

USER MANUAL

# Spectronus

Trace Gas & Isotopes Analyser

Version: 3.15

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## Manufacturer's Statement

Thank you for selecting the Acoem Australasia Spectronus Trace Gas & Isotopes Analyser.

The instrument uses Fourier Transform Infrared (FTIR) spectroscopy to quantify the mixing ratios of several trace gas species (including CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, CO, H<sub>2</sub>O, as well as  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  in CO<sub>2</sub> and optionally  $\delta\text{D}$  and  $\delta^{18}\text{O}$  in H<sub>2</sub>O vapour). When used in conjunction with micrometeorological and chamber systems it can be used to estimate the fluxes of these gases to and from the atmosphere [Citation: Chapter 8, Point 3].

This User Manual provides a complete product description including operating instructions, calibration and maintenance requirements for the Spectronus Trace Gas & Isotopes Analyser.

Reference should also be made to the relevant local standards, which should be used in conjunction with this manual. Some relevant standards are listed in the References section of this manual.

If, after reading this manual you have any questions or you are still unsure or unclear on any part of the Spectronus then please do not hesitate to contact Acoem Australasia or your local Acoem distributor.



Please help the environment and recycle any printed pages of this manual when finished using it.

## Notice

The information contained in this manual is subject to change without notice. Acoem Australasia reserves the right to make changes to equipment construction, design, specifications and/or procedures without notice.

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This work is copyright. Apart from any use permitted under the Copyright Act 1968, no part may be reproduced by any process, nor may any other exclusive right be exercised, without the permission of Acoem Australasia, 1492 Ferntree Gully, Road Knoxfield VIC, 3180, copyright © 2024.

## Safety Requirements

Read all the safety information in this section prior to using the equipment. To reduce the risk of personal injury caused by potential hazards, follow all safety notices and warnings in this documentation.

The following internationally recognised symbols are used on Acoem Australasia equipment:

**Table 1 – Internationally Recognised Symbols**

	ON (Supply)	IEC 60417-5007
	OFF (Supply)	IEC 60417-5008
	Electrical fuse	IEC 60417-5016
	Earth (ground) terminal	IEC 60417-5017
	Protective conductor terminal	IEC 60417-5019
	Alternating current	IEC 60417-5032
	Caution, hot surface	IEC 60417-5041
	Caution, risk of danger. Refer to accompanying documents	ISO 7000-0434
	Caution, risk of electric shock	ISO 3864-5036

These symbols will also be found throughout this manual to indicate relevant safety messages.

**Note:** Notes are used throughout this manual to indicate additional information regarding a particular part or process.

## Important Safety Messages

To reduce the risk of personal injury caused by electrical shock, follow all safety notices and warnings in this documentation.

If the equipment is used for purposes not specified by Acoem Australasia, the protection provided by this equipment may be impaired.

The safety of any system incorporating the equipment is the responsibility of the assembler of the system.

Replacement of any part should only be carried out by qualified personnel, using only parts specified by Acoem Australasia as these parts meet stringent Acoem Australasia quality assurance standards. Always disconnect the power source before removing or replacing any components.



### CAUTION

Hazardous voltages exist within the analyser. All analyser panels should be closed and secured when the analyser is connected to the mains power. Ensure the power cord is maintained in a safe working condition.



### CAUTION - Magnesium Perchlorate

The chemical dryer should be filled with magnesium perchlorate supplied by the user. Magnesium perchlorate is a hazardous substance that has particular safety and shipping requirements and is not allowed on an aircraft. The user must obtain and adhere to the directions from the supplier's material safety data sheet (MSDS) for magnesium perchlorate. The user must not ship the magnesium perchlorate dryer with the instrument.



### CAUTION - Heavy

The analyser is heavy and should not be manually lifted. It should only be lifted by an appropriate mechanical lifting aid, such as a fork lift (entire unit) or appropriately rated electric lift trolley (individual module).



### CAUTION

Laser radiation exists within the IRcube. Never look directly into the laser beam, or use any kind of optical instruments to look into the beam as this may cause permanent eye damage. Refer to the IRcube manual.



### CAUTION - Front Rails must Remain in Place

Module outer case front rails must be secured in place when the module is in the case.



### CAUTION

Earth strap must be secured to the outer case for both Auxiliary module and Optical module before turning ON the power. Failure to secure the earth strap will mean that the outer case will not be properly earthed.

## Warranty

This product has been manufactured in an ISO 9001 facility with care and attention to quality.

The product is subject to a 12-month warranty on parts and labour from date of shipment (the warranty period). The warranty period commences when the product is shipped from the factory. Lamps, fuses, batteries and consumable items are not covered by this warranty.

Each analyser is subjected to a vigorous testing procedure prior to despatch and will be accompanied with a test results for Allan Variance, Cross-Sensitivities and Multipoint Calibration thereby enabling the analyser to be installed and ready for use without any further testing.

## Service & Repairs

Our qualified and experienced technicians are available to provide fast and friendly service between the hours of 8:30 am - 5:00 pm AEST Monday to Friday. You are welcome to speak to a service technician regarding any questions you have about your instrument.

### Service Guidelines

This manual is designed to provide the necessary information for the setup, operation, testing, maintenance, and troubleshooting of your instrument.

Should you still require support after consulting the documentation, we encourage you to contact your local distributor for support.

To contact Acoem Australasia directly, please e-mail our Technical Support Specialist group at [support.au@acoem.com](mailto:support.au@acoem.com) or to speak with someone directly:

Please dial 1300 364 946 if calling from within Australia

Please dial +61 3 9730 7800 if calling from outside of Australia

Please contact Acoem Australasia and obtain a Return Material Authorization (RMA) number before sending any equipment back to the factory. This allows us to track and schedule service work and to expedite customer service. Please include this RMA number when you return equipment, preferably both inside and outside the shipping packaging. This will ensure you receive prompt service.

When shipping instrumentation, please also include the following information:

- Name and phone number
- Company name
- Shipping address
- Quantity of items being returned
- Model number/s or a description of each item
- Serial number/s of each item (if applicable)
- A description of the problem and any fault-finding completed
- Original sales order or invoice number related to the equipment

#### **Shipping Address:**

Attention Service Department

Acoem Australasia

1492 Ferntree Gully Road,

Knoxfield, VIC, Australia 3180

## Product Compliance and Approvals

The Spectronus Trace Gas & Isotopes Analyser, as manufactured by Acoem Australasia, complies with the essential requirements of the directives listed below (including CE compliance). The respective standards have been applied:



### Low Voltage Directive (LVD) Directive 2014/35/EU

**EN 61010-1:2010**

Safety requirements for electrical equipment, for measurement, control and laboratory use - General requirements

### Electromagnetic Compatibility (EMC) Directive 2014/30/EU

**EN 61326-1:2013**

Electrical equipment for measurement, control and laboratory use - EMC requirements - General requirements

### Radio Equipment Directive (RED) 2014/53/EU

**EN 300 328 V2.1.1**

Wideband transmission systems - Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques



### Regulatory Compliance Mark (RCM) - Australia

**AS/NZS 4268:2017**

Radio equipment and systems - Short range devices - Limits and methods of measurement

**ARPANSA  
Radiation Protection Standard**

Maximum Exposure Levels to Radiofrequency Fields - 3 kHz - 300 GHz - Radiation Protection Series Publication No. 3: 2002

## Manual Revision History

Manual PN: M010042  
 Current revision: 3.15  
 Date released: 10 October 2024  
 Description: User Manual for the Spectronus Trace Gas & Isotopes Analyser

This manual is the full user manual for the Spectronus Trace Gas & Isotopes Analyser. This manual contains all relevant information on theory, specifications, installation, operation, maintenance and calibration. Any information that cannot be found within this manual can be obtained by contacting Acoem Australasia.

This manual uses cross reference links extensively throughout this manual. The hot keys below will greatly reduce the amount of time scrolling between references:

- You can access the links by pressing the following:  
     CTRL + LEFT MOUSE CLICK: Move to the link location
- You can switch between links by pressing the following:  
     ALT + LEFT ARROW KEY: Returns you to previous Link  
     ALT + RIGHT ARROW KEY: Swaps back

**Table 2 – Manual Revision History**

Edition	Date	Summary
3.4	November 2011	First release of Acoem Australasia manual
3.5	July 2012	Changed file and path names and screenshots and plumbing diagram and analog input numbers and pictures
3.6	September 2012	Changed references from OPUS 6.5 to OPUS 7 and Spectronus 9.0.5
3.6	September 2012	110 V version, Analysis time from 15 - 20s (4 windows), 2 <sup>nd</sup> MFC updates, Software supplied, CSV files, Initial Start-up, 4 - 20 mA input description corrected. Sections references cross-referenced
3.7	March 2013	Changed equation numbering. Added spare parts section
3.8	May 2013	Added more spare parts. Re-arranged order of sections. Updated plumbing and software diagrams. Added precision checks, leak check, MFC Zero check & adjust, opening the case sections. Changed Analysis time from 20 - 13s (MALT 5.2.2)
3.9	July 2013	Added warnings to remove magnesium perchlorate before shipping. Removed most second person references. dXdP cycle description. Removed optional last

Edition	Date	Summary
		¼ powder dryer, now all granules. Added correct to dry air in ppm equation
3.10	October 2013	Manual part #, Windows 7, new hardware, separation of hardