DISSOLVED OXYGEN SENSOR BT34i

USER'S GUIDE

CENTRE FOR MICROCOMPUTER APPLICATIONS

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Short description

The CMA Dissolved Oxygen (DO) sensor BT34i measures the concentration of dissolved oxygen in water samples in the range from 0 to 20 mg/L. It consists of a DO probe and a membrane cap and is delivered with:

- replacement membrane cap,
- polishing strip,
- oxygen probe electrolyte, saturated potassium chloride(KCl) solution: add 22,37 g of solid potassium chloride (KCl) to 100mL of distilled water.
- filling pipette,
- calibration bottle (empty, lid with hole), and
- Sodium Sulfite Calibration Standard (2 M Na_2SO_3).

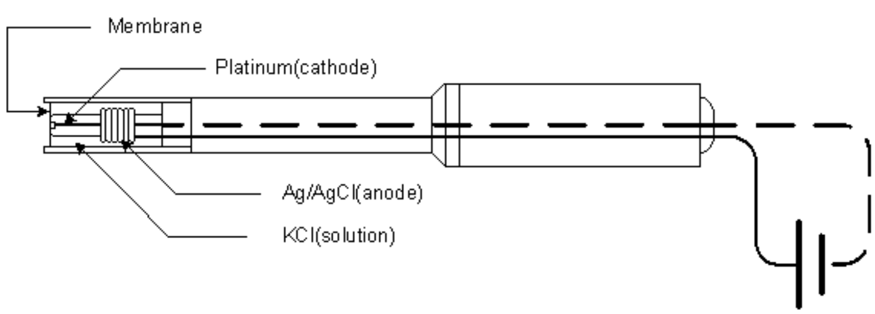
The Dissolved Oxygen sensor can be directly connected to the analog BT inputs of the CMA interfaces.

Sensor recognition

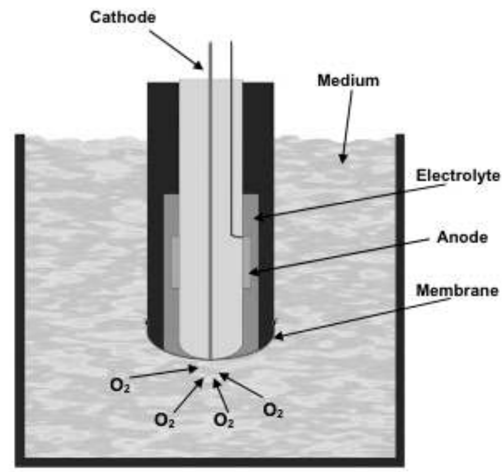
The Dissolved Oxygen sensor BT34i has a memory chip (EEPROM) with information about the sensor: its name, measured quantity, unit and calibration. Through a simple protocol this information is read by the CMA interfaces and the sensor is automatically recognized when it is connected to these interfaces. If your Dissolved Oxygen sensor is not automatically detected by an interface you have to manually set up your sensor by selecting it from the Coach Sensor Library.

How the sensor works

The CMA Dissolved Oxygen sensor uses a Clark-type polarographic electrode, which consists of a silver/silver chloride anode and a platinum cathode immersed in an electrolyte (typically an aqueous potassium chloride (KCl) solution) and separated from the sample by a gas-permeable Teflon membrane.



Oxygen molecules that are dissolved in the sample diffuse through the membrane to the sensor at a rate proportional to the pressure difference across it. A constant polarizing voltage is applied across the electrodes, which causes oxygen to be reduced at the cathode (it is chemically converted to OH^-). The resulting current is directly proportional to the dissolved oxygen content of the electrolyte. The more oxygen passing through the membrane and being reduced at the cathode, the greater the electrical current read by the probe.



