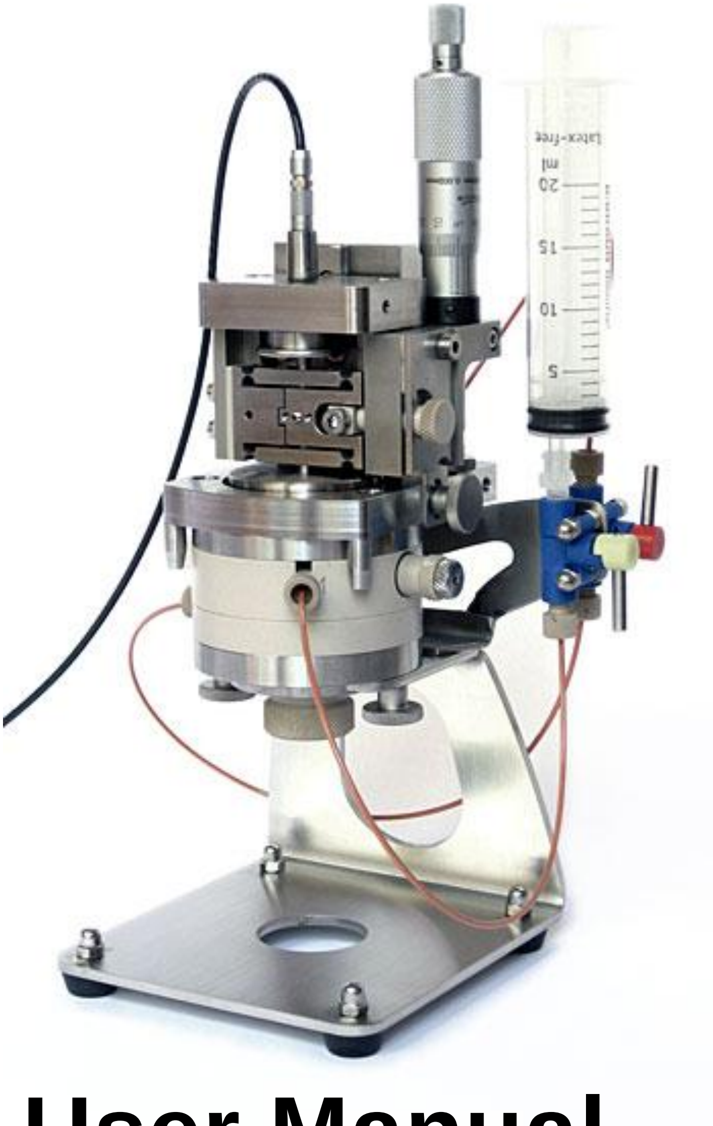
electrochemical test equipment

Electrochemical Dilatometer ECD-nano



User Manual

Serial-No.

Release: 2.2
2012-02-02

The information in this manual has been carefully checked and believed to be accurate; however, no responsibility is assumed for inaccuracies.

Contents

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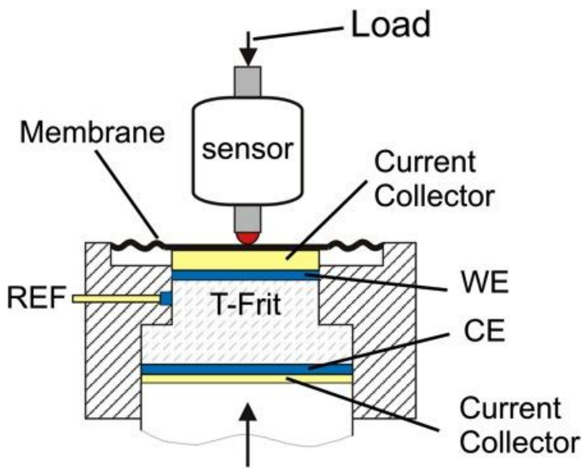
1 Product Description

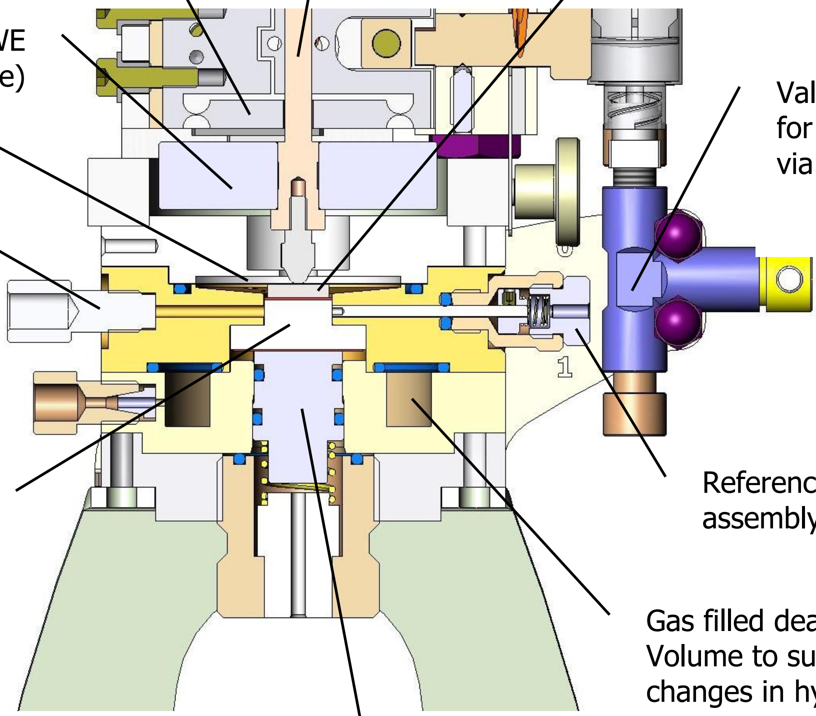
The ECD-nano electrochemical dilatometer is dedicated to the measurement of charge-induced strain (expansion and shrinkage) of electrodes down to the nanometer range. The ECD-nano is particularly developed for the investigation of Li-ion battery and other insertion-type electrodes. It may, however, also be used for many other electrochemical systems utilizing organic as well as aqueous electrolyte solutions. The electrode materials used can either be bound films, single crystals (e.g. HOPG), or binder-free powders. The maximum electrode size is 10 mm x 1 mm (diameter x thickness).

The heart of the ECD-nano is an electrochemical cell, hermetically tight against ambient atmosphere. The two electrodes inside are separated by a stiff glass frit that is fixed in position. The upper (working) electrode is sealed by means of a thin metal membrane, through which any charge-induced height change is transmitted towards the sensor/load unit above. This working principle allows determining the height change of the working electrode (WE) without any interference from that of the counter electrode (CE).

A high-resolution displacement transducer detects dimensional changes of the WE ranging from 5 nanometers up to 250 micrometers, during one and the same experiment that may last between a few minutes to many days. A simple weight serves to adjust the load on the working electrode. For best accuracy and drift stability, we recommend operating the ECD-nano inside a temperature controlled chamber.

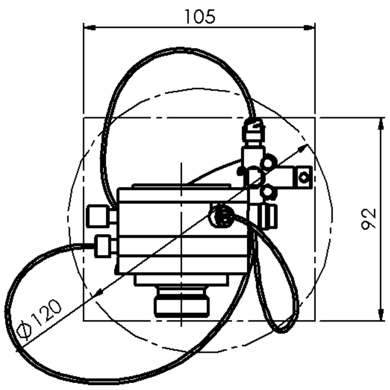


This manual covers the ECD-nano Standard version together with the optionally available re-fitting kit for aqueous electrolytes.

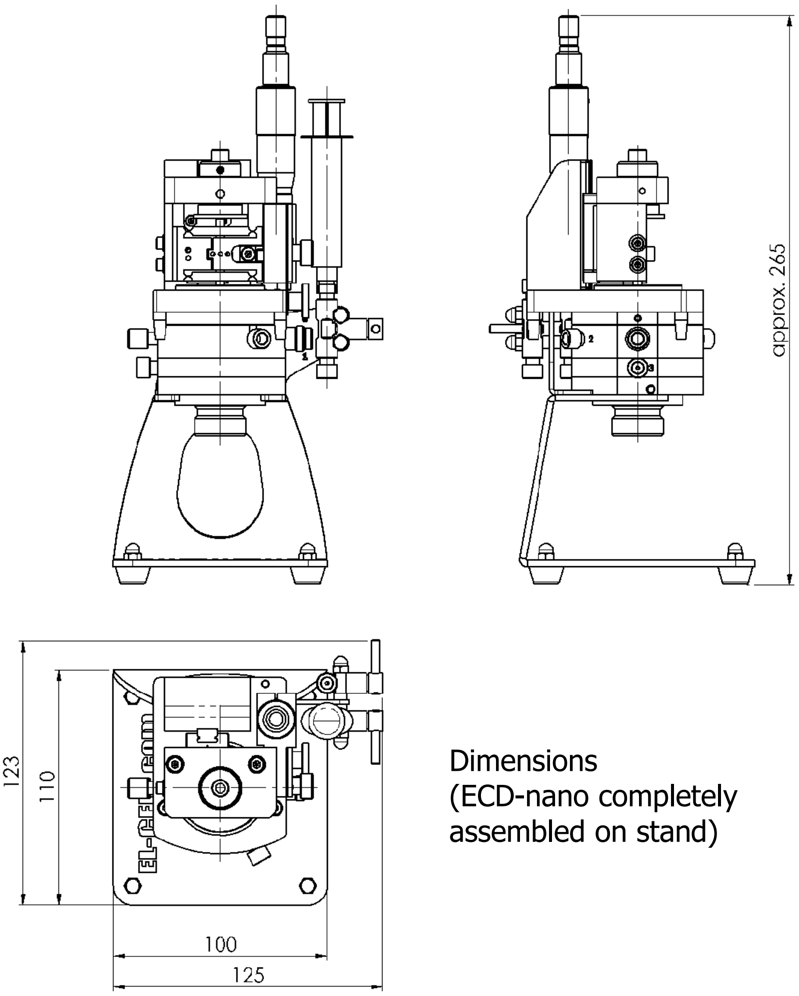


2 Technical Specifications

- Capacitive sensor with dc voltage output -10 to +10 V.
- Signal conditioning for connection to a data logger and / or to the analog input channels of the controlling potentiostat / battery tester.
- Two measurement ranges: ±50 µm (standard) and ±125 µm (extended)
- Resolution of < 5 nm
- Drift stability of < 20 nm/hour (sample-free instrument at constant temperature)
- Sample (working electrode):
  bound electrode film, binder-free powder, or single crystal / grain
  max. sample size 10 mm x 1 mm (diameter x thickness)
- Load on working electrode: 1 N (optional variable load 0.1 to 1 N))
- Electrolyte volume: < 3 mL
- Materials in contact with electrolyte: PEEK, borosilicate glass, EPDM rubber, stainless steel 316L for aprotic, gold for aqueous electrolytes
- Operating temperature range
  Cell and Sensor: -20 to +70 °C
  Controller and Data Acquisition System: 0 to +40 °C



minimum dimensions for antechamber-transfer into glove box (stand detached)



Dimensions (ECD-nano completely assembled on stand)

3 Safety Precautions

Use proper safety precautions when using hazardous electrolytes. Wear protective glasses and gloves to protect you against electrolyte that may accidentally spill out of the instrument during filling, operation, and disassembly.

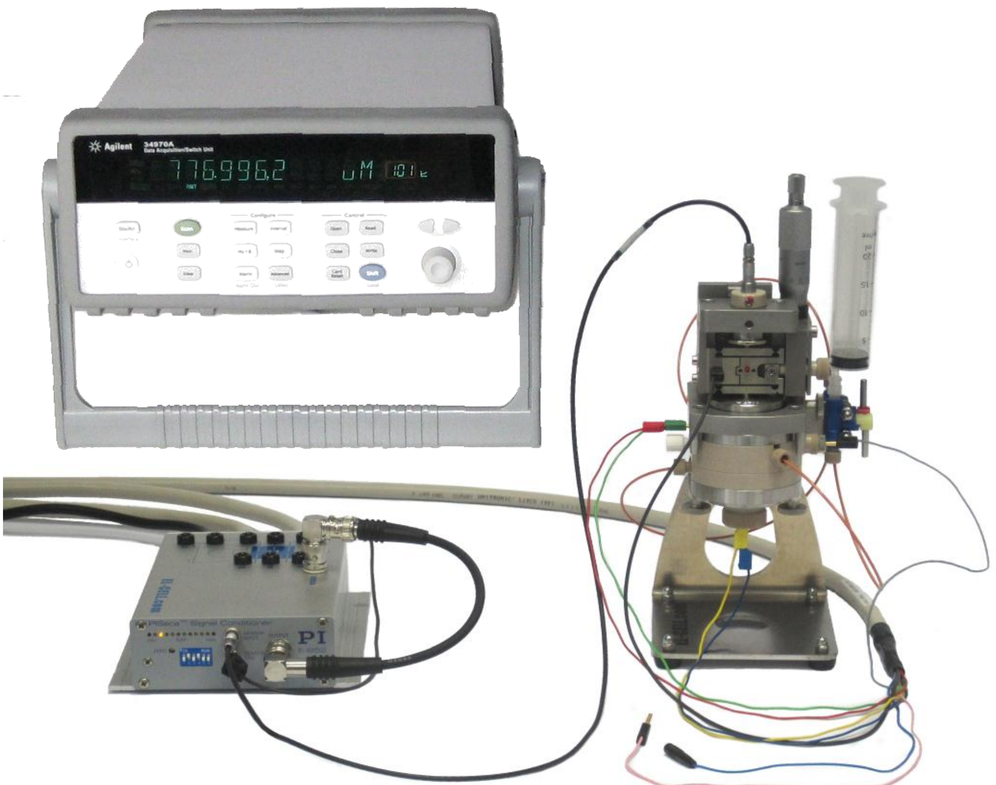
4 Unpacking

Check the contents of the packages against the list given below to verify that you have received all of the components. Contact the factory if anything is missing or damaged.

NOTE: Damaged shipments must remain with the original packaging for freight company inspection.

List of Components (Standard Version)

1. ECD-nano dilatometer (in the assembled state, equipped for use with aprotic electrolytes)
2. Signal conditioning electronics (controller box) with DC power supply
3. Cell cable (including line for target grounding)
4. Sensor cable
5. Data logger cable
6. Agilent 34970A Data Acquisition System (“Data Logger”) with 34901A 20 channel multiplexer board, and 34825A Benchlink Data Logger Software, and documentation/drivers on CD
7. 20 ml syringe with polysiloxane sealing
8. Vacuum pipette and tweezers for electrode handling
9. Hex wrenches for assembly and maintenance
10. 3 tubing assemblies for interconnection between cell, valves and syringe
11. Activated carbon electrode set (5 pcs) for reference measurements
12. Re-fitting kit for aqueous electrolytes (to be ordered separately)



ECD-nano Standard

5 ECD-nano Operation

5.1 Assembly

The following photographs refer to the use of the dilatometer with aprotic electrolytes. For aqueous electrolytes, the assembly differs slightly as indicated in the respective figure captions.

Insert o-rings into cell body
(21.95 x 1.78 and 41 x 1.78)

Insert glass frit (T frit 10/20 mm dia) into cell body

Place CE (dia <= 20 mm) on top of the glass frit

Insert the central CE piston into the cell bottom (O-ring size 9.75 x 1.78 mm)
NOTE: For aqueous electrolytes, additionally place the gold current collector on top of the CE, and use the gold pin piston instead

Stack cell bottom (with central CE piston inserted) on top of the cell bottom

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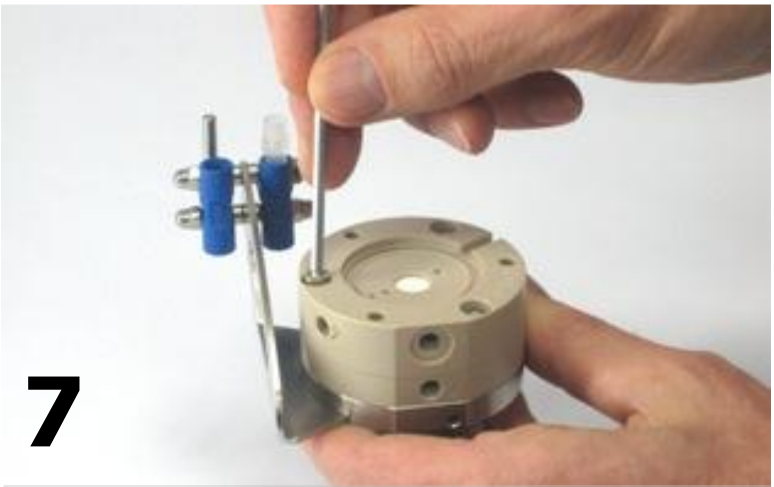
Put base flange (with valve support attached) on top, hold the assembly tightly together, and turn it around

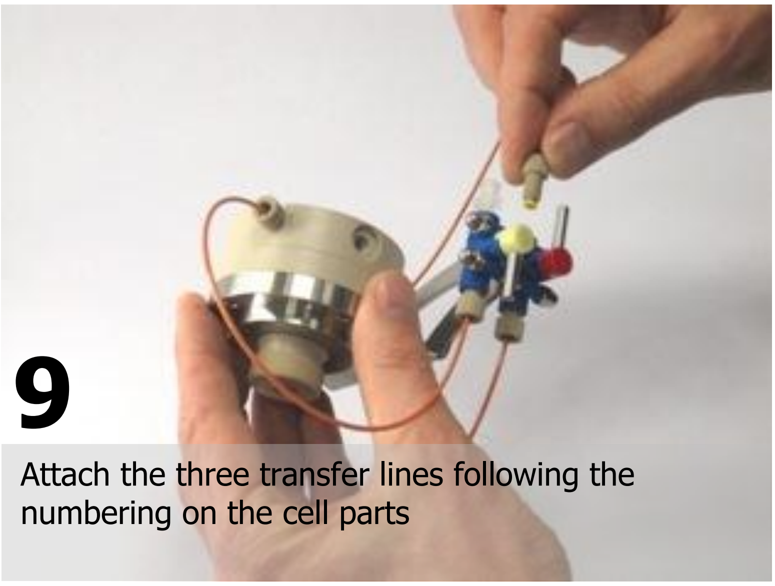


7

Screw the assembly together by means of the 3 hex socket screws M4x25

8

Screw in the CE spring load from below to its uppermost position, then release it slightly by turning the screw back (ccw) by appr. 45°



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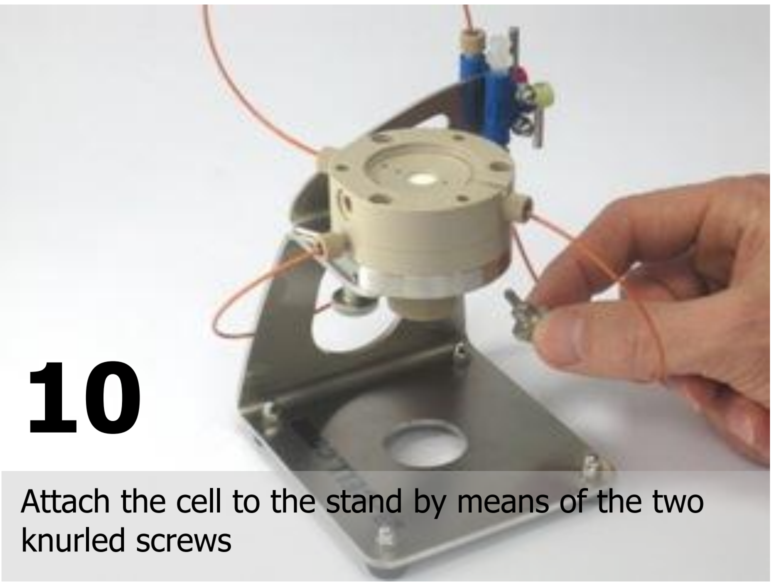
Attach the three transfer lines following the numbering on the cell parts



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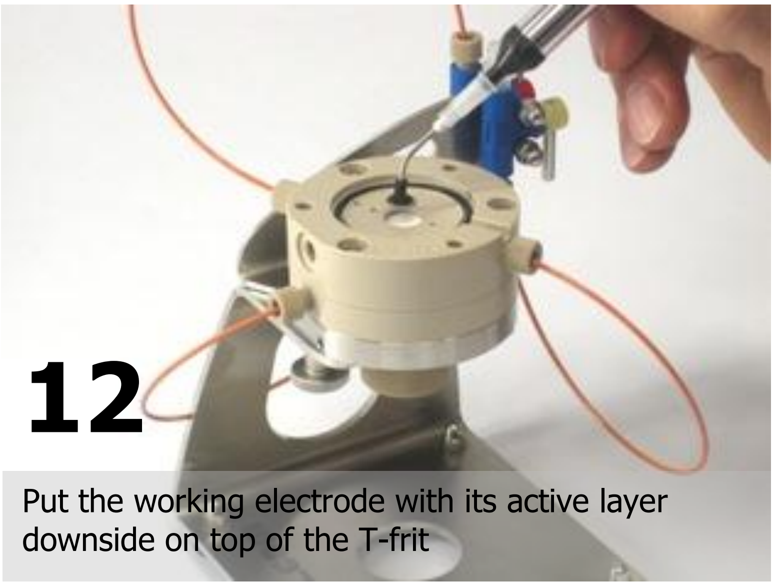
Attach the cell to the stand by means of the two knurled screws

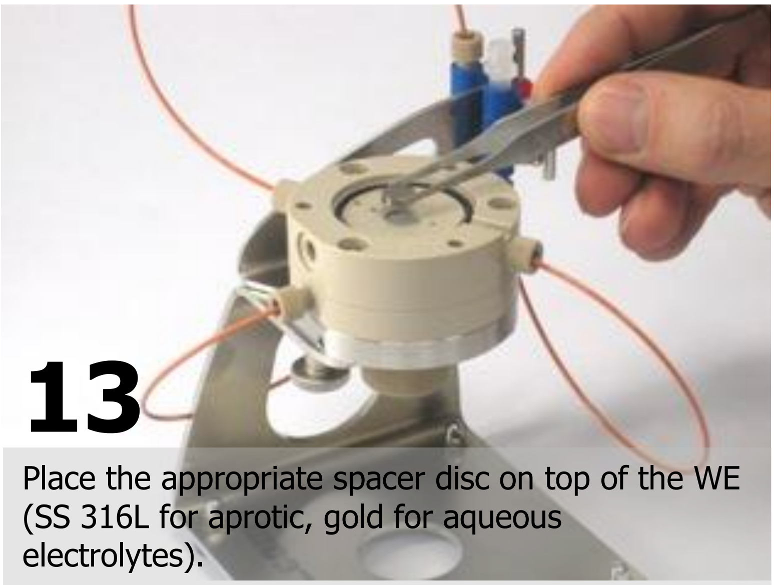
11

Insert the membrane O-ring seal



12

Put the working electrode with its active layer downside on top of the T-frit



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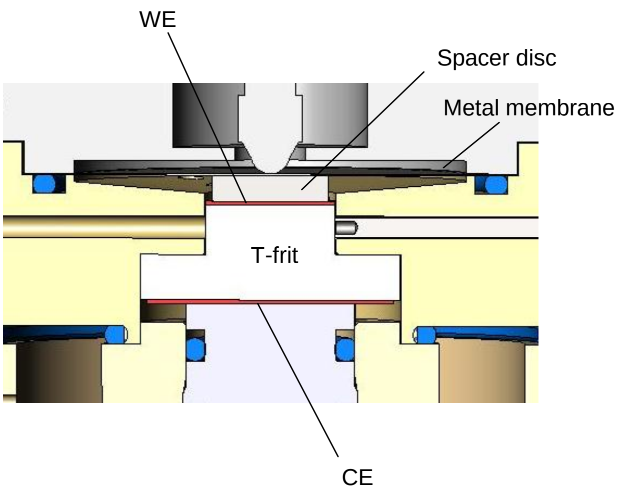
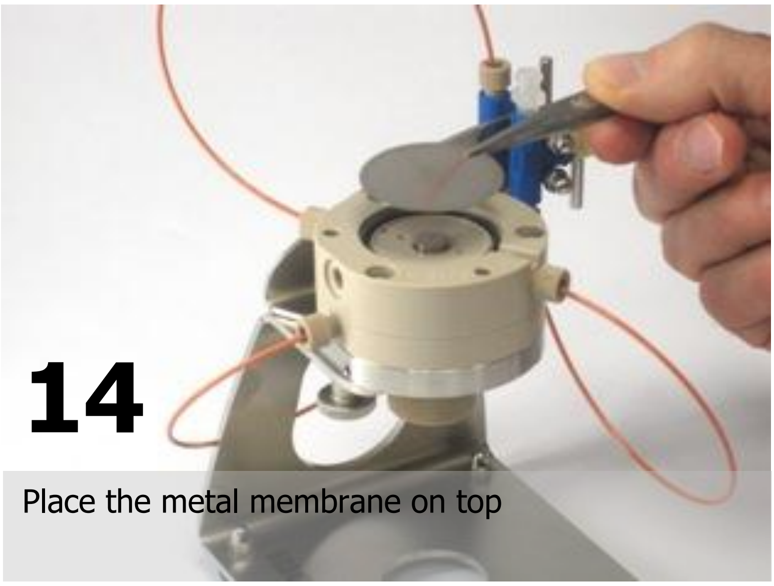
Place the appropriate spacer disc on top of the WE (SS 316L for aprotic, gold for aqueous electrolytes).

NOTE: Three different spacer discs (thickness 2.1, 2.2 and 2.3 mm) are provided to initially adjust the membrane for a given WE thickness close to its neutral (flat) position (see sketch below). The 2.2 mm disc corresponds to an initial WE thickness of 250 µm.





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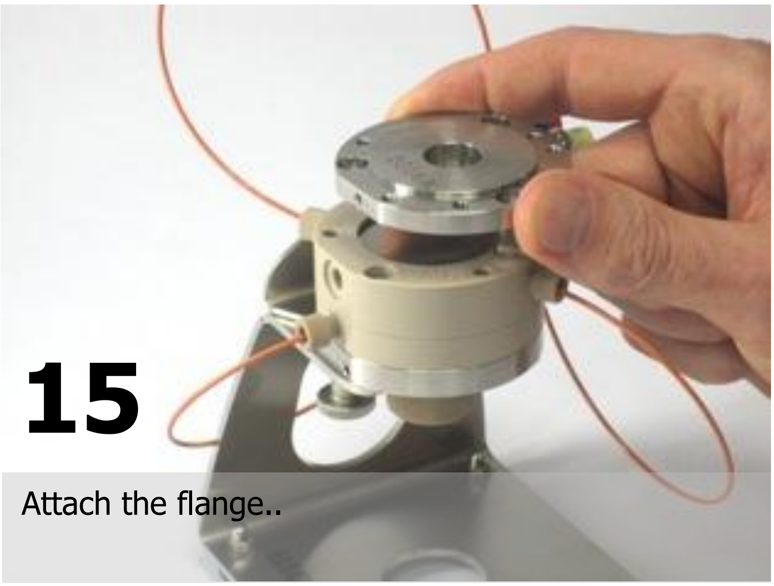
Place the metal membrane on top



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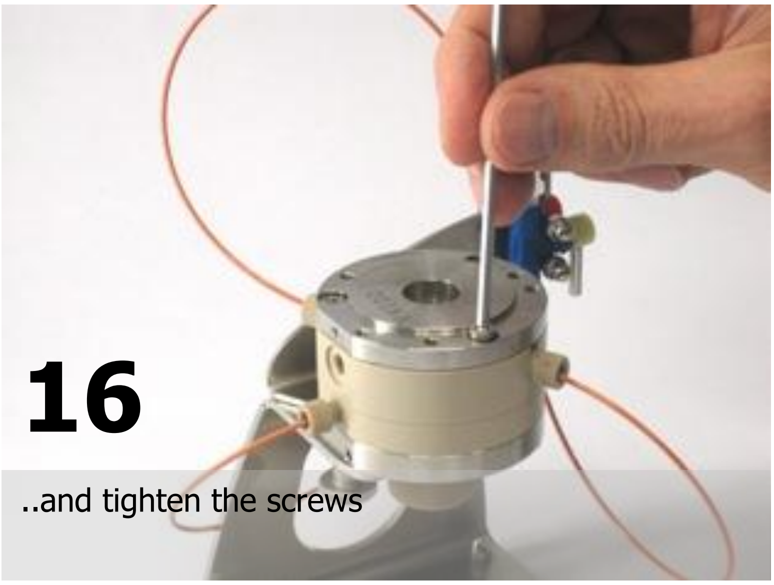
Attach the flange..



16

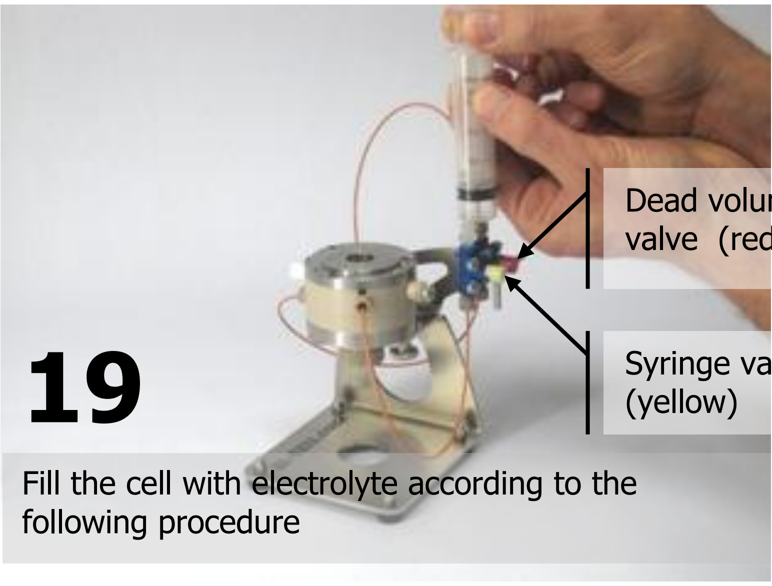
..and tighten the screws

17

Plug the auxiliary port

18

Load the reference pin with the appropriate reference material (e.g. by picking up lithium metal) and attach the reference assembly to the cell.



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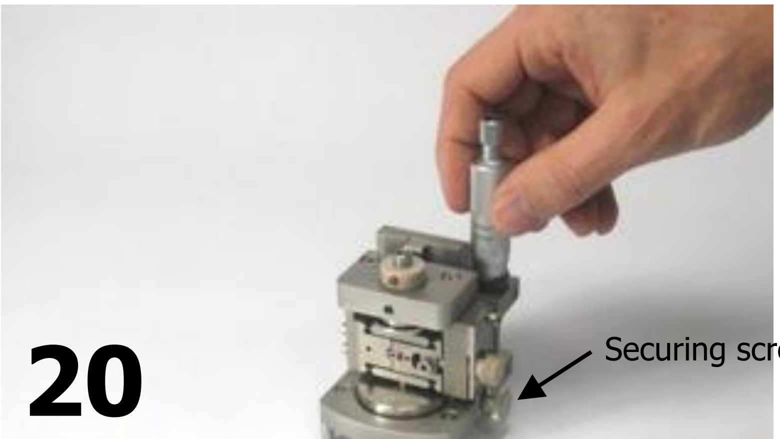
Fill the cell with electrolyte according to the following procedure

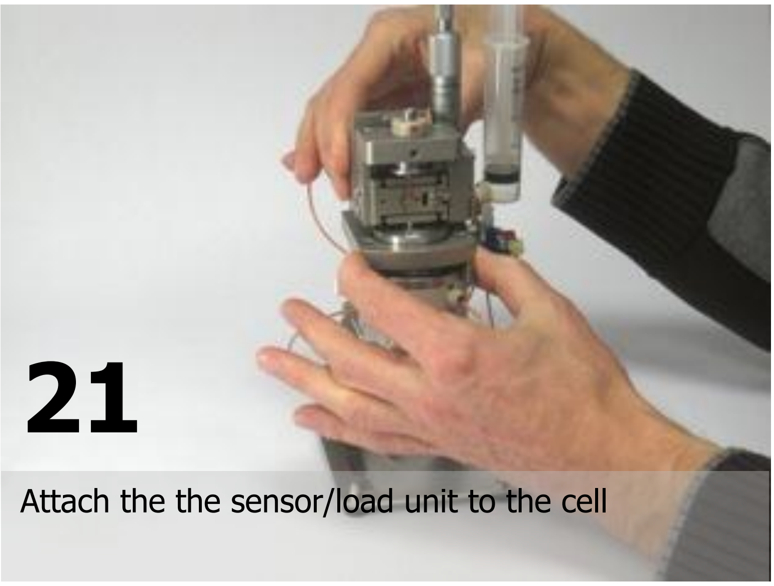
1. Charge a 20 ml syringe with ca. 3 ml of electrolyte.
   NOTE: We recommend one-time use PP plastic syringes with low friction polysiloxane pistons.
1. Connect the syringe to the Luer adapter of the inner (syringe) valve
2. Open the syringe valve, and close the outer (dead volume) valve
3. Pull the syringe piston back to evacuate the cell. Hold the piston a few seconds in the strained position.
4. Release the piston so that the electrolyte is drawn into the cell.
5. Repeat the two previous steps to complete filling.
6. Close the syringe valve, and open the dead volume valve

NOTE: The cell is now filled and hermetically tight. Up to this point, for air-sensitive systems, assembly and filling has to be done in a glove box. All subsequent steps may be carried out in ambient atmosphere.



20

Release the carriage securing screw, then move the carriage into the uppermost position by turning the micrometer screw clockwise



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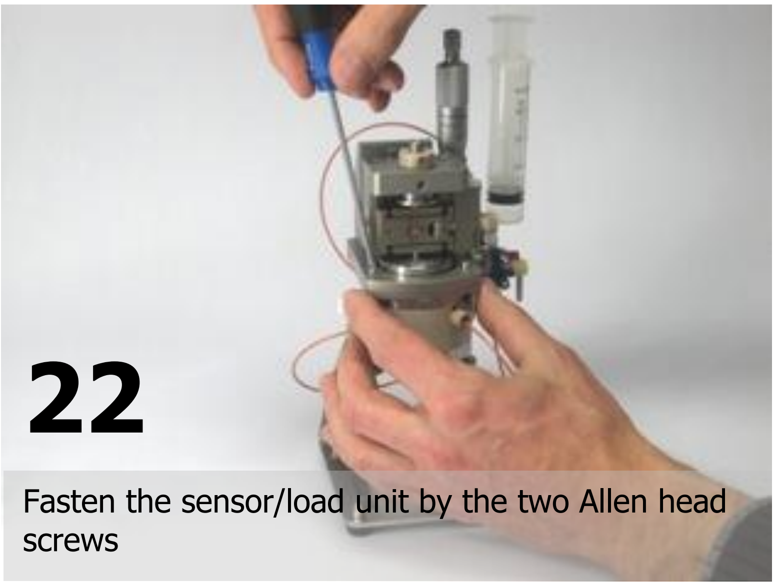
Attach the the sensor/load unit to the cell



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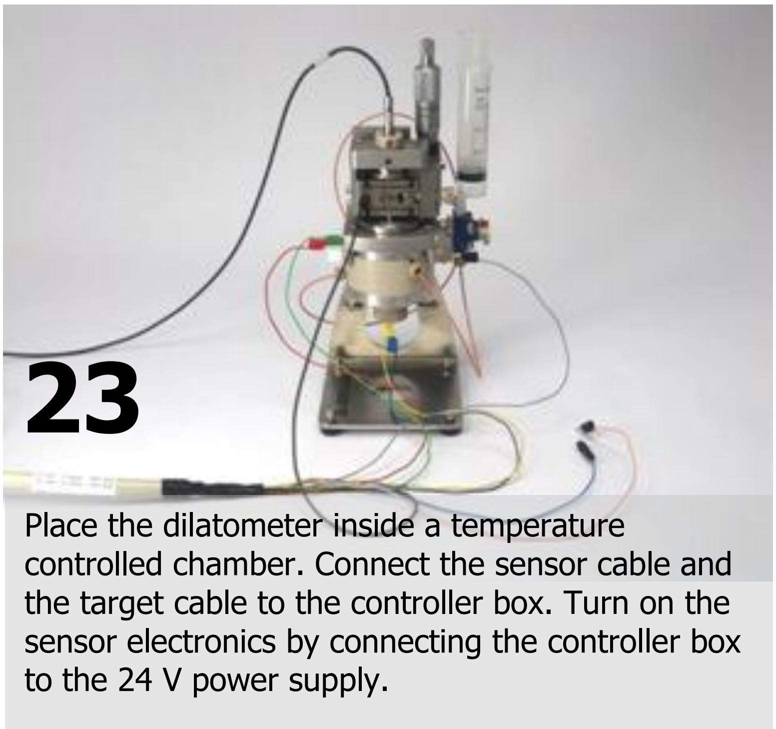
Fasten the sensor/load unit by the two Allen head screws



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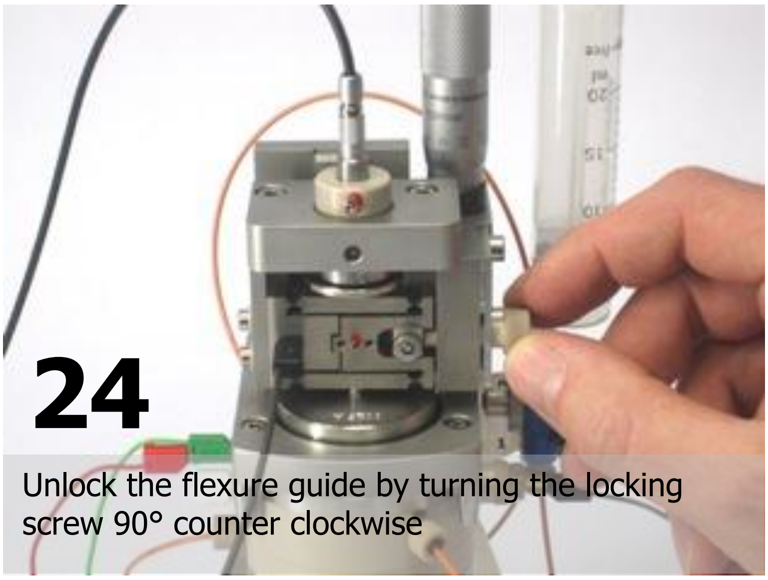
Place the dilatometer inside a temperature controlled chamber. Connect the sensor cable and the target cable to the controller box. Turn on the sensor electronics by connecting the controller box to the 24 V power supply.



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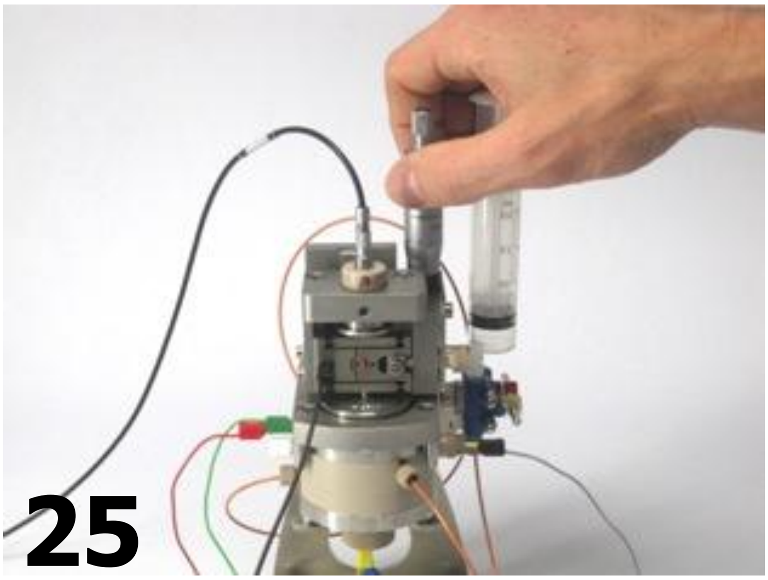
Unlock the flexure guide by turning the locking screw 90° counter clockwise



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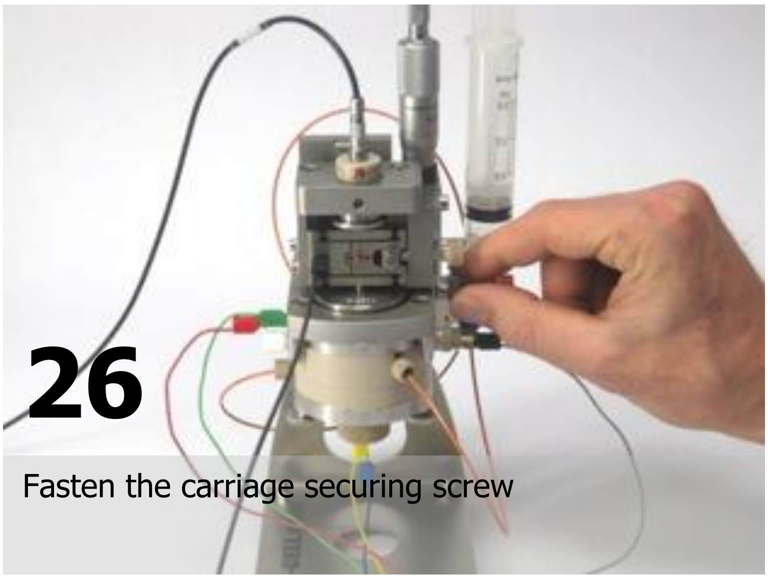
Adjust the sensor target by turning the micrometer screw counter clockwise until the bar graph indicator at the controller box is in mid position. For fine tuning, adjust the sensor output voltage as displayed by the data logger and/or potentiostat to 0V ±1V.



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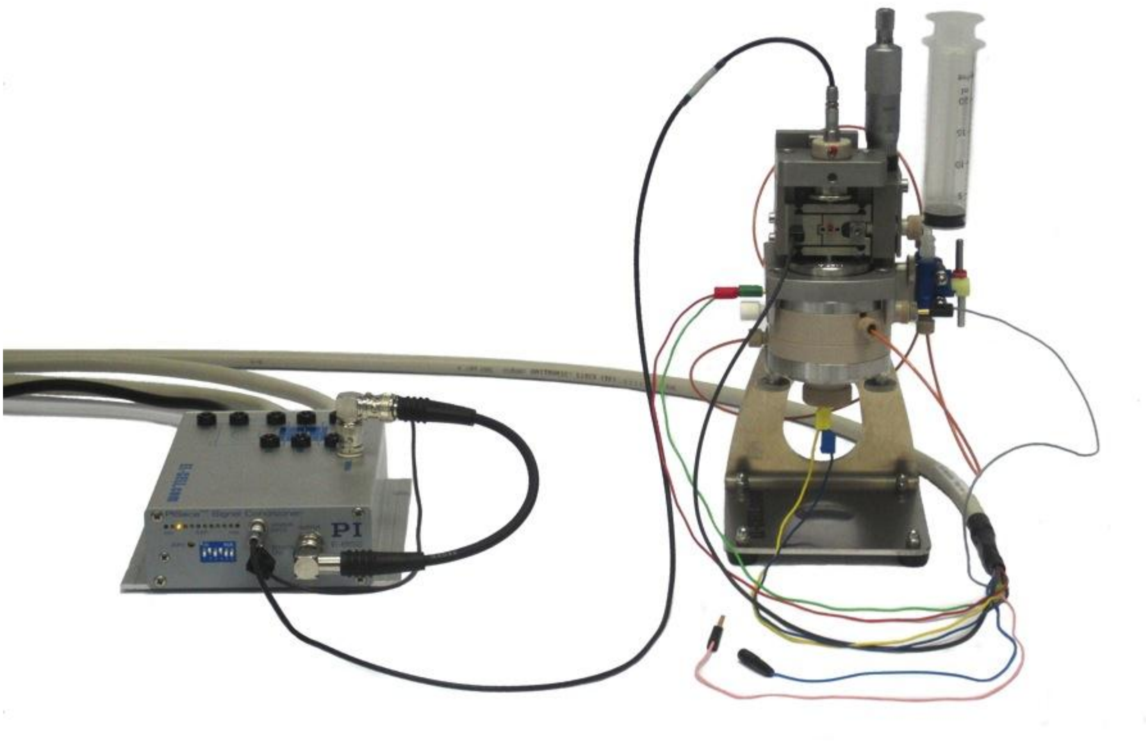
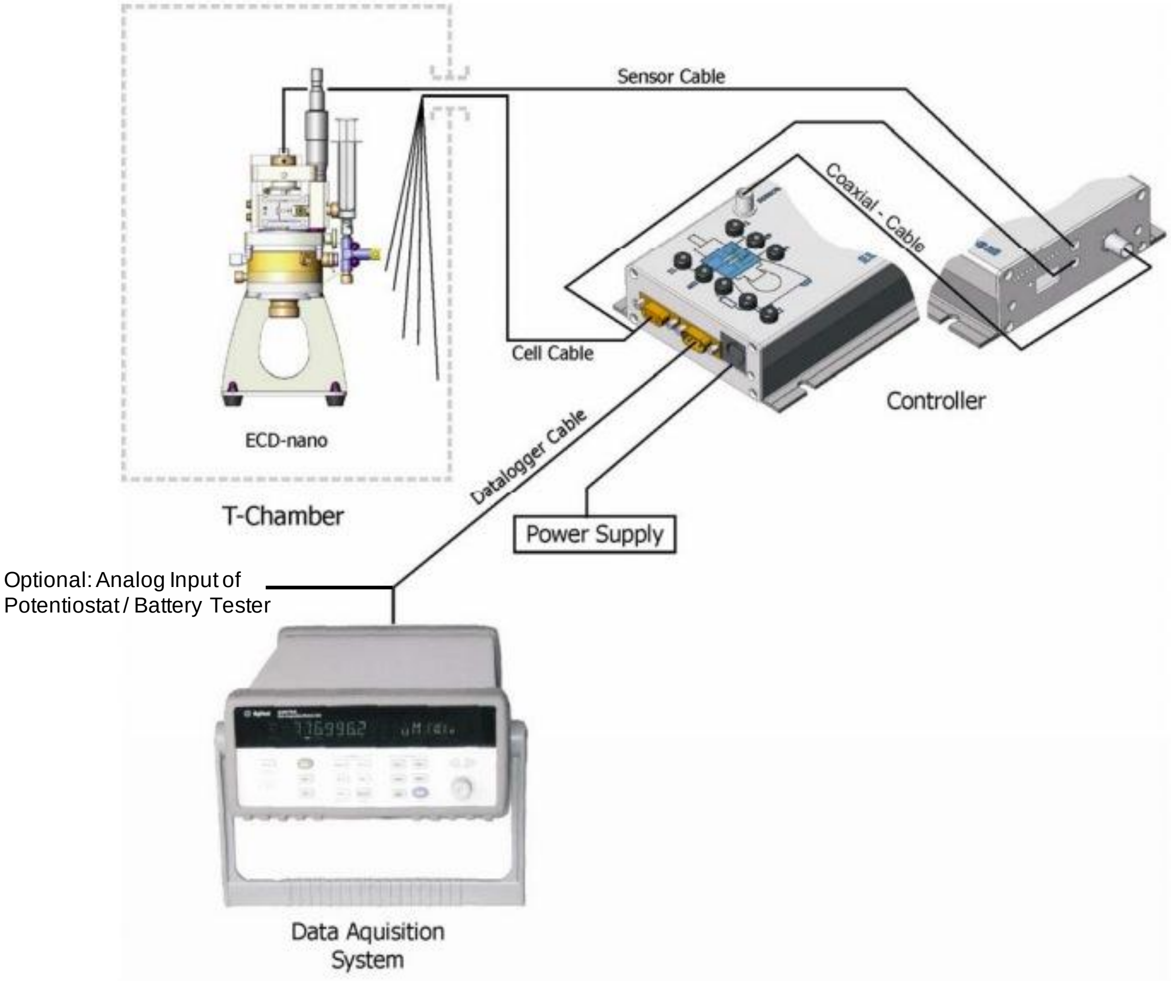
Fasten the carriage securing screw



5.2 Running the Experiment



Connection Diagram

1. Place the ECD-nano inside a temperature controlled chamber, at a constant temperature between -20 to +80°C.
2. Establish all electrical connections between dilatometer, controller, and data logger according to the diagram given above.
3. Connect your potentiostat or battery tester to the 4 mm jacks on the front panel of the controller box. Refer to the table given below.

Controller Box	Potentiostat
I2	CE
REF	REF
I1	WE Current
V1	WE Sense

4. Connect the 2mm banana plugs of the cell cable to the dilatometer cell. Refer to the photo on page 17.

   The displacement signal can be recorded via the data logger, or, if available, by an analog input of the potentiostat that is used for charging the electrochemical cell. It is also possible to record the displacement signal simultaneously on both the data logger and the potentiostat. Two analog output signals V_1 and V_2 are provided by the controller box. The slope $\Delta h/\Delta V_1$ of signal V_1 is to be adjusted via the DIP switches on the controller box.

Switch 1 = ON, 2 = OFF: $(\Delta h/\Delta V)_1$ = 5 µm/V, full range = 100 µm (Default)

Switch 1 = OFF, 2 = ON: $(\Delta h/\Delta V)_1$ = 2 µm/V, full range = 250 µm

Signal V_2 is related to signal V_1 by a settable gain G of 1, 2, 5 or 10. $(\Delta h/\Delta V)_2 = (\Delta h/\Delta V)_1$ / G. By default, G = 5. A DIP switch inside the controller box serves to set the gain. Consult EL-CELL for more instructions.

5.1 Recording the displacement signal with the data logger

The standard version of the ECD-nano comes with the Agilent 34970A data logger and the associated Benchlink software application. The data logger has to be configured to record the displacement signal along with the cell current, the electrode potentials, and the temperature inside the chamber. Set up the data logger's channel list according to the screenshot given below. For software installation and data logger operation refer to the separate instructions coming along with the data logger.

Configure Instruments | Configure Channels | Scan and Log Data | Schnelldiagramm

Channels	Enable Channel		Measurement				Scaling (Mx+B)			
Instruments	Scan	Name	Function	Range	Res	More	Scale	Gain (M)	Offset(B)	Label
1. Not Connected										
34901A										
101	☑	Sensor Voltage	DC Voltage	Auto	6.5	More	☐	1	0	VDC
102	☑	Shunt Voltage	DC Voltage	Auto	6.5	More	☐	1	0	VDC
103	☑	Cell Voltage 1 vs 2	DC Voltage	Auto	5.5	More	☐	1	0	VDC
104	☑	WE Potential 1 vs REF	DC Voltage	Auto	5.5	More	☐	1	0	VDC
105	☑	CE Potential 2 vs REF	DC Voltage	Auto	5.5	More	☐	1	0	VDC
106	☐	AUX Potential AUX vs REF	DC Voltage	Auto	5.5	More	☐	1	0	VDC
107	☑	Temperature	Temp 4-Wire RTD	None	C	More	☐	1	0	C
108	☐	Sensor Voltage x 10	DC Voltage	Auto	6.5	More	☐	1	0	VDC
109	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
110	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
111	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
112	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
113	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
114	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
115	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
116	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
117	☐	Temperature	Temp 4-Wire RTD	None	C	More	☐	1	0	C
118	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
119	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
120	☐		DC Voltage	Auto	5.5	...	☐	1	0	VDC
121	☐		DC Current	Auto	5.5	...	☐	1	0	ADC
122	☐		DC Current	Auto	5.5	...	☐	1	0	ADC
Computed Channel										
901		Displacement	Multiply	101	1	....	☑	5E-06	0	M
902		Cell Current	Multiply	102	1	....	☑	0.01	0	ADC

For best precision, set the resolution of channels 101, 102 and 107/117 to 6.5 digits (10 NPLC). Notice the impact of the resolution chosen and the number of channels activated on the maximum scanning speed of the data logger. At optimum precision and when all channels in the scan list are check marked, the scanning speed is limited to approximately 0.5 Hz (2 seconds each scan).

Channel 102/902: To record the cell current, the voltage drop across a 100 Ohm resistor looped into the CE supply line is fed to channel 102. The 100 Ohm (1 Watt, 1%) resistor is located inside the controller box and is protected against overload by a 100 mA fuse. Both the resistor and the fuse can be replaced as necessary.

For convenience, add two computed channels to the data logger’s scan list in order to directly display the electrode displacement in meters and the cell current in Amperes. Refer to the two computed channels at the bottom of the scan list shown above.

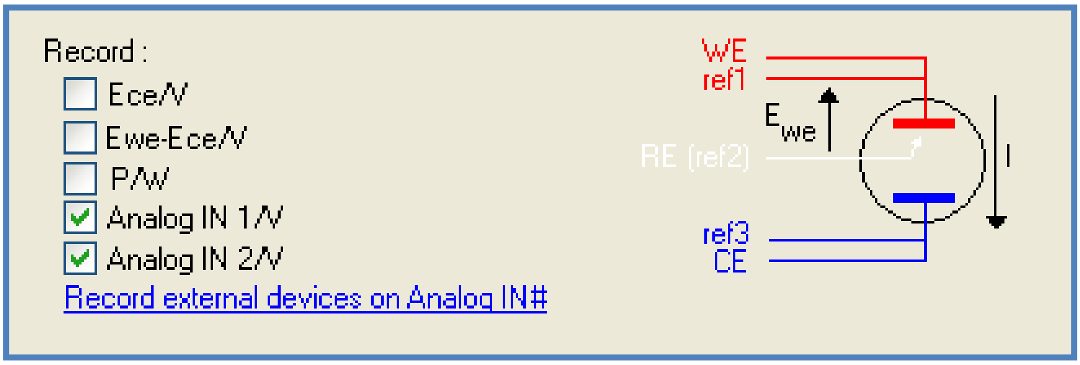
Channels 107/117: These two channels are configured to measure the temperature by means of a 4-wire Pt100 sensor that is located inside the cell cable terminal close to the dilatometer.

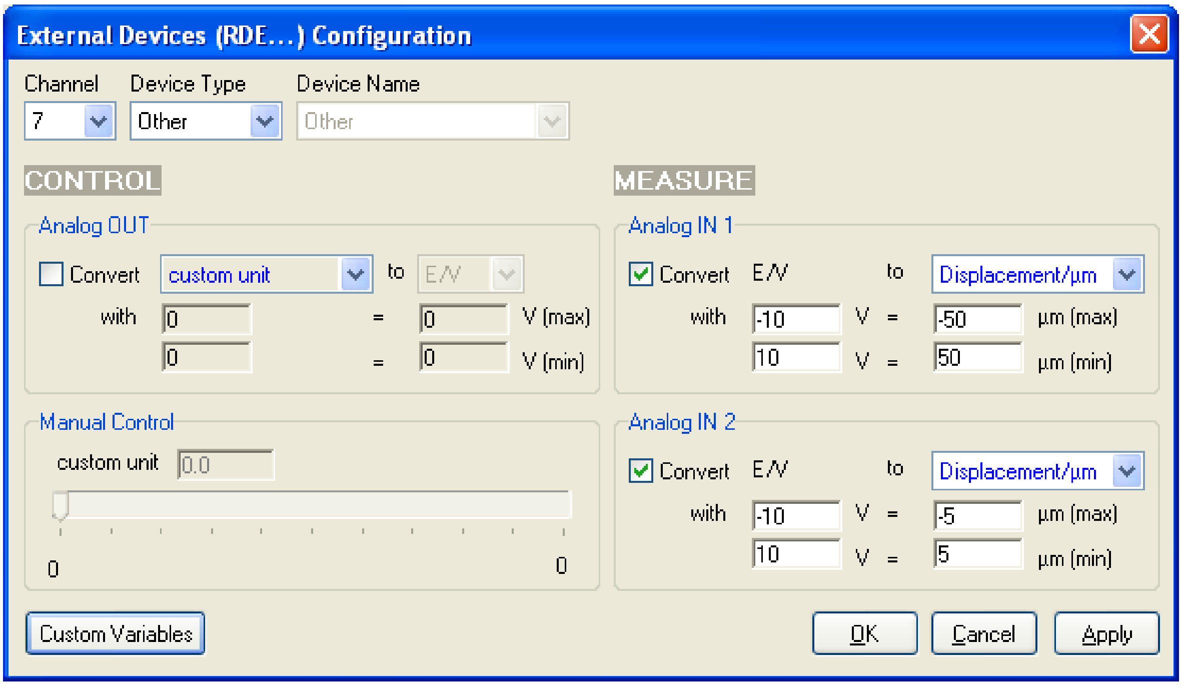
5.2 Recording the displacement signal via the potentiostat (Optional)

Many battery testers and potentiostats provide additional analog input channels that may be used to record the displacement signal along with cell current and potential. In the following, connection of the ECD-nano to the Biologic VMP3 is described. Adaption to many other potentiostats is possible as well.

I. Connect the 9-pin Sub-D connector of the data logger cable to the analog input of the respective VMP3 channel.

II. Edit the cell characteristics settings of the channel so as to record either one or both of the two analog inputs. Refer to the screenshot from the Biologic EC-Lab software given below. Analog IN1 is connected to the displacement sensor voltage V_1, Analog IN2 to the amplified sensor voltage V_2 with a settable gain of 1, 2, 5 or 10. By default the gain is set to $V_2/V_1 = 5$.





6. Start the electrochemical protocol. We recommend applying the charging profile only after an open-circuit settling period to allow for baseline stabilization. Following this procedure helps to discern charging induced dimensional changes from creeping.

   NOTE: All materials display a more or less pronounced creeping. They tend to shrink after applying a load, and to swell when removing this load. Creeping of the working electrode is initially induced when applying the load. It is also induced each time the mechanical properties of the working electrode are significantly altered by charging. Therefore, each charging induced height change is followed by some creeping. Both the initial and the charging induced creeping effects are real and not artefacts of the measurement.

5.3 ECD-nano Disassembly

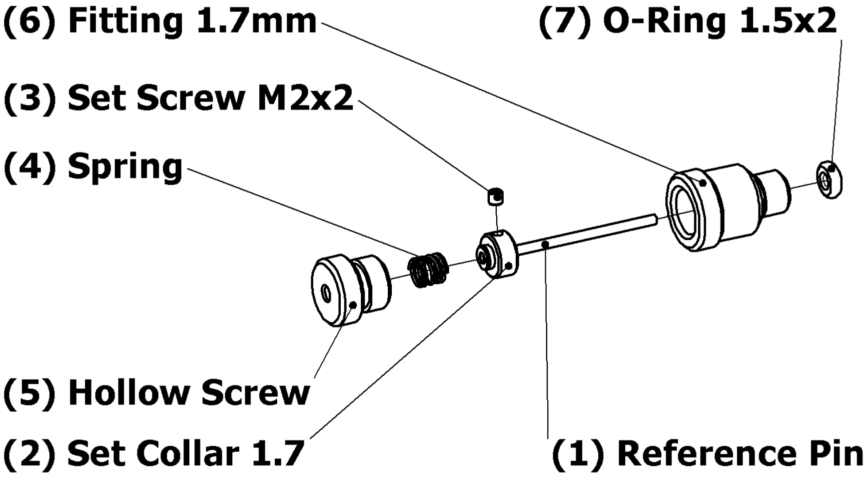
1. Switch off the potentiostat and disconnect the power supply of the controller box. Disconnect all cables from the dilatometer. Then remove the instrument from the temperature chamber.
2. Lock the flexure guide by turning the locking screw 90° clockwise
3. Release the carriage securing screw, move the carriage upwards by turning the micrometer screw clockwise, and fasten the carriage securing screw again.

   NOTE: This step is required to safely prevent damage upon re-assembly with a much thicker sample. Experienced users may discard this step when always using samples with similar thickness.
4. Detach the sensor/load unit.
5. Remove the plug from the cell body, and open the syringe valve. Then draw any free electrolyte back into the syringe, and close the syringe valve.
6. Detach the cell from the bracket.
7. Detach the reference electrode.
8. Disconnect the tubing from the valves and from the cell.
9. Remove the cover flange, the metal membrane, the spacer disc, and the working electrode.
10. Unscrew the counter electrode spring load.
11. Unfasten the cell body, and remove the T-frit from the cell body.

    NOTE: Take care not to jam or break the frit. The frit may accidentally slip out of the cell body.
12. Clean all wetted parts right after disassembly. Ultrasonic cleaning with detergent wash is recommended. Purge valves and tubing with the aid of a syringe. Dry all parts immediately after cleaning in vacuum at 80°C overnight. It is highly recommended to additionally dry two of the cell parts, cell body and cell bottom, in vacuum at 150°C overnight. Absorbed moisture may otherwise adversely affect test results.

5.4 Using the Reference Electrode

The reference electrode assembly is comprised of the reference pin (1), the set collar (2) attached to the pin by means of a set screw (3), the fitting (6), the spring (4), and the hollow screw (5), cf. the sketch below. The hollow screw serves to apply the spring pressure on the set collar, thereby gently pushing the reference pin against the glass frit. The blind bore on the tip of the reference pin is intended for taking up the reference electrode material. For most lithium ion chemistries the reference material may be a small piece of lithium metal picked up by the reference pin. For other aprotic electrolytes, and also for some aqueous systems, a piece of PTFE bound activated carbon may serve as the (pseudo) reference material. The optional gold reference pin is recommended for use in aqueous electrolytes. **NOTE**: Do not use the gold reference pin in combination with lithium metal.



5.5 Using an Auxiliary Electrode

As an option, the ECD-nano may be equipped with an additional electrode face to face with the reference electrode. This auxiliary electrode may be a second reference electrode, or simply a bare metal wire. For instance, in aqueous solutions, a platinum wire auxiliary electrode may be cycled against the counter electrode to determine the actual electrode potential of a simultaneously attached pseudo reference electrode. The auxiliary electrode assembly is virtually identical with the reference electrode assembly, except that the reference pin is replaced by a metal wire with 1.5 or 1.6 mm diameter.

5.6 Using Single Crystals or Grains as the Working Electrode

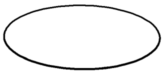
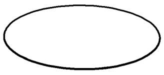
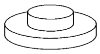
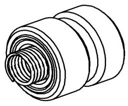
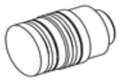
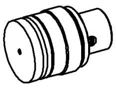
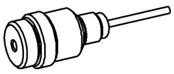
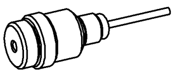
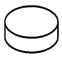
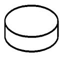
As an option, the ECD-nano may be loaded with a single crystal or grain as the working electrode. For this purpose, the ball tip of the sensor/load unit is to be replaced by a flat tip, and the membrane is directly placed on top of the crystal, without the spacer disc in between. More detailed instructions come with the optionally available Part Kit for Single Crystals.

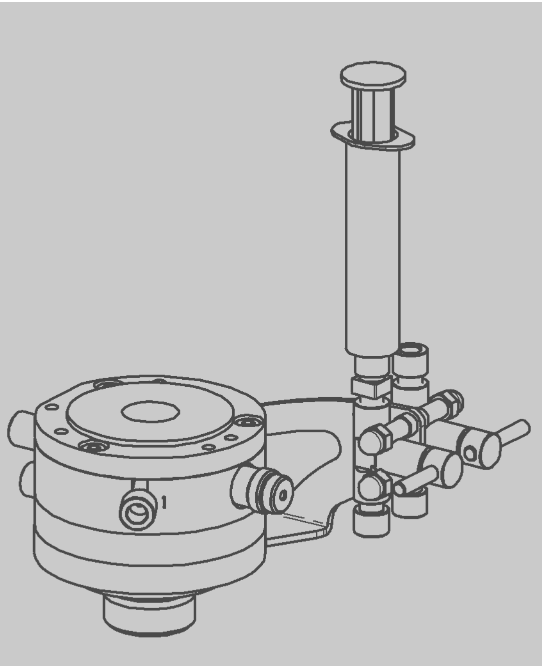
5.7 Using Powder-Type Working Electrodes

The ECD-nano is also capable of using binder-free powders as the working electrode. Simply place a separator on top of the glass frit (to prevent contamination of the frit), and subsequently a small amount of the powder, appr. 5 to 15 mg. Just as for the measurements of single grains, cover the sample directly with the metal membrane, and use the sensor/load unit equipped with the flat tip (Part kit for Single Crystals). Filling the cell by the syringe/ vacuum technique prevents that loose powder is flushed away during the filling procedure.

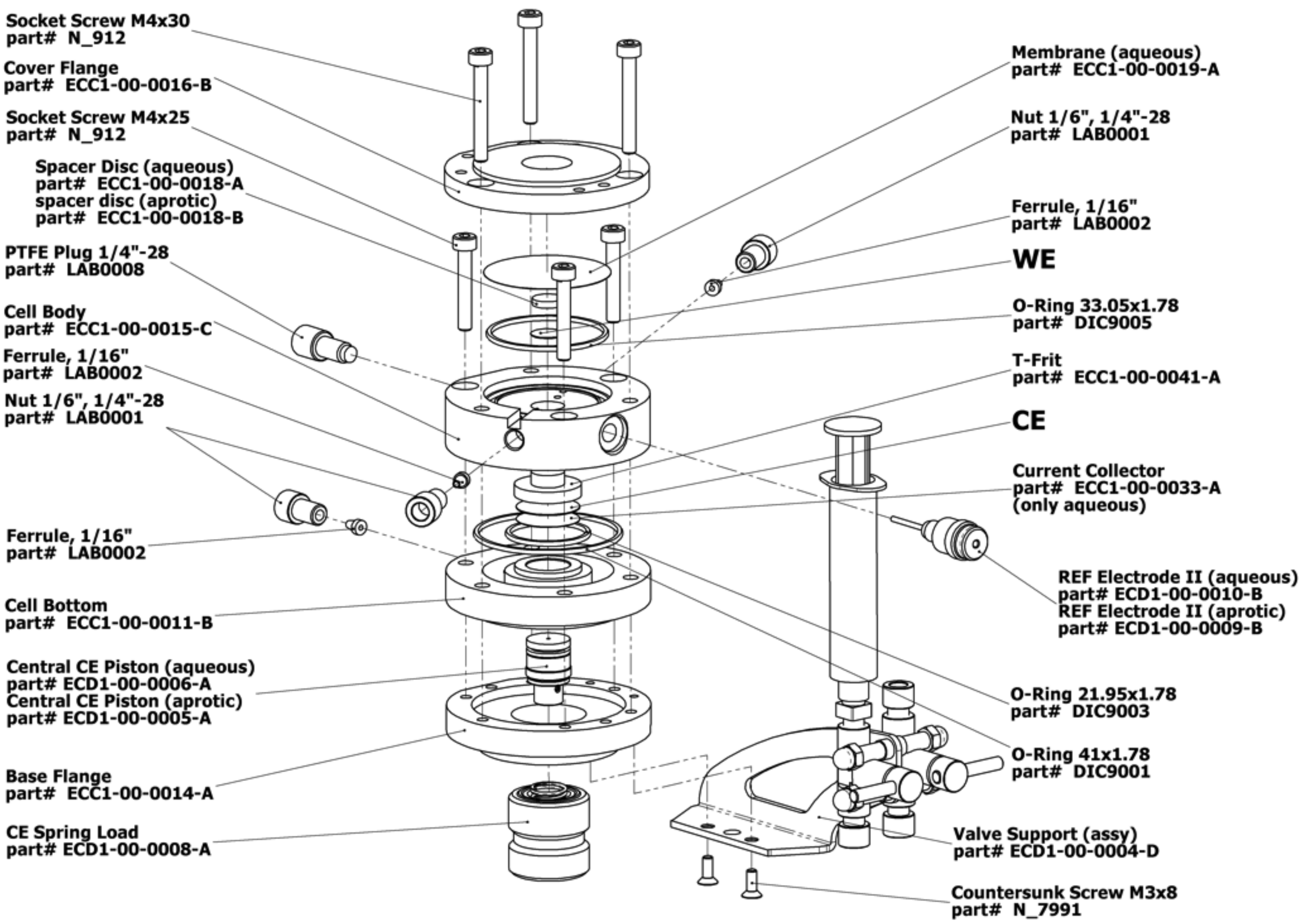
NOTE: Make sure that the sample has sufficient electronic conductivity, and that the contact resistance between sample and membrane is tolerable. An additional interlayer (e.g. gold foil for aqueous, carbon coated aluminium or copper foil for aprotic electrolytes) between sample and membrane may reduce the contact resistance drastically.

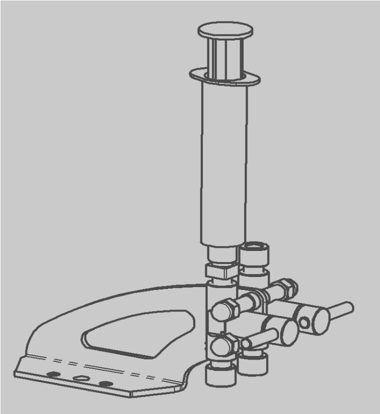
6 Accessories and Spare Parts

	ECC1-00-0019-C	membrane (aprotic)	stainless steel 316L
	ECC1-00-0019-A	membrane (aqueous)	gold
	ECD1-00-0014-A	Part Kit "Sealings"	
	ECC1-00-0041-A	T-Frit (20/10)	Duran sinter glass (poros. 3)
	ECD1-00-0018-A	Part Kit for single crystal WE	
	ECD1-00-0008-B	CE Spring Load II	
	ECD1-00-0005-B	Central CE Piston II (aprotic)	1.4404
	ECD1-00-0006-B	Central CE Piston II (aqueous)	PEEK/1.4305/ gold
	ECC1-00-0033-A	Current Collector	gold
	ECD1-00-0013-A	Part Kit "Flexure Unit"	
	ECD1-00-0015-A	Part Kit "Screws"	
	ECD1-00-0017-B	Part Kit "Springs" II	
	ECD1-00-0016-A	Part Kit "Tubings"	
	ECD1-00-0010-B	Reference Assembly (aqueous) UNF1/4"-28	gold
	ECD1-00-0009-B	Reference Assembly (aprotic) UNF1/4"-28	1.4430
	ECC1-00-0018-B	2 mm spacer disk (aprotic)	stainless steel 316L
	ECC1-00-0018-A	2 mm spacer disk (aqueous)	gold
	ECD1-00-0020-A	Terminal board with 2nd Data Logger Cable	

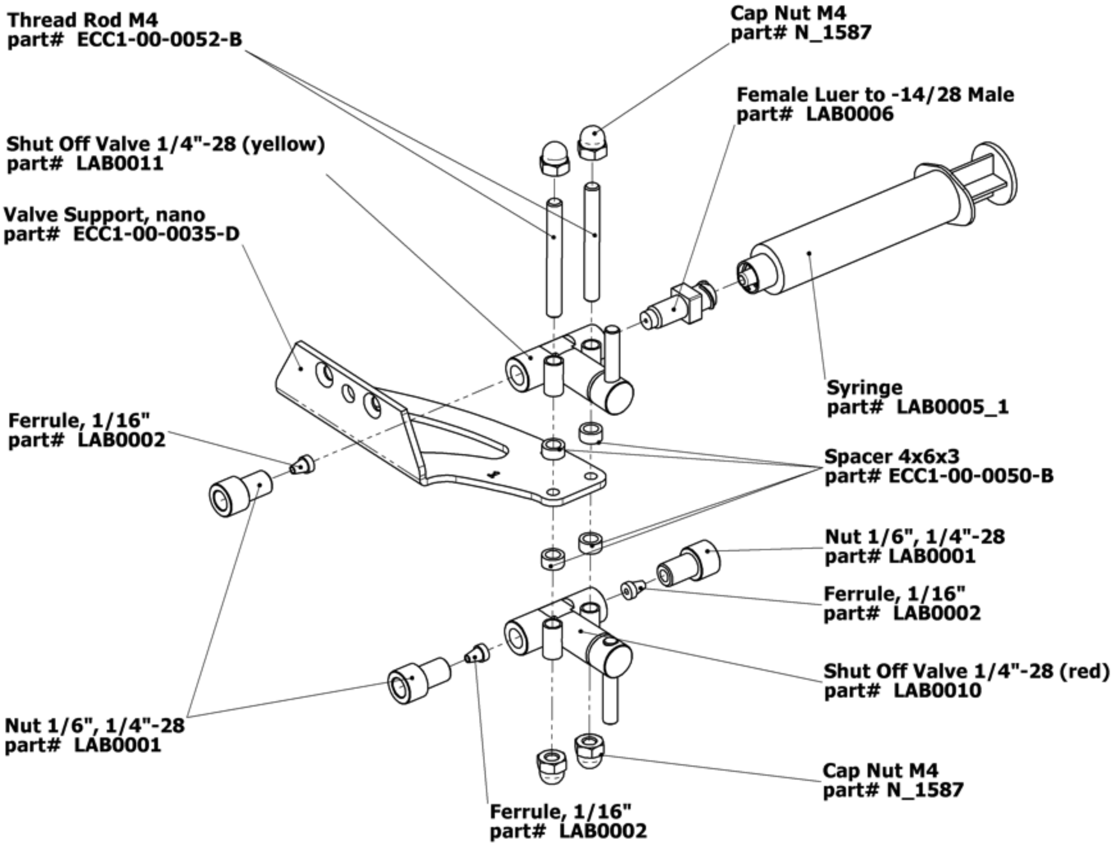


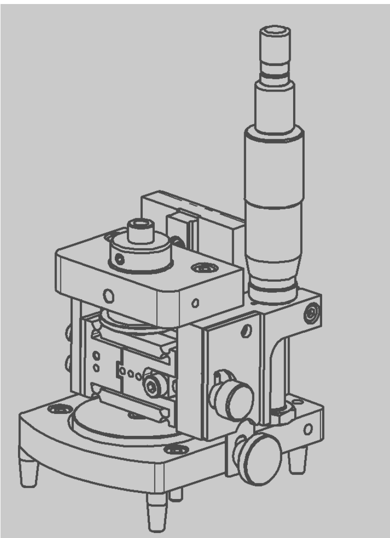
Cell II (assy)
part# ECD1-00-0002-D





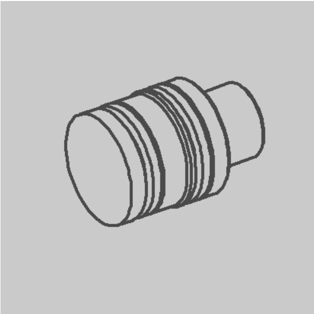
Valve Support III (assy)
part# ECD1-00-0004-D



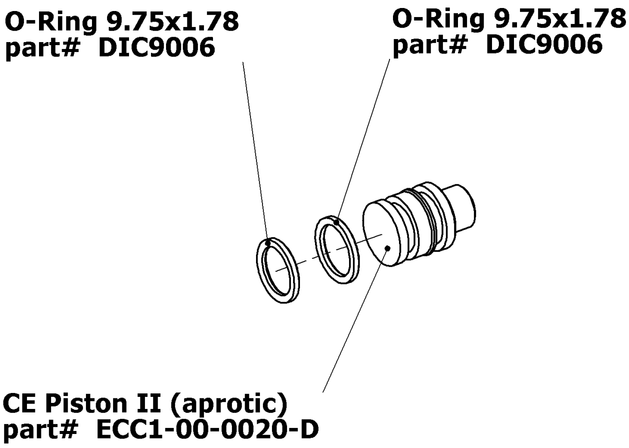


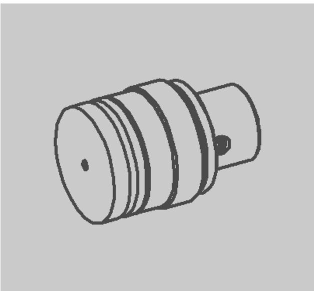
Sensor unit
part#   ECD1-00-0030-A

Note: This unit must not be disassembled by the user.
For repair, always send back the whole sensor/load unit.
Single spare parts for this unit are not available.

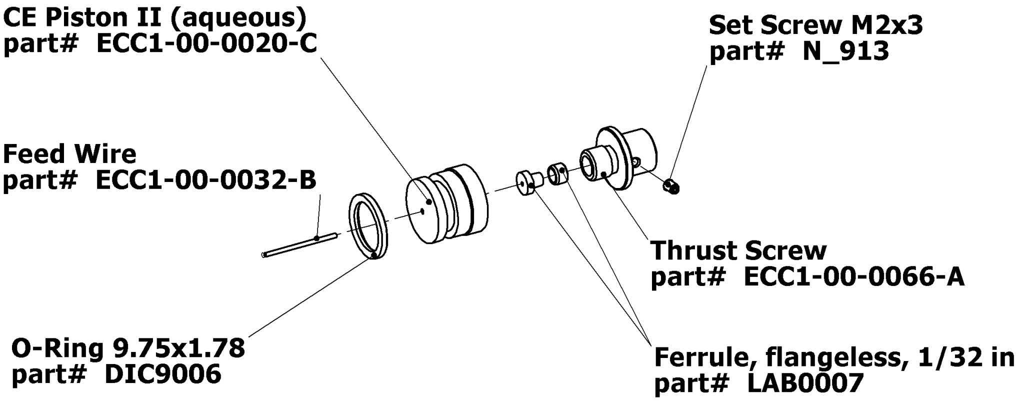


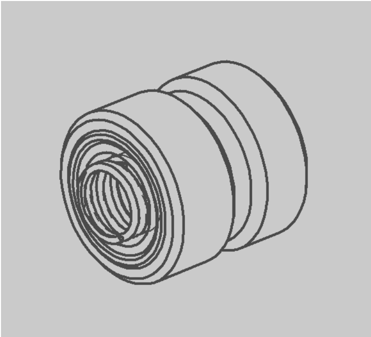
Central CE Piston II (aprotic)
part#   ECD1-00-0005-B



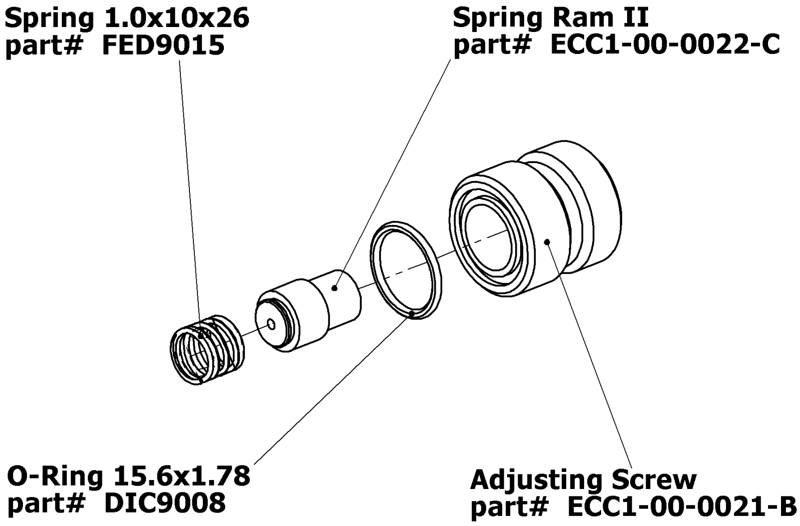


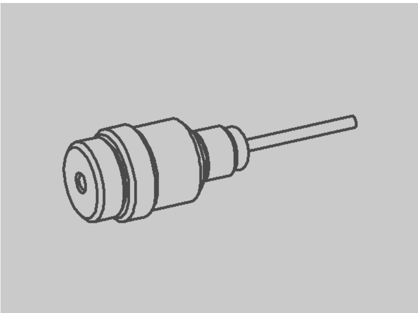
Central CE Piston II (aqueous)
part#   ECD1-00-0006-B





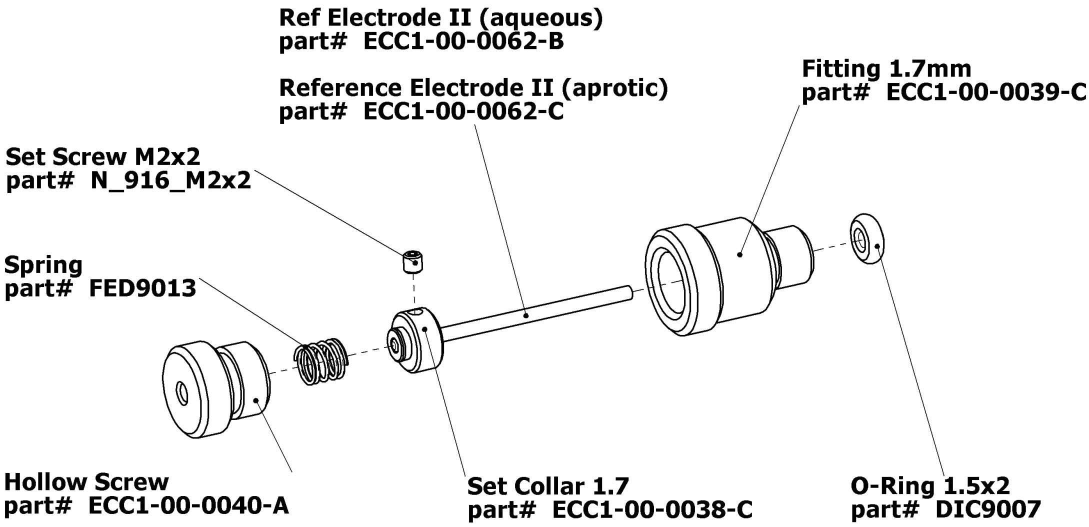
CE Spring Load II
part# ECD1-00-0008-B





Reference Electrode II (aqueous)
part# ECD1-00-0010-B

Reference Electrode II (aprotic)
part# ECD1-00-0009-B



7 Connector and Cable Pin-out

Cell Cable (8 x 2 TP, shielded)

One end of the cable is terminated with a Sub-D HD M15 connector (to box); the other end is terminated with 2 mm banana connectors (to ECD-nano cell).

Pin #	Signal	Cable Color	Color of 2mm Connector
1	V1	Red	red
2	V2	Blue	blue
3			
4	REF	Grey	black
5	I2	Yellow	yellow
6	AUX	Pink	black
7			
8			
9			
10	I1	Green	green
11	Pt100(1)	Violet	(R2)
12	Pt100(2)	Black	(R1)
13	Pt100(3)	White	(R1)
14	Pt100(4)	Brown	(R2)
15			

Data Logger Cable (8x2 TP, shielded)

One end of the cable is terminated by a Sub-D HD F15 connector (to box); the other end is terminated by the multiplexer card of the data logger.

Pin #	Signal	Cable Color	Logger Channel
1	V1	Red	#3HI, #4HI
2	V2	Blue	#3LO, #5HI
3	RA	brown/green	#2LO
4	REF	grey	#4LO, #5LO, #6LO
5	Sensor Signal 1	green	#1LO
6	AUX	pink	#6HI
7	RB	White/green	#2HI
8			
9			
10	AGND	yellow	#1HI, #8HI
11	Pt100(1)	violet	#7HI
12	Pt100(2)	black	#7LO
13	Pt100(3)	white	#17LO
14	Pt100(4)	brown	#17HI
15	Sensor Signal 2	white/yellow	#8LO

Analog Output Cable (2x2, shielded)

Optionally, the datalogger cable is split into a second cable that is terminated with a Sub-D M9 connector. This connector fits directly into the auxiliary input connector of the Biologic VMP3 potentiostat. Adaption to other second-party instrumentation is available on request. Note that two displacement signals are provided to the potentiostat, one with unity gain, one with a gain of 10.

Pin #	Signal	Cable Color	VMP3 AUX connector
1	Sensor Signal 1	green	Analog IN1
2	-		
3	-		
4	-		
5	-		
6	Sensor Signal 2	white	Analog IN2
7	GND	brown	GND
8	-		
9	-		

8 Maintenance

Right after finishing an experiment, disassemble the instrument, dispose the electrodes, and clean all parts that have been in contact with electrolyte. Depending on the electrolyte and electrodes used, the wetted parts may be cleaned with water, dilute detergent wash, ethanol or acetone. Ultrasonic cleaning is recommended. Dry all parts immediately after cleaning in vacuum at 80°C overnight. It is highly recommended to additionally dry cell body and cell bottom in vacuum at 150°C overnight. Absorbed moisture may otherwise adversely affect test results. Check O-ring seals and the T-frit visually for damage and replace as necessary.

9 Technical Support

Technical support for this product is exclusively handled by EL-Cell GmbH.
The following procedure must be followed when the ECD-nano or any part of it is returned to EL-Cell GmbH for repair:

1. Send an e-mail to info@el-cell.com to obtain a return authorization number and a decontamination report form.
2. Sign the decontamination report asserting that the instrument has been decontaminated and is safe for technicians to work on it.
3. Describe in detail what is wrong.
4. Include a contact name, address, telephone number, and email address.
5. Return the instrument to

EL-Cell GmbH
Tempowerkring 7
D-21079 Hamburg
Germany
Email info@el-cell.com

10 Warranty

For a period of one year from the date of shipment, EL-Cell GmbH (hereinafter Seller) warrants the goods to be free from defect in material and workmanship to the original purchaser. During the warranty period, Seller agrees to repair or replace defective and/or nonconforming goods or parts without charge for material or labour, or, at the Seller's option, demand return of the goods and tender repayment of the price. Buyer's exclusive remedy is repair or replacement of defective and nonconforming goods, or, at Seller's option, the repayment of the price.

Seller excludes and disclaims any liability for lost profits, personal injury, interruption of service, or for consequential incidental or special damages arising out of, resulting from, or relating in any manner to these goods.

This Limited Warranty does not cover defects, damage, or nonconformity resulting from abuse, misuse, neglect, lack of reasonable care, modification, or the attachment of improper devices to the goods. This Limited Warranty does not cover expendable items. This warranty is void when repairs are performed by a non-authorized person or service center. At Seller's option, repairs or replacements will be made on site or at the factory. If repairs or replacements are to be made at the factory, Buyer shall return the goods prepaid and bear all the risks of loss until delivered to the factory. If Seller returns the goods, they will be delivered prepaid and Seller will bear all risks of loss until delivery to Buyer. Buyer and Seller agree that this Limited Warranty shall be governed by and construed in accordance with the laws of Germany.

The warranties contained in this agreement are in lieu of all other warranties expressed or implied, including the warranties of merchantability and fitness for a particular purpose.

This Limited Warranty supersedes all prior proposals or representations oral or written and constitutes the entire understanding regarding the warranties made by Seller to Buyer. This Limited Warranty may not be expanded or modified except in writing signed by the parties hereto.