

TD218 Operating Manual

Oxygen Optode 3830, 3930 and 3975



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NOTE! The latest version of the FAQ for the 3830 Oxygen Optode is available on our web site

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Introduction

Purpose and scope

This document is intended to give the reader knowledge of how to operate, calibrate and maintain the Aanderaa Oxygen Optode 3830, Oxygen Optode/Temperature Sensor 3930 and Oxygen Optode 3975. It also aims to give insight in how these sensors work.

Since oxygen is involved in most biological and chemical processes in aquatic environments, it is the single most important parameter needing to be measured. Oxygen can also be used as a tracer in oceanographic studies.

For environmental reasons it can be critical to monitor oxygen in areas where the supply of oxygen is limited compared to demand e.g.:

- ❑ In shallow coastal areas with significant algae blooms
- ❑ In fjords or other areas with limited exchange of water
- ❑ Around fish farms
- ❑ In areas interesting for dumping of mine or dredging waste

Document overview

The document starts by giving a short description of the Oxygen Optodes.

Subsequently operating instructions, communication with the sensor, oxygen calculations and maintenance issues are presented.

The Appendix includes the principle behind the oxygen optodes, electronic and mechanical design, specifications, calibration procedures, illustrations, and finally a chapter on Frequently Asked Questions.

Additional Documents

- ❑ Form 620 Test & Specification Sheet, Oxygen Optode
- ❑ Form 621 Calibration Certificate, O₂ Sensing Foil 3853
- ❑ Form 622 Calibration Certificate, Oxygen Optode 3830
- ❑ Data sheet D335, Oxygen Optode 3830, 3930, 3975
- ❑ Technical Note TN242, Disk 3829 for 5 Submersible Sensors

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Abbreviations

O ₂	Oxygen molecule
LED	Light Emitting Diode
ADC	Analogue to Digital Converter
DSP	Digital Signal Processor
EPROM	Erasable Programmable Read Only Memory
ASCII	American Standard Code for Information Interchange
MSB	Most significant bit
UART	Universal Asynchronous Transmitter and Receiver
RTC	Real Time Clock

CHAPTER 1 Description of the Oxygen Optodes

The Aanderaa Oxygen Optode series consist of three sensors: 3830, 3930 and 3975.

- ❑ **Oxygen Optode 3830** is a digital Optode intended for mounting on Aanderaa Current meters/profilers. The sensor can also be used as a stand alone sensor, connected to a custom data logger via cable. In this case, use our 3485 cable for a depth capability of 1000m, or adaptor 3979 together with cable 3976 for a depth capability of 6000m.

- ❑ **Oxygen Optode 3930** comprise of the digital 3830 optode and an adaptor for sensor with 16mm foot (adaptor 3714). 3930 is intended as an immersion body for cable and sensor strings. The maximum operating depth is 1000m
- ❑ **Oxygen Optode 3975** comprise of the digital 3830 attached to an analogue adaptor (adaptor 3966) for analogue output. 3975 is intended as an immersion body with analogue and serial outputs. The maximum operating depth is 6000m

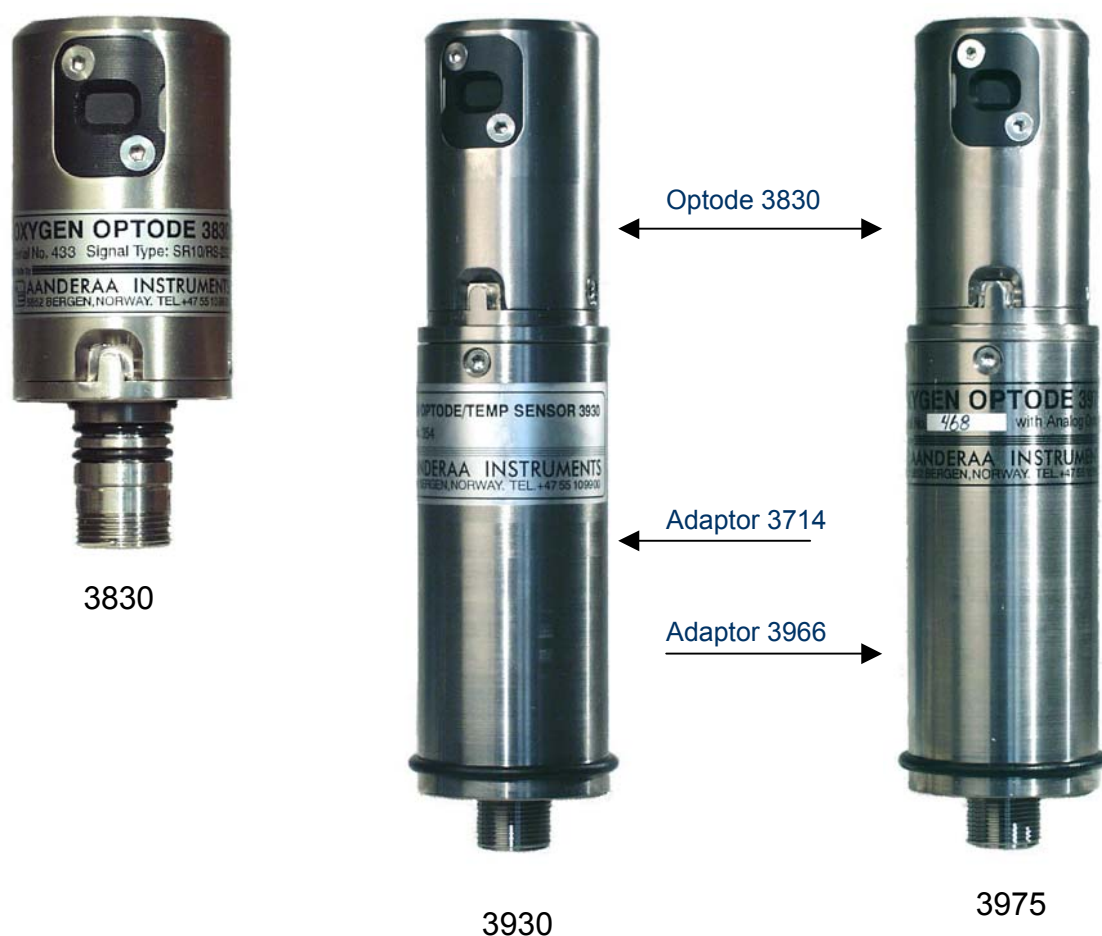


Figure 1-1 Illustration of the Oxygen Optodes: 3830 to the left, 3930 in the middle and 3975 to the right

The Aanderaa Oxygen Optode is based on the ability of selected substances to act as dynamic fluorescence quenchers.

The fluorescent indicator is a special platinum porphyrin complex embedded in a gas permeable foil that is exposed to the surrounding water. A black optical isolation coating protects the complex from direct incoming sunlight and fluorescent particles in the water.

The sensing foil is pushed against a sapphire window by a screw mounted securing plate, providing optical access to the measuring system from inside a watertight titanium housing.

The foil is excited by modulated blue light, and the phase of a returned red light is measured, ref Appendix 2. By linearizing and temperature compensating, with an incorporated temperature sensor, the absolute O₂-concentration can be determined.

The lifetime-based luminescence quenching principle, as used in Aanderaa Oxygen Optodes, offers the following advantages over electrochemical sensors:

- ❑ Not stirring sensitive (it consumes no oxygen).
- ❑ Measures absolute oxygen concentrations without repeated calibrations.
- ❑ Better long-term stability (stable for at least one year).

- ❑ Less affected by pressure.
- ❑ Pressure behaviour is predictable and fully reversible.

The digital Optodes (3830 and 3930) output data in both RS232 and Aanderaa SR10 format (the 3930 must be opened, page 22). The analogue Optode (3975) outputs data as 0 - 5V or 4 - 20mA, and/or as RS232.

The Optodes can be logged directly by a PC (via the RS232 protocol) and by most custom made dataloggers and systems.

RS232 output the absolute oxygen content in µM, the relative air saturation in %, the temperature, °C, and a number of raw data parameters.

The SR10 output can be configured to present oxygen content in µM or air saturation when logged by an Aanderaa instrument (e.g. the Recording Current Meter, RCM 9 MkII or RCM 11, and the Recording Doppler Current Profiler, RDCP 600). Optode 3830 and 3975 are designed to operate down to 6000 meters.

NOTE! Optode 3930 can operate down to 1000 m.

For the Oxygen Optodes, the current drain is independent of the battery voltage (due to use of a linear regulator).

Refer Appendix 5 for general and specific specifications for all three optodes.

Manufacturing and Quality Control

Aanderaa Instruments have proven reliability. With over 30 years of producing instruments for the scientific community around the world, you can count on our reputation for designing some of the most reliable products available.

We are guided by three underlying principles: quality, service, and commitment. We take these principles

seriously, for they form the foundation upon which we provide lasting value to our customers.

Our quality is based on a relentless program of continuous monitoring to maintain the highest standards of reliability.

CHAPTER 2 Operating Instructions

Hand-held Oxygen Optodes

All three optode versions can be used as Real-Time hand held sensors together with Aanderaa Instruments PC based Software *OxyView* for communication and presentation of measurements. Use sensor cable 3855 between the optode and the PC (refer Figure A 12, page 54). Refer page 24 for information about *OxyView*. The RS232 signal from the optodes 3830 and 3975 is available from the sensor foot and the adaptor foot, respectively. To access the RS232 signal from the optode 3930 the housing has to be opened, refer page 22.

The Oxygen Optode 3830 for mounting on Aanderaa Current meters/profilers

If the Oxygen Optode is ordered as part of an Aanderaa Current Meter/Profiler (RCM 9 MkII, RCM11 or RDCP600), the optode has been mounted to the instrument prior to delivery. Configurations have been made according to user requests.

However, if the optode has been ordered separately for use on an Aanderaa Current Meter/Profiler, follow the mounting and configuration descriptions given in the Operating Manual for the instrument.

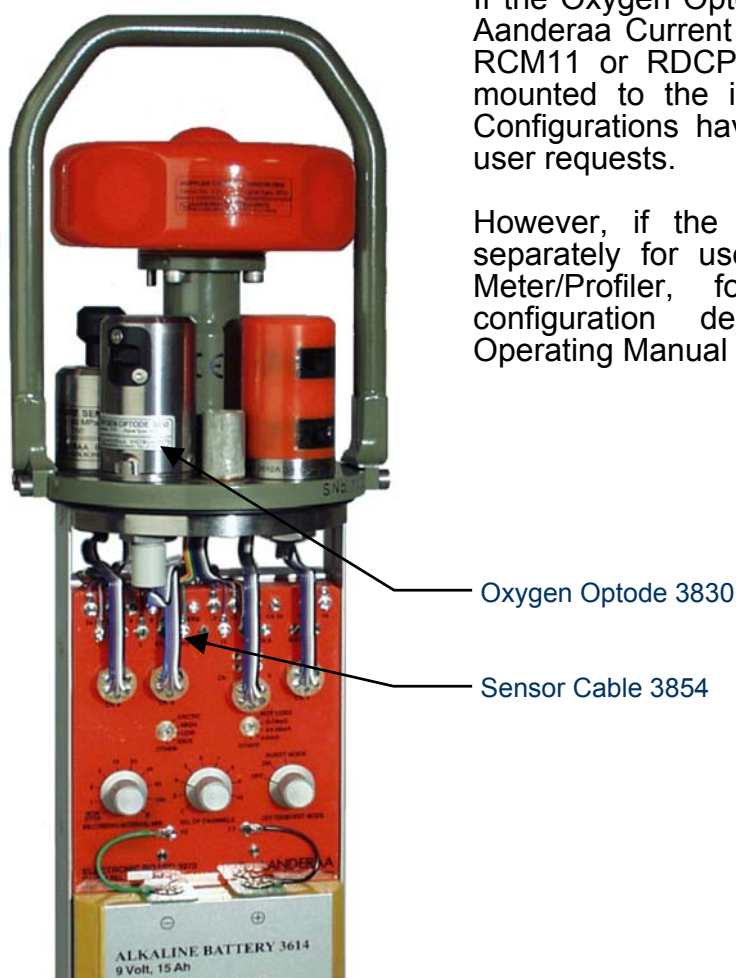


Figure 2-1 Oxygen Optode 3830 mounted on an RCM 9 Mk II

The Oxygen Optode 3930 used with buoys and sensor disks

The 3930 Optode can be used with Aanderaa datalogger series, as a sensor to Aanderaa Data Buoy 4280 or other Aanderaa self contained recording instruments like e.g. the Display Unit 3315 as stand-alone for single sensor measuring system.

Optode 3930 used with Data Buoy 4280

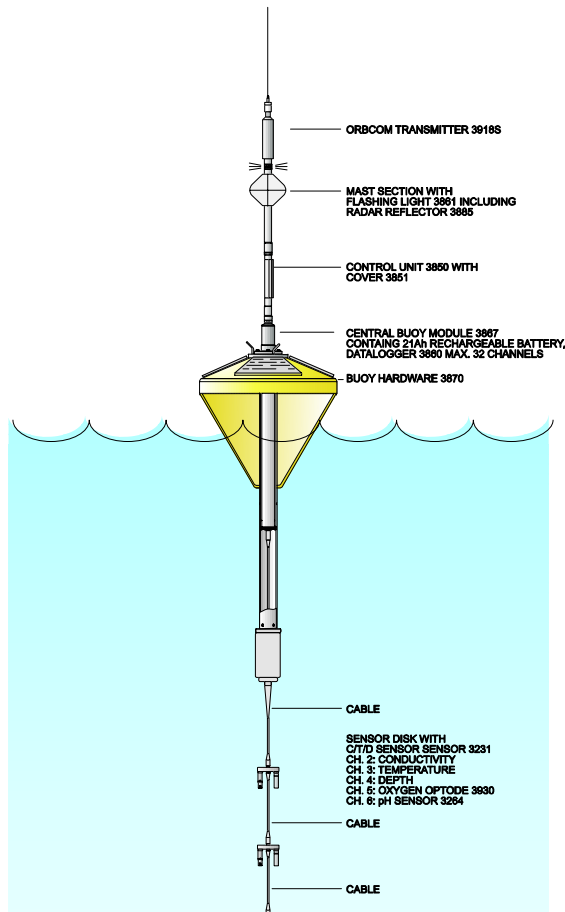


Figure 2-2 Illustration of one of our Buoy Deployment with Sensor Disk 3829 for 5 submersible sensors, like e.g. Oxygen Optode 3930.

When used in a Buoy Deployment, the Oxygen Optode 3930 can be mounted to Sensor Disk 3829 as illustrated in Figure 2-2.

The Sensor Disk is connected to a sub sea cable. Measurements are configured in the datalogger, e.g. Aanderaa Datalogger 3860.

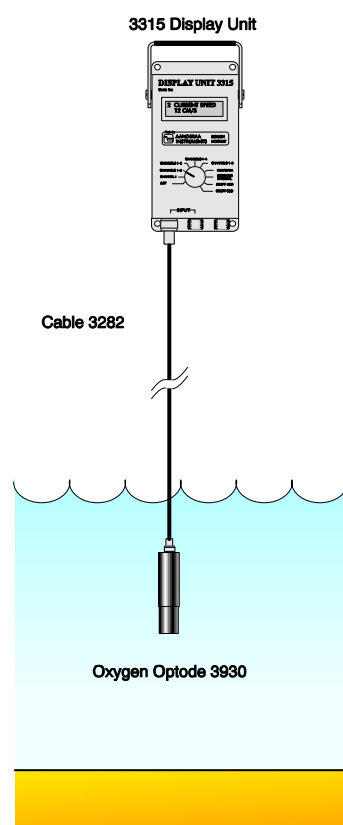
Ref. Operating Manual TD 216 for communication with datalogger 3860.

Sensor Disk 3829 is designed for up to 5 submersible sensors, refer Figure 2-3. The Sensor Disk is fitted with Aanderaa standard 10-pin receptacles and an internal switch for presetting of the number of channels in use for each sensor connected. For connection and disconnection of sensors to the Sensor Disk, ref Technical Note TN 242.



Figure 2-3 Sensor Disk 3829

Optode 3930 used with Display Unit 3315



For a single sensor measuring system, the Oxygen Optode 3930 can be connected to a Real-Time Display Unit 3315 via cable 3282, as illustrated in Figure 2-4.

In cases where two or more sensors are needed we strongly recommend to connect the sensors to Aanderaa Sensor Disk 3829 (ref. Page 12). Use Cable 3809 between the Sensor Disk and the Display Unit.

Sensor Configurations are performed on the Display Unit.

Figure 2-4 Display Unit 3315 used with a submersible sensor like e.g. Oxygen Optode 3930.

The Oxygen Optode 3975 used with analogue or serial output

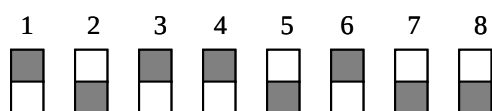
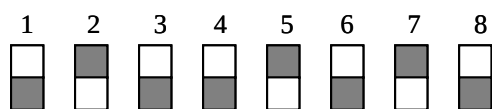
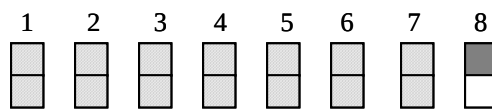
The Oxygen Optode 3975 can be used with third party dataloggers, e.g. CTD's, ARGO floats, ROV's, PLC's, process industry controllers, recorders, and data acquisition and control systems. For connection of sensors to these systems, refer to the specific systems Operating Manual.

Switch settings 0 - 5 V and 4 – 20 mA

A dipswitch contact is *OFF* when the switch is in the upper position. The three valid settings are shown in Figure 2-5, Figure 2-6, and Figure 2-7. Note that when the Analogue Adaptor 3966 is switched off by setting contact no. 8 in the *OFF* position, the sensor connected to the adaptor is still powered. The RS232 lines are wired straight through the analogue adaptor and are thus not affected by the switch settings. Refer Table 3-4 page 21 for channel output.

Table 2-1 Switch settings for Optode 3975

Switch	Function	Remarks
1	Enable 4 – 20mA	Output 1
2	Enable 0 – 5V	
3	Power, 4 – 20mA transmitter	
4	Enable 4 – 20mA	Output 2
5	Enable 0 – 5V	
6	Enable 4 – 20mA voltage ref	
7	Enable 0 – 5V voltage ref.	
8	Power	

**Figure 2-5 Switch setting for 0 – 5 V analogue output (the dark square represents the switch). Upper position is OFF.****Figure 2-6 Switch setting for 4 – 20 mA analogue output (the dark square represents the switch). Upper position is OFF.****Figure 2-7 Switch setting for switching the analogue adaptor off (the dark square represents the switch). Upper position is OFF.**

CHAPTER 3 Communication with the sensor

For communication with the sensor we recommend you to use OxyView software, which is available for a nominal license fee. The software is user friendly and provides graphic and tabular display for set-up, calibration, and logging. These functions are easily accessed without deeper knowledge about the sensor. Read more about OxyView on page 24.

As an alternative you can also communicate with the sensor using any standard Terminal communication program (such as HyperTerminal included in Windows or Terra Terminal). Read the guidelines

carefully and type in every command separately. Refer page 16 for guidelines.

***NOTE!** We recommend that you write standard lines in a text document and copy the text lines into the terminal program, refer page 22. You can also copy lines from a text editor and paste into the Terminal program.*

The standard factory setting is SR10 output from the Optodes (unless other arrangements has been made).

Sensor integrated Software

The sensor integrated software's main tasks are to control the transmitter, sample the returned signal, extract the phase of this signal, and convert it into oxygen concentration and/or Air Saturation.

All properties that can be changed for each individual sensor, i.e. calibration coefficients, are called sensor properties. The properties can be displayed and changed using the RS232 port (refer the *RS232 protocol*, page 16, for how to communicate with the sensor using a Terminal communication Program).

The Oxygen Optode will perform an oxygen sample and present the result within the first 1.5 seconds after the optode has been powered up.

The RS232 input buffer is checked for 100 milliseconds after each sample (including the first sample).

If the buffer contains any characters the timeout is increased to 1 second and the software starts interpreting the RS232 input.

If the input buffer is empty the sensor will continue to sample and present data according to the setting of the *Interval* property.

If the *Interval* is set to zero the user can initiate a new sample by use of a *Do_Sample* command. Figure 3-1 illustrates the operation sequence.

After approximately 20 seconds without valid command inputs the sensor enters sleep mode until the next interval starts.

In sleep mode the sensor will not respond to RS232 input commands. If the time interval is long, the best way to start communication with the sensor is to first disconnect and then reconnect the power to the sensor.

However, before entering sleep mode the sensor stops the host's transmission by sending out a *XOFF* handshake-control character.

After waking up and finishing the next sample, the host transmission is switched back on.

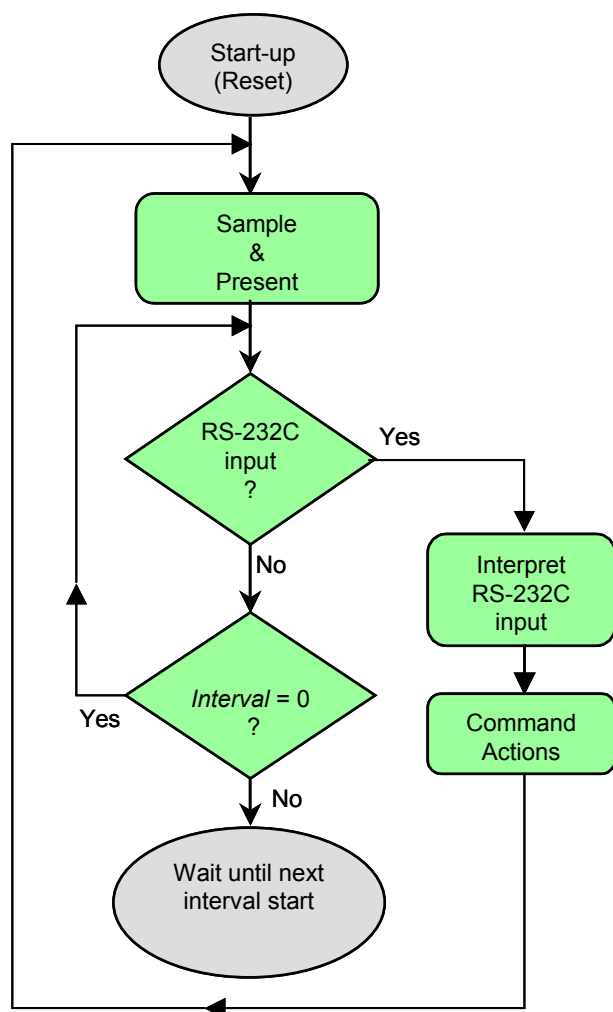


Figure 3-1 Operational Sequence of the internal Software

When the handshake method is used the host's output will be buffered until the sensor is ready to receive.

This relieves the host from the need to synchronize the communication with the sensors sampling interval.

When the Optode is connected to an Aanderaa Instrument or datalogger, the power to the sensor is switched ON as the Control Voltage becomes active (initiated by the Instrument or the datalogger).

The sensor will then take one sample in the start of the recording interval and present this at the SR10 output.

When the datalogger has finished reading the SR10/VR22 sensors, the Control Voltage is switched OFF and the Optode is powered down.

RS232 protocol

The RS232 protocol describes how to communicate with the sensor.

For connection to a PC the 1.5-meter Sensor Cable 3855 can be used (refer Figure A 12, page 54).

Most terminal programs, such as e.g. the HyperTerminal[®] by Hilgraeve Inc (included in Microsoft operating systems), can be used for communication with the sensor.

All commands described in this chapter are available by single mouse clicks in OxyView Software.

The following RS232 setup should be used for the terminal setup:

9600 Baud
8 Data bits
1 Stop bit
No parity
Xon/Xoff Handshake

NOTE! Select one of the options 'Sent line ends with line feeds' or 'Echo line ends with line feeds' in the Hyper Terminal.

All communication is ASCII coded with the following rules:

- ❑ All inputs to the sensor are given as commands with the following format: *MainCmd_SubCmd* or *MainCmd_Property(Value..., Value)*
- ❑ The main command, *MainCmd_SubCmd* is followed by an optional subcommand (*SubCmd*) or sensor property (*Property*).
- ❑ The *MainCmd* and the *SubCmd/Property* must be separated with the underscore character '_' or a space ' ' character.
- ❑ When entering new settings the *Property* is followed by a parentheses containing comma-separated values.
- ❑ The command string must be terminated by a Line Feed character (ASCII code 10). Termination with Carriage Return followed by Line Feed is also allowed.
- ❑ The command string is not case sensitive (UPPER/lower-case).
- ❑ A valid command string is acknowledged with the character '#' while character '*' indicates an error. Both are followed by Carriage Return/ Line Feed (CRLF).
For most errors a short error message is also given subsequent to the error indicator.

The RS232 protocol describes how to communicate with the sensor. All inputs to the sensor are given as commands; a list of the main commands are given in Table 3-1:

Table 3-1 Main RS232 commands available for the Oxygen Optode.

Command	Description
Do_Subcmd	Execute <i>Subcmd</i> (refer Table 3-2)
Get_Property	Output <i>Property</i> value (refer Table 3-3)
Get_All	Output all property values
Set_Property(Value,... Value)	Set <i>Property</i> to <i>Value</i> ,... <i>Value</i>
Save	Store current settings
Load	Load stored settings
Help	Print help information

Available subcommands and properties for the Oxygen Optode

Available subcommands and properties for the Oxygen Optodes are given in Table 3-2 and Table 3-3 respectively.

Table 3-2 Available Subcommands for the Oxygen Optode

Subcommand	Description	Write Protection
Sample	Execute an oxygen measurement and presents the result	No
Calibrate	Execute calibration function	Yes
CalAir	Collect calibration data in air	Yes
CalZero	Collect calibration data in zero solution	Yes
Test	Execute a test function and present the result	No

A property may contain one or more equal elements of the type Character, Integer or Float. The Character type is stored as an 8-bit bit word and may be signed (value –128 to 127) or unsigned (0-256).

The Integer type is stored as a 16-bit word and may be signed (value –32768 to 32767) and unsigned (0 to 65535).

The Float consists of 32-bit and has a range from 1.19209290e–38 to 3.4028235e+38.

The *Get* command is used for reading the value/values of a property.

The command name *Get*, is followed by *_Property* and returns a string on following format:

Property ProductNo SerialNo Value, ..Value

The string starts with the name of the property (*Property*), continues with the product number and serial number of the sensor, and finally the value or values of the property.

All names and numbers are separated by tabulator spacing (ASCII code 9).

The string is terminated by Carriage Return and Line Feed (ASCII code 13 & 10).

Example:

Get_Salinity

Returns:

Salinity 3830 116 3.500000E+01 #

A special version, *Get_All*, reads out all available properties in the sensor.

Table 3-3 Available Properties for the Oxygen Optode; NA = Not Applicable

Properties	Type	No. of elements	Use	Write protection	Default setting
<i>Protect</i>	Int	1	Protection of property read and write access	No	0
<i>PhaseCoef</i>	Float	4	Curve fitting coefficients for phase measurements	Yes	NA
<i>TempCoef</i>	Float	4	Curve fitting coefficients for temperature measurement	Yes	NA
<i>FoilNo</i>	Int	1	Foil batch number	Yes	NA
<i>C0Coef</i>	Float	4	Temperature Coefficients in the [O ₂] phase	Yes	NA
<i>C1Coef</i>	Float	4		Yes	NA
<i>C2Coef</i>	Float	4		Yes	NA
<i>C3Coef</i>	Float	4		Yes	NA
<i>C4Coef</i>	Float	4		Yes	NA
<i>Salinity</i>	Float	1	Salinity setting	No	0
<i>CalAirPhase</i>	Float	1	Calibration data in air, phase	Yes	NA
<i>CalAirTemp</i>	Float	1	Calibration data in air, temperature	Yes	NA
<i>CalAirPressure</i>	Float	1	Calibration data in air, pressure	Yes	NA
<i>CalZeroPhase</i>	Float	1	Calibration data in zero solution, phase	Yes	NA
<i>CalZeroTemp</i>	Float	1	Calibration data in zero solution, temperature	Yes	NA
<i>Interval</i>	Int	1	Sample Interval in seconds.	No	30
<i>AnCoef</i>	Float	2	Offset and slope correction coefficients for I2C output to Analogue Adaptor	Yes	0,1
<i>Output</i>	Char	1	Output setting	Yes	-1

The *Set* command is used for changing a property.

Example:

```
Set_TempCoef(-124,1.6644E-4, 3.3456E-12,0)
```

Returns:

```
#
```

Float values may be entered on normal decimal form or exponential form, either with 'e' or 'E' leading the exponent. Extra 'Space' characters in front or after a value are allowed.

When one or more properties are changed, the sensor will start using the new properties.

If the *Save* command is executed the new setting will be stored in the internal EEPROM.

If a *Load* is executed instead, the previous stored setting will be reloaded.

To avoid accidental change, most of the properties are write-protected.

A special property called *Protection* must be set to 1 before changing the value of properties with this write protection.

The *Protection* property always returns to zero after power up or execution of the *Load* or *Save* command.

The *Do_Sample* command or an interval initiated measurement result in one output string containing the obtained data.

Output Control

A property called *Output* controls the presentation of the measured data. When the *Output* value is set to 1 a comprehensive RS-232 string containing raw data is presented:

```
MEASUREMENT 3830 392 Oxygen: 277.04 Saturation: 98.12
Temperature: 20.22 Dphase: 26.90 Bphase: 27.40
Rphase: 0.00 Bamp: 319.97 Bpot: 222.00
Ramp: 0.00 RawTem.: -18.81
```

When the *Output* property is set to 0 a normal string with the following format is transmitted:

```
MEASUREMENT 3830 104 Oxygen: 234.87 Saturation: 104.75
Temperature: 28.78
```

If the *Output* is set to 100 or 101 the output string is as for the 0 and 1 setting but with all the text removed: The leading word, MEASUREMENT, is followed by the sensor's product number and serial number. All words and numbers are followed by a tabulator spacing (ASCII code 9). The string is terminated by Carriage Return and Line Feed (ASCII code 13 and 10).

Setting a negative *Output* property value enables either the SR10 outputs or the I2C output to the Analogue Adaptor, ref. Table 3-4.

Table 3-4 Negative Output properties for the Oxygen Optodes (Positive Outputs 0, 1, 100, 101 gives RS232 Output and are described in the text above).

Output	Data on SR10 Output	Unit/scaling coefficients	Data on Analogue Adaptor; Output 1	Data on Analogue Adaptor; Output 2
-1	O ₂ Concentration	[μM] A = 0 B = 0.488281		
-2	O ₂ Saturation	[%] A = 0 B = 0.146484		
-100	Test, fixed reading	777		
-101			O ₂ Concentration	Temperature
-102			O ₂ Saturation	Temperature
-103			Compensated phase measurement ¹ (ref CHAPTER 4)	Temperature
-110			Test, fixed reading 4V/16.8mA	Test, fixed reading 1V/7.2mA
-111			Test, fixed reading 1V/7.2mA	Test, fixed reading 4V/16.8mA

NOTE! The Oxygen Optode 3975 has analogue outputs: 0-5 Volt or 4-20 mA. Refer page 14 for dip-switch settings for the analogue adaptor.

When the analogue output or the SR10 output is enabled, all measurements are also presented at the RS232 port.

¹ Temperature compensation is done externally by the user, often used in oxygen profiling.

After the very first sample additional information about setting and scaling coefficients are presented. An example of information and scaling coefficients for Oxygen Optode 3830 are given below:

MEASUREMENT	3830	104	Oxygen:	234.87	Saturation:	104.75.....
0-5V	Output 1: Oxygen		1.367 V, use scaling coef.	A:= 0.000000E+01	B:= 6.600000E+00	
0-5V	Output 2: Temperature		3.766 V, use scaling coef.	A:=-5.000000E+00	B:= 8.000000E+00	
4-20mA	Output 1: Oxygen		6.56 mA, use scaling coef.	A:= 1.175000E+01	B:= 2.062500E+00	
4-20mA	Output 2: Temperature		16.05 mA, use scaling coef.	A:=-1.500000E+01	B:= 2.500000E+00	

Scripting -sending a string of commands

Often it may be usefully to collect more than one command in a text file. For example the instructions below can be written in an ordinary text editor and saved as a text file, which can be sent to the sensor. In the HyperTerminal click *send text file* in the *Transfer* menu, and select the correct file.

Example of text file:

```
// Set sampling interval to 30 seconds
Set_Protect(1)
Set_Interval(30)
Save
Get_All
```

NOTE! The last line, Get_All, reads out available properties for the sensor.

The first line is a comment line that is disregarded by the sensor. Strings starting with either ‘//’ or ‘;’ are ignored by the software, and do not produce errors or acknowledgements.

Communication with the Oxygen Optode 3930

In order to change settings or to calibrate Optode 3930 the sensor has to be connected to a PC.

NOTE! New 3930 sensors do not have the securing ring, ref Figure 1-1. The RS232 signal can be accessed by following the outlined procedure, neglecting the text regarding the securing ring.

Follow the procedure given below to gain access to the Optode’s RS232 signals:



Figure 3-2

1. Remove the setscrew, ref. Figure 3-2.
2. Unscrew the black securing ring, ref. Figure 3-3

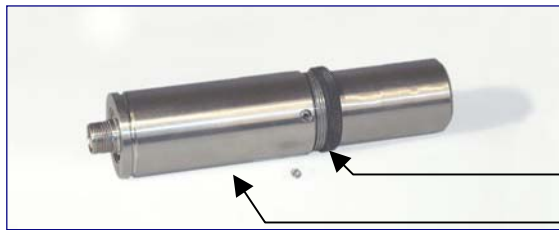


Figure 3-3

3. Remove the cylindrical body by pulling upwards towards the sensor receptacle, ref. Figure 3-3.



Figure 3-4

4. Gently pull out the internal plug connected to the Optode, ref. Figure 3-4, Figure 3-5 and Figure 3-6.



Figure 3-5



Figure 3-6

5. Use Sensor Cable 3855 to carefully connect the Optode to the serial connector of a PC, ref. Figure 3-7, Figure 3-8 and Figure 3-9.



Figure 3-7

Refer page 16, *RS232 protocol*, for communicating with the sensor.

Reassemble the housing in reverse order after calibration and/or settings have been performed. Please make sure that both O-rings in the Optode housing are clean and undamaged. If necessary: change the O-rings.

Remount the setscrew before tightening the securing ring.

**Figure 3-8****Figure 3-9 Sensor cable 3855**

Serial port for PC

USB Connection to supply the sensor with power
(5-14V possible)

Connection for sensor

NOTE! Many new PC's do not have a serial port. Use an USB/serial Adaptor for the connection.

Communication with the Oxygen Optode 3975

The RS232 signal is accessed from the adaptor foot directly. For communication with the sensor via OxyView or Hyper Terminal, connect

sensor cable 3855 between the adaptor foot and the COM port on your PC.

OxyView

OxyView is a Windows Application designed for use with the Oxygen Optode in Real-Time situations. The program is intuitive, and will allow display of Oxygen Concentration, Oxygen Saturation and Temperature in table and graphical form.

Included in the software is a Calibration Wizard to help calibrate Oxygen Optode sensors.

System requirements

- ☐ 233 MHz or faster Pentium or compatible
- ☐ 1MB of free hard disk space
- ☐ Microsoft Windows 98, 2000 or XP
- ☐ 64MB of RAM
- ☐ SVGA (640x480) colour display
- ☐ Local CD-ROM Drive
- ☐ Internet Explorer (4.0 or later)

Installation of the Software

To install OxyView, run OxyView setup.exe found on the product CD. This will install OxyView in a program folder on your machine. In the same folder, a help file and an operating manual can be found.

To uninstall OxyView, run unwize.exe found in the same folder as OxyView.exe.

If you have an old version of OxyView uninstall this one before installing the latest version (run unwize.exe).

Before start

At startup OxyView tries to establish a connection with the Oxygen Optode by sending 'Get_Interval' commands. If the sensor is in sleep mode it will not respond to RS232 commands before the sampling interval elapses.

If the interval is greater than about 60 seconds, OxyView will not be able to get information regarding the sampling

interval and will then create a graph assuming that the time between ticks is 2 seconds.

To force the sensor out of sleep mode, disconnect and reconnect the power to the sensor (normally the USB plug on your PC will supply 5V).

About OxyView

The OxyView user interface consists of four main parts:

- ☐ The Menu Bar
- ☐ The Graph Window
- ☐ The Input Pane
- ☐ The Output Pane

The Menu Bar

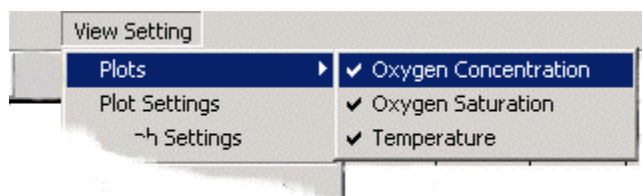
The most important Menu Items are:

- ☐ View Settings
- ☐ DAQ Settings
- ☐ Tools

The *View Settings* menu enable users to modify graph settings like time scale, Y-scale, line colour etc.

Table 3-5 Commands available in the View settings Menu.

Commands	Description
Plots	By default, OxyView display three graphs, ref. Figure 3-10: ☐ Oxygen Concentration ☐ Oxygen Saturation ☐ Temperature Use the <i>Plot</i> command to add or remove plots. A check mark to the left of a plot name indicates that the plot line is displayed. Click on the plot name to add or hide the plot line.
Plot Settings	Use the <i>Plot Settings</i> command to bring up a dialog that enables the user to modify the color, style or the y-axis scale for the individual plot lines, ref Figure 3-11.
SetGraphRange	Use the <i>SetGraphRange</i> command to bring up a dialog that enables the user to modify the range of the time axis.
Run/Stop	Use the <i>Run/Stop</i> command to start or stop sampling. <i>Shortcut key: SPACE</i>

**Figure 3-10 View Setting Menu**

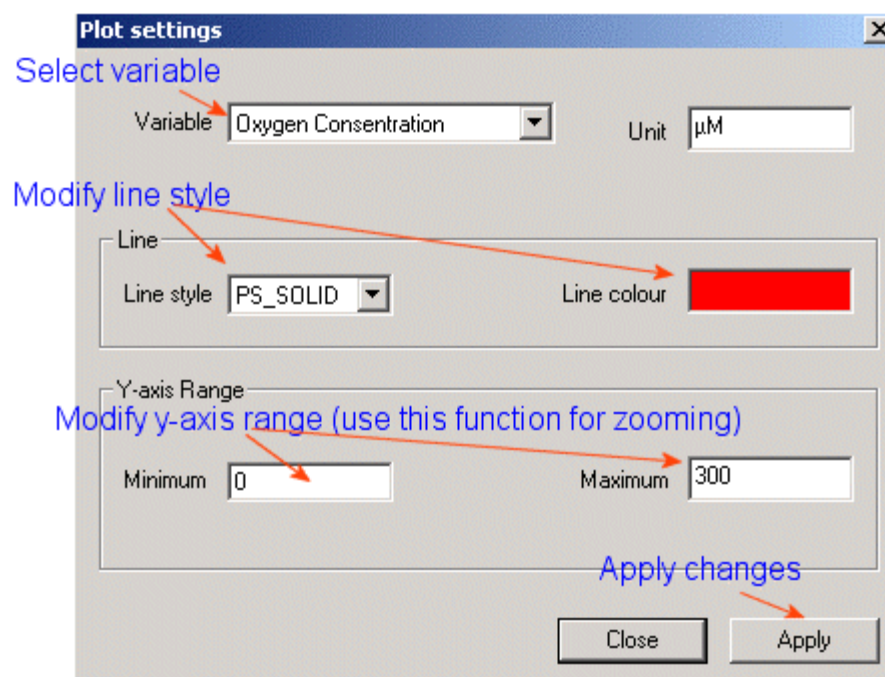


Figure 3-11 Plot Settings

The *DAQ settings* menu enables users to set sample interval, to start logging of data to file and to change COM port.

Table 3-6 Commands available in the DAQ settings Menu.

Commands	Description
COM port	Use the <i>COM port</i> command to select another serial port.
Logging	Use the <i>Logging</i> command to enable logging of data and to specify the path to and the name of the data file (text file with tab delimiter).
Sample Interval	Use the <i>Sample Interval</i> command to bring up a Set Sampling Interval dialog. Note that clicking on the watch symbol at the short cut toolbar brings up the same dialog.

From the *Tools* menu the user can start a Calibration Wizard and the Command Tool Dialog. By use of the Command Tool Dialog, the user can run all command supported by the Oxygen Optode Sensor. When clicking on a command, its function is fully explained in a dialogue box. Note that most users do not need to use this tool. For more information about these commands, refer page 17 - 22.

Table 3-7 Commands available in the Tools Menu.

Commands	Description
Calibrate	Invoking the <i>Calibrate</i> command to bring up the calibration wizard. Follow the instructions on the screen to perform a one or two point calibration of the sensor. <i>Shortcut: Press the weight symbol on the short cut toolbar.</i>
Run	Invoke the <i>Run</i> command to bring up a dialog box that enables the user to run all commands supported by the Oxygen Optode Sensor. Select command, sub-command or property. Enter property values if necessary and press send. <i>Note that most users do not need to use this tool.</i>

The Graph Window

The Graph Window displays plot lines for Oxygen Concentration, Oxygen Saturation and temperature with separate y-axis scales to the right of the graph.

The Input Pane

Text strings (raw data) arriving from the Oxygen Optode Sensor are presented in this pane.

The Output Pane

Text strings sent from OxyView to the Oxygen Optode Sensor are presented in this pane.

CHAPTER 4 Oxygen Calculations in the sensor

The Optodes internal software calculates engineering values (calibrated oxygen concentrations) based on the sampled raw-data and a set of stored ('flushed') coefficients.

After converting the phase raw data to degrees, a compensated phase difference is calculated as a 3rd degree polynomial of the phase measurement with blue light excitation. The coefficients in this polynomial are called *PhaseCoef*.

The temperature, °C, is calculated from a similar polynomial with coefficient called *TempCoef*.

The O₂-concentration is calculated in micro Molar, μM , from a 4th degree polynomial:

$$[\text{O}_2] = C_0 + C_1P + C_2P^2 + C_3P^3 + C_4P^4$$

where

$C_0, \dots, C_4$ = temperature dependent coefficients (ref. Appendix 6)

P = compensated phase difference

Based on O₂-concentration, temperature and salinity setting, the *Calculate* function also calculates the relative O₂ saturation.

The following equation by Garcia and Gordon, ref page 6, gives the O₂ solubility (C^*) at standard air mixture and pressure (1013 hPa).

$$\ln(C^*) =$$

$$A_0 + A_1T_s + A_2T_s^2 + A_3T_s^3 + A_4T_s^4 + A_5T_s^5 + S(B_0 + B_1T_s + B_2T_s^2 + B_3T_s^3) + C_0S^2$$

where:

T_s = scaled temperature

$$= \ln \left[\frac{298.15 - t}{273.15 + t} \right]$$

t = Temperature, °C

S = Salinity (fixed setting)¹

$$A_0 = 2.00856 \quad B_0 = -6.24097\text{e-}3$$

$$A_1 = 3.22400 \quad B_1 = -6.93498\text{e-}3$$

$$A_2 = 3.99063 \quad B_2 = -6.90358\text{e-}3$$

$$A_3 = 4.80299 \quad B_3 = -4.29155\text{e-}3$$

$$A_4 = 9.78188\text{e-}1$$

$$A_5 = 1.71069$$

$$C_0 = -3.11680\text{e-}7$$

The relative O₂ saturation in % can now be calculated as:

$$O_{2Sat} = \frac{[\text{O}_2] \cdot 2.2414}{C^*}$$

where:

$[\text{O}_2]$ = O₂-concentration, μM

C^* = Solubility, cm^3/liter

¹ Default setting for salinity is zero

Salinity Compensation

The O₂-concentration sensed by the Optode is in fact the O₂-concentration in the sensing foil.

Since this foil is only permeable to gas and not water, the Optode can not sense the effect of salt dissolved in the water, hence the Optode always measures as if immersed in fresh water.

If the salinity variation on site is minor (less than ±1ppt), the O₂-concentration can be corrected by setting the internal property *Salinity* to the average salinity at the measuring site.

However, if the salinity varies significantly and a measured salinity is available a more accurate correction may be applied by a post compensation of the data.

The O₂-concentration, μM , should then be multiplied by the following factor:

$$O_{2c} = [O_2] \cdot e^{S(B_0 + B_1 T_s + B_2 T_s^2 + B_3 T_s^3) + C_0 S^2}$$

where :

S = salinity in ppt

T_s = scaled temperature

$$= \ln \left[\frac{298.15 - t}{273.15 + t} \right]$$

t = temperature, °C

$$B_0 = -6.24097\text{e-}3 \quad C_0 = -3.11680\text{e-}7$$

$$B_1 = -6.93498\text{e-}3$$

$$B_2 = -6.90358\text{e-}3$$

$$B_3 = -4.29155\text{e-}3$$

If the salinity setting in the Optode is set to other than zero (zero is the default value), the O₂-concentration must also be divided by the above expression substituting S with the fixed salinity setting.

Depth Compensation

The response of the sensing foil decreases to some extent with the ambient water pressure (4% lower response per 1000 m of water depth).

This effect is however totally and instantly reversible and easy to compensate for by the following equation:

$$O_{2c} = O_2 \cdot \left(1 + \frac{0.04 \cdot d}{1000} \right)$$

where

d is depth in meters

O_{2c} is compensated O₂-concentration in either μM or %, depending on the unit of the O₂ input.

NOTE! Depth Compensation is not performed within the Optode.

CHAPTER 5 Maintenance

The Oxygen Optode requires very little maintenance.

When the membranes on traditional oxygen consuming sensors (based on electrochemical principles), often called Clark sensors, are fouled the water mixing in front of the sensor membrane becomes poorer, which influences the measurement directly.

Since the Optode consumes no Oxygen, the ability to diffuse gas has no influence on the measurement accuracy.

However, if the fouling is in the form of algae that produce or consume oxygen, the measurement might not reflect the oxygen concentration in the surrounding water correctly.

Also the response time of the measurements might increase if the sensing foil is heavily fouled.

Therefore, the sensor should be cleaned at regular intervals from 1 month to a year depending on the required accuracy and the fouling condition at the site.

The Optode housing can be cleaned using a brush and clean water. Carefully, use a wet cloth to clean the sensing foil.

Fouling consisting of calcareous organisms (e.g. barnacles), can be dissolved by dipping the sensor/instrument in a weak acid solution (e.g. 7% Vinegar).



Figure 5-1 Example of fouling on an RCM 9 Mk II with an Oxygen Optode 3830 mounted to it: The Optode was still giving correct readings.

To increase the deployment time in the marine environment we recommend attaching a securing plate of copper in front of the optical window (this typically triples the deployment interval between cleaning).

The securing plate prevents fouling to grow directly onto the sensing foil. The copper plate does not improve the sensor performance in wastewater applications since bacteria can settle behind the foil and change the local oxygen conditions.

If the sensing foil is scratched or if the protective black layer on the foil is removed the sensor will still work as long as there is enough Fluorophore on the foil.

If severely damaged (so that the sensor gives unrealistic readings) the sensing foil should be replaced (Sensing Foil Kit 3853) and the sensor recalibrated. ***NOTE! Enter new calibration coefficients when changing the sensor foil.***

Due to the measurement technology,

the optodes do not drift over time (within the given specifications).

It is recommended that the sensor is recalibrated annually (refer page 32), although feedback tells us that the sensors are stable over a longer time period.

Sensing Foil Kit 3853

If the sensing foil gets damaged and has to be changed you need the Sensor foil Kit 3853. The content of Kit 3853 is given in Table 5-1, and a procedure for changing the foil is given below the table.

NOTE! If you use a foil from a different batch, new calibration coefficients must be entered. If not, the sensor will be inaccurate and there is no way of post compensating your data.

Table 5-1 Contents of Sensor Foil Kit 3853

Part no.	Pieces	Description
962203	2	Sensing Foil packed in aluminium foil
642710	2	Hex countersink screw 3 x 6mm Din 7991 A4
913015	1	2mm Hex Key
Form No. 621	Calibration Sheet for Sensing Foil (each batch of foils is calibrated)	

Procedure for changing the sensor foil:

- ☐ The Sensor Foil is changed by unscrewing the 2 hex screws in the securing plate, ref Figure A 7.
- ☐ Remove the securing plate and the old foil.
- ☐ Clean the window and place the new foil with the black side outwards.
- ☐ Square the foil in the window and remount the securing plate.
- ☐ Control and if necessary update the sensing foil coefficients according to the foil certificate, refer next chapter or Technical Note TN 275.
- ☐ Recalibrate the sensor.

Calibration

If the sensor foil has not been removed or changed recalibration is normally not necessary. Feedback from our users shows that the sensors (and foils) are stable for one to several years.

The easiest and fastest way for a user to calibrate the Oxygen Optode is to use OxyView Software, refer page 24. OxyView is a window based Software containing a wizard, which guides the user step by step through the calibration procedure.

The present chapter describes how to perform the calibration procedure without using OxyView. A calibration primer which presents equations used by the oxygen sensor is given in Appendix 6.

Losing power during the flashing process can cause corruption of vital settings, such as coefficients, serial number, model number etc. If losing power, contact Aanderaa Instruments for new setting file for the specific optode with further instructions.

NOTE!

Flashing is carried out when running the Do_CalAir, DO_CalZero and Do_Calibrate commands.

When opening the Optode 3930 to access the RS232 signal, the adaptor part of the optode can not longer be exposed to liquid.

Calibration Procedure using a terminal program

- 1) Prepare a suitable container with fresh water. Aerate (apply bubbling) the water using an ordinary aquarium pump together with an airstone, and let the temperature stabilize (might take hours).
- 2) Prepare a zero oxygen solution by dissolving 5 grams of sodium sulfite (Na_2SO_3) in 500 ml of water. Other substances that removes oxygen can also be used.

NOTE! Stripping of the oxygen with e.g. N_2 gas is also possible, but not recommended, since it is uncertain when an absolute zero Oxygen level is reached using this method.

- 3) Connect the sensor to a PC by use of the Sensor Cable 3855 (refer Figure A 12). Start a terminal program, i.e. the HyperTerminal by Hilgraeve Inc (included in Microsoft operating systems), with the following set-up:
 - 9600 Baud
 - 8 Data bits
 - 1 Stop bit
 - No Parity
 - Xon/Xoff Handshake

NOTE! Select one of the options 'Sent line ends with line feeds' or 'Echo line ends with line feeds' in the Hyper Terminal.

Control, and if necessary update, the C0Coef, C1Coef, C2Coef, C3Coef and C4Coef properties accordingly to the Calibration Certificate for the sensing foil in use (refer CHAPTER 3 for communication with the sensor).

Example of changing foil coefficients:

```
Set_Protect(1)
```

```
Set_FoilNo(1403)
```

```
Set_C0Coef(3.95439E+03,-1.38606E+02,2.98835E+00,-2.73775E-02)
```

```
Set_C1Coef(-2.46937E+02,7.58489E+00,-1.62433E-01,1.50790E-03)
```

```
Set_C2Coef(6.32108E+00,-1.67391E-01,3.64539E-03,-3.50274E-05)
Set_C3Coef(-7.61504E-02,1.72586E-03,-3.95623E-05,4.02602E-07)
Set_C4Coef(3.52769E-04,-6.78062E-06,1.70524E-07,-1.86920E-09)
Save
```

Type Get_All to verify the new coefficients.

- 4) Submerge the optode into the aerated water. Set the *Interval* property to e.g. 30 seconds. Enter the *Save* command and wait until both the temperature and the phase measurements have stabilized:

```
Set_Protect(1)
Set_Interval(30)
Save
```

- 5) Store calibration values by typing:

```
Set_Protect(1)
Do_CalAir
```

The *save* command is automatically performed when you type *Do_CalAir*.

- 6) Set the *CalAirPressure* property to the actual air pressure in hPa¹ at the site.

```
Set_Protect(1)
Set_CalAirPressure(..)
Save
```

NOTE! For maximum accuracy do not compensate the air pressure for height above sea level.

- 7) Submerge the optode in the zero solution. Make sure that the sensing foil is free from air bubbles. Wait until both the temperature and the phase measurements have stabilized.
- 8) Enter the *Do_CalZero* command to store calibration values. The *save* command is automatically performed.

```
Set_Protect(1)
Do_CalZero
```

- 9) Enter the *Do_Calibrate* command to effectuate the new calibration. The *save* command is automatically performed.

```
Set_Protect(1)
Do_Calibrate
```

- 10) Check that the sensor is working properly by taking it up into the air and rinse off. In dry air, the sensor should show close to 100% oxygen saturation at sea level. Put the sensor back into the anoxic water; the reading should drop to zero.

¹ Conversion between hPa and other units depends on the temperature. Examples of conversion factors at 15.56°C: 1 mm/hg $\approx$ 1.329 hPa, 1 inch/hg $\approx$ 33.768 hPa, 1 mbar = 1 hPa

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Appendix 1 Theory of Operation

The Oxygen Optode is based on a principle called dynamic luminescence quenching.

This phenomenon is the ability of certain molecules to influence the fluorescence of other molecules.

Fluorescence is the ability of a molecule to absorb light of a certain energy and later emit light with lower energy (longer wave length).

Such a molecule, called a luminophore, will after absorbing a photon with high enough energy, enter an excited state.

After a while the luminophore will emit a photon of lower energy and return to its initial state.

Some types of luminophores might also return to the initial state when colliding with certain other molecules.

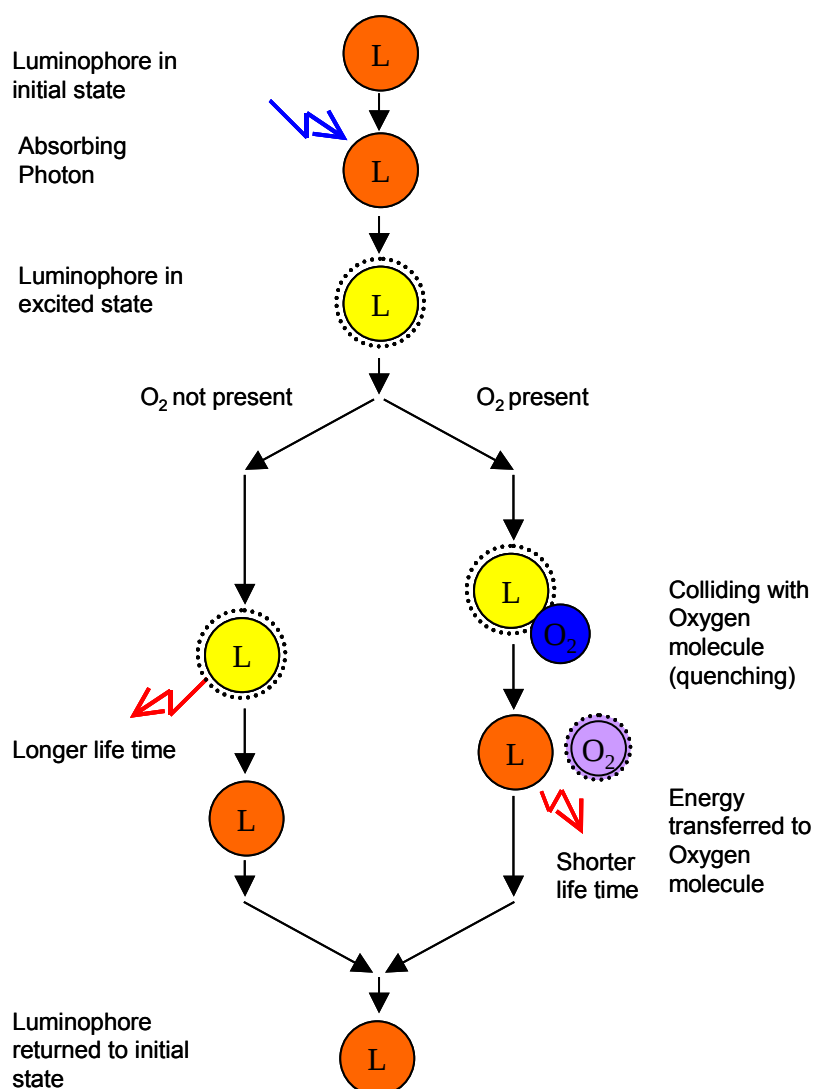


Figure A 1 Dynamic Luminescence Quenching

The luminophore will then transfer parts of its excitation energy to the colliding molecule, with the result that less photons (giving a shorter life time) are emitted from the luminophore.

This effect is called dynamic luminescence quenching, and in the Oxygen Optode the colliding molecules are O_2 .

The luminophore used in the Oxygen Optode is a special molecule called platinum porphyrine. These luminophores are embedded in a polymer layer, called the indicator

layer (coated on a thin film of polyester support).

To avoid potential influence from fluorescent material surrounding the sensor or direct incoming sunlight when measuring in the photic zone, the foil is also equipped with gas permeable coating.

The coating gives optical isolation between the indicator layer and the surroundings.

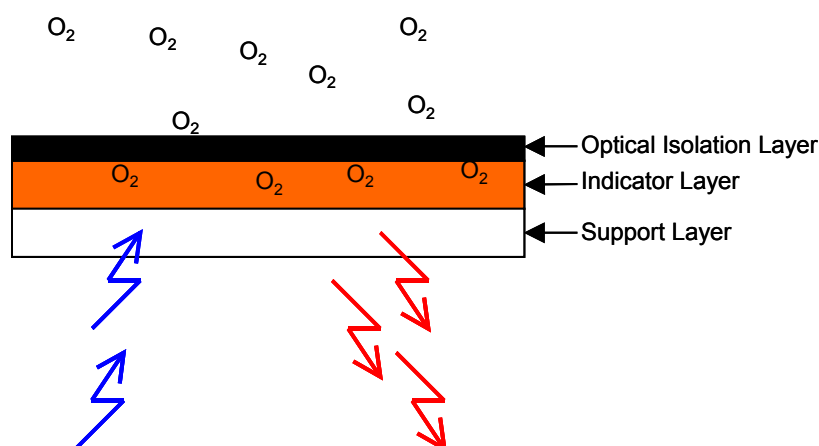


Figure A 2 Sensing Foil

Luminescence Decay Time

Due to its fluorescent behaviour the sensing foil will return a red light when it is excited with a blue-green light (505 nm). If there is O_2 present this fluorescent effect will be quenched.

The amount of returned light will therefore depend on the O_2 -concentration in the foil.

The intensity of the returned light is however not the optimal property to measure since it depends on many

other factors as i.e. optical coupling or bleaching of the foil.

Since the returned light is delayed with respect to the excitation light, the presence of O_2 will also influence the delay.

This property is called luminescence decay time (or lifetime) and it will decrease with increasing O_2 -concentrations.

The relationship between the O₂-concentration and the luminescence decay time can be described by the Stern-Volmer equation:

$$[O_2] = \frac{1}{K_{SV}} \left\{ \frac{\tau_0}{\tau} - 1 \right\}$$

where:

τ = decay time

τ_0 = decay time in the absence of O₂

K_{SV} = Stern-Volmer constant (the quenching efficiency)

In order to measure this luminescence decay time, the sensing foil is excited

with a blue-green light modulated at 5 kHz.

The decay time is a function of the phase of the received signal.

In the Oxygen Optode the relationship between the phase and the O₂-concentration is used directly, without calculating the decay time.

Figure A 3 shows a typical relationship between the phase measurement and O₂-concentration.

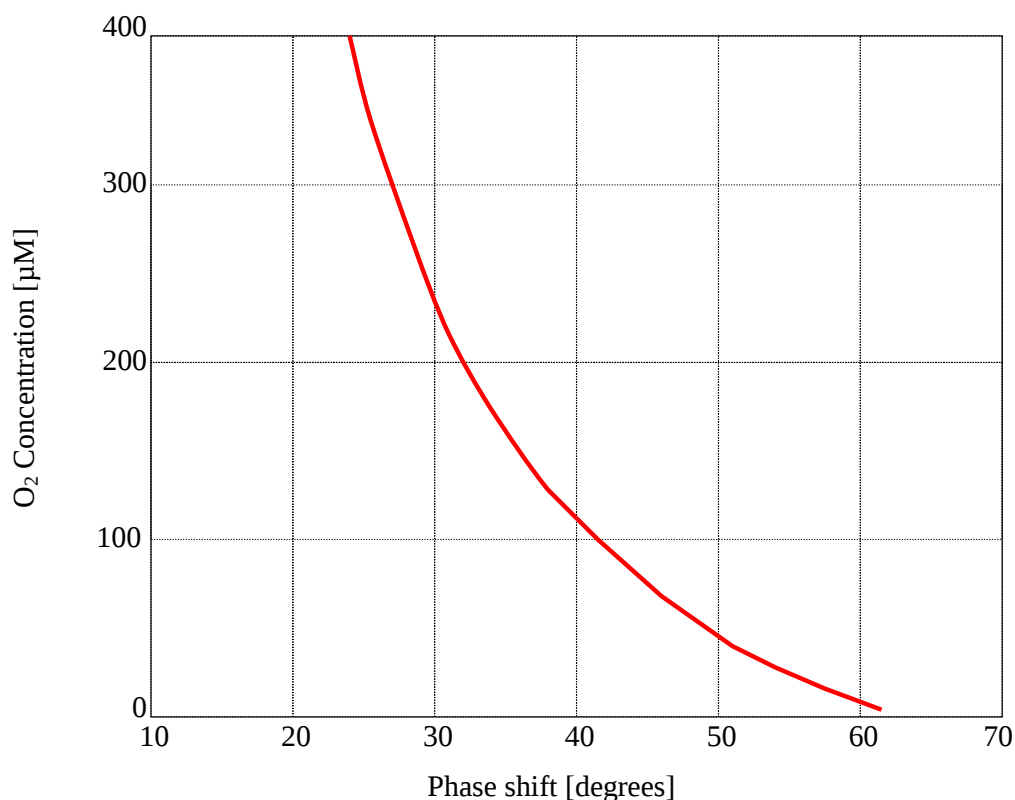


Figure A 3 Typical Phase/O₂ response

Appendix 2 The Optical Design

An illustration of the optical design is given in Figure A 4.

The sensing foil is mounted outside the optical window and is exposed to the surrounding water. The foil is held in place by a screw fixed PVC plate.

Two light emitting diodes (LEDs) and one photodiode is placed on the inside of the window. A blue-green LED is used for excitation of the foil. The photodiode is used for sensing the fluorescent light.

Even though the sensing foil is highly fluorescent part of the light will be directly reflected.

The photo diode is equipped with a colour filter that stops light with short wavelengths to minimize the influence of the reflected light. Further, the blue-green LED is equipped with a filter that stops light with long wavelengths.

In addition, a red 'reference' LED was included to compensate for potential drift in the electronics of the transmitter and receiver circuit.

As of today the red LED does not improve the sensor characteristics and is consequently not connected.

The spectral response of the LEDs and the filter are illustrated in Figure A 5.

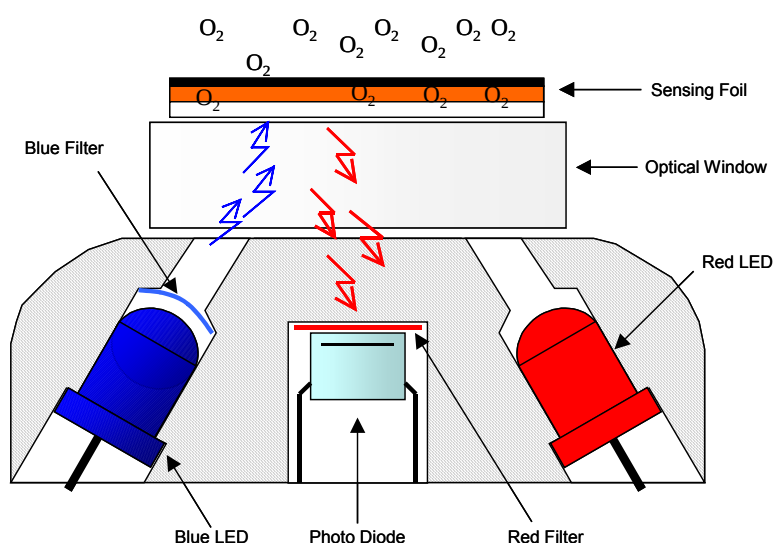


Figure A 4 The Optical Design

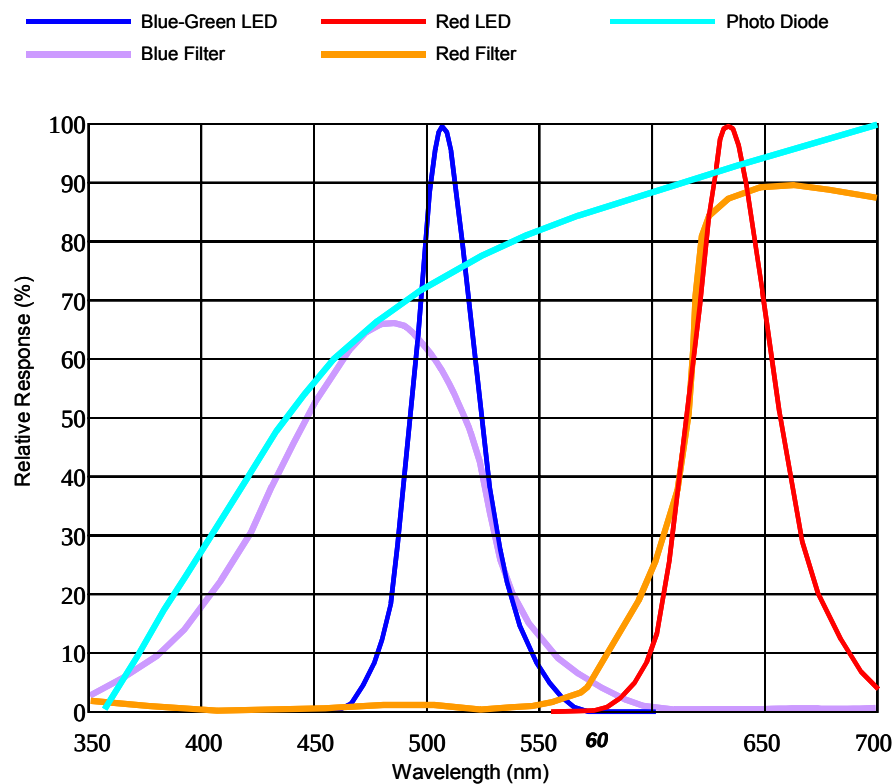


Figure A 5 An example of the Spectral Response

Appendix 3 Electronic Design

Figure A 6 illustrates the main functions of the electronics.

To obtain good oxygen measurements the electronic circuit must be able to measure the phase between the

excitation signal and the received signal accurately and with good resolution.

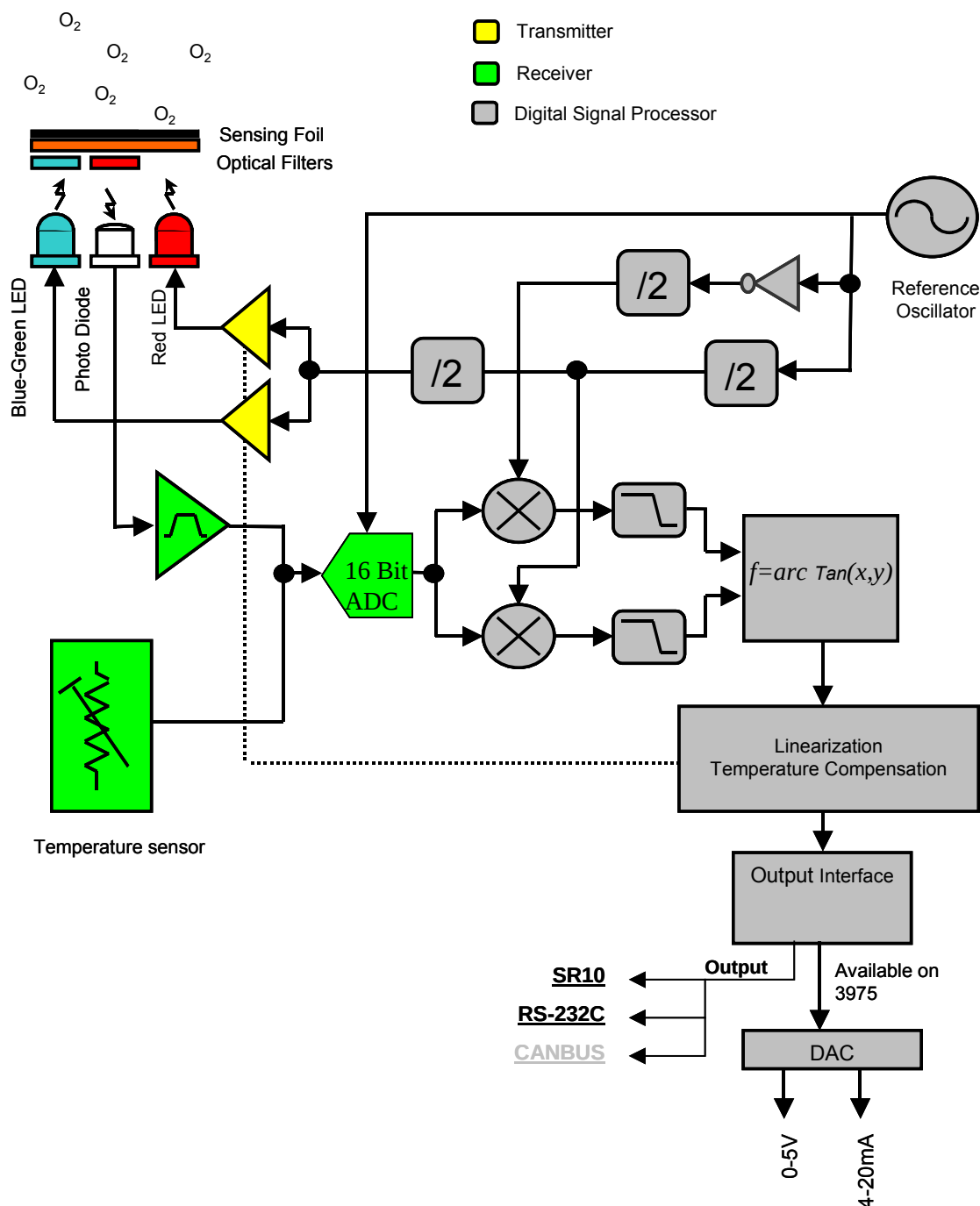


Figure A 6 Functional Diagram

The received signal is sampled with a frequency of four times the excitation frequency. Two signal components with a phase difference of 90 degrees are extracted from these samples and is used for calculations of the phase of the received signal.

The O₂-concentration is calculated after linearizing and temperature compensating the phase measurements.

A thermistor thermally connected to the sensor body, provides the temperature measurement.

Appendix 4 Mechanical Design

Refer Figure A 7 and Figure A 8 for illustration of the Oxygen Optode.

A cylindrical titanium housing shields the electronics from the surrounding water and high pressure.

A 4mm thick sapphire window provides the optical connection between the optics inside the optode and the sensing foil on the outside.

The foil is fixed to the window by a securing plate in PVC and is easily replaceable.

A 10-pin receptacle in the sensor foot provides all electrical connection to the sensor.

To prevent potential leakage from the sensor to the rest of the measurement system, the receptacle is first moulded inside a receptacle housing.

Refer CHAPTER 5 for instructions concerning changing the Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing can breach the warranty (ref. CHAPTER 5, page 32 for instructions on how to change the Sensing Foil).

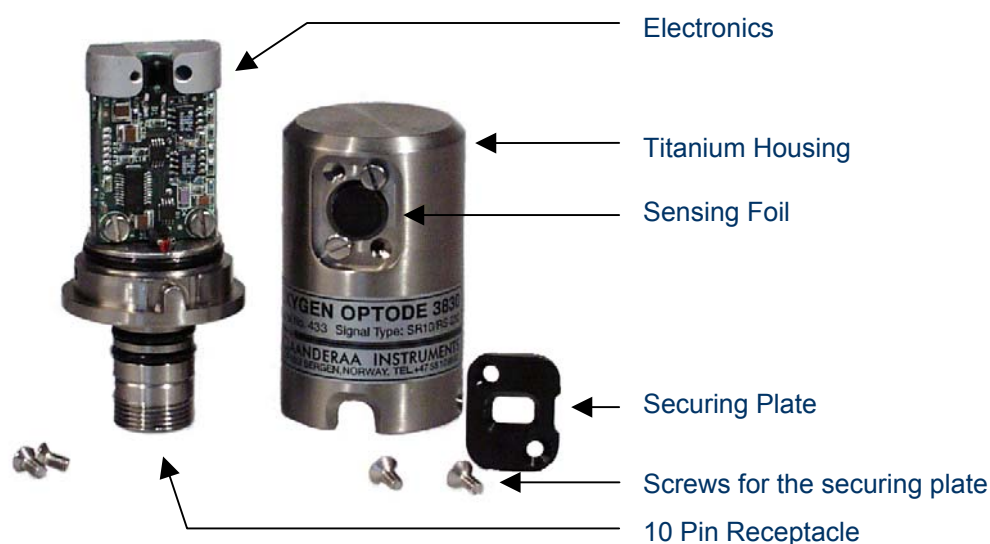


Figure A 7 Oxygen Optode components.

NOTE! The sensor housing should not be opened.

Electrical Connections

Refer Figure A 12 for illustration of cables.

The 10-pin receptacle in the sensor foot mates with an Aanderaa 3216A plug on the top end plate of Aanderaa Current Meters/Profilers (RCM 9 MkII, RCM 11 and RDCP600). Use Sensor

Cable 3854 between the top-end plate and the electronic board.

For connection between the optode and a PC the 1.5 meter Sensor Cable 3855 can be used. This cable has a watertight 10-pin plug to be connected to the sensor, and a 9 pin D-Sub plug

to be connected to the PC serial port (RS232).

The additional USB plug is used for providing power to the sensor (the USB port normally gives 5V power).

Power may alternatively be connected to an included extension to the USB plug (5-14V).

NOTE! By using a Cable Coupler 3472 and a standard Connecting Cable

3282 this connection can be extended up to 15 meters.

Maximum cable length for RS232 communication is 15 meters.

Maximum cable length for SR10 output is 400 meters.

The optodes pin configuration are given in Table A 1.

Table A 1 Pin Configuration

3830	3930	3975
1: Positive Supply ^{A), B)}	1: System Ground	1: Positive Supply
2: Ground ^{C)}	2: <i>Not Connected</i>	2: Ground
3: -9V ^{D)}	3: -9V	3: Analogue Output 1
4: Reserved, <i>Do Not Connect</i>	4: <i>Not Connected</i>	4: Return Ground 1
5: Bridge Voltage (BV)	5: Bridge Voltage (BV)	5: Analogue Output 2
6: Reserved, <i>Do Not Connect</i>	6: SR10 (Oxygen)	6: Return Ground 2
7: RXD (RS232)	7: <i>Not Connected</i>	7: RXD
8: TXD (RS232)	8: <i>Not Connected</i>	8: TXD
9: Control Voltage	9: Control Voltage	9: <i>Not Connected</i>
10: SR10 (Oxygen)	10: VR22 (Temperature)	10: <i>Not Connected</i>

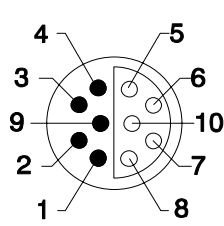
A) Ground for SR10

B) Supply for RS232

C) Ground for RS232

D) Supply for SR10

Receptacle, exterior view; pin = ● , bushing = ○



Appendix 5 Optode Specifications

Oxygen Optode 3830

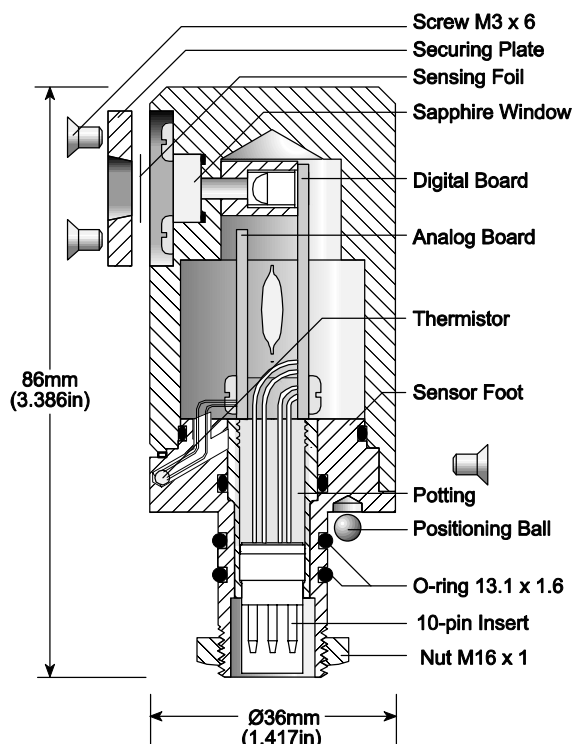


Figure A 8 Illustration of the Oxygen Optode 3830

Table A 2 Specifications for the Oxygen Optode 3830

	Channel1 Oxygen	
	O ₂ -Concentration	Air saturation
Measuring Range	0-500 μM ¹	0 – 120%
Resolution	< 1 μM	0.4%
Accuracy	< 8 μM or 5% ² whichever is greater	< 5% ²
Settling time (63%)	< 25 sec	
	Channel2 Temperature	
Range	0 to +36°C	
Resolution	0.01°C	
Accuracy	±0.05°C	
Settling time	<25 sec	
	General specifications	
Operating Temperature	0 to +40°C (32 to 104°F)	
Operating Depth	0 – 6000m (19,690 ft)	
Output Formats	Aanderaa SR10, RS232 ³	
Sampling rate	SR10: SR10 Controlled by the datalogger. RS232: From 1s to 255min	
Current Consumption	SR10: 10mA/T where T is recording interval in min RS232: 80mA/s +0.3mA where s is recording interval in sec	
Supply Voltage	SR10: -6 to –14 Vdc RS232: +5 to +14Vdc	
Dimensions	Ø36x86mm (Ø1.42x3.386in)	
Weight	230g (8.113oz)	
Materials	Titanium, Hostaform (POM)	
Warranty	Two years against faulty material and workmanship	
Accessories	Sensor Cable 3854	
Accessories not included	Sensor Cable 3855 to PC ⁴ Foil Service Kit 3853 PST ₃	

¹ O₂-Concentration in μM = $\mu\text{mol/l}$. To obtain mg/l, divide by 31.25

² Valid with pressure and salinity compensations, ref CHAPTER 4.

³ Terminal settings: 9600 Baud, 8 data bits, 1 stop bit, No Parity, Xon/Xoff Handshake

⁴ In order to change settings or calibrating the Optode the sensor must be connected to a PC, ref CHAPTER 3

Oxygen Optode 3930

The Oxygen/Temperature Optode 3930 consist of an Adaptor 3714 mounted to an Optode 3830. Refer Figure A 8 for illustration of the Oxygen Optode 3830. An illustration of the Adaptor 3714 is given in Figure A 9.

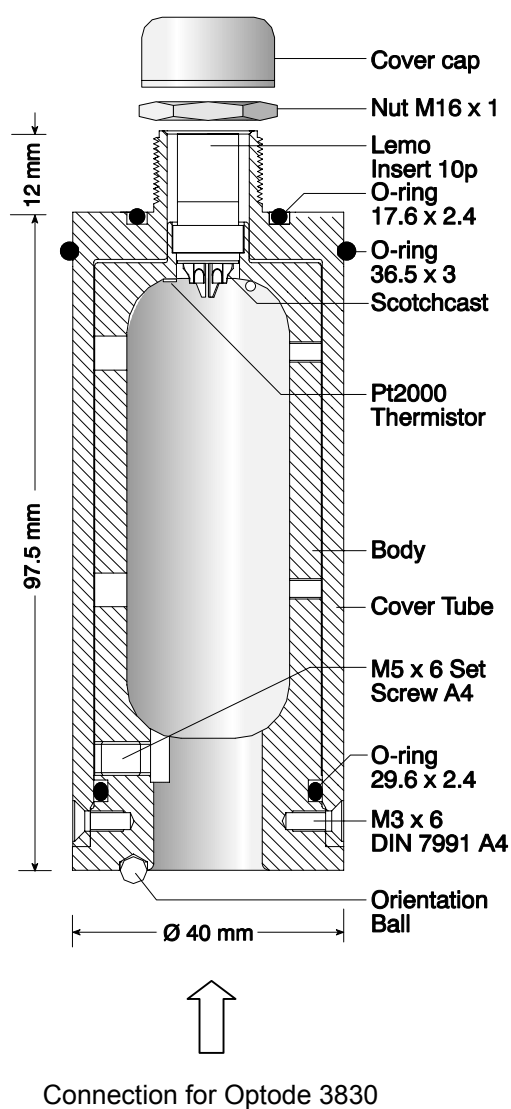


Table A 3 Specifications for the Oxygen/Temperature Optode 3930

	Channel1 Oxygen	
	O ₂ -Concentration	Air saturation
Measuring Range	0-500 µM ¹	0 – 120%
Resolution	< 1 µM	0.4%
Accuracy	< 8 µM or 5% ² whichever is greater	< 5% ²
Settling time (63%)	< 25 sec	
	Channel2 Temperature	
	Range	-7.5 to +41°C
	Resolution	0.05°C
	Accuracy	±0.1°C
	Settling time	30 sec
	General specifications	
	Operating Temperature	0 to +40°C (32 to 104°F)
	Operating Depth	0 – 1000m (19,690 ft)
	Output Formats	Aanderaa SR10 ³ (Oxygen), VR22 ³ (Temperature)
	Sampling rate	Controlled by the datalogger
	Current Consumption	10mA/T where T is recording interval in min
	Supply Voltage	SR10: -6 to -14 Vdc
	Dimensions	Ø40x168mm (OD1.575x6.61in)
	Weight	495g (17.5oz)
	Materials	Titanium, Hostaform (POM)
	Warranty	Two years against faulty material and workmanship
	Accessories not included	Sensor Cable 3855 to PC ⁴ Foil Service Kit 3853 PST ₃

Figure A 9 Illustration of Adaptor 3714

¹ O₂-Concentration in µM = µmol/l. To obtain mg/l, divide by 31.25

² Valid with pressure and salinity compensations, ref CHAPTER 4.

³ Aanderaa SR10/VR22 are signals protocols that are used with Aanderaa equipment only

⁴ In order to change settings or calibrating the Optode the sensor must be connected to a PC, ref CHAPTER 3

Oxygen Optode 3975

The Oxygen Optode 3975 consist of an Adaptor 3966 mounted to an Optode 3830. Refer Figure A 8 for illustration of the Oxygen Optode 3830. An illustration of the Adaptor 3966 is given in Figure A 10.

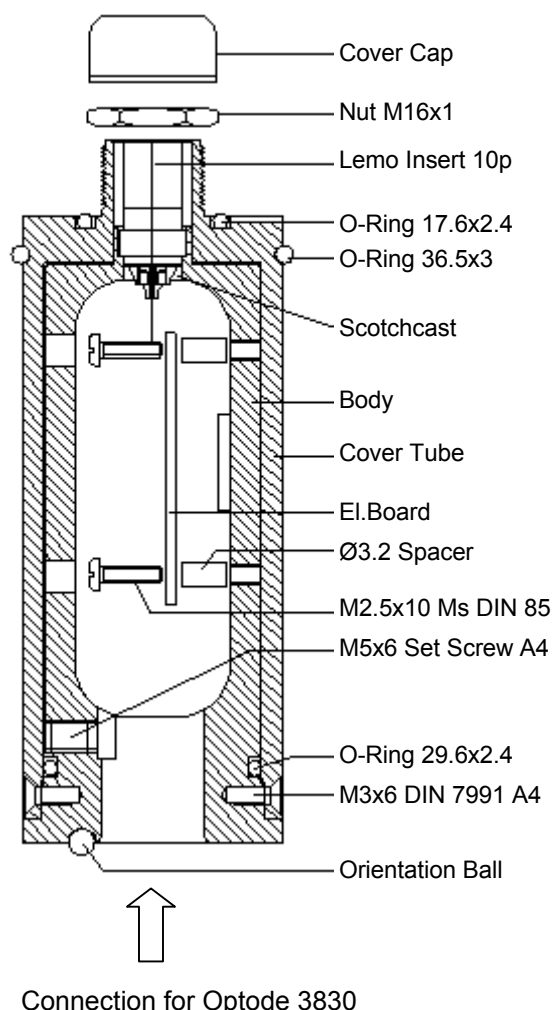


Figure A 10 Illustration of Adaptor 3966

Table A 4 Specifications for the Oxygen Optode 3975

	Channel1 Oxygen	
	O ₂ -Concentration	Air saturation
Measuring Range	0-500 μM ¹	0 – 120%
Resolution	< 1 μM	0.4%
Accuracy	< 8 μM or 5% ² whichever is greater	< 5% ²
Settling time (63%)	< 25 sec	
	Channel2 Temperature	
Range	0 to +36°C	
Resolution	0.01°C (0-5V) / 0.02°C (4-20mA)	
Accuracy	± 0.1°C (0-5V) / ± 0.15°C (4-20mA)	
Settling time	30 sec	
	General specifications	
Operating Temperature	0 to +40°C (32 to 104°F)	
Operating Depth	0 – 6000m (19,690 ft)	
Output Formats	0-5V output: ± 0.1% of FS ³ 4-20mA output: ± 0.2% of FS ³ RS232 ⁴	
Sampling rate	From 1s to 255min	
Current Consumption	80mA/s +0.3mA + I _a where s is recording interval in sec and I _a is quiescent: 5 to 45mA when analogue adaptor is enabled	
Supply Voltage	Analogue: -6 to –14 Vdc RS232: +5 to +14Vdc	
Dimensions	Ø40x175.5mm (Ø1.42x6.9in)	
Weight	480g (16.93oz)	
Materials	Titanium, Hostaform (POM)	
Warranty	Two years against faulty material and workmanship	
Accessories not included	Sensor Cable 3855 to PC ⁵ Foil Service Kit 3853 PST ₃	

¹ O₂-Concentration in µM = µmol/l. To obtain mg/l, divide by 31.25

² Valid with pressure and salinity compensations, ref CHAPTER 4.

³ The accuracy in 0-5V output mode is specified to 0.1% of FS. At the end of the scale (<0.0-0.07> and <4.93-5.0>) the error may be larger

⁴ Terminal settings: 9600 Baud, 8 data bits, 1 stop bit, No Parity, Xon/Xoff Handshake

⁵ In order to change settings or calibrating the Optode the sensor must be connected to a PC, ref CHAPTER 3

Appendix 6 Calibration Procedure-Primer

Each batch of sensing foils is delivered with calibration data describing the behaviour with respect to oxygen concentration and temperature. When changing the sensing foil the following 20 coefficients must be updated:

$C0Coef_{0..3}$

$C1Coef_{0..3}$

$C2Coef_{0..3}$

$C3Coef_{0..3}$

$C4Coef_{0..3}$

These coefficients are found in the Calibration Certificate for the Sensing Foil 3853, refer enclosed documentation. Refer page 32 for changing foil coefficients.

If the sensor foil has been changed or removed, the phase measurement of individual sensors should be calibrated, using the *PhaseCoef* property, in addition to the above mentioned coefficient update. The *PhaseCoef* property contains coefficients for a 3rd-degree polynomial used prior to the modified Stern-Volmer equation, refer CHAPTER 5. A two-point calibration is sufficient.

NOTE! In order to ease this calibration procedure, the following calculation is performed inside the sensor. If you have OxyView available, these steps are automatically performed in the calibration wizard (refer CHAPTER 3).

Two controlled oxygen concentrations are relatively easy to obtain, one in air saturated water, and one in a zero-oxygen solution.

An air-saturated solution is obtained by inserting freshwater in a glass and bubble it with a standard aquarium pump. For a more efficient bubbling it is recommended to use a bubble dispenser. The water should be allowed to achieve temperature

stability for at least 1 hour. We recommend the zero oxygen solution to be obtained by preparing another glass of the same water (as for air saturation) and dissolving 5g of sodium sulfite (Na_2SO_3) in 500ml water.

When measuring in vapour-saturated air the sensor will respond equal to measuring in air-saturated fresh water. The O_2 -concentration will in this case be given by the following equation:

$$[O_2] = \left(\frac{p - p_v(t)}{1013} \right) \cdot \frac{100 \cdot R_{O_2}}{V_m} \cdot \alpha(t)$$

where:

p = atmospheric pressure in hPa

t = temperature, °C

$p_v(t)$ = vapour pressure in hPa

$$\approx e^{\left(52.5 - \frac{6690.9}{t+273.15} - 4.681 \cdot \ln(t+273.15) \right)}$$

α = Bunsen absorption coefficient

$$\approx 48.998 - 1.335t + 2.755 \cdot 10^{-2}t^2 - 3.22 \cdot 10^{-4}t^3 + 1.598 \cdot 10^{-6}t^4$$

$R_{O_2} = 20.95\%$ = volume percentage of O_2

$V_m = 22.414$ l/mol = molar volume of O_2

Solving for the square roots in the equation for $[O_2]$ and $[O]$ gives the ideal phase measurement at zero and 100% oxygen:

$$[O_2]_{100} = C_0 + C_1 P_{C1} + C_2 P_{C1}^2 + C_3 P_{C1}^3 + C_4 P_{C1}^4$$

$$[O_2]_0 = C_0 + C_1 P_{C0} + C_2 P_{C0}^2 + C_3 P_{C0}^3 + C_4 P_{C0}^4$$

where:

P_{C1} = compensated phase in air saturated water

P_{c0} = compensated phase at zero
oxygen

f_1, f_2 = temperature independent
coefficients, f_1 and f_2 property

$[O_2]$ = oxygen concentration in air
saturated water

$C_0, \dots, C_4$ are temperature dependent coefficients calculated from:

$$C_n = A + B \cdot t + C \cdot t^2 + D \cdot t^3$$

where t = the temperature, °C

The A, B, C, D coefficients are stored respectively in the $C0Coef_{0-3}$ to $C1Coef_{0-3}$ property.

The first two coefficients of the *PhaseCoef* (A and B) can be calculated by ordinary linear curve fitting:

$$B = \frac{P_{c1} - P_{c0}}{P_1 - P_0} \quad A = P_{c0} - \left(\frac{P_{c1} - P_{c0}}{P_1 - P_0} \right) P_0$$

where:

P_0 = uncompensated phase measurement calibration at zero oxygen

P_{c0} = compensated phase measurement calibration at zero oxygen

P_1 = uncompensated phase measurement calibration in air

P_{c1} = compensated phase measurement calibration in air

The *Do_Calibrate* command starts a function that calculates and stores the above coefficients based on the following properties:

<i>CalAirPhase</i> :	Uncompensated phase measurement at calibration point in air bubble solution.
<i>CalAirTemp</i> :	Temperature measurement in °C at calibration point in air bubble solution.
<i>CalAirPressure</i> :	Air pressure in hPa at calibration point.
<i>CalZeroPhase</i> :	Uncompensated phase measurement at calibration point in zero solution.
<i>CalZeroTemp</i> :	Temperature measurement in °C at calibration point in zero solution.

These properties may be entered manually or by use of the *Do_AirCal* and the *Do_ZeroCal* commands.

When the readings have stabilized in air the *Do_AirCal* command can be entered to sample and store values in the *CalAirTemp* and *CalAirPressure* property.

Likewise, the *Do_ZeroCal* command is used for sampling and storing value to the *CalZeroPhase* and *CalZeroTemp* property after stabilization in the zero solution.

A subsequent execution of the *Do_Calibrate* command effectuates a new calibration.

Appendix 7 Improve accuracy of the Oxygen Optode 3975 (1 – 4 V)

Introduction:

A digital to analogue adaptor will induce a slightly poorer accuracy. Before a sensor outputs a digital value, the output value is modified by the following equation:

$$D_{out} = a_0 + a_1 D$$

where D_{out} is the digital value set out by the sensor, D is the digital value calculated e.g. on the basis of the current temperature measurement and a_0 , a_1 are coefficients. As default, $a_0 = 0.0$ and $a_1 = 1.0$, so that $D_{out} = D$.

By measuring the zero-code-error and the gain-error, new coefficients can be calculated and higher accuracy than $\pm 0.1\%$ of FS can be obtained. The coefficients are modified by means of the `Set_AnCoef( $a_0$ ,  $a_1$ )` command.

NOTE! Most user will find the accuracy in the 3975 optode satisfactory.

Illustration:

The solid line in Figure A 11 shows the output from an ideal Digital to Analogue Converter (DAC); if the digital input is zero, the analogue output is also zero and if the digital input is 65536 (for a 16 bits DAC) the analogue output is 5 volt. The dotted line shows the actual output due to zero-code error and gain error.

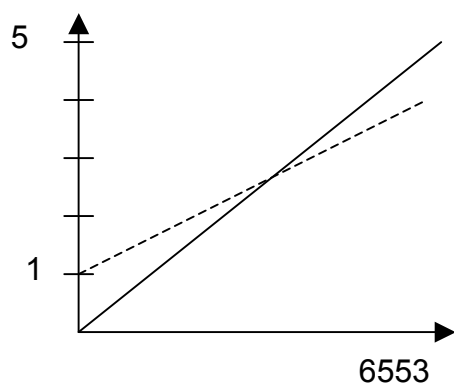


Figure A 11 DAQ output

Procedure:

NOTE! Refer CHAPTER 3 for communication with the sensor before performing this correction!

Connect the Optode to the PC via Hyper Terminal or OxyView Software.

Measure the output signal on Output 1 (connect a Voltmeter over pin 3 and 4) in sensor mode –111 for 1 Volt setting at channel 1. Type:

`Set_Protect(1)`

`Set_Output(-111)`

`Save`

Write down the Voltmeter reading: X_{11} .

Measure the output signal on Output 2 (connect a Voltmeter over pin 5 and 6) in sensor mode –110 for 1 Volt setting at channel 2. Type:

`Set_Protect(1)`

`Set_Output(-110)`

`Save`

Write down the Voltmeter reading, X_{21} .

Calculate the a_0 coefficient by:

$$a_0 = \left(1.0 - \frac{(X_{11} + X_{21})}{2} \right) \cdot 2^{16}$$

Store a_0 in the oxygen optode by typing:

`Set_Protect(1)`

`Set_AnCoeff( $a_0$ , 1.0)`

`Save`

Repeat this procedure for measurements of X_{11} , X_{12} , X_{22} , X_{21} for 4 V setting at channel 1 and channel 2:

Sensor Mode	Output 1	Output 2
-111	X_{11}	X_{22}
-110	X_{12}	X_{21}

Store the coefficients in the oxygen optode by typing:

Set_Protect(1)

Set_AnCoeff(a₀, a₁)

Save

Calculate the a_1 coefficient by:

$$a_1 = \frac{(4.0 - 1.0)}{\left(\left(\frac{(X_{12} + X_{22})}{2} \right) - \left(\frac{(X_{11} + X_{21})}{2} \right) \right)}$$

Appendix 8 Illustrations

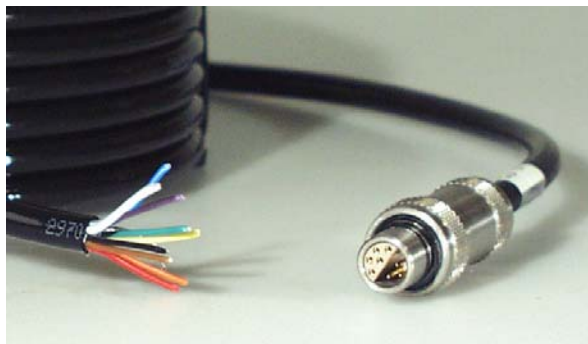
Figure no.	Description
Figure A 12	Illustration of some cables
Figure A 13	Drawing Cable 3854
Figure A 14	Drawing Cable 3855
Figure A 15	Drawing Cable 3296
Figure A 16	Drawing Cable 3485
Figure A 17	Drawing Cable 3976
Figure A 18	Drawing Cable 3980



3296. Connecting cable 10 pin to 6 pin (1000m depth capability).



3854. Connecting cable 10 pin to Cell Plug. Used with Aanderaa Current Meters.



3485. Connecting cable 10 pin to free end (1000m depth capability).



3855. Connecting cable for PC. *NOTE! The connector is made in aluminium and is not recommended for long term use in salt water.*



3976¹. Flange connecting cable 10 pin to free end (6000m depth capability).



3980¹ Flange connecting cable 10 pin to 10 pin (1000m depth capability).

Figure A 12 Illustration of some cables

¹ Used with coupling 3979 for 36mm sensors and coupling 3977 for 40mm sensors.