The oxidation-reduction reactions for a typical Clark cell are as follows:

Cathode: $O_2 + 2H_2O + 4e- \rightarrow 4OH^-$

Anode: $4Ag + 4Cl^- \rightarrow 4AgCl + 4e^-$

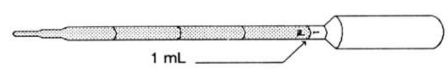
Overall: $O_2 + 2H_2O + 4Ag + 4Cl^- \rightarrow 4OH^- + 4AgCl$

Temperature compensation

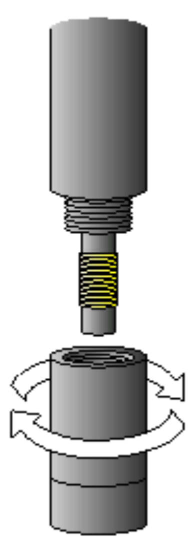
The oxygen permeability of the membrane is temperature dependent. This variation is automatically compensated by a temperature compensation thermistor over the 5 to 45°C operating range.

DO probe preparation

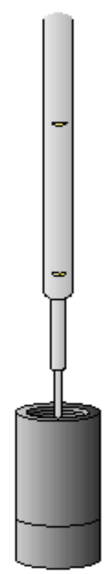
1. If needed unscrew the membrane cap from the probe. Rinse the inside and outside of the cap with distilled water and blot dry.
2. Rinse the probe anode/cathode assembly with distilled water and blot dry.



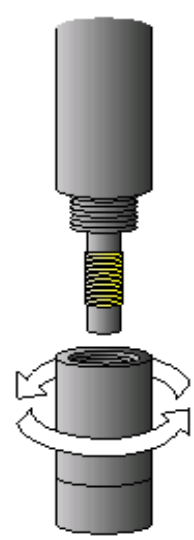
3. Using the provided pipette, fill the membrane cap with 1 mL of DO Electrolyte. Mind that there are no air bubbles in the electrolyte.
4. Carefully screw the membrane cap onto the probe until the cap is hand tight.



Remove membrane cap



Add electrolyte



Place the membrane cap back

5. Connect the sensor to your CMA interface. In most cases the sensor will be automatically detected. If this does not happen manually select the Dissolved

Oxygen sensor BT34i from the Coach Sensor Library.

6. Polarize the probe. Place the probe into a beaker filled with about 100-mL of distilled water and leave it in water for at least 10 minutes. The sensor must stay connected to the interface at all times. If disconnected it will be necessary to polarize the probe again.
7. The sensor is ready for measurement.

Calibration

The CMA Dissolved Oxygen sensor BT34i is supplied calibrated. The output of the sensor is linear with respect to the dissolved oxygen level. The supplied calibration function is:

$$DO(mg/L) = 3.27 * V_{out}(V) – 0.327.$$

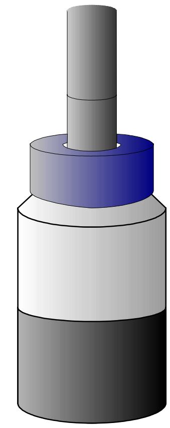
The Coach software allows selecting the calibration supplied by the sensor memory (EEPROM) or the calibration stored in the Coach 6 Sensor Library.

For better accuracy it is recommended to calibrate the sensor on a regular base. Such calibration can be done using the water-saturated air method. At any given temperature and barometric pressure, the partial pressure of oxygen in air- saturated water is equal to the partial pressure of oxygen in water-saturated air (air at 100% relative humidity). This means that a probe calibrated in water-saturated air will correctly read the partial pressure of oxygen in a water sample.

To perform two-point calibration of the DO sensor:

- Prepare the DO probe and polarize it for about 10 minutes.
- Zero-Oxygen Calibration Point
  - Use the provided Sodium Sulfite Calibration Solution. Sodium sulfite is a good reducing agent that readily removes dissolved oxygen from a solution. If the sulfite solution has been stored brim fully in its storage bottle, you can assume it to be oxygen free.

- Remove the sensor from the distilled water and insert the probe at an angle and then submerged its tip 1-2 cm into the Sodium Sulfite Calibration Solution.
- **Important:** Beware that no air bubbles will be trapped below the tip of the probe. If the voltage does not rapidly decrease, tap the side of the bottle with the sensor to dislodge the bubble.
- When the voltage stabilizes (circa 1 minute) enter the value of 0.0 mg/L.



- Saturated DO Calibration Point
  - Rinse the sensor with distilled water and blot dry.
  - Fill the provided calibration bottle partly with distilled water and leave it for 15 minutes. This will provide 100% water-saturated air.
  - Insert the probe into the bottle. Make sure the probe is suspended about 1 cm above the water and there is no water on the surface of the DO probe. Do not touch the membrane.
  - When the voltage stabilizes (circa 1 minute) enter the correct saturated dissolved-oxygen value in mg/L, for example if you calibrate the DO probe at 25°C and 760 mm Hg barometric pressure (assume salinity is negligible), the value you enter for the saturated oxygen calibration point would be 8.36 mg/L. Since both temperature and barometric pressure affect the partial pressure of oxygen in air-saturated water read the correct mg/L value from Table 1 on page 9 for your barometric pressure and air temperature.

Salinity correction

Another variable that affects DO concentration is the salinity of the water sample. As the salinity of water increases, its ability to dissolve oxygen decreases. For example, oxygen saturated freshwater with 0 salinity at 25^{o}C contains 8.26 mg/L of oxygen while oxygen saturated sea water (36 ppt) at the same pressure and temperature contains only 6.73 mg/L of dissolved oxygen. The solubility of oxygen in water is reduced by the salt content in that water and a dissolved oxygen measurement with a DO sensor does not detect this fact. To correct this value use the Conductivity or Salinity sensor to determine the salinity value and correct the measured DO value by using the salinity correction factor listed in Table 2 on page 10.

Calibrating Using Units of Percent Saturation

Instead of calibrating using units of mg/L (equal to parts per million or ppm), you may also calibrate dissolved oxygen using units of % saturation. When doing a calibration for units of % saturation, the calibration point taken in the sodium sulfite solution (zero oxygen) is assigned a value of 0%, and that for water-saturated air a value of

100%. The last value represents an oxygen-saturated solution only at that particular temperature, pressure, and salinity level. If you intend to compare your measured dissolved oxygen values with data collected under a different set of conditions, a preferable method would be to use units of mg/L.

If you have calibrated your Dissolved Oxygen Probe in units of mg/L, you can easily calculate percent saturation using the formula:

$$\% \text{ Sat} = (\text{Actual DO reading} / \text{Saturated DO reading from Table 1}) \times 100$$

Collecting data

After the sensor has been calibrated it is ready for data collection.

- Place the tip of the probe into the water being tested (submerge 4-6 cm). Do not completely submerge. The handle is not waterproof.
- Gently stir the probe in the water sample.
- Monitor the dissolved oxygen concentration.

Practical information

- As the probe measures the electrochemical reaction takes place in which oxygen is removed from the thin layer of water in contact with the membrane. Because of this process it is necessary to renew this layer i.e. by stirring the probe or by natural water flow or by means of a suitable stirrer. This flow must not generate any air bubbles.
- Treat the membrane carefully as it is fragile. Do not touch it or allow it to touch the bottom of a container.
- The DO sensor interacts with some other sensors, if they are placed in the same solution (for example in the same aquarium or beaker), and they are connected to the same interface. This situation arises because the DO sensor outputs a signal in the solution, and this signal can affect the reading of another sensor. The Conductivity, Salinity and pH sensors *cannot* be connected to the same interface as a DO sensor and placed in the same solution.

Suggested experiments

Dissolved oxygen levels are used as a general indicator of water quality. Oxygen is essential to life and vital for countless aquatic forms.

The sensor can be used to perform a variety of experiments:

- Monitoring dissolved oxygen in an aquarium containing different combinations of plant and animal species.
- Measuring changes in dissolved oxygen concentration resulting from photosynthesis and respiration in aquatic plants.
- Measuring dissolved oxygen concentration in a stream or lake survey, in order to evaluate the capability of the water to support different types of plant and animal

life.

- Measure Biological Oxygen Demand (B.O.D.) in water samples containing organic matter that consumes oxygen as it decays.
- Determine the relationship between the dissolved oxygen concentration and the temperature of a water sample.

Using the DO sensor for measuring concentration of gas oxygen O_2 e.g. in air

The atmosphere is made up of approximately 78% nitrogen and 20.9% oxygen. The remaining % consists of small amounts of argon, CO_2 and other gases. The standard value for atmospheric oxygen level in dry air (0% humidity) is **20.9%**.

The DO sensor is in principle meant for measurements of dissolved oxygen but can also be used to measure gas oxygen. When doing a calibration for % O_2, the calibration point done in the sodium sulfite solution (zero oxygen) is assigned a value of 0%, and that for dry air is given a value of 20.9 %.

As water vapor enters the atmosphere the percentage of gasses, including oxygen, will reduce very slightly i.e. 25% RH = 20.7% O_2, 50% RH = 20.5% O_2, 75% RH = 20.3% O_2, 100% RH = 20.1% O_2. If the relative humidity is known then these values can be substituted for 20.9% during calibration.

Storage and maintenance of the DO sensor

Follow these steps when storing the electrode.

Short-term storage (less than 24 hours):

Store the sensor with the membrane end submerged in about 2 cm of distilled water. *Important:* Storing the sensor in this manner for longer than 24 hours may result in damage to the membrane.

Long-term storage (more than 24 hours):

- Unscrew the membrane cap and remove any electrolyte solution from the cap.
- Rinse the inside and outside of the cap with distilled water. Shake the membrane cap dry.
- Rinse the probe anode/cathode assembly with distilled water and blot dry.
- Screw the membrane cap onto the probe until the membrane cap is hand tight. The probe should be stored dry.

Polishing the metal electrodes

Since the net result of the chemical reaction is AgCl, over time, a build up of AgCl (black/brown stains) will coat the anode. Once the entire anode is covered, reaction stops and the oxygen probe stops working properly. This AgCl deposit may be removed by polishing the metal electrodes with the polishing strip that is provided with the sensor. Perform this operation only as needed to restore electrode performance (necessary circa once every year).

- Remove the membrane cap.
- Thoroughly rinse the inner elements of the sensor with distilled water to remove all filling solution.
- Cut a piece of the polishing sand strip paper.
- Wet the dull (abrasive) side of the polishing strip with distilled water.
- Using a circular motion, gently polish the center glass element of the cathode (on the very end of the electrode). Polish only enough to restore a bright, clean surface to the center element. Next, polish the silver anode located around the base of the electrode inner element. Polish only enough to restore a silver appearance. *Important*: Aggressive polishing will damage the sensor inner elements. *Be sure* to use only gentle pressure when performing the polishing of the anode and cathode.
- When you have completed the polishing, rinse the cathode and anode elements thoroughly and dry with a lab wipe.

With normal use, the Dissolved Oxygen sensor will last for years. The membrane cap will, however, require replacement after about 6 months of continuous use. Replacement of the membrane is recommended when your Dissolved Oxygen sensor will no longer respond rapidly during calibration or when taking DO readings. Use of your Dissolved Oxygen Sensor in samples that are non-aqueous or in those that contain oil, grease, or other coating agents will result in shortened membrane life. Replacement membranes can be obtained from CMA.

Maintaining and replenishing the Sodium Sulfite Calibration Solution

Here are some suggestions for maintaining and replacing the Sodium Sulfite Calibration Solution:

- After your first use of the solution for calibration, the solution will no longer be brim full. If you cap the solution with an air space above the sensor, oxygen gas in the space will dissolve in the sodium sulfite solution - as a result, the solution may not be oxygen free. To prevent this from occurring, before putting on the lid, gently squeeze the bottle so the level of the solution is at the very top of the bottleneck; with the solution at this level, screw on the lid. The bottle will remain in this "collapsed" position.
- When the measured in the solution dissolved oxygen value becomes too high the calibration solution has to be replaced. The 2.0 M sodium sulfite (Na_2SO_3) solution can be prepared from solid sodium sulfite crystals: add 25.0 g of solid anhydrous sodium sulfite crystals (Na_2SO_3) to enough distilled water to yield a final volume of 100 mL of solution. Prepare the solution 24 hours in advance of doing the

calibration to ensure that all oxygen has been depleted[1]. If solid sodium sulfite is not available, you may substitute either 2.0 M sodium hydrogen sulfite solution, (20.8 g of $NaHSO_3$ per 100 ml of solution) or 2.0 M potassium nitrite (17.0 g of KNO_2 per 100 ml of solution).

Table 1
Solubility of oxygen in fresh water at various temperatures and pressures

Temp.	Barometric Pressure (mm Hg)											
(°C)	660	670	680	690	700	710	720	730	740	750	760	770
0	12.69	12.88	13.07	13.27	13.46	13.65	13.85	14.04	14.23	14.43	14.62	14.81
1	12.34	12.52	12.71	12.9	13.09	13.28	13.46	13.65	13.84	14.03	14.22	14.4
2	12	12.18	12.37	12.55	12.73	12.91	13.1	13.28	13.46	13.65	13.83	14.01
3	11.68	11.86	12.03	12.21	12.39	12.57	12.75	12.93	13.1	13.28	13.46	13.64
4	11.37	11.54	11.72	11.89	12.07	12.24	12.41	12.59	12.76	12.93	13.11	13.28
5	11.08	11.25	11.42	11.59	11.75	11.92	12.09	12.26	12.43	12.6	12.77	12.94
6	10.8	10.96	11.13	11.29	11.46	11.62	11.79	11.95	12.12	12.28	12.45	12.61
7	10.53	10.69	10.85	11.01	11.17	11.33	11.49	11.66	11.82	11.98	12.14	12.3
8	10.27	10.43	10.58	10.74	10.9	11.06	11.21	11.37	11.53	11.69	11.84	12
9	10.02	10.18	10.33	10.48	10.64	10.79	10.94	11.1	11.25	11.41	11.56	11.71
10	9.79	9.94	10.09	10.24	10.39	10.54	10.69	10.84	10.99	11.14	11.29	11.44
11	9.56	9.71	9.85	10	10.15	10.29	10.44	10.59	10.73	10.88	11.03	11.17
12	9.34	9.48	9.63	9.77	9.91	10.06	10.2	10.35	10.49	10.63	10.78	10.92
13	9.13	9.27	9.41	9.55	9.69	9.83	9.97	10.11	10.26	10.4	10.54	10.68
14	8.93	9.07	9.20	9.34	9.48	9.62	9.76	9.89	10.03	10.17	10.31	10.44
15	8.74	8.87	9.00	9.14	9.27	9.41	9.54	9.68	9.81	9.95	10.08	10.22
16	8.55	8.68	8.81	8.95	9.08	9.21	9.34	9.47	9.61	9.74	9.87	10
17	8.37	8.5	8.63	8.76	8.89	9.02	9.15	9.28	9.41	9.54	9.66	9.79
18	8.2	8.32	8.45	8.58	8.7	8.83	8.96	9.09	9.21	9.34	9.47	9.59
19	8.03	8.15	8.28	8.4	8.53	8.65	8.78	8.9	9.03	9.15	9.28	9.4
20	7.87	7.99	8.11	8.24	8.36	8.48	8.6	8.73	8.85	8.97	9.09	9.21
21	7.71	7.83	7.95	8.07	8.19	8.31	8.43	8.55	8.67	8.79	8.92	9.04
22	7.56	7.68	7.8	7.92	8.04	8.15	8.27	8.39	8.51	8.63	8.74	8.86
23	7.42	7.53	7.65	7.77	7.88	8	8.11	8.23	8.35	8.46	8.58	8.69
24	7.28	7.39	7.51	7.62	7.73	7.85	7.96	8.08	8.19	8.3	8.42	8.53
25	7.14	7.25	7.37	7.48	7.59	7.7	7.81	7.93	8.04	8.15	8.26	8.38
26	7.01	7.12	7.23	7.34	7.45	7.56	7.67	7.78	7.89	8	8.11	8.22
27	6.88	6.99	7.1	7.21	7.32	7.43	7.53	7.64	7.75	7.86	7.97	8.08
28	6.76	6.87	6.97	7.08	7.19	7.29	7.4	7.51	7.61	7.72	7.83	7.93
29	6.64	6.74	6.85	6.95	7.06	7.16	7.27	7.38	7.48	7.59	7.69	7.8

[1] Adding one or two crystals of solid cobalt chloride solid ($CoCl_2$) to 100 ml of the sodium sulfite solution will catalyze the initial removal of oxygen.

30	6.52	6.63	6.73	6.83	6.94	7.04	7.14	7.25	7.35	7.46	7.56	7.66
31	6.41	6.51	6.61	6.71	6.82	6.92	7.02	7.12	7.23	7.33	7.43	7.53
32	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7	7.1	7.2	7.3	7.41
33	6.19	6.29	6.39	6.49	6.59	6.69	6.79	6.89	6.98	7.08	7.18	7.28
34	6.08	6.18	6.28	6.38	6.48	6.57	6.67	6.77	6.87	6.97	7.06	7.16
35	5.98	6.08	6.18	6.27	6.37	6.47	6.56	6.66	6.76	6.85	6.95	7.05
36	5.88	5.98	6.07	6.17	6.26	6.36	6.45	6.55	6.65	6.74	6.84	6.93
37	5.78	5.88	5.97	6.07	6.16	6.26	6.35	6.44	6.54	6.63	6.73	6.82
38	5.69	5.78	5.87	5.97	6.06	6.15	6.25	6.34	6.43	6.53	6.62	6.71
39	5.59	5.69	5.78	5.87	5.96	6.05	6.15	6.24	6.33	6.42	6.52	6.61
40	5.5	5.59	5.69	5.78	5.87	5.96	6.05	6.14	6.23	6.32	6.41	6.5

Dissolved Oxygen Solubility in mg/L. Values based on published equations by Benson and Krause (1980 and 1984).

Table 2
Salinity correction factors for dissolved oxygen in water based on salinity

Temp.	**Salinity (permil – ppt)**								
(^{o}C)	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
0	1	0.9656	0.9324	0.9004	0.8694	0.8396	0.8107	0.7828	0.7559
1	1	0.9659	0.9330	0.9013	0.8706	0.8409	0.8123	0.7846	0.7579
2	1	0.9663	0.9336	0.9021	0.8717	0.8423	0.8139	0.7864	0.7599
3	1	0.9666	0.9342	0.9030	0.8728	0.8436	0.8154	0.7881	0.7618
4	1	0.9669	0.9348	0.9038	0.8739	0.8449	0.8169	0.7898	0.7636
5	1	0.9671	0.9354	0.9046	0.8749	0.8462	0.8184	0.7915	0.7655
6	1	0.9674	0.9359	0.9055	0.8760	0.8474	0.8198	0.7931	0.7673
7	1	0.9677	0.9365	0.9062	0.8770	0.8487	0.8213	0.7948	0.7691
8	1	0.9680	0.9370	0.9070	0.8780	0.8499	0.8227	0.7964	0.7709
9	1	0.9683	0.9375	0.9078	0.8790	0.8511	0.8241	0.7979	0.7726
10	1	0.9685	0.9381	0.9085	0.8799	0.8523	0.8254	0.7995	0.7743
11	1	0.9688	0.9386	0.9093	0.8809	0.8534	0.8268	0.8010	0.7760
12	1	0.9690	0.9391	0.9100	0.8818	0.8545	0.8281	0.8025	0.7776
13	1	0.9693	0.9395	0.9107	0.8827	0.8556	0.8294	0.8039	0.7792
14	1	0.9695	0.9400	0.9114	0.8836	0.8567	0.8306	0.8053	0.7808
15	1	0.9698	0.9405	0.9121	0.8845	0.8578	0.8319	0.8068	0.7824
16	1	0.9700	0.9410	0.9127	0.8854	0.8589	0.8331	0.8081	0.7839
17	1	0.9703	0.9414	0.9134	0.8862	0.8599	0.8343	0.8095	0.7854
18	1	0.9705	0.9418	0.9141	0.8871	0.8609	0.8355	0.8108	0.7869
19	1	0.9707	0.9423	0.9147	0.8879	0.8619	0.8366	0.8121	0.7884
20	1	0.9709	0.9427	0.9153	0.8887	0.8629	0.8378	0.8134	0.7898
21	1	0.9711	0.9431	0.9159	0.8895	0.8638	0.8389	0.8147	0.7912
22	1	0.9714	0.9435	0.9165	0.8903	0.8648	0.8400	0.8159	0.7926

23	1	0.9716	0.9439	0.9171	0.8910	0.8657	0.8411	0.8172	0.7939
24	1	0.9718	0.9443	0.9177	0.8918	0.8666	0.8421	0.8184	0.7952
25	1	0.9720	0.9447	0.9182	0.8925	0.8675	0.8432	0.8195	0.7966
26	1	0.9722	0.9451	0.9188	0.8932	0.8684	0.8442	0.8207	0.7978
27	1	0.9724	0.9455	0.9193	0.8939	0.8692	0.8452	0.8218	0.7991
28	1	0.9725	0.9458	0.9199	0.8946	0.8700	0.8462	0.8229	0.8003
29	1	0.9727	0.9462	0.9204	0.8953	0.8709	0.8471	0.8240	0.8015
30	1	0.9729	0.9465	0.9209	0.8959	0.8717	0.8481	0.8251	0.8027
31	1	0.9731	0.9469	0.9214	0.8966	0.8725	0.849	0.8261	0.8039
32	1	0.9733	0.9472	0.9219	0.8972	0.8732	0.8499	0.8272	0.8050
33	1	0.9734	0.9476	0.9224	0.8979	0.8740	0.8508	0.8282	0.8062
34	1	0.9736	0.9479	0.9228	0.8985	0.8747	0.8516	0.8292	0.8073
35	1	0.9738	0.9482	0.9233	0.8991	0.8755	0.8525	0.8301	0.8083
36	1	0.9739	0.9485	0.9238	0.8997	0.8762	0.8533	0.8311	0.8094
37	1	0.9741	0.9488	0.9242	0.9002	0.8769	0.8542	0.8320	0.8104
38	1	0.9742	0.9491	0.9246	0.9008	0.8776	0.8550	0.8329	0.8115
39	1	0.9744	0.9494	0.9251	0.9014	0.8783	0.8557	0.8338	0.8124
40	1	0.9745	0.9497	0.9255	0.9019	0.8789	0.8565	0.8347	0.8134

Factors are dimensionless. Values based on published equations by Benson and Krause (1984).

Both tables were generated from DOTABLES (Dissolved oxygen solubility tables) program available at http://water.usgs.gov/software/DOTABLES/.

DOTABLES is a very useful on-line program that generates tables of dissolved oxygen (DO) solubility values and (or) salinity correction factors over a range of user-specified values for water temperature, barometric pressure, and salinity or specific conductance. In addition to generating tables, DOTABLES can compute a single-value of oxygen solubility and percent saturation for a specific instance of temperature, pressure, and salinity.

Technical Specifications

Sensor kind	Analog, generates an output voltage between 0 - 5 V
Measurement range	0 .. 20 mg/L
Accuracy	Typical 2% after calibration at 25 °C
Respond time	95% of final reading in 30 s, 98% in 45 s
Temperature compensation	Automatic between 5 - 45 °C
Pressure compensation	Manual
Salinity compensation	Manual
Storage temperature	0 ~ 50°C
Minimum sample flow	20 cm/s
Calibration function	DO(mg/L) = 3.27 * V_{out}(V) – 0.327 (stored in the sensor memory) DO(ppm) = 3.27 * V_{out}(V) – 0.327
Membrane	Teflon PTFE
Connection	BT sensor cable attached to the sensor

Warranty:

The Dissolved Oxygen Sensor BT34i is warranted to be free from defects in materials and workmanship for a period of 24 months from the date of purchase provided that it has been used under normal laboratory conditions. This warranty does not apply if the sensor has been damaged by accident or misuse.

Note: *This product is to be used for educational purposes only. It is not appropriate for industrial, medical, research, or commercial applications.*

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