

## Theory of Operation

The SO series are galvanic-cell type sensors that measure oxygen gas ( $O_2$ ) in air. Sensors include a lead anode, a gold cathode, an acid electrolyte, and a fluorine resin membrane. The current flow between the electrodes is proportional to the oxygen concentration being measured. An internal bridge resistor is used to provide a mV output linearly proportional to  $O_2$ . Unlike polarographic oxygen sensors, galvanic do not require a power supply.

The mV output responds to the partial pressure of oxygen in air. The standard units for partial pressure are kPa. However, gas sensors that respond to partial pressure are typically calibrated to read out in mole fraction of the gas in air, or units of moles of oxygen per mole of air. These units can be directly converted to %  $O_2$  in air, or ppm  $O_2$  in air. The concentration of oxygen in our atmosphere is 20.95%. This precise percentage has not changed for decades. It is also constant across changing temperatures or pressures. This allows for precise calibration of the instrument.

Being a galvanic cell type sensor, a small amount of oxygen is consumed in the reaction in order to produce the current flow and subsequent mV output. The oxygen consumption was measured to be 2.2 umol  $O_2$  per day when the  $O_2$  concentration was 20.95% at 23 C.

All models are equipped with an internal thermistor or type-K thermocouple for measuring sensor body temperature. All models also come with built-in heaters, designed to warm the sensor body to a temperature slightly above ambient in order to keep condensation from forming on the sensor membrane where oxygen diffusion occurs.



## Using the Sensor

For the most stable reading, the sensor should be used with the sensor opening facing down. This facilitates the best contact of the electrolyte and the electronics.

1. Connect the O<sub>2</sub> lead wires to a volt meter or a datalogger capable of measuring small mV signals.
2. To calibrate, measure the mV output in a well-ventilated area. Do not breathe on the sensor as exhaled breath has a lower O<sub>2</sub> concentration compared to ambient air (20.95%). The output is approximately 50 mV for the SO-100 series and 12 mV for the SO-200 series in ambient air. To derive the multiplier, divide 20.95 by the mV output minus the zero offset. The zero offset can be measured in pure N<sub>2</sub> gas or approximated as 3.0 mV for the SO-100 series and 0.35 mV for the SO-200 series.

Example:  $20.95\% / (50 - 3.0 \text{ mV}) = 0.446\% \text{ O}_2 \text{ per mV}$

To derive the intercept, multiply the measured zero offset by the calibration factor.

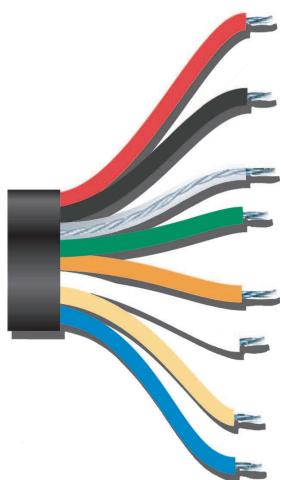
Example:  $3.0 \text{ mV} * 0.446\% \text{ O}_2 \text{ per mV} = 1.338\% \text{ O}_2$

The calibration factor and intercept are correct for the current elevation, pressure, temperature, and humidity.

3. Calibration establishes the multiplier and offset necessary to convert the mV reading to % O<sub>2</sub>. Install the multiplier and offset values in your datalogger program.

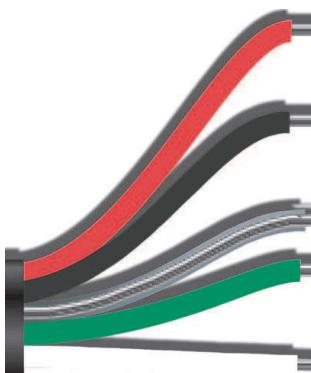
# Wiring Instructions

## Sensor with Thermistor



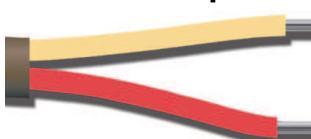
<b>Red</b>	High side of differential channel (positive lead for O <sub>2</sub> sensor)
<b>Black</b>	Low side of differential channel (negative lead for O <sub>2</sub> sensor)
<b>Clear</b>	Analog ground (shield wire)
<b>Green</b>	Single-ended channel (positive lead for thermistor)
<b>Orange</b>	Analog ground (negative lead for thermistor)
<b>White</b>	Excitation channel (excitation for thermistor)
<b>Yellow</b>	12V port (positive lead for heater)
<b>Blue</b>	Ground (negative lead for heater)

## Sensor with Thermocouple



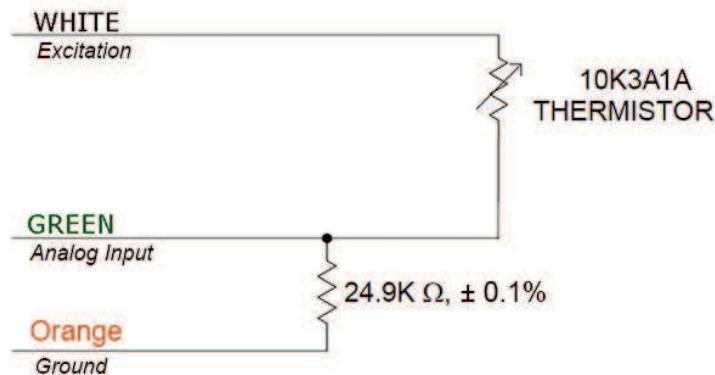
<b>Red</b>	High side of differential channel (positive lead for O <sub>2</sub> sensor)
<b>Black</b>	Low side of differential channel (negative lead for O <sub>2</sub> sensor)
<b>Clear</b>	Analog ground (shield wire)
<b>Green</b>	12V port (positive lead for heater)
<b>White</b>	Ground (negative lead for heater)

## Thermocouple



<b>Yellow</b>	High side of differential channel (positive lead for thermocouple)
<b>Red</b>	Low side of differential channel (negative lead for thermocouple)

## Convert Thermistor Output to Temperature



The models SO-110 and SO-210 incorporate a thermistor to directly measure sensor body temperature. The resistance of the thermistor ( $R_T$ ) changes with temperature. Because most dataloggers do not measure resistance directly, a half-bridge measurement is used to determine resistance from the ratio of the measured voltage ( $V_{OUT}$ ) and excitation voltage ( $V_{EX}$ ):

$$R_T = 24900 \left( \frac{V_{EX}}{V_{OUT}} - 1 \right)$$

From resistance, temperature is calculated with the Steinhart-Hart equation and thermistor-specific coefficients.

$$T_K = \frac{1}{A + B \ln(R_T) + C(\ln(R_T))^3}$$

Where  $T_K$  is temperature in Kelvin. The Steinhart-Hart coefficients are:

$$A = 1.129241 \times 10^{-3}$$

$$B = 2.341077 \times 10^{-4}$$

$$C = 8.775468 \times 10^{-8}$$

**Note:** The thermistor is considered a passive device and requires no warm-up time once a voltage is applied. A 2.5 V excitation is recommended to minimize self-heating and power draw.

# Characteristics

## Zero Offset

The mV output in ultra-pure nitrogen gas (0.000% O<sub>2</sub>) is typically 6% of the ambient (20.95%) output for the SO-100 series and 3% of the ambient output for the SO-200 series. Precise measurements of hypoxic and anaerobic conditions can be made by making a periodic zero calibration of the sensor with ultra-pure nitrogen gas.

## Life Expectancy

The life expectancy of the sensor is expressed in %-years as follows:

$$[\text{Oxygen Concentration (\%)} * \text{Exposure Time (years)}]$$

The life of the SO-100 series is approximately 10 years of continuous use at 21% oxygen and 20 C. Under the same conditions the life of the SO-200 series is approximately 5 years.

## Storage Temperature

The life of the sensor can be extended by storage at a lower temperature. For example, a sensor stored at 0 C will have a life expectancy approximately twice that of a sensor stored at 20 C. The minimum storage temperature is -20 C. Below -20 C, the electrolyte will freeze. This does not damage the sensor, but to resume measurement the electrolyte must be thawed. Maximum storage temperature is 60 C.

## Shock and Vibration

The sensor is resistant to 2.7 g of shock. However, vibration may influence the sensitivity of the sensor and should be minimized.



# Factors Affecting Output

## Influence from Various Gases

The sensor is unaffected by CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, H<sub>2</sub>S, H<sub>2</sub>, and CH<sub>4</sub>. There is a small effect (approximately 1%) from NH<sub>3</sub>, HCl, and C<sub>6</sub>H<sub>6</sub> (benzene). The sensor is sensitive to SO<sub>2</sub> and can be damaged by O<sub>3</sub>.

## Temperature Sensitivity

A change in temperature changes the amount of O<sub>2</sub> available to the sensor and therefore changes the mV output that correlates to the atmospheric constant of 20.95%. Additionally, the sensor electronics have a small temperature dependence. To eliminate temperature effects, simply recalibrate or use the correction equations detailed in the write-up, "Understanding Oxygen in Air", located in the Knowledge Base of the Apogee website.

## Pressure Sensitivity

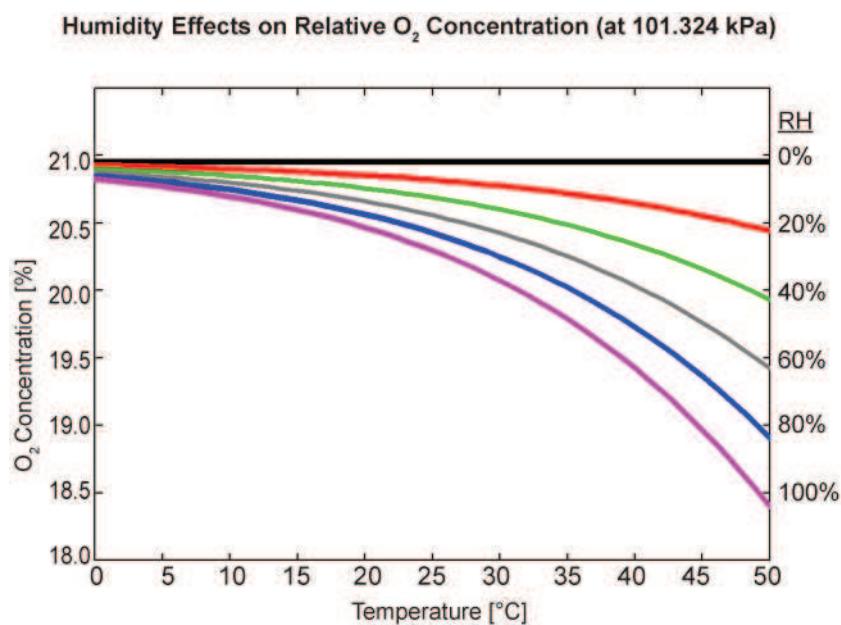
A change in barometric pressure changes the amount of O<sub>2</sub> available to the sensor and therefore changes the mV output that correlates to the atmospheric constant of 20.95%. To eliminate pressure effects, simply recalibrate or use the correction equations detailed in the write-up, "Understanding Oxygen in Air", located in the Knowledge Base of the Apogee website. Direct compensation requires a pressure measurement, which can be done with the Apogee barometric pressure sensor, model SB-100 (shown below).



## Factors Affecting Output (cont.)

### Humidity Sensitivity

The graph below shows the humidity effect on output. The sensor chemistry is not influenced by humidity, but its output decreases because  $O_2$  is displaced by water vapor molecules in the air. The effect of humidity is larger at warmer temperatures because there is more water vapor in the air.



**Note:** In applications where the relative humidity is at or near 100%, continuous power to the built-in heaters is required. For calibration purposes, take the calibration measurement over water in a sealed container as shown at right. To account for humidity effects, simply recalibrate or use the correction equations detailed in the write-up, "Understanding Oxygen in Air", located in the Knowledge Base of the Apogee website.

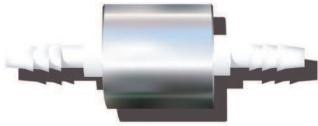


## Accessories

The following head attachments for Apogee oxygen sensors can be purchased separately.



**AO-001:** the Diffusion Head is designed to maintain an air pocket and provide protection for the sensor's O<sub>2</sub> permeable membrane. The attachment is ideal for measurements in soil.



**AO-002:** the Flow-Through Head is designed for laboratory applications requiring in-line measurements. The head comes with 1/4" barbed Nylon fittings for connecting to a hose.

# Specifications

## Range

- 0 to 100% O<sub>2</sub>

## Stability

- $\pm 0.05\%$  O<sub>2</sub> under stable atmospheric conditions

## Repeatability

- $\pm 0.001\%$  O<sub>2</sub> (10 ppm)

## Operating Environment

- -20 to 60 °C
- 0 to 100% relative humidity
- 60 to 140 kPa

## Mass

- 175 g

## Response Time

- SO-100 Series: 60 seconds
- SO-200 Series: 12 seconds

## Output (at 20.95% O<sub>2</sub>)

- SO-100 Series: 50 mV
- SO-200 Series: 12 mV

## Gas Effect

- CO<sub>2</sub>, CO, NO, NO<sub>2</sub>, H<sub>2</sub>S, H<sub>2</sub>, CH<sub>4</sub> - No effect
- NH<sub>3</sub>, HCl, C<sub>6</sub>H<sub>6</sub> (Benzene) - <1%

## Power Requirement

- 12 V for heaters (74 mW)
- 2.5 V excitation for thermistor

## Diffusion Head (Accessory)

- 3.5 cm long by 3.5 cm diameter
- 125 mesh screen

## Flow-Through Head (Accessory)

- 3.2 cm long by 3.2 cm diameter
- 1/4" barbed adapters for hose connections

## Cable

- 5 meters of twisted-pair wire
- Foil shield
- Santoprene jacket
- Ending in pigtail leads
- Additional cable is available in multiples of 5 meters

## Warranty

- 1 year against defects in materials and workmanship