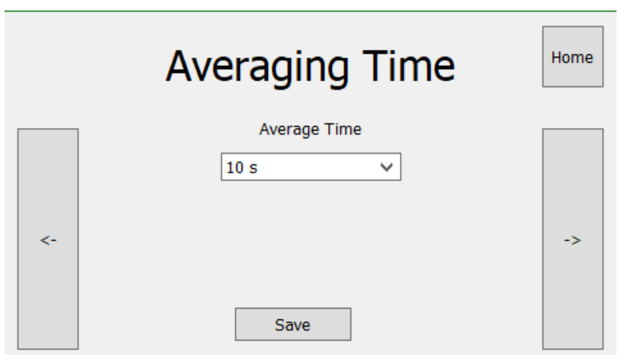
Once an input value is changed, it must be saved on the main setup screen. Hitting the **Save** button will bring up the following pop-up message.




Hitting **OK** will update the new values and changes to the **Settings** will implemented.

### *4.2.1. Averaging Time*

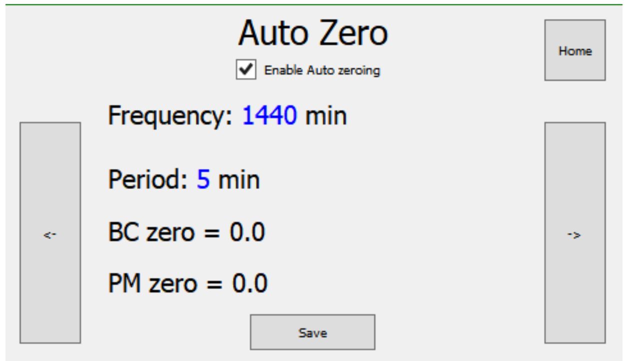
When the **Avg Time** button is selected, the user is taken to the following page:




The user can use the drop-down menu on this screen to select the *Average Time* – or the rate at which data will be saved to the logging file and output through the serial port. The options are 10 sec, 1 min, 5 min, or 60 min. When averaging times > 10 sec are selected, the current measurements on the **Home** screen will still update every 10 seconds; however, data is only being saved or output via the serial port at the selected averaging time. Hit the **Save** button to initiate data output at the new averaging time.

### *4.2.2. Auto Zero*

The internal zeroing function can be scheduled by the user to occur automatically. The frequency and duration are configured via the **Auto Zero** screen.




Clicking on either the **Period** or the **Frequency** will cause a numeric keyboard to appear that can be used to change the input value. **Period** gives the length of time that the instrument will be measuring particle-free air and can be varied from 0 to 60 minutes. **Frequency** can be varied from 0 to 1499 minutes and designates how often the zeroing will occur. For example, if the **Frequency** is set to 1440 and **Period** is set to 10, the Black Carbon Photometer will zero once a day for 10 minutes. After a new zero is completed, the 880 nm (BC) and 405 nm (PM) zeros (in $Mm^{-1}$) will be updated on this screen. After selecting the desired **Frequency** and **Period**, select the **Enable Auto Zeroing** checkbox and hit **Save** to initiate the auto zeroing. Timing until the next zeroing period begins at this point. Unchecking the **Enable Auto Zeroing** checkbox (and then hitting **Save**) will disable the auto zeroing and the offsets will revert to those entered into the **Calibration Parameters** screen (section 4.2.5).

**Note:** The user will be prompted to save the new input values if they leave this screen before new values are saved.

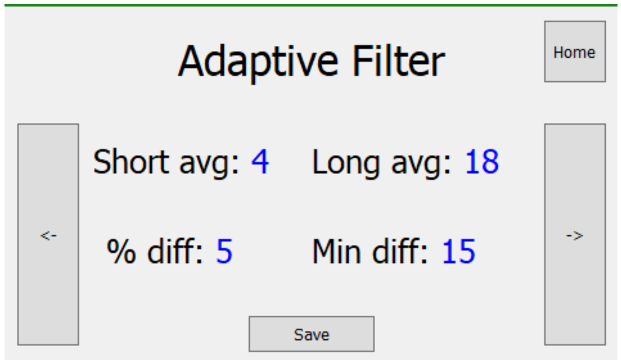
**Note: Frequency** should be set at least 2 times larger than **Period**.

Within the data files the status indicator in the output data (Section 3.6) will change to "1" to allow the user to distinguish (and, thus parse) zeroing periods within the data files during post-processing. For most applications, running the **Auto Zero** once or twice daily, for ~ 5 to 10 minutes is sufficient.

**Warning!** It is not recommended to use the Auto Zero function when other instruments are connected to the same inlet line. When using the Auto Zero function, a small flow of particle-free air is pushed out of the Sample port of the Black Carbon Photometer. This can impact measurements by instrumentation sharing the same inlet line.

### *4.2.3. Adaptive Filter*

The **Adaptive Filter** screen can be used to change the four parameters used by the adaptive averaging filter described in Section 3.9. Clicking on **Short Avg**, **Long Avg**, **% Diff** or **Min Diff** will cause a numeric keyboard to appear that can be used to change the input value (similar to that shown in Section 4.2). Once values are selected, hit the **SAVE** button on the main settings screen to input new values.

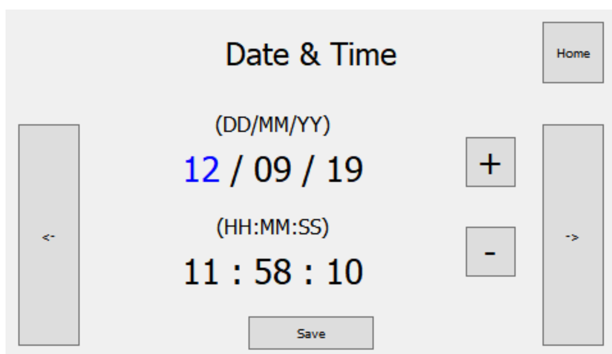



The default values of the adaptive filter are: **Short Avg**= 4 samples (short average of 40 seconds), **Long Avg** = 18 samples (long average of 3 minutes), **% Diff** = 5% and minimum absolute difference **Min Diff** = 15 $Mm^{-1}$. One can disable the adaptive filter (to measure discrete 10-sec. samples) by setting both the **Min Diff** and **% Diff** to 0.

**Note:** The user will be prompted to save the new input values if they leave this screen before new values are saved.

### *4.2.4. Date and Time*

Here the user can see and change the current date and time in the instrument.

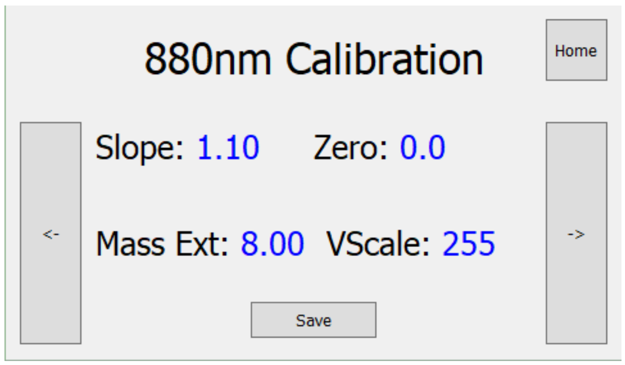



Selecting any of the date or time fields will highlight the value in blue (**DD** is highlighted in the above figure). The **[+]** and **[-]** buttons can then be used to increase or decrease the selected value. The date is entered in European format, DDMMYY. Once the date and/or time is input, hit the **Save** button to enter the new value into the instrument. As in setting a digital watch, the seconds should be set in advance of the real time since the clock starts to run again only when the set time is entered by hitting the **Save** button. Changing the time or date will change the time tags within any subsequent output data, but it will not rename or start a new logging file.

**Note:** The user will be prompted to save the new values if they leave this screen before new values are saved.

### *4.2.5. Calibration Parameters Screens*

There are 2 screens used for inputting calibration coefficients - one for each wavelength (880 nm and 405 nm). On each screen there will be inputs for: (1) Offset (**Zero**), (2) Span (**Slope**), (3) Mass Extinction coefficient (**Mass Ext)**, and (4) Analog Scaling factor (**VScale**). Below is the screen shown for the **880nm Calibration** – an analogous one appears when the **405nm Calibration** button is selected. Upon making any changes to the **Calibration** menus, one must hit the **Save** button to incorporate those changes.




The **Slope** and **Zero** are calibrated at 2B Technologies as described in Sections 7 and 8, respectively. These are used to correct for any instrumental offsets or electronic biases in the measurement of the light extinction (or attenuation). The instrument is calibrated at 2B Technologies, where **Slope** and **Zero** parameters for the 880 and 405 nm extinction are entered into the instrument's memory prior to the instrument being packaged and shipped. These preset calibration parameters are given in the instrument's Birth Certificate. However, these calibration parameters can be changed by the user based on their own calibrations. For example, it may be desirable to provide a positive offset by a known amount (e.g., 10 Mm$^{-1}$) if the analog output is being used for external data logging since the analog output is unipolar and does not output negative voltages corresponding to extinctions below 0 Mm$^{-1}$. Because of noise and/or an inherent offset, some measured values will be below zero at very low extinctions. (When measuring zero extinction, there should be an equal number of negative and positive values if the instrument is properly zeroed.) Also, the instrument zero may drift by a few Mm$^{-1}$ over time (see Section 8). <u>For both wavelengths, the **Zero** value must be entered in units of Mm$^{-1}$.</u> The value of **Zero** <u>is added</u> to the measured extinction at either wavelength (880 or 405 nm), and the value of **Slope** is then multiplied by the measured value. For example, if the instrument reads an average of 3.2 Mm$^{-1}$ with an external particulate scrubber in place, the value of **Zero** should be set to –3.2. If after correction for the zero, the instrument consistently reads 2% low, the value of **Slope** should be set to 1.02.

The **Mass Ext** coefficient is used to convert extinction (Mm$^{-1}$) to mass density units ($\mu$g m$^{-3}$) and is in units of m$^2$ g$^{-1}$. This coefficient often depends upon the single-scattering albedo type as well as other properties (size, composition) of the aerosol being sampled. The mass density (BC or PM) is calculated by dividing the measured extinction by the **Mass Ext** (Eqn. 4). For example, an extinction measurement of 50

$Mm^{-1}$ at 880 nm will be converted to 6.4 $\mu g\ m^{-3}$ when using the default MEC value of 7.77 $m^2\ g^{-1}$ (for black carbon absorption).

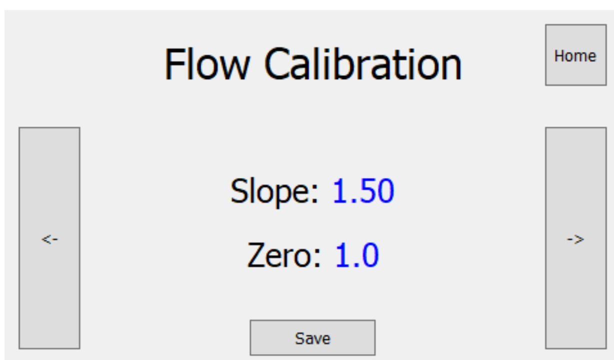
The **VScale** button is used to input an extinction value (in $Mm^{-1}$, range of 25 to 1000) that represents a 1 Volt analog output. All analog output voltages for the respective wavelength are then scaled according to this scaling factor. For example, a setting of 500 $Mm^{-1}$ designates an output voltage of 1.0 V is equivalent to 500 $Mm^{-1}$, thus 2 mV is equal to 1 $Mm^{-1}$. There is a small positive offset, typically 2 mV in the analog output, but this offset varies from instrument to instrument. Note that the total full-scale range of the analog output is 2.5 V which is higher than the **VScale** setting.

**Note:** The **VScale** factors are input in extinction units ($Mm^{-1}$). If the user wants to scale the analog outputs according to mass density units ($\mu g\ m^{-3}$), the **Mass Ext** factor can be incorporated into the **VScale** factor. For example, to obtain a desired scaling of 1 V = 50 $\mu g\ m^{-3}$, one would multiply 50 $\mu g\ m^{-3}$ by the **Mass Ext** coefficient (in screen shown earlier in this section, 8 $m^2\ g^{-1}$), giving a **VScale** = 400 $Mm^{-1}$.

### *4.2.6. Flow Calibration*

Flow rates and flow meter calibration parameters should not be changed unless certain parts of the instrument are replaced, which are normally done by technicians at the factory. The user should check and adjust flow rates if the instrument setup is changed (see Section 3.3.2). The scaling factor of the Cell Flowmeter can be adjusted if necessary.

Selecting the **Flow Calibration** button gives:



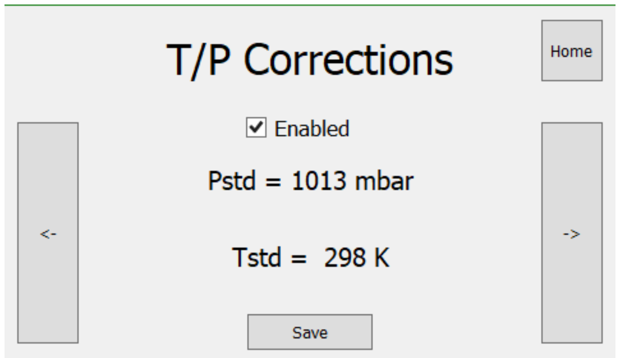

where a scaling factor (**Slope**) and offset (**Zero**) for the **Cell Flow** can be input by the user. These are calibrated by 2B Technologies prior to shipping and the user should NOT change this setting without contacting 2B Technologies.

### *4.2.7. T & P Correction*

Selecting this button allows the user to decide whether to correct the measured extinctions (and, subsequently, the mass densities) to a standardized temperature and pressure. When turned **ON**, extinctions are normalized to the standard conditions of 1 atmosphere (1013.25 mbar) and 298.15 Kelvin (25°C) via

$$B_{ext}(T,P\ corrected) = B_{ext} * \frac{1013.25\ mbar}{Cell\ Pressure,\ \ mbar} * \frac{(Cell\ Temperature(^{O}C) + 273.15K)}{298.15\ K}$$

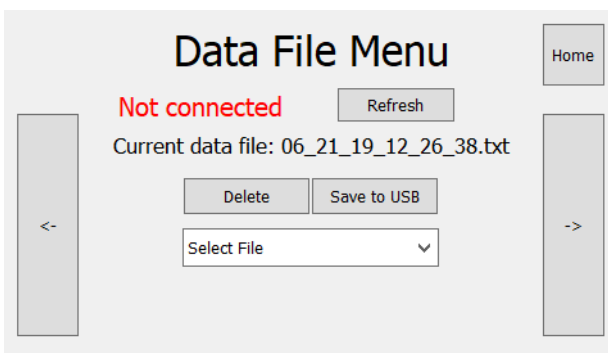
The **T & P Corrections** button brings up a check box allowing the user to decide whether to apply this correction.




Here, we have chosen to use reference conditions dictated by the US-EPA (25°C and 1 atm). However, other standardizing organizations often define other reference conditions (e.g., IUPAC defines $T_{std}$ = 273.15 K). Please contact 2B Technologies if other standard conditions are desired.

### *4.2.8. Data File Menu*

This screen can be used to manipulate files saved internally or to the USB memory drive.




The screen will read Not Connected when there is no USB memory stick inserted into the instrument. If a USB memory stick is present, the message will read USB Connected. If the USB stick is inserted or removed while viewing this screen, the user must hit the **Refresh** button before it will acknowledge the change in connection status. Once a USB stick is connected, the drop-down menu can be used to select the internally stored data files that the user would like to copy to the USB memory drive. The name of the current data file that is being logged is shown just above this drop-down menu (for example, 06_21_19_12_26_38.txt, which is in the format of MM_DD_YY_HH_MM_SS.txt). Files can be selected and then transferred by hitting the **Save to USB** button. Internally saved data files can also be deleted using the drop-down menu, by selecting files and hitting the **Delete** button. This command DOES NOT delete the files from the USB drive.

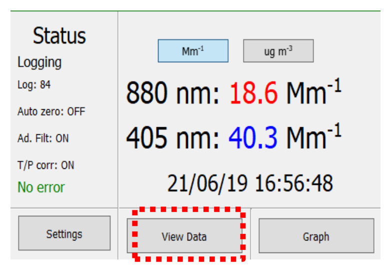
**Warning!** Once datafiles are deleted internally, they cannot be recovered!! Make sure they are transferred and saved on the external USB drive before removing from the internal logger.

### *4.2.9. About*

This screen gives the current firmware and software version installed in the instrument.


## 4.3. View Data Screen

When the **View Data** button is selected from the **Home** screen, the table below left is displayed giving the current measurement values.




**Data 1**

| Log: | 84 | Cell Temp,°C | 25.1 |
|---|---|---|---|
| EXT(880),$Mm^{-1}$ | 18.6 | Cell Press, mbar: | 824.7 |
| BC,ug $m^{-3}$ | 2.3 | Cell Flow, ccm: | 1495.0 |
| EXT(405),$Mm^{-1}$ | 40.3 | PDV(880),V: | 0.847539 |
| PM,ug $m^{-3}$ | 40.3 | PDV(405),V: | 2.170915 |

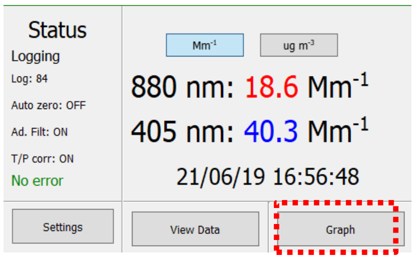
**Data 2**

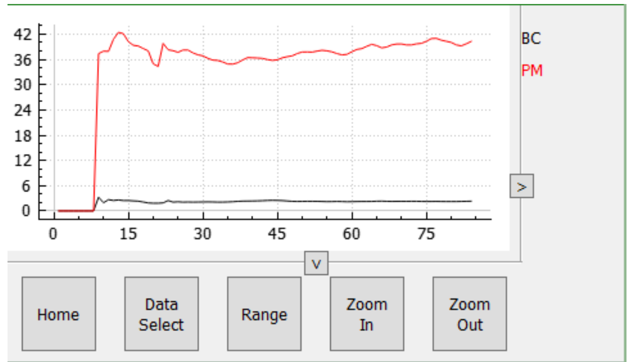
| Flow Temp,°C | 0.0 | RH,%: | 33.5 |
|---|---|---|---|
| Status: | 0 | | |
| Date: | 06/21/19 | Time: | 12:32:10 |
| | | | |
| | | | |

Values of the extinctions at both wavelengths (**EXT(880)** and **EXT(405)**) and their corresponding mass densities (**BC** and **PM**) are given here and updated with every 10-second measurement. Other diagnostic measurements are also given: cell temperature, pressure, flow rate, and light intensities at the two wavelengths (**PDV**). Arrow buttons on either side scroll to a second table (above right) to show additional diagnostics.

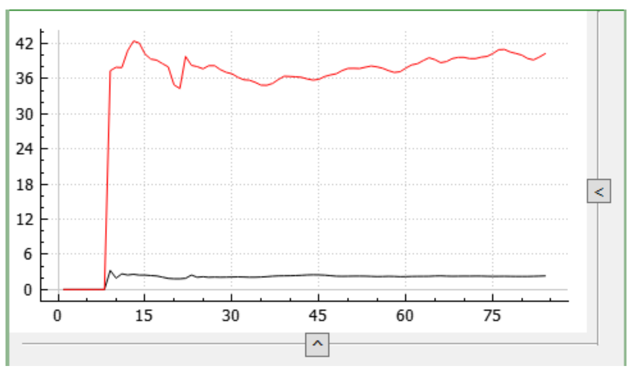
## 4.4. Graph Screen

When the **Graph** button is selected from the **Home** screen, a time series from the current data file is plotted on the screen.




Data are plotted vs. the Log number (1st column in saved output files). A legend is shown in the upper right-side of the graph. The buttons **Data Select**, **Range**, **Zoom In,** and **Zoom Out** are shown at the bottom. Selecting the **V** or **>** arrows hides the bottom buttons or the legend, respectively.

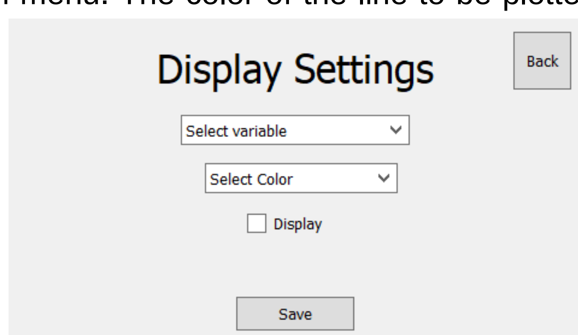



Selecting the up arrow (**Λ)** or left arrow button (**<**) on the right side of the screen returns the buttons and legend to the graph display.

### *4.4.1. Data Select*

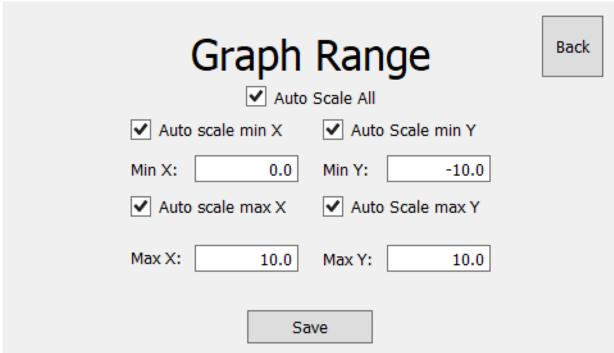
Selecting the **Data Select** button allows the user to select up to 11 measured variables to plot using the **Select Variable** drop down menu. The color of the line to be plotted can also be selected via the **Select Color** drop down menu.

Once a variable and color are chosen, select the **Display** checkbox and then push the **Save** button. The instrument will then plot that variable once the **Back** button is pushed to return to the **Graph** page.



### *4.4.2. Range*

The **Range** button allows the user to either select a set range for the displayed graph, or use auto-ranging of both the x and y axes.




Both the minimum and maximum x and y values can be independently selected or allowed to auto-range. Clicking in the boxes allows set values to be input via a numeric keypad that will appear. Remember to hit the **Save** button to confirm the new input values before returning to the **Graph** page (via the **Back** button).

### *4.4.3. Zoom In, Zoom Out*

These buttons allow the user to zoom in or out on the graph scale. After selecting the axis (x or y) by touching it, the **Zoom In** / **Zoom Out** buttons will expand/compress the selected axis. Dragging the fingers across the graph either horizontally or vertically will cause the graph to scroll in that respective direction.

## 5. REMOTE OPERATION VIA SERIAL CONNECTION

The Black Carbon Photometer can also be accessed and controlled remotely through the RS-232 serial port located on the back of the instruments (see Figure 10.5). Measurements and logging tasks can be accessed via the serial port using a terminal emulator such as Tera Term or HyperTerminal running on an attached computer. Current data is automatically output via the serial port at the selected averaging rate with the port settings described in Section 3.6 of this manual.

### 5.1. Serial Commands

If the letter **m** is sent as a command in the terminal emulator window, measurements will stop and **menu>** will be displayed in the window. When the serial menu is accessed, the instrument is no longer making measurements; it is waiting for the next command to be entered. The touchscreen display will also no longer update measurements while the instrument is paused via the serial menu. The following is the list of menu items accessible from this point. This help list can be displayed on the terminal window by sending a **?** command. For each item, a capitalized letter will only display the current setting. To change a setting, the small letter command must be sent and then the user will be prompted to enter a new value. Typing an **x** will exit the serial menu and re-initiate measurements.

| Keystroke | | Description |
|---|---|---|
| **View** | **Change/Input** | |
| 0 | | View all current settings |
| 1 | | View logging status |
| 2 | | Output column headers |
| A | a | View/Set Period for Auto Zero function |
| B | b | View/Set Frequency for Auto Zero function |
| C | c | View/Set Short Average on adaptive filter |
| D | d | View/Set Long Average on adaptive filter |
| E | e | View/Set Min. Difference on adaptive filter |
| F | f | View/Set % Difference on adaptive filter |
| G | g | View/Set T/P corrections |
| H | h | View/Set Averaging time |
| I | i | View/Set Vout Scale for 405 nm |
| J | j | View/Set Vout Scale for 880 nm |
| K | k | View/Set 405 nm Ext Slope |
| L | l | View/Set 405 nm Ext Zero |
| M | m | View/Set 405 nm mass extinction coefficient |
| N | n | View/Set 880 nm Ext Slope |
| O | o | View/Set 880 nm Ext Zero |
| P | p | View/Set 880 nm mass extinction coefficient |
| Q | q | View/Set Flow Slope |
| R | r | View/Set Flow Zero |
| S | s | View/Set Date |
| T | t | View/Set Time |
| U | u | View/Set serial baud rate |
| X | x | Exit serial menu |
| | ? | Output the help menu |

## 5.2. Status Codes

The current measurement mode can be determined from the status code in each serial data line.

0 = Sampling
1 = Measuring Zero offset for both channels.

# 6. MAINTENANCE

The Black Carbon Photometer is designed to be nearly maintenance free. Components that require routine maintenance include periodic replacement of the LEDs, particulate filters, and the air pump. The LEDs should be replaced when the light intensity is ≤ 0.2 V and the low intensity is not due to optics contamination (see Section 9). Particulate filters should be changed once a year. The pump has a rated lifetime of 15,000 hours (~1 year and 8 months) of operation and will need to be replaced when the flow rates can no longer be brought into proper operating range (see Section 3.3.2). Operation with a high restriction on the sample inlet will reduce the lifetime of the pump. The instrument is designed so that pump replacement is relatively easy. Other user-serviceable components include the clock battery and solenoid valves, which are easily replaced should they fail. See Section 9 of this manual for other troubleshooting information.

A wide range of Technical Notes are provided on the 2B Tech website. These Tech Notes are continuously updated and new ones created.

Also, please note that all 2B Tech instrument manuals are posted online at:

https://2btech.io/downloads/

For your convenience, a Service Log, which may be printed, is provided at the end of this manual for recording calibrations, replacement of pumps, LEDs, etc. Records of repairs made at 2B Tech are maintained in a database at 2B Technologies as well. That database also includes detailed information about the construction and initial calibration of your instrument, including digital of photos of its interior.

Maintenance recommendations are summarized below.

| **Maintenance Recommendation** | **Frequency** | **Section Reference** |
|---|---|---|
| Recalibrate instrument | At least once per year or at 4000 hours; sooner if span and offset are large, or if instrument undergoes major disassembly | 7 |
| Check flow path for contamination | Every 6 months of continuous operation (~4,000 hrs); otherwise annually | Contact 2B Tech if contamination is suspected |
| Check particulate filters | Every 6 months of continuous operation (~4,000 hrs); otherwise annually | 6 |
| Monitor flow rates and replace pump if indicated | Nominal 15,000 hours pump lifetime | 6 |

# 7. FACTORY CALIBRATION

Since the Black Carbon Photometer relies on measuring relative light intensities to compute extinctions, it is theoretically an absolute method and does not need calibration. However, small uncertainties in the path length (*L*) or nonlinearities in the detector response can result in biases in the measurements. Furthermore, every analytical instrument is subject to some drift and variation in response, making it necessary to periodically check the calibration.

Calibration of the Black Carbon Photometer is recommended annually by returning the instrument to 2B Technologies for calibration and servicing. Please contact Customer Service at 2B Tech via our web ticketing software to arrange for factory calibration:

https://2btech.io/support/

Alternatively, you can email us at techsupport@2btech.io or call us at +1(303) 273-0559.

During this calibration, the 405 nm channel (PM) is calibrated using nitrogen dioxide ($NO_2$) absorption. For this calibration the instrument is modified by removing Particulate Filter #1 (see Figure 1.1) and replacing it with an $NO_2$ scrubber. The analyzer's 405 nm channel is then calibrated according to the procedures outlined in Code of Federal Regulations (Title 40, Part 50, Appendix F: https://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol2/pdf/CFR-2011-title40-vol2-chapI.pdf). Commercial $NO_2$ calibrators employ the reaction of excess nitric oxide (NO) with ozone ($O_3$) which generates a stoichiometric amount of $NO_2$:

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (8)$$

The concentration of ozone prior to reaction can be measured using a photometer with a NIST-traceable calibration and then compared to the final measured $NO_2$ concentration. The $NO_2$ is quantified using the Beer-Lambert law (analogous to Eq. 1):

$$[NO_2] = \frac{1}{\sigma_{NO2} L} \ln\left(\frac{I_o}{I}\right) \qquad (9)$$

where $\sigma_{NO2}$ is the absorption cross section of $NO_2$ at 405 nm ($6.0 \times 10^{-19}$ cm$^2$ molec$^{-1}$).

$NO_2$ concentrations in the range of 0 to 300 ppb (equivalent to ~ 450 Mm$^{-1}$ at 1 atm and 298 K) are added to the modified Black Carbon Photometer. This allows for zero and slope (span) coefficients to be calculated for the 405 nm channel, which corrects for small errors in path length and nonlinearities in detector response and associated electronics.

A $NO_2$ multipoint calibration should be performed annually, whenever major disassembly of components is performed, or any time the periodic zero or span checks give results outside of acceptable limits. As this procedure requires significant rearrangement of the analyzer, it is not recommended to be carried out by the user unless they have significant expertise.

The 880 nm channel (BC) is then verified relative to the 405 nm channel (PM) by sampling lab-generated aerosols and measuring the ratio of the 405 nm extinction to that at 880 nm.  500 or 750 nm diameter Polystyrene Latex spheres (PSLs) are used for this calibration since: (1) they produce a monodisperse aerosol size distribution, (2) the PSLs are spherical and (3) extinction at both wavelengths is due solely to scattering ($B_{sct} = B_{ext}$).  When these conditions are met, Mie's theory can be used to accurately calculate the ratio of the extinctions at 405 and 880 nm for comparison with the observed measured value.

# 8. USER CALIBRATION: PERIODIC ZERO CHECKS

Full calibration should be carried out annually by returning the instrument to the factory.

As mentioned in previous section, to ensure quality data, periodic zero checks by the user are recommended. This is especially important during continuous monitoring or when measuring low aerosol extinction levels (< 10 $Mm^{-1}$). In these situations, a daily check of the zero offset is recommended. For all zero checks the instrument should be turned on and allowed to warm up for at least 30 minutes.

## 8.1. Setup for a Zero Offset Check

The electronic zeros for both the 880 and 405 nm channels can be routinely tested by introducing particle-free air to the analyzer. Particle-free air can be easily generated by pulling sample air through a particulate filter. It can also be generated by pushing air through a particulate filter (at a flow rate larger than the analyzer flow rate) and then sampling into the instrument via an overflow tee. Numerous particulate filters are available. We recommend using one comparable to Parker/Balston #9933-11-BX, which removes particles down to diameters of 0.01 microns at flow rates of 2 Lpm, yet maintains relatively high conductance. It is important that the internal instrument pressure while measuring the zero offset remain within ~ 10-15 mbar of that when sampling ambient air. It is also recommended that the analyzer be exposed to ~5 minutes of particle-free air such that a stable and accurate zero can be established.

See Section 4.2.5 for a description of how to enter a new zero offset value. <u>For both wavelengths, the **Zero** value must be entered in units of $Mm^{-1}$.</u>

## 8.2. Internal Zeroing Function

The Black Carbon Photometer is equipped with an internal means of generating particle-free air that can be used to test and measure the zero offset of both extinction channels. An automatic zeroing function can be initiated either via the touchscreen **Settings** menu (Section 4.2.2) or remotely via the serial port (Section 5). Upon initiation of an internal zero, the zero valve re-directs the effluent of the analyzer pump through a particulate filter (Parker/Balston #9933-11-BX) and then directs the flow to the sample inlet just inside the instrument enclosure. Due to the VSO valve and the small throttle needle valve (which adjusts the total cell flow rate), the output flow of the pump is typically about 300-500 cc/min greater than the cell flow rate. When zeroing, this effectively creates an overflow tee at the juncture just inside the photometer enclosure, with excess flow exiting the analyzer through the **Sample** port. While the analyzer is zeroing, the status byte in the output data will read “1” and the analyzer will sample particle-free air. When the zeroing **Period** is over, the zero valve will be turned off and analyzer will revert back to sampling ambient air via the **Sample** inlet port (and status byte will return to “0”).

**Warning:** Use precaution when using the internal zeroing option if the inlet sampling line for the Black Carbon Photometer is shared with other instrumentation. During internal zeroing, particle-free air exits the sample port into the inlet sampling line and could affect the response of other instrumentation.

# 9. TROUBLESHOOTING

Table 9.1 provides troubleshooting information that can be used to diagnose problems with the instrument. If the problem cannot be easily corrected, please contact Customer Service at 2B Tech via our web ticketing software at:

https://2btech.io/support/

Alternatively, you can email us at techsupport@2btech.io or call us at +1(303) 273-0559. If we mutually determine that the instrument cannot be repaired onsite, we will provide you with a Return Authorization number and a short form to be filled out and returned to our Service Department along with the instrument.

The figures in Section 10 provide a "guided tour" of the Black Carbon Monitor™ so that critical components and connectors may be easily identified. A list of serviceable parts is provided in Section 12 of this manual.

**Table 9.1. Troubleshooting the Black Carbon Photometer for performance problems.**

| Problem/Symptom | Likely Cause | Corrective Action |
|---|---|---|
| ***Instrument does not turn on.*** | Power not connected properly or circuit breaker open. | Check external power connection for reverse polarity or a short and wait a few minutes for the thermal circuit breaker to reset. |
| | Power cable not connected to circuit board. | Remove top cover and disconnect and reconnect power cable to circuit board. |
| ***Instrument turns on then powers off.*** | Burned out air pump. | Remove top cover and unplug air pump. Turn instrument on; if it remains running, then the air pump motor is burned out and shorting. Replace air pump. |
| ***Display goes blank/black momentarily.*** | Program error. | The instrument will continue to run (gathering serial data if activated) and the display will restart itself. A line of data may be lost on the internal logger. Serial data will be unaffected. |
| ***Display goes black and stays black.*** | Touchscreen has become disconnected. | Remove top cover, plug it back in, and restart (refer to Figure 10.1, 10.3). |

| Problem/Symptom | Likely Cause | Corrective Action |
|---|---|---|
| ***Cell temperature reads low by several 10's of degrees.*** | Absent or loose connection of temperature probe cable to circuit board. | Remove top cover and reattach connector to circuit board. |
| ***Readings are noisy with standard deviations much greater than 6 $Mm^{-1}$ using 10-second averaging.*** | LED output is weak | If photodiode voltage is less than 0.2 V, replace LED. Remove top cover and check LED connection to circuit board. |
| | Excessive vibration | Provide additional vibration insulation for the instrument such as a foam pad. |
| | Flow path contaminated | Contact 2B Technologies for instructions if contamination is suspected. |
| ***Analog output is constant or does not track front display.*** | Cable not properly connected between analog output BNC and circuit board. | Remove top cover and reconnect cable between analog output and circuit board. |
| | Wrong scaling factor selected in Calibration Menu. | Check and reset analog output scaling factor in the Calibration menu (Section 4.2.6). |
| ***Serial port does not work.*** | Cable not properly connected between serial 9-pin connector and circuit board. | Remove top cover and reconnect serial port cable to circuit board. |
| | Wrong serial cable used. | A "straight through" serial cable is provided. Some data collection devices require a "cross over" cable in which pins 1 and 3 are exchanged between the two ends of the cable. Use a "cross over cable or additional connector that switches pins 1 and 3. |
| | Wrong baud rate selected. | Make sure that the baud rate of your data acquisition program is 2400 (this is the baud rate of the Black Carbon Photometer). |

| Problem/Symptom | Likely Cause | Corrective Action |
|---|---|---|
| ***Instrument always reads low or close to zero with known aerosol concentrations.*** | Solenoid valve cable is not properly connected to circuit board. | Reattach solenoid valve cable to circuit board. |
| | Solenoid valve is contaminated and not opening & closing properly. | Remove solenoid valve, rinse with methanol, dry with zero air, and replace. |
| | Reference particulate filter is bad. | Replace reference particulate filter. |
| | Insufficient flow rate through instrument. | Verify by observing measured flow rates. If below 1000 cc/min, replace all particulate filters. If still below 1000 cc/min, check for leaks. If there are no leaks, replace the air pump. |

# 10. LABELED INSTRUMENT PHOTOS

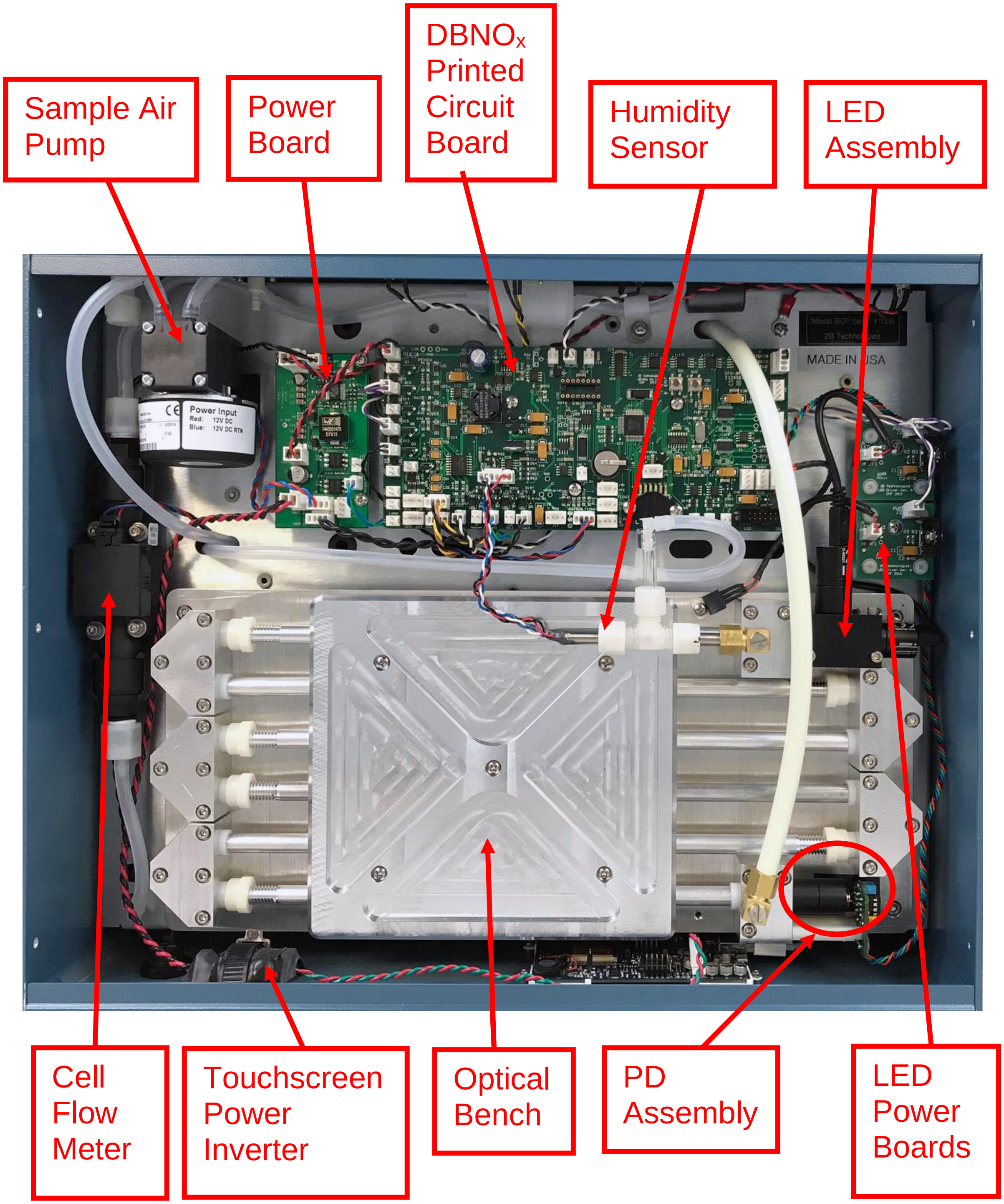



**Figure 10.1.** ***Top view of Black Carbon Photometer with cover removed.***

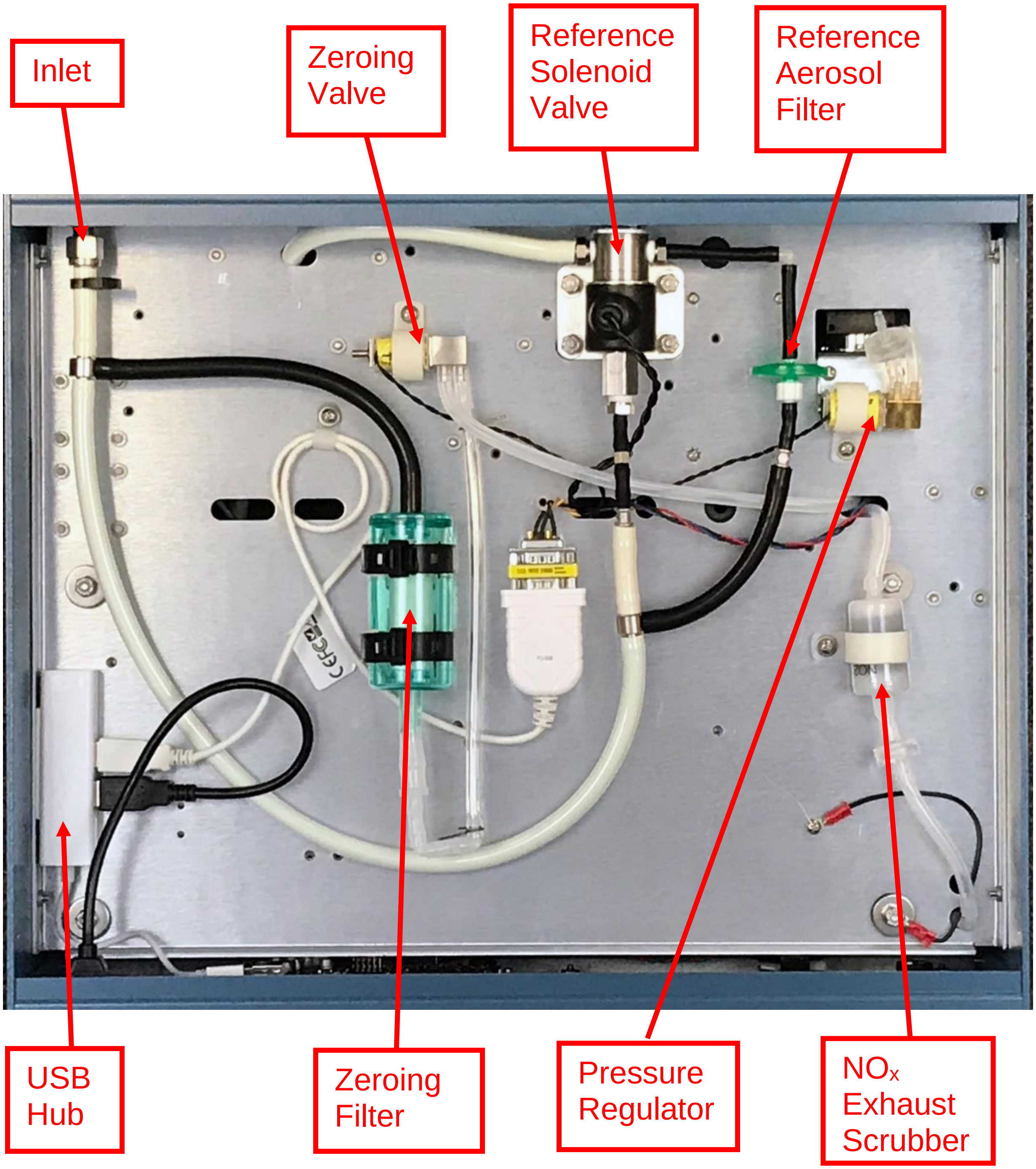



**Figure 10.2.** ***Bottom view of Black Carbon Photometer with cover removed.***

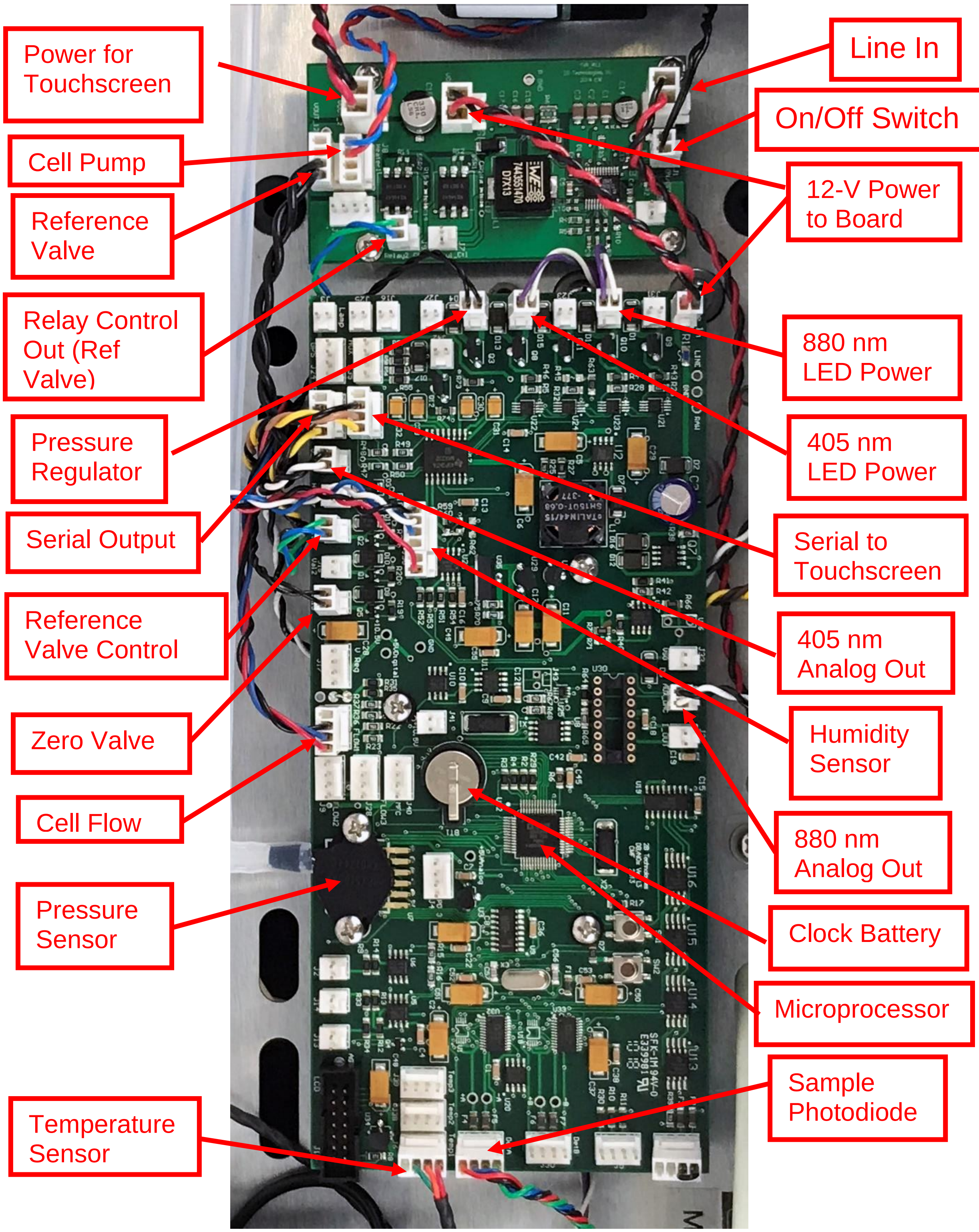



**Figure 10.3.** ***DBNOx Printed Circuit Board***

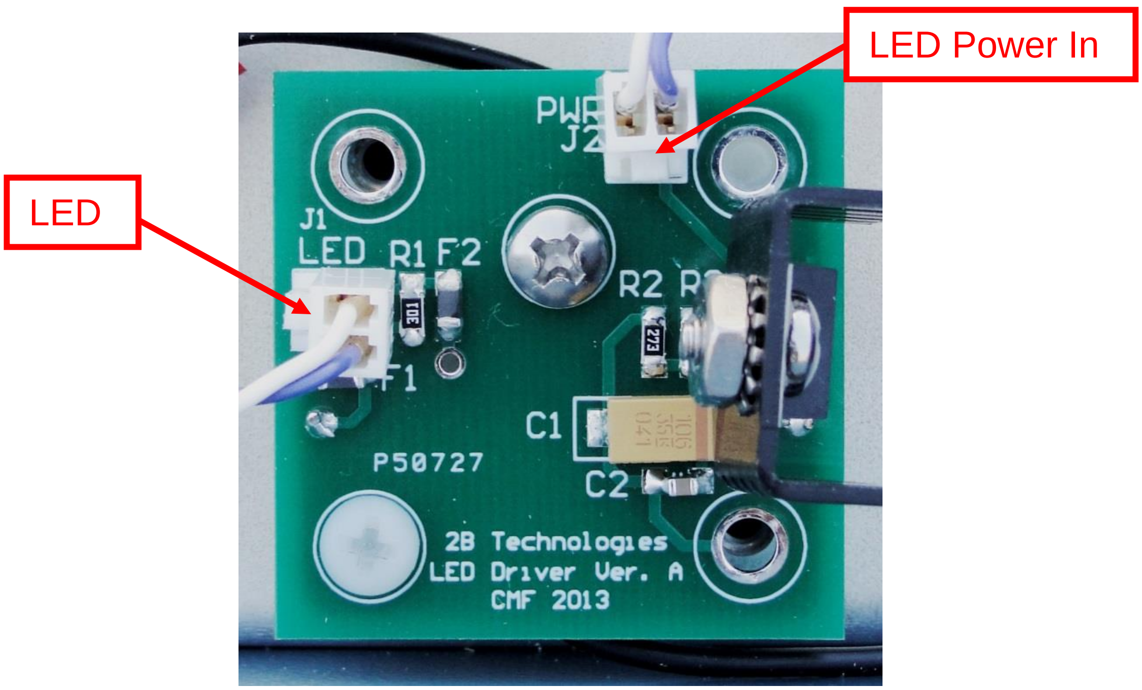



**Figure 10.4.** ***LED Power Board***

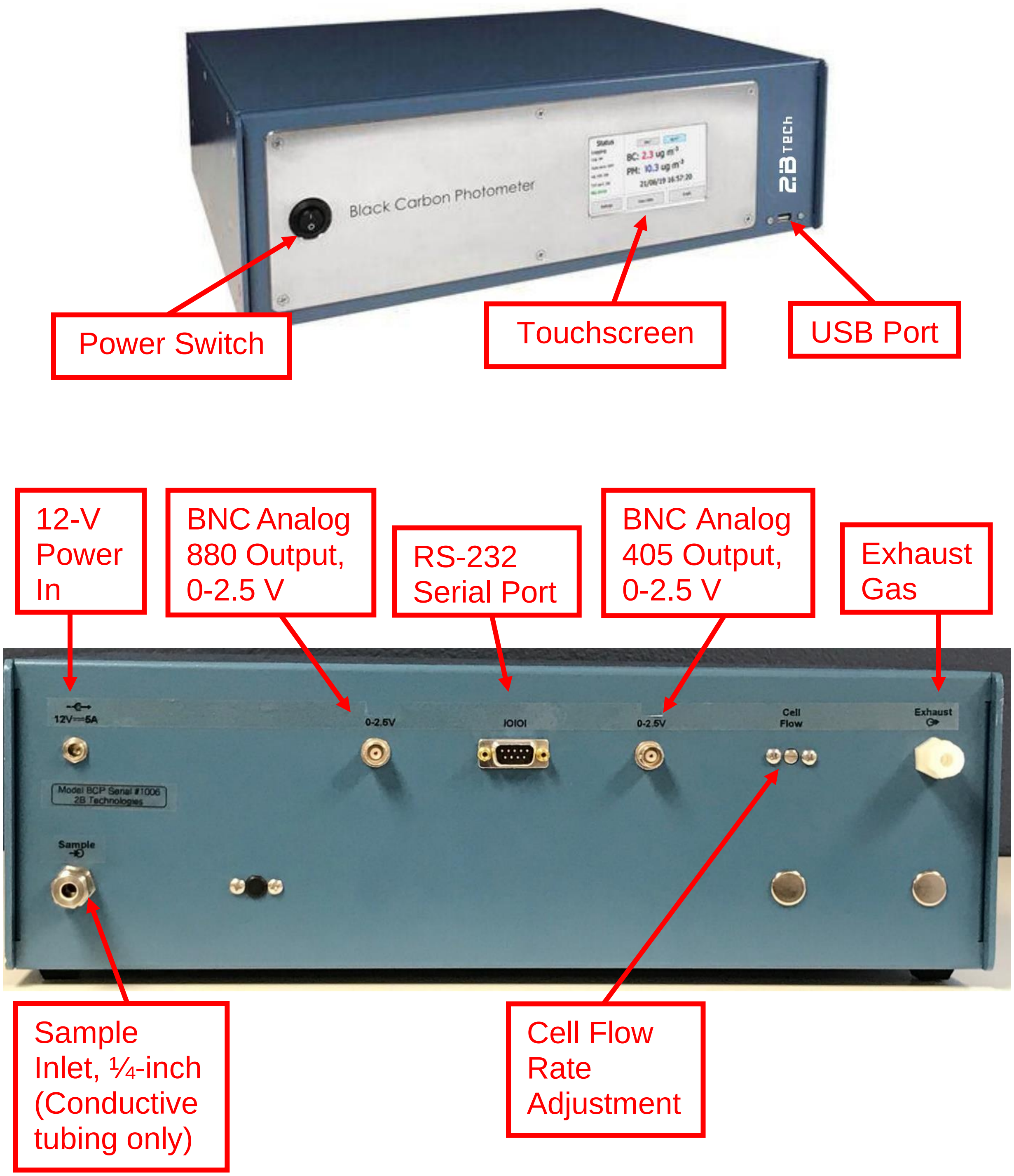



**Figure 10.5.** ***Front and Back of Instrument***

## 11. WIRING CONNECTIONS

*[For DBNOx board: Counter clockwise from upper right corner of Figure 10.3.]*

| Description | Circuit Board | Connection | Lead Colors |
|---|---|---|---|
| Line In | Main (DBNOx) | J12 | Red/Black |
| 880 nm LED Power Out | Main (DBNOx) | J22 | Purple/White |
| 405 nm LED Power Out | Main (DBNOx) | J21 | Purple/White |
| Pressure Regulator | Main (DBNOx) | J20 | Black/Black |
| SD Data Logger | Main (DBNOx) | J35 | Red/Yellow/Brown/Black |
| Serial RS-232 | Main (DBNOx) | J26 | Yellow/Brown/Black |
| Serial to Touchscreen | Main (DBNOx) | J34 | Yellow/Brown/Black |
| 405 nm Analog Output | Main (DBNOx) | J11 | White/Black |
| Reference Valve (Control) | Main (DBNOx) | J19 | Green/Blue |
| Humidity Sensor | Main (DBNOx) | J36 | Red/Blue/White/Black |
| Zero Valve | Main (DBNOx) | J15 | Yellow/Black |
| Cell Flow | Main (DBNOx) | J32 | Red/Blue/Black |
| Cell Temperature | Main (DBNOx) | J6 | Red/Orange/Green |
| Sample Photodiode | Main (DBNOx) | J29 | Red/Blue/Black/Green |
| Power Jumper | Main (DBNOx) | J1 | Black/Black |
| 880 nm Analog Output | Main (DBNOx) | J7 | White/Black |
| | | | |
| On/Off Switch | Power | J1 | Black/Black |
| Line In | Power | J4 | Red/Black |
| Power Out to DBNOx | Power | J5 | Red/Black |
| Power to Touchscreen | Power | J6 | Red/Black |
| Sample Pump | Power | J8 | Red/Blue |
| Relay Control In (Valve) | Power | J9 | Blue/Green |
| Reference Valve Power | Power | J10 | Black/Black |
| | | | |
| LED(s) | LED Driver | J1 | Red/Black |
| Power In | LED Driver | J2 | Purple/White |

# 12. SPARE PARTS

The following list includes those parts of the Black Carbon Photometer that are user serviceable. (Some part numbers reflect the fact that the parts are also used in our Model 405 $NO_2$/NO/$NO_x$ Monitor.)

| Part Number | Description |
|---|---|
| NOXPUMP405 | Sample pump |
| OZVLV405 | Zero solenoid valve |
| PDASSEMBLY405 | Photodiode assembly and cable |
| NOXBRD405 | DBNOx printed circuit board |
| SERCABL | Serial port cable, straight-through, female-to-female (to computer) |
| CIGADAP | 12 V DC cigarette lighter adapter |
| PWRPK-5.0A | Power Pack for BCP, 100-240 VAC input, 5.0 Amp output at 12 V |

Please contact 2B Technologies (303-273-0559 or email us at sales@2btech.io for these other BCP-related spare parts:

| | |
|---|---|
| LED405BCP | LED for the Black Carbon Photometer, 405 nm |
| LED880BCP | LED for the Black Carbon Photometer, 880 nm |
| REFVGEMSBCP | Reference Solenoid Valve (GEMS, B3113-1-C203) |
| ZEROFILTBCP | Zeroing Filter, (Parker/Balston, 9933-11-BX) |

**Other Recommended Items:**

| Description | Vendor | Part No. |
|---|---|---|
| Sharp Cut Cyclone for PM1.0 | BGI Mesa Labs | SCC0.732 |
| Sharp Cut Cyclone for PM2.5 | BGI Mesa Labs | SCC1.197 |

Please contact BGI Mesa Labs for flow rate specifications.

## 13. SERVICE LOG

Model: Black Carbon Photometer Serial #: _________ Purchase date:________

| Date | Calibrated | Cleaned | New Filter | New Pump | New LED | Other |
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| Date | Calibrated | Cleaned | New Filter | New Pump | New LED | Other |
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