V-8699

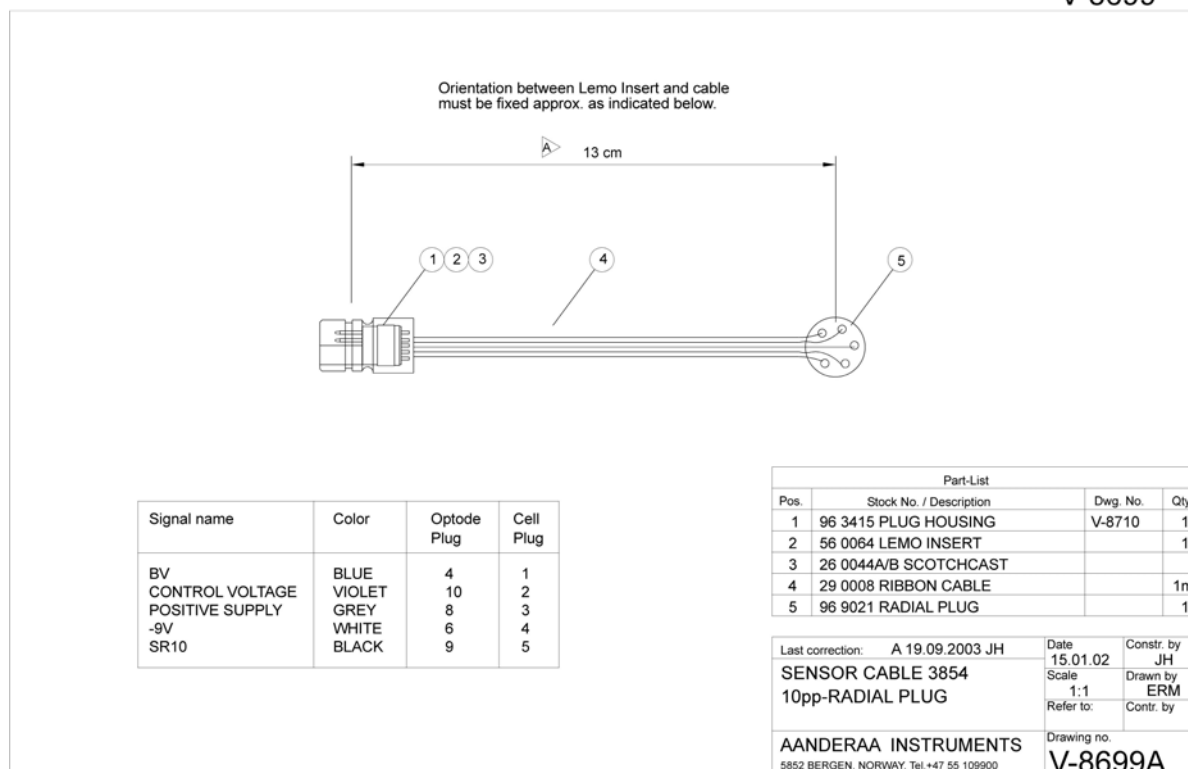


Figure A 13 Drawing Cable 3854

V-8700

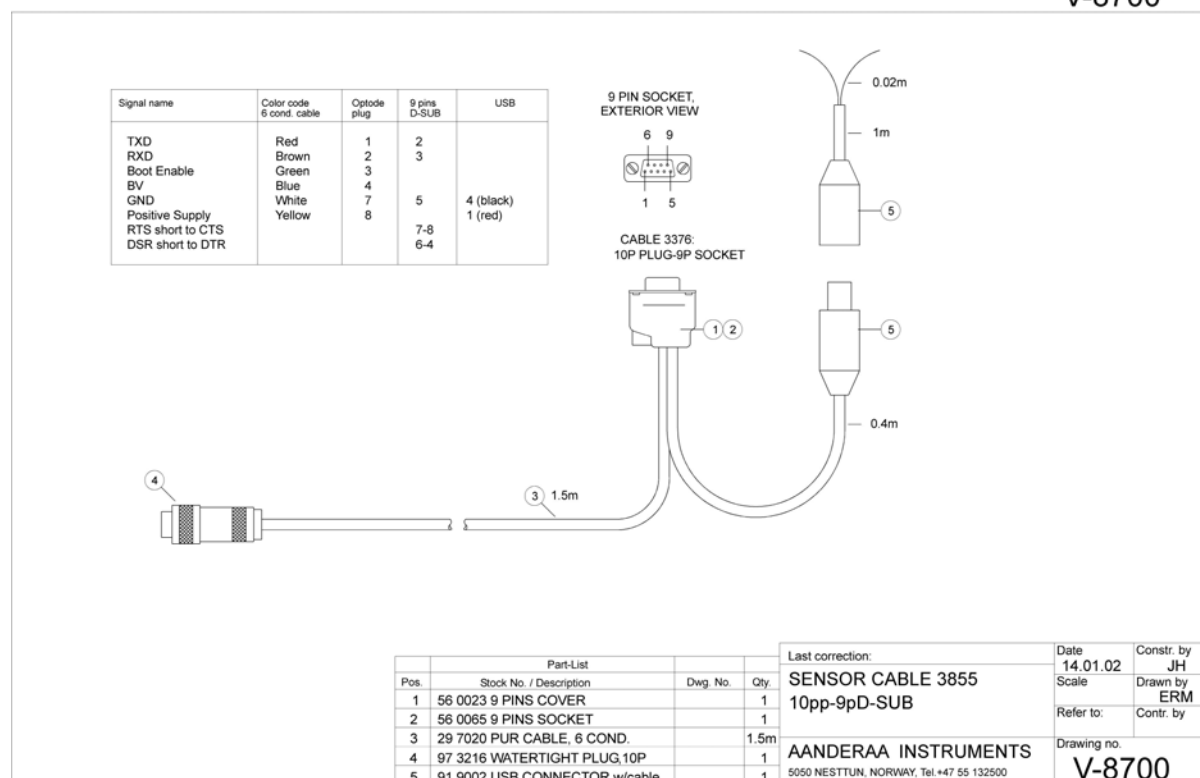


Figure A 14 Drawing Cable 3855

V-6288

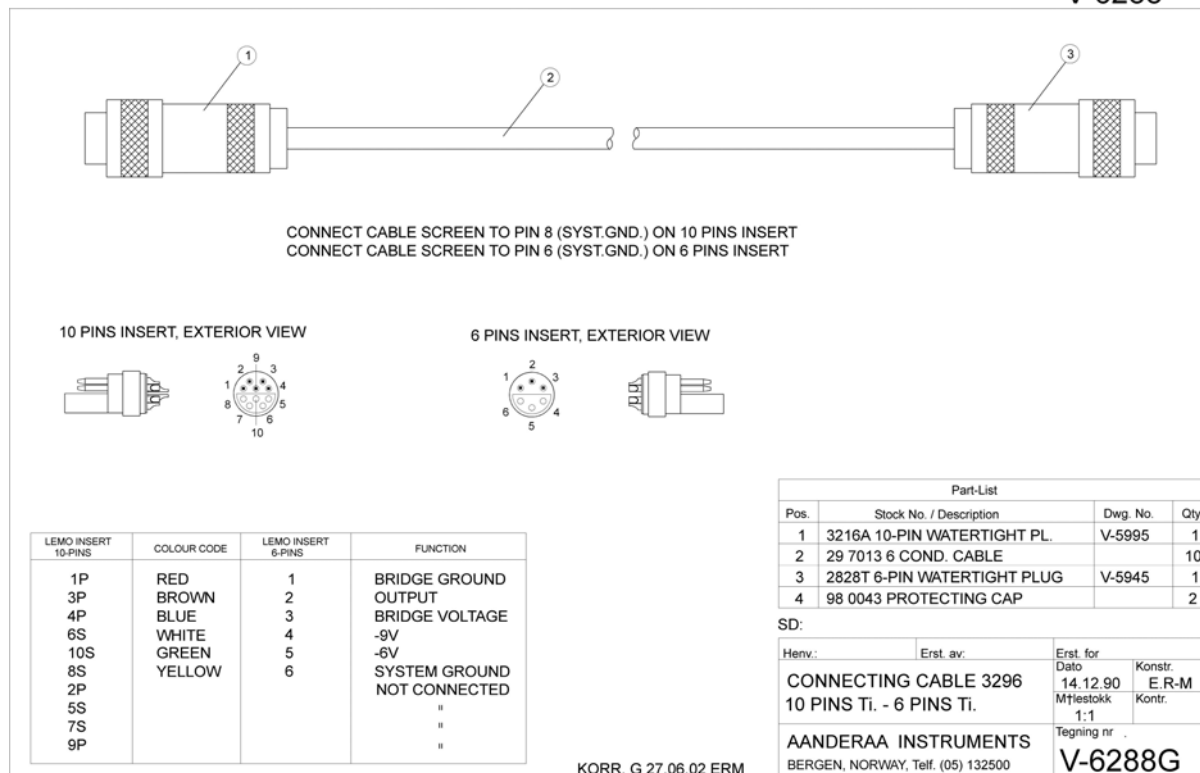


Figure A 15 Drawing Cable 3296

V-6667

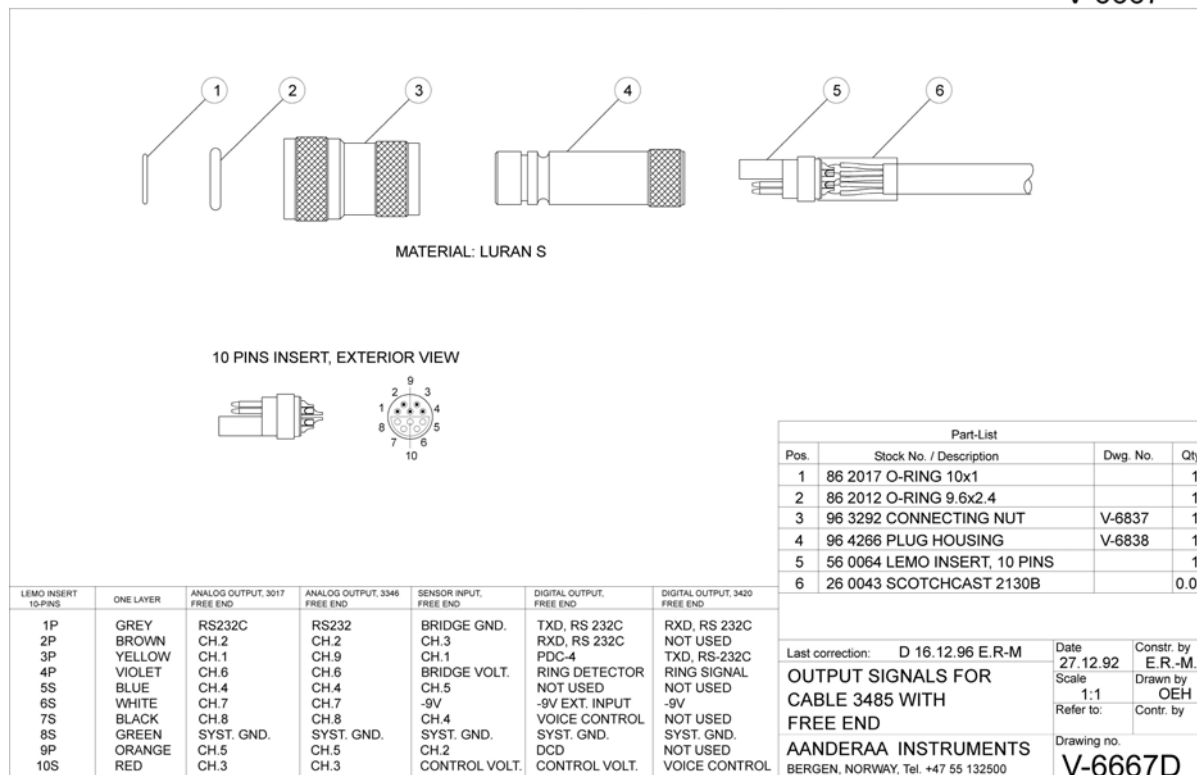


Figure A 16 Drawing Cable 3485

V-9171

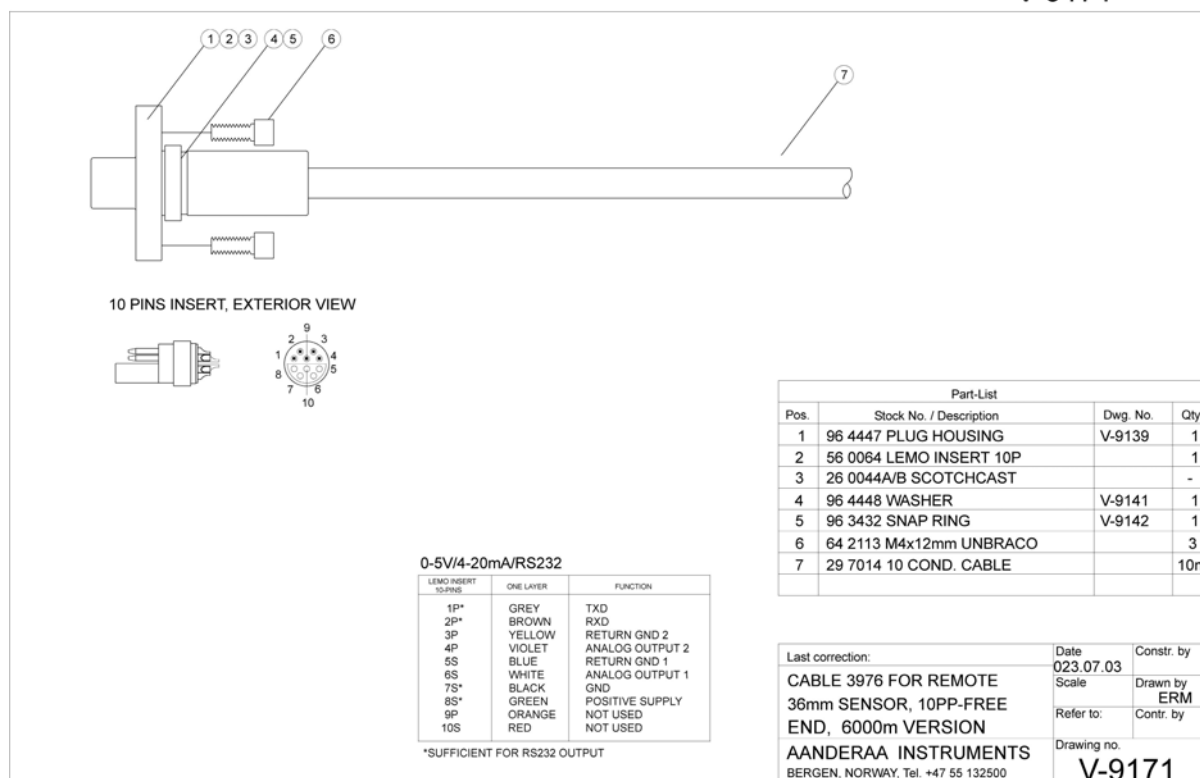


Figure A 17 Drawing Cable 3976

V-9151

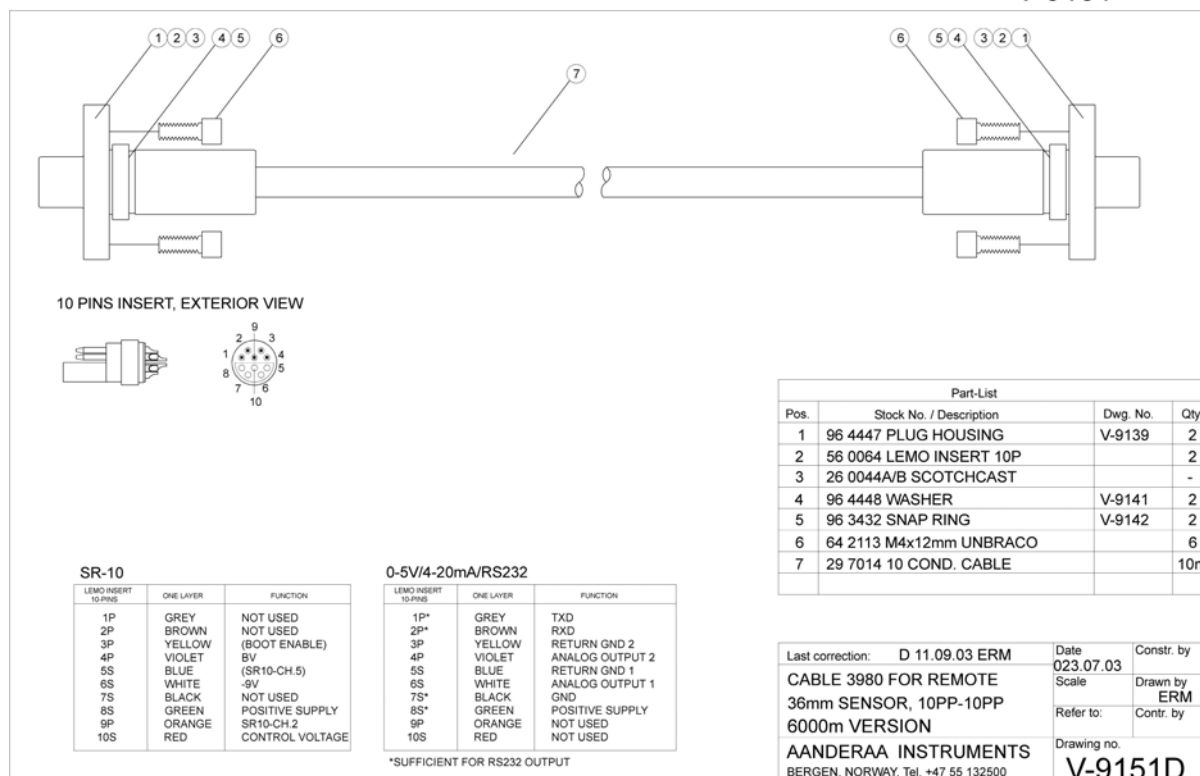


Figure A 18 Drawing Cable 3980

Appendix 9 Frequently Asked Questions -FAQ

In this chapter we present a copy of our FAQ for the optodes. The latest version is on our web site, refer <http://www.aanderaa.com/>

FAQ about Software, Settings and Communication

Q: How do I most easily communicate and use the sensor from my PC? How do I calibrate it and set it up?

A: We recommend to use the OxyView software, which is available for a nominal license fee. This software is more or less self-explanatory and provides utilities, graphic & tabular display for set-up, calibration, logging etc. These functions are easily accessed without deeper knowledge about the sensor. As an alternative you can also communicate with any standard Terminal program (such as HyperTerminal included in Windows or Terra Terminal) but then you will have to read the Operating Manual carefully and every command has to be typed in separately.

Q: Many new PC's do not have a serial port. How can I communicate with the sensor without this?

A: The only way to communicate with the sensor is through the serial port. There are adaptors available that convert from USB to serial port. Experience has shown that these do not always function out of the box and may not be fully compatible with Windows or with your computer's specific software. It is recommended that you download the latest drivers from the Internet site of the manufacturer of the USB/serial adaptor. It has turned out that the drivers delivered with the adaptor are not always up to date.

Q: Which COM port is normally used when I use an USB/serial adaptor.

A: This varies from PC to PC and it has to be found out in the operative system.

Q: Is OxyView required to change the sampling interval? If not, how is it done?

A: No. However, it makes this process simpler. Communication and setting of sample intervals can all be done from a standard terminal program (like HyperTerminal). All this is explained in detail in the Operating Manual.

Q: What is the minimum supply voltage for the sensor?

A: The minimum supply is 5V the maximum is 14V.

Q: What is the peak current consumption for the sensor?

A: Less than 100mA (for 0.5 second).

Q: Is it possible to drive the Rx, Tx signals from the Optode directly by the 0-5V without a transceiver?

A: No, you must use RS232 levels

Q: When logging the sensor in RS232 format what is the minimum of signal lines we have to connect?

A: The minimum is four; TX, RX, Positive Supply and GND. For more information refer the Operating Manual.

Q: If you switch ON / switch OFF the power supply between the data acquisition, do you have to keep a delay time before acquiring some data or after a new switch ON?

A: Yes, the sensor will always do a sample after power up. The data output is after approximately 2 seconds. Approximately 2 seconds power off is needed to assure a new reset of the Optode.

Q: If I have internally set the sensors sample interval to 2 s and then decide to mount it on e.g. an RCM9 current meter, logging at a 1 h sample interval, will there be a conflict between the sensor's internal interval and the one used by the RCM9?

A: No there will not be any conflict. When the Optode is used with an Aanderaa data logger the power is only applied when the data-logger scans the connected sensors (Control Voltage is active). Every time the sensor is powered up, regardless of the internal interval settings, it will output one data reading (requires that the SR10 output is enabled, see Operating Manual for more information). The same happens for the RS232 output. Even if the sensor is set up for long measurement intervals it will output new data every time power is connected. If power is connected continuously the sensor will measure at the internally programmed time interval.

Q: I have connected the Optode to my Aanderaa current meter but no data is delivered from the sensor, why?

A: The Optode output has to be set to -1 or -2 to present data on the SR10 output channel. Please refer to the Operating Manual or the OxyView software for more information on how this is done.

FAQ about Calibration, Calibration Coefficients, Accuracy and Precision

Q: What calibration coefficients are used in the sensor, how can I make sure that I use the correct ones?

A: The sensor has several sets of calibration constants stored in its memory. These can be verified from your PC via the OxyView software or with a terminal communication program. The coefficients are:

1. The internal temperature sensor has its own calibration constants that can not and do not need to be changed by the user.
2. The sensing foil has a set of 20 constants C_0 to C_4 (in a 5 x 4 matrix), which are specific to that batch of foils (normally produced in batches of 100). If you change the foil with a foil from a different batch you must update the foil constants stored in the sensor with a set of new constants by entering them manually into the sensor. These constants are delivered on a calibration certificate together with the new foil.
3. The sensor and the foil has a set of calibration constants (called phase coefficients) that are obtained and automatically stored in the sensor when a two point calibration is performed, using a 100 % air saturated solution and 0 % oxygen solution. When changing or removing the foil a new calibration must be performed to obtain accuracy and precision. The most efficient way to do this calibration is to use the OxyView software.
4. When data from the sensor is registered on an Aanderaa data-logger (e.g. on a RCM9, a buoy etc.) SR10 format is used. These readings then need to be post-processed (converted to the desired engineering units) by multiplying with a constant. This constant is obtained by dividing the range by the 10-bit resolution of the SR10 format. If you have selected to output oxygen concentration in μM in the SR10 format you will have to multiply the obtained data by 0.488281. If you select to output % saturation you will have to multiply with 0.146484.

Q: If I change the foil and forget to update the internal constants but I made a new calibration can I back-calculate to get the correct data?

A: If the foil is from the same batch it will have the same constants and the data should be ok. If the foil is not from the same batch it will not be possible to post-compensate the obtained data. **It is imperative to use the correct foil constants and to do a new two-point calibration if the foil has been changed or moved.**

Q: It appears as if the specifications for accuracy and precision of the sensor are conservative compared to its actual performance, why?

A: After calibration the sensors normally perform considerably better than the given specifications. Aanderaa has a tradition to be conservative when giving sensor specifications so that these reflect the “worst situation” performance in the field.

Q: Can the accuracy of the sensor be further improved?

A: Yes if the individual sensor was calibrated in more calibration points, both with respect to oxygen concentration and temperature compensation of the foil, the accuracy would be improved. However, this means an increase in the production cost and requires the sensor to be sent back to the factory for recalibration if the foil is changed after delivery. Some customers that need particularly high accuracy have established their own calibration procedures.

Q: How often do I need to re-calibrate the sensor?

A: If the foil is not mechanically damaged or moved no recalibrations are needed within the time of one year. We recommend a recalibration once a year but from field experiences we see that the sensor is stable over much longer time periods than this. For investigators that have experience with electrochemical sensors it might be tempting to make frequent foil changes and recalibrations but this is not needed.

Q: The brochure says “accuracy of 8 μ M or 5% (whichever is greater)”. Does this mean that at very low levels the accuracy is 5% of the measurement?

A: No this means that the accuracy is 8 μ M for readings below 160 μ M and 5% for readings above 160 μ M.

Q: Is there a minimum measuring point or will the sensor go all the way down to zero?

A: It will go all the way to 0. There is no minimal measuring point.

Q: When calibrating, which substance should I use to remove the oxygen in the water?

A: At Aanderaa we use Sodium sulfite for this purpose. Sodium sulfite rapidly removes the oxygen and as long as crystals of the compound can be seen the oxygen level in the water will stay at 0. Sodium sulfite also has the advantage of being inexpensive and the level of toxicity is low. There are many other chemical substances that could be used for the purpose. Some investigators use Sodiumdithionit, which is also effective but more expensive and more toxic. Bubbling with gases (e.g. N₂, Argon etc) will also “strip off” the oxygen from the water but this takes longer time and sometimes, especially if the water volume is large, it can be difficult to know when zero oxygen level has been reached.

FAQ about Response Time and Performance Checks

Q: Why is the response time of the sensor slow?

A: It is slow because of two reasons. First, the foil is covered with an opaque optical isolation layer to make it more rugged. The optical isolation slows down the time it takes for oxygen to equilibrate within the foil. Second, the response time of the temperature sensor, needed to

compensate the optical readings, is also a limiting factor. In most long term applications the response time ($t_{63} < 25$ s) is sufficient but when doing fast profiling (e.g. with a CTD or on a towed vehicle) the response time can be a limiting factor.

Q: Can the response be improved?

A: Yes by using non-optically isolated foils the response time of the primary element, the optical part, will be at least 3 times faster. These foils are however less rugged and the lifetime is shorter. We are performing tests to decide whether or not to implement this option. We are also looking into the possibility of offering a mechanical funnel construction that pushes the water directly to the foil when moving through the water during profiling.

Q: How should I connect the sensor if I want to use it mounted on a CTD or a towed vehicle?

A: In spite of the relatively slow response time with respect to these applications many customers have chosen to use the sensor mounted on a CTD, a profiling vehicle or a towed vehicle with good results (compared to Winkler titration). If the CTD is equipped with a fast responding temperature sensor it is sensible to do the temperature compensation externally. This will improve the accuracy when subjected to fast temperature changes. The Optode must then be configured to output raw phase information. Based on this data and the external temperature data, the oxygen concentration can be calculated (see the Operating Manual for more details). If the CTD is not able to receive the RS232 output, the Optode 3975 with analog output can be used

Q: What is the maximal sampling rate of the sensor?

A: 1 sample/second (1 Hz)

Q: Can I check that the sensor is giving correct readings without doing any Winkler titration's?

A: Yes if you have a glass of water that is open to the air and bubbled with an air pump (normally used in aquariums) the water will rapidly become 100 % saturated and it stays saturated if you continue the bubbling. The bubbling also ensures mixing in the glass so that oxygen gradients do not form in the water. The absolute concentration (in μM or mg/l) in this water, at saturation, is dependent on three parameters: the salinity, the temperature and the air pressure. For example if the salinity is 0 ppt and the temperature is 20 degC the oxygen concentration should be around 284 μM but this value is given for an air-pressure of 1013 mbar. The saturation values can be obtained from tables and/or mathematical formulas given in the Operating Manual. If the air pressure is higher, for example 1030, you should expect higher readings of about $(1030-1013) / 1013 = 27 / 1013 = 2.7$ % and if it is lower the readings should be lower. If you would like to go further with your tests you can vary the temperature in the glass either by adding ice or by heating the water. The saturation should then stay close to 100 % at all the times but the absolute concentration will increase when the temperature goes down and decrease when it increases. Of course the sensor should drop to 0 when you bubble the water with a different gas than air or oxygen (e.g. N_2 or Argon) or when you add for example Sodium sulfite to your water solution. Please note that it can take quite some time before the water reaches a zero oxygen level when bubbling with gas.

FAQ about Measurement Related Topics

Q: Can I measure oxygen in air with the sensor?

A: Yes but in dry air you should expect slightly higher readings since there is no water vapor present. The space normally taken by vapor in humid air is here replaced by more air and consequently the sensor should give slightly higher readings. Please be aware that there is a

high risk of having a different temperature at the foil compared to the temperature of the sensor in air. This might lead to errors in the temperature compensation and to readings that are not correct.

Q: What is the reason that several sensors plunged into the same water do not give exactly the same values?

A: From experience we know that at occasions when this question was raised the user had not mixed the water well and consequently the oxygen concentrations were different at different locations in the water bath. Due to the simple two point calibration (see above) differences (within specifications) between sensors should be expected. It has happened that customers that want a higher accuracy have developed their own calibration procedures. This can improve the accuracy significantly.

Q: What physical factors will affect the sensor?

A: Temperature (which is already internally compensated), salinity (see below or Operating Manual) and pressure (see below or Operating Manual). The two latter parameters are easily compensated for by simple formulas which are common for all sensors.

Q: What chemical factors/elements will affect the sensor?

A: There exists no cross sensitivity for carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3), pH, any ionic species like sulfide (S_2^{2-}), sulfate (SO_4^{2-}) or chloride (Cl^-). The sensors can also be used in methanol- and ethanol -water mixtures as well as in pure methanol and ethanol. It should not be used in other organic solvents, such as acetone, chloroform or methylene chloride, which may swell the foil matrix and destroy it. Interferences (cross-sensitivity) are found for gaseous sulfur dioxide (SO_2) and gaseous chlorine (Cl_2).

Q: Is the sensor sensitive to H_2S ?

A: No it is not. It will not be damaged by H_2S and it is not cross-sensitive to it. If H_2S is present the oxygen concentration should be zero or very close to zero since O_2 and H_2S rarely coexists, especially over longer time periods.

Q: Why is a salinity compensation needed?

A: The sensor does not react to changes in salinity or water density, it only responds to the Partial Pressure of the Oxygen molecule in solution. This can be verified by having two glasses of air-bubbled water, at the same temperature, next to each other. One filled with freshwater (0 ppt) and the other with saltwater (e.g. 35 ppt). When moving the sensor from one glass to the other it should read the same absolute oxygen concentration, in μM , even if though the oxygen solubility in the salt water is lower. The saturation level should also be the same, around 100 %. By manually changing the internal salinity setting in the sensor (preferably using the OxyView software) to the correct value the sensor will give the correct absolute saturation concentration in the salt water. This means that when working in waters with a constant and known salinity this value can be entered into the sensor prior to deployment. If working in an environment with varying salinities this parameter has to be measured in parallel with oxygen and the data should be post compensated. The formula used for this is the same standard formula that is used to calculate oxygen saturation with varying temperature and salinity. It is given in the Operating Manual. It will soon be included as a virtual sensor in the 5059 software delivered from Aanderaa (Q1 2004).

Q What is the pressure behavior of the sensor?

A: The pressure effect is that the sensor reads 4% lower readings/1000 m of water depth which means that at 1000 m you will have to multiply your readings with 1.04 to get the

correct absolute values and at 2000 m with 1.08 etc. This effect is the same for every sensor, it is linear and fully instantaneously reversible, when the pressure is released.

Q: Can I log data of oxygen concentration, oxygen saturation and temperature simultaneously on the SR10 output (e.g. on a RCM9/RCM11/Buoy etc.).

A: No, the Optode only has one SR-10 output channel. You can either select to log oxygen concentration or oxygen saturation on your instrument. To see how this set-up is done see the Operating Manual or the OxyView software. If you also would like to log the Optode's internal temperature sensor you will have to order the Oxygen Optode model 3930 which can output the temperature in parallel in VR22 format. Note this is normally not necessary as our recording instruments include a separate temperature sensor.

Q: *Why is the sensor limited to a range of 0-120 % and 0-500 μM ?*

A: These limitations are only present when logging the sensor in SR10 or analog formats. If logging the sensor in RS232 or CAN bus there are no upper limits for the measurements range. However the user should be aware of the sensors and the foils are only calibrated to 500 μM beyond these limits a lower accuracy and precision should be expected. The 120 % saturation limit is given for extreme conditions, which will rarely occur in reality. At 0 °C at a salinity of 0 ppt the 100 % saturation reading of water is 457 μM . It is unlikely that in such waters there would be supersaturation since there is normally no or low primary production in water that is freezing. Sea water (35 ppt) at 0 °C contains 358 μM at 100 % saturation so here there is margin of up to 140 % before the sensor reaches the SR10 measuring limit of 500 μM . To conclude the limitation when logging the sensor in SR10 or analog format is 500 μM = 16 mg /l the corresponding saturation limitations in % can be calculated when the temperatures and salinities are known.

Q: *How fouling sensitive is the sensor?*

A: The sensor does not consume any oxygen and it is not stirring sensitive therefore it is less sensitive to fouling than electrochemical sensors. The fouling sensitivity varies from case to case. In the marine environment with high fouling conditions an unprotected Optode will give accurate readings as long as the fouling is not changing the local oxygen conditions around the sensing foil. Some user experiences have shown that this, in the worst cases, can start to occur already after one week in warm and highly productive waters. To prolong the deployment times in such environments Aanderaa can supply a copper plate to mount the sensing foil with. This has enhanced the deployment periods to at least one month and in some cases to more than a year. Wrapping a beryllium-copper mesh (normally used for domestic cleaning) has produced the same positive effect as the copper plate. In some freshwater applications and in waste water treatment plants there have been occasions where the copper plate has not prolonged the deployment time significantly. This is because a bacterial slime builds up behind the plate and consumes the oxygen in front of the foil. In such applications, especially in wastewater treatment plants, daily automatic water flushing of the sensor have prolonged the deployment times from about two weeks to at least 6 months.

Q: *For how long time can you run the sensor before it will not work anymore?*

A: The most critical limitation for the operational time (foil life) is foil bleaching. When excited for a long time with strong blue light the foil will bleach and eventually reach a stage where the amplitude of the returning signal (even if it is lifetime based) will be too weak to be registered. Laboratory tests at 2 s intervals have shown that the sensor can measure more than a year with this interval setting. This means that it can for example measure 5 years at a 10 s interval. Exposure to direct sunlight will also excite/bleach the foil over time however this effect is minimal with the protection provided by the opaque/optical isolation layer.

Q: Can the 3830 sensor be used down to full ocean depth just by connecting it to a standard titanium connector from Aanderaa?

A: No for high pressures, beyond 100 bar, the Cable Adapter (model # 3979) and Flange Connecting Cable (model # 3976) should be used. These are pressure rated to 600 bar. Please look in the Operating Manual or contact Aanderaa for more information.

Q: Can I use the sensor for long-term measurements, in for example an on-line system, just by connecting it to a PC with the PC communication cable (model # 3855) that was delivered with the sensor?

A: Yes and No. It is not a problem to connect and log the sensor like this but you should be aware that the connector on the cable is made out of anodized Aluminium that will start to corrode when it is used for too long times in salt water. The sensor is of Titanium and will not corrode. For long-term applications you should use a Titanium connector. Please ask Aanderaa for more information.

Q: The Aanderaa Optode and/or software appear to be programmed to only report percent saturation relative to sea level. How is it intended to take into account the barometric pressure, i.e., elevation, in reporting percent saturation?

A: External calculation and post-processing must be used for calculating “real” saturation with respect to barometric/water pressure. The Optode’s internal software has not been prepared for measurements at high altitudes.

Q: How high a temperature operation and storage temperature can the sensor stand?

A: Operating 0 to 40°C; Transport -40°C to 70°, for storage we recommend room temperature or lower.

FAQ about Mechanical and Maintenance issues

Q: How do I clean the foil after a deployment if it has been fouled?

A: In all cases the cleaning procedure should be done with caution so that the protective coating is not removed. If the fouling is calcareous it can normally be dissolved with household vinegar (essig in German, eddik in Norwegian). Another substance that can be used is commercially called muriatic acid, which is a 5% HCl solution (dilute solution by 50% should be tested to see how well it dissolves growth before using a stronger concentration). If needed, the Optode can be submerged in vinegar/HCl over night, or longer. If the marine growth remains use Q-tips to gently wipe it off after it has been softened by soaking in vinegar/HCl. After cleaning the sensor it should be rinsed well in clean tap water before storing or reuse. Do not use any organic solvents such as: Acetone, Chloroform and Toluene since these and others will damage the foil.

Q: My foil has been damaged so that I can see scratches in the black protective layer and some blue light is coming out when measuring. Do I need to change the foil?

A: No normally not. Even if quite heavily damaged the foil continues to work, in most cases. As long as enough of the fluorophore remains on the foil the sensor will measure correctly. If heavily damaged it is however recommended to recalibrate the sensor (with a standard two point calibration, see Operating Manual or OxyView software). If the sensor behaves normally when placed in an air-bubbled water solution (showing close to 100 % saturation) the foil should be ok. If the foil is not ok the sensor will return values that are illogical to what should be expected. Then the foil needs to be exchanged, new calibration constants entered and a new two point calibration performed. Remember that the Optode sensors can also be operated with transparent foils so the black protective layer is not essential. If using a

transparent foil it should then be noted that blue light will be spread out into the water. This might induce primary production if measuring at a frequent time interval without moving the sensor.

Q: I have an old RCM7/RCM8 can I mount the Optode and log it with this instrument.

A: No the sensor does not fit physically on the top plate. Neither will the RCM7/8 be able to read the standard SR10 signal.

Appendix 10 Oxygen Dynamics in Water

Seawater and Gases

Refer Unisense AS for tabulated physical parameters of interest to those working with micro sensors in marine systems:

<http://www.unisense.com/support/support.html>

Tables

Refer Unisense AS for Gas tables with diffusion coefficients, solubility of oxygen in seawater, density of water versus temperature and salinity, and much more:

http://www.unisense.com/support/pdf/gas_tables.pdf

Copies of Unisense AS tables for *solubility of oxygen in seawater* are given in Figure A 19, Figure A 20, and Figure A 21.

NOTE! Refer Unisens AS for more information about the tables.



Oxygen solubility at different temperatures and salinities of seawater

Units: $\mu\text{mol/l}$

Salinity (‰)	Temperature (°C)																							
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0			
0.0	456.6	444.0	431.9	420.4	409.4	398.9	388.8	379.2	369.9	361.1	352.6	344.4	336.6	329.1	321.9	314.9	308.3	301.8	295.6	289.7	283.9			
1.0	453.5	441.0	429.0	417.6	406.7	396.3	386.3	376.7	367.6	358.8	350.4	342.3	334.5	327.1	319.9	313.0	306.4	300.0	293.9	287.9	282.2			
2.0	450.4	438.0	426.1	414.8	404.0	393.6	383.7	374.3	365.2	356.5	348.1	340.1	332.4	325.0	317.9	311.1	304.5	298.2	292.1	286.2	280.6			
3.0	447.3	435.0	423.2	412.0	401.3	391.0	381.2	371.8	362.8	354.2	345.9	338.0	330.4	323.0	316.0	309.2	302.7	296.4	290.4	284.5	278.9			
4.0	444.2	432.0	420.4	409.2	398.6	388.5	378.7	369.4	360.5	351.9	343.7	335.9	328.3	321.0	314.0	307.3	300.9	294.6	288.6	282.9	277.3			
5.0	441.1	429.1	417.5	406.5	396.0	385.9	376.3	367.0	358.2	349.7	341.6	333.7	326.2	319.0	312.1	305.5	299.0	292.9	286.9	281.2	275.7			
6.0	438.1	426.1	414.7	403.8	393.3	383.3	373.8	364.6	355.9	347.5	339.4	331.6	324.2	317.1	310.2	303.6	297.2	291.1	285.2	279.5	274.0			
7.0	435.1	423.2	411.9	401.1	390.7	380.8	371.3	362.3	353.6	345.2	337.2	329.6	322.2	315.1	308.3	301.7	295.4	289.4	283.5	277.9	272.4			
8.0	432.1	420.3	409.1	398.4	388.1	378.3	368.9	359.9	351.3	343.0	335.1	327.5	320.2	313.1	306.4	299.9	293.6	287.6	281.8	276.2	270.8			
9.0	429.1	417.5	406.3	395.7	385.5	375.8	366.5	357.6	349.0	340.8	333.0	325.4	318.2	311.2	304.5	298.1	291.9	285.9	280.1	274.6	269.2			
10.0	426.1	414.6	403.6	393.0	383.0	373.3	364.1	355.2	346.8	338.6	330.8	323.4	316.2	309.3	302.6	296.2	290.1	284.2	278.5	273.0	267.6			
11.0	423.2	411.8	400.8	390.4	380.4	370.8	361.7	352.9	344.5	336.5	328.7	321.3	314.2	307.3	300.8	294.4	288.3	282.5	276.8	271.3	266.1			
12.0	420.3	409.0	398.1	387.8	377.9	368.4	359.3	350.6	342.3	334.3	326.7	319.3	312.2	305.4	298.9	292.6	286.6	280.8	275.1	269.7	264.5			
13.0	417.4	406.2	395.4	385.2	375.3	366.0	357.0	348.3	340.1	332.2	324.6	317.3	310.3	303.5	297.1	290.8	284.8	279.1	273.5	268.1	262.9			
14.0	414.5	403.4	392.7	382.6	372.8	363.5	354.6	346.1	337.9	330.0	322.5	315.3	308.3	301.7	295.2	289.1	283.1	277.4	271.9	266.5	261.4			
15.0	411.7	400.6	390.1	380.0	370.4	361.1	352.3	343.8	335.7	327.9	320.5	313.3	306.4	299.8	293.4	287.3	281.4	275.7	270.2	265.0	259.9			
16.0	408.8	397.9	387.4	377.4	367.9	358.7	350.0	341.6	333.5	325.8	318.4	311.3	304.5	297.9	291.6	285.5	279.7	274.0	268.6	263.4	258.3			
17.0	406.0	395.2	384.8	374.9	365.4	356.4	347.7	339.4	331.4	323.7	316.4	309.4	302.6	296.1	289.8	283.8	278.0	272.4	267.0	261.8	256.8			
18.0	403.2	392.5	382.2	372.4	363.0	354.0	345.4	337.2	329.2	321.7	314.4	307.4	300.7	294.2	288.0	282.1	276.3	270.8	265.4	260.3	255.3			
19.0	400.4	389.8	379.6	369.9	360.6	351.7	343.1	335.0	327.1	319.6	312.4	305.5	298.8	292.4	286.3	280.3	274.6	269.1	263.8	258.7	253.8			
20.0	397.7	387.1	377.0	367.4	358.2	349.3	340.9	332.8	325.0	317.6	310.4	303.5	296.9	290.6	284.5	278.6	273.0	267.5	262.3	257.2	252.3			
21.0	394.9	384.5	374.5	364.9	355.8	347.0	338.6	330.6	322.9	315.5	308.4	301.6	295.1	288.8	282.7	276.9	271.3	265.9	260.7	255.7	250.8			
22.0	392.2	381.8	371.9	362.4	353.4	344.7	336.4	328.5	320.8	313.5	306.5	299.7	293.2	287.0	281.0	275.2	269.7	264.3	259.1	254.1	249.3			
23.0	389.5	379.2	369.4	360.0	351.0	342.4	334.2	326.3	318.7	311.5	304.5	297.8	291.4	285.2	279.3	273.5	268.0	262.7	257.6	252.6	247.9			
24.0	386.8	376.6	366.9	357.6	348.7	340.2	332.0	324.2	316.7	309.5	302.6	295.9	289.6	283.4	277.5	271.9	266.4	261.1	256.0	251.1	246.4			
25.0	384.1	374.0	364.4	355.2	346.4	337.9	329.8	322.1	314.6	307.5	300.7	294.1	287.8	281.7	275.8	270.2	264.8	259.5	254.5	249.6	244.9			
26.0	381.5	371.5	361.9	352.8	344.0	335.7	327.7	320.0	312.6	305.5	298.7	292.2	285.9	279.9	274.1	268.5	263.2	258.0	253.0	248.2	243.5			
27.0	378.8	368.9	359.5	350.4	341.7	333.4	325.5	317.9	310.6	303.6	296.8	290.4	284.2	278.2	272.4	266.9	261.6	256.4	251.5	246.7	242.1			
28.0	376.2	366.4	357.0	348.0	339.5	331.2	323.4	315.8	308.6	301.6	294.9	288.5	282.4	276.5	270.7	265.3	260.0	254.9	250.0	245.2	240.6			
29.0	373.6	363.9	354.6	345.7	337.2	329.0	321.2	313.8	306.6	299.7	293.1	286.7	280.6	274.7	269.1	263.6	258.4	253.3	248.5	243.8	239.2			
30.0	371.0	361.4	352.2	343.4	334.9	326.9	319.1	311.7	304.6	297.8	291.2	284.9	278.8	273.0	267.4	262.0	256.8	251.8	247.0	242.3	237.8			
31.0	368.5	358.9	349.8	341.1	332.7	324.7	317.0	309.7	302.6	295.9	289.3	283.1	277.1	271.3	265.8	260.4	255.3	250.3	245.5	240.9	236.4			
32.0	365.9	356.5	347.4	338.8	330.5	322.5	314.9	307.7	300.7	294.0	287.5	281.3	275.4	269.6	264.1	258.8	253.7	248.8	244.0	239.4	235.0			
33.0	363.4	354.0	345.1	336.5	328.3	320.4	312.9	305.6	298.7	292.1	285.7	279.5	273.6	268.0	262.5	257.2	252.2	247.3	242.6	238.0	233.6			
34.0	360.9	351.6	342.7	334.2	326.1	318.3	310.8	303.7	296.8	290.2	283.9	277.8	271.9	266.3	260.9	255.7	250.6	245.8	241.1	236.6	232.2			
35.0	358.4	349.2	340.4	332.0	323.9	316.2	308.8	301.7	294.9	288.3	282.0	276.0	270.2	264.6	259.3	254.1	249.1	244.3	239.7	235.2	230.9			
36.0	355.9	346.8	338.1	329.7	321.7	314.1	306.7	299.7	293.0	286.5	280.3	274.3	268.5	263.0	257.7	252.5	247.6	242.8	238.2	233.8	229.5			
37.0	353.5	344.4	335.8	327.5	319.6	312.0	304.7	297.7	291.1	284.6	278.5	272.5	266.8	261.4	256.1	251.0	246.1	241.4	236.8	232.4	228.2			
38.0	351.0	342.0	333.5	325.3	317.4	309.9	302.7	295.8	289.2	282.8	276.7	270.8	265.2	259.7	254.5	249.5	244.6	239.9	235.4	231.0	226.8			
39.0	348.6	339.7	331.2	323.1	315.3	307.9	300.7	293.9	287.3	281.0	274.9	269.1	263.5	258.1	252.9	247.9	243.1	238.5	234.0	229.7	225.5			
40.0	346.2	337.4	329.0	320.9	313.2	305.8	298.7	292.0	285.4	279.2	273.2	267.4	261.8	256.5	251.4	246.4	241.6	237.0	232.6	228.3	224.1			

Figure A 19 Copy of Data Table 6 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure



Oxygen solubility at different temperatures and salinities of seawater

Units: $\mu\text{mol/l}$

Salinity (‰)	Temperature (°C)						26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0
	20.0	21.0	22.0	23.0	24.0	25.0															
0.0	283.9	278.3	273.0	267.8	262.8	257.9	253.2	248.7	244.3	240.0	235.9	231.9	228.0	224.2	220.5	217.0	213.5	210.1	206.7	203.5	200.4
1.0	282.2	276.7	271.4	266.3	261.3	256.5	251.8	247.3	243.0	238.7	234.6	230.6	226.8	223.0	219.4	215.8	212.3	209.0	205.7	202.5	199.3
2.0	280.6	275.1	269.8	264.7	259.8	255.0	250.4	245.9	241.6	237.4	233.3	229.4	225.6	221.8	218.2	214.7	211.2	207.9	204.6	201.4	198.3
3.0	278.9	273.5	268.3	263.2	258.3	253.6	249.0	244.6	240.3	236.1	232.1	228.1	224.3	220.6	217.0	213.5	210.1	206.8	203.6	200.4	197.3
4.0	277.3	271.9	266.7	261.7	256.8	252.1	247.6	243.2	238.9	234.8	230.8	226.9	223.1	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3
5.0	275.7	270.3	265.2	260.2	255.4	250.7	246.2	241.8	237.6	233.5	229.5	225.7	221.9	218.3	214.7	211.3	207.9	204.6	201.4	198.3	195.3
6.0	274.0	268.7	263.6	258.7	253.9	249.3	244.8	240.5	236.3	232.2	228.3	224.4	220.7	217.1	213.6	210.2	206.8	203.6	200.4	197.3	194.3
7.0	272.4	267.2	262.1	257.2	252.5	247.9	243.4	239.1	235.0	230.9	227.0	223.2	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3	193.3
8.0	270.8	265.6	260.6	255.7	251.0	246.5	242.1	237.8	233.7	229.7	225.8	222.0	218.3	214.8	211.3	207.9	204.7	201.5	198.3	195.3	192.3
9.0	269.2	264.1	259.1	254.2	249.6	245.1	240.7	236.5	232.4	228.4	224.5	220.8	217.2	213.6	210.2	206.8	203.6	200.4	197.3	194.3	191.3
10.0	267.6	262.5	257.6	252.8	248.2	243.7	239.4	235.2	231.1	227.1	223.3	219.6	216.0	212.5	209.1	205.7	202.5	199.4	196.3	193.3	190.3
11.0	266.1	261.0	256.1	251.3	246.7	242.3	238.0	233.8	229.8	225.9	222.1	218.4	214.8	211.3	208.0	204.7	201.4	198.3	195.3	192.3	189.4
12.0	264.5	259.5	254.6	249.9	245.3	240.9	236.7	232.5	228.5	224.6	220.9	217.2	213.7	210.2	206.8	203.6	200.4	197.3	194.2	191.3	188.4
13.0	262.9	257.9	253.1	248.4	243.9	239.6	235.3	231.2	227.3	223.4	219.7	216.0	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.3	187.4
14.0	261.4	256.4	251.6	247.0	242.5	238.2	234.0	229.9	226.0	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.3	195.2	192.2	189.3	186.5
15.0	259.9	254.9	250.2	245.6	241.1	236.8	232.7	228.6	224.7	220.9	217.3	213.7	210.2	206.8	203.6	200.4	197.2	194.2	191.2	188.3	185.5
16.0	258.3	253.4	248.7	244.2	239.8	235.5	231.4	227.4	223.5	219.7	216.1	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.2	187.4	184.6
17.0	256.8	252.0	247.3	242.8	238.4	234.2	230.1	226.1	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.2	195.2	192.2	189.3	186.4	183.6
18.0	255.3	250.5	245.9	241.4	237.0	232.8	228.8	224.8	221.0	217.3	213.7	210.2	206.8	203.5	200.3	197.2	194.1	191.2	188.3	185.4	182.7
19.0	253.8	249.0	244.4	240.0	235.7	231.5	227.5	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.1	190.2	187.3	184.5	181.7
20.0	252.3	247.6	243.0	238.6	234.3	230.2	226.2	222.3	218.6	214.9	211.4	207.9	204.6	201.3	198.2	195.1	192.1	189.2	186.3	183.5	180.8
21.0	250.8	246.1	241.6	237.2	233.0	228.9	224.9	221.1	217.3	213.7	210.2	206.8	203.5	200.3	197.1	194.1	191.1	188.2	185.4	182.6	179.9
22.0	249.3	244.7	240.2	235.8	231.7	227.6	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.0	190.1	187.2	184.4	181.6	179.0
23.0	247.9	243.2	238.8	234.5	230.3	226.3	222.4	218.6	214.9	211.4	207.9	204.6	201.3	198.1	195.0	192.0	189.1	186.2	183.4	180.7	178.0
24.0	246.4	241.8	237.4	233.1	229.0	225.0	221.1	217.4	213.7	210.2	206.8	203.4	200.2	197.1	194.0	191.0	188.1	185.2	182.5	179.8	177.1
25.0	244.9	240.4	236.0	231.8	227.7	223.7	219.9	216.2	212.5	209.0	205.6	202.3	199.1	196.0	193.0	190.0	187.1	184.3	181.5	178.8	176.2
26.0	243.5	239.0	234.7	230.5	226.4	222.5	218.6	214.9	211.4	207.9	204.5	201.2	198.0	194.9	191.9	189.0	186.1	183.3	180.6	177.9	175.3
27.0	242.1	237.6	233.3	229.1	225.1	221.2	217.4	213.7	210.2	206.7	203.4	200.1	197.0	193.9	190.9	188.0	185.1	182.4	179.6	177.0	174.4
28.0	240.6	236.2	231.9	227.8	223.8	219.9	216.2	212.5	209.0	205.6	202.3	199.0	195.9	192.9	189.9	187.0	184.2	181.4	178.7	176.1	173.5
29.0	239.2	234.8	230.6	226.5	222.5	218.7	215.0	211.4	207.9	204.5	201.2	198.0	194.8	191.8	188.9	186.0	183.2	180.5	177.8	175.2	172.6
30.0	237.8	233.5	229.3	225.2	221.3	217.4	213.7	210.2	206.7	203.3	200.1	196.9	193.8	190.8	187.9	185.0	182.2	179.5	176.9	174.3	171.7
31.0	236.4	232.1	227.9	223.9	220.0	216.2	212.5	209.0	205.5	202.2	199.0	195.8	192.7	189.8	186.9	184.0	181.3	178.6	175.9	173.4	170.9
32.0	235.0	230.7	226.6	222.6	218.7	215.0	211.3	207.8	204.4	201.1	197.9	194.7	191.7	188.7	185.9	183.0	180.3	177.6	175.0	172.5	170.0
33.0	233.6	229.4	225.3	221.3	217.5	213.8	210.1	206.7	203.3	200.0	196.8	193.7	190.7	187.7	184.9	182.1	179.4	176.7	174.1	171.6	169.1
34.0	232.2	228.0	224.0	220.0	216.2	212.5	209.0	205.5	202.1	198.9	195.7	192.6	189.6	186.7	183.9	181.1	178.4	175.8	173.2	170.7	168.2
35.0	230.9	226.7	222.7	218.8	215.0	211.3	207.8	204.3	201.0	197.8	194.6	191.6	188.6	185.7	182.9	180.1	177.5	174.9	172.3	169.8	167.4
36.0	229.5	225.4	221.4	217.5	213.8	210.1	206.6	203.2	199.9	196.7	193.6	190.5	187.6	184.7	181.9	179.2	176.5	173.9	171.4	168.9	166.5
37.0	228.2	224.1	220.1	216.2	212.5	208.9	205.4	202.1	198.8	195.6	192.5	189.5	186.6	183.7	180.9	178.2	175.6	173.0	170.5	168.1	165.7
38.0	226.8	222.7	218.8	215.0	211.3	207.7	204.3	200.9	197.7	194.5	191.4	188.5	185.6	182.7	180.0	177.3	174.7	172.1	169.6	167.2	164.8
39.0	225.5	221.4	217.5	213.8	210.1	206.6	203.1	199.8	196.6	193.4	190.4	187.4	184.5	181.7	179.0	176.3	173.8	171.2	168.7	166.3	164.0
40.0	224.1	220.1	216.3	212.5	208.9	205.4	202.0	198.7	195.5	192.4	189.3	186.4	183.5	180.8	178.1	175.4	172.8	170.3	167.9	165.5	163.1

Figure A 20 Copy of Data Table 7 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure



Oxygen solubility at different temperatures and salinities of seawater

Units: $\mu\text{mol/l}$

Salinity (‰)	Temperature (°C)																							
	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0
0.0	456.6	398.9	352.6	314.9	283.9	257.9	235.9	217.0	200.4	185.6	172.2	159.9	148.3	137.2	126.5	115.9	105.5	95.1	84.7	74.5	64.3	54.1	43.9	33.7
5.0	441.1	385.9	341.6	305.5	275.7	250.7	229.5	211.3	195.3	181.0	168.1	156.2	145.0	134.2	123.8	113.6	103.4	93.3	83.2	73.2	63.3	53.1	42.9	32.7
10.0	426.1	373.3	330.8	296.2	267.6	243.7	223.3	205.7	190.3	176.6	164.1	152.6	141.7	131.3	121.2	111.3	101.4	91.6	81.7	71.9	62.2	52.0	41.8	31.6
15.0	411.7	361.1	320.5	287.3	259.9	236.8	217.3	200.4	185.5	172.3	160.2	149.1	138.6	128.5	118.7	109.0	99.4	89.8	80.2	70.7	61.2	51.0	40.8	30.6
20.0	397.7	349.3	310.4	278.6	252.3	230.2	211.4	195.1	180.8	168.0	156.4	145.6	135.5	125.7	116.2	106.8	97.5	88.1	78.8	69.4	60.2	50.0	39.8	29.6
25.0	384.1	337.9	300.7	270.2	244.9	223.7	205.6	190.0	176.2	163.9	152.7	142.3	132.4	123.0	113.7	104.6	95.5	86.4	77.3	68.2	59.2	49.0	38.8	28.6
30.0	371.0	326.9	291.2	262.0	237.8	217.4	200.1	185.0	171.7	159.9	149.0	139.0	129.4	120.3	111.3	102.5	93.6	84.8	75.9	67.0	58.2	48.0	37.8	27.6
35.0	358.4	316.2	282.0	254.1	230.9	211.3	194.6	180.1	167.4	155.9	145.5	135.7	126.5	117.7	109.0	100.4	91.8	83.2	74.5	65.8	57.2	47.0	36.8	26.6
40.0	346.2	305.8	273.2	246.4	224.1	205.4	189.3	175.4	163.1	152.1	142.0	132.6	123.7	115.1	106.7	98.3	90.0	81.6	73.1	64.7	56.3	46.0	35.8	25.6
45.0	334.4	295.8	264.6	238.9	217.6	199.6	184.2	170.8	159.0	148.3	138.6	129.5	120.9	112.6	104.4	96.3	88.2	80.0	71.8	63.5	55.3	45.0	34.8	24.4
50.0	323.0	286.1	256.3	231.7	211.3	194.0	179.2	166.3	154.9	144.7	135.3	126.5	118.2	110.1	102.2	94.3	86.4	78.5	70.5	62.4	54.4	44.2	34.0	24.2
55.0	311.9	276.7	248.2	224.7	205.1	188.5	174.3	161.9	151.0	141.1	132.1	123.6	115.5	107.7	100.0	92.4	84.7	77.0	69.2	61.3	53.5	43.2	33.0	23.0
60.0	301.3	267.7	240.4	217.9	199.1	183.2	169.6	157.7	147.1	137.6	128.9	120.7	112.9	105.4	97.9	90.5	83.0	75.5	67.9	60.2	52.6	42.2	32.0	22.0
65.0	291.0	258.9	232.8	211.3	193.3	178.1	165.0	153.5	143.4	134.2	125.8	117.9	110.4	103.1	95.8	88.6	81.4	74.1	66.6	59.2	51.7	41.2	31.0	21.0
70.0	281.0	250.4	225.5	204.9	187.7	173.0	160.5	149.5	139.8	130.9	122.8	115.2	107.9	100.8	93.8	86.8	79.8	72.6	65.4	58.1	50.8	40.2	30.0	20.0
75.0	271.4	242.2	218.4	198.7	182.2	168.2	156.1	145.6	136.2	127.7	119.9	112.5	105.5	98.6	91.8	85.0	78.2	71.2	64.2	57.1	50.0	39.0	29.0	19.0
80.0	262.2	234.2	211.5	192.6	176.8	163.4	151.9	141.7	132.7	124.6	117.0	109.9	103.1	96.4	89.9	83.3	76.6	69.9	63.0	56.1	49.1	38.0	28.0	18.0
85.0	253.2	226.6	204.8	186.8	171.7	158.8	147.7	138.0	129.3	121.5	114.2	107.3	100.8	94.3	88.0	81.6	75.1	68.5	61.8	55.1	48.3	37.0	27.0	17.0
90.0	244.5	219.1	198.3	181.1	166.7	154.3	143.7	134.4	126.0	118.5	111.5	104.9	98.5	92.3	86.1	79.9	73.6	67.2	60.7	54.1	47.5	36.0	26.0	16.0
95.0	236.2	211.9	192.1	175.6	161.8	150.0	139.8	130.8	122.8	115.6	108.8	102.4	96.3	90.2	84.3	78.2	72.1	65.9	59.6	53.1	46.6	35.0	25.0	15.0
100.0	228.1	205.0	186.0	170.3	157.1	145.8	136.0	127.4	119.7	112.7	106.2	100.0	94.1	88.3	82.5	76.6	70.7	64.6	58.4	52.2	45.8	34.0	24.0	14.0
105.0	220.3	198.2	180.2	165.1	152.5	141.7	132.3	124.0	116.7	109.9	103.6	97.7	92.0	86.3	80.7	75.0	69.3	63.4	57.4	51.2	45.1	33.0	23.0	13.0
110.0	212.7	191.7	174.5	160.1	148.0	137.7	128.7	120.8	113.7	107.2	101.2	95.4	89.9	84.4	79.0	73.5	67.9	62.1	56.3	50.3	44.3	32.0	22.0	12.0
115.0	205.4	185.4	169.0	155.2	143.7	133.8	125.2	117.6	110.8	104.5	98.7	93.2	87.9	82.6	77.3	72.0	66.5	60.9	55.2	49.4	43.5	31.0	21.0	11.0
120.0	198.4	179.3	163.6	150.5	139.5	130.0	121.8	114.5	108.0	102.0	96.4	91.0	85.9	80.8	75.7	70.5	65.2	59.8	54.2	48.5	42.8	30.0	20.0	10.0
125.0	191.6	173.4	158.5	146.0	135.4	126.3	118.4	111.5	105.2	99.4	94.1	88.9	83.9	79.0	74.0	69.0	63.9	58.6	53.2	47.7	42.1	29.0	19.0	9.0
130.0	185.0	167.7	153.4	141.5	131.4	122.8	115.2	108.5	102.5	97.0	91.8	86.9	82.0	77.3	72.5	67.6	62.6	57.5	52.2	46.8	41.3	28.0	18.0	8.0
135.0	178.7	162.2	148.6	137.2	127.6	119.3	112.1	105.7	99.9	94.6	89.6	84.8	80.2	75.6	70.9	66.2	61.3	56.4	51.2	46.0	40.6	27.0	17.0	7.0
140.0	172.6	156.9	143.9	133.1	123.8	115.9	109.0	102.9	97.3	92.2	87.4	82.9	78.4	73.9	69.4	64.8	60.1	55.3	50.3	45.1	39.9	26.0	16.0	6.0
145.0	166.6	151.7	139.4	129.0	120.2	112.7	106.0	100.2	94.9	90.0	85.4	80.9	76.6	72.3	67.9	63.5	58.9	54.2	49.3	44.3	39.2	25.0	15.0	5.0
150.0	160.9	146.7	134.9	125.1	116.7	109.5	103.2	97.5	92.4	87.7	83.3	79.0	74.9	70.7	66.5	62.2	57.7	53.1	48.4	43.5	38.6	24.0	14.0	4.0
155.0	155.4	141.9	130.7	121.3	113.3	106.4	100.3	95.0	90.1	85.6	81.3	77.2	73.2	69.1	65.1	60.9	56.6	52.1	47.5	42.7	37.9	23.0	13.0	3.0
160.0	150.1	137.2	126.5	117.6	110.0	103.4	97.6	92.5	87.8	83.4	79.3	75.4	71.5	67.6	63.7	59.6	55.4	51.1	46.6	42.0	37.2	22.0	12.0	2.0
165.0	144.9	132.7	122.5	114.0	106.7	100.5	94.9	90.0	85.5	81.4	77.4	73.6	69.9	66.1	62.3	58.4	54.3	50.1	45.7	41.2	36.6	21.0	11.0	1.0
170.0	139.9	128.3	118.7	110.5	103.6	97.6	92.3	87.6	83.4	79.4	75.6	71.9	68.3	64.7	61.0	57.2	53.2	49.1	44.9	40.5	36.0	20.0	10.0	0.0
175.0	135.1	124.1	114.9	107.2	100.6	94.9	89.8	85.3	81.2	77.4	73.8	70.2	66.8	63.3	59.7	56.0	52.1	48.2	44.0	39.7	35.3	19.0	9.0	-1.0
180.0	130.5	120.0	111.3	103.9	97.6	92.2	87.4	83.1	79.1	75.5	72.0	68.6	65.2	61.9	58.4	54.8	51.1	47.2	43.2	39.0	34.7	18.0	8.0	-2.0
185.0	126.0	116.0	107.8	100.8	94.8	89.6	85.0	80.9	77.1	73.6	70.3	67.0	63.8	60.5	57.1	53.7	50.1	46.3	42.4	38.3	34.1	17.0	7.0	-3.0
190.0	121.7	112.2	104.3	97.7	92.0	87.0	82.7	78.7	75.2	71.8	68.6	65.4	62.3	59.2	55.9	52.6	49.1	45.4	41.6	37.6	33.5	16.0	6.0	-4.0
195.0	117.5	108.5	101.0	94.7	89.3	84.6	80.4	76.7	73.2	70.0	66.9	63.9	60.9	57.9	54.7	51.5	48.1	44.5	40.8	36.9	32.9	15.0	5.0	-5.0
200.0	113.5	104.9	97.8	91.8	86.7	82.2	78.2	74.6	71.4	68.3	65.3	62.4	59.5	56.6	53.6	50.4	47.1	43.6	40.0	36.3	32.4	14.0	4.0	-6.0

Figure A 21 Copy of Data Table 8 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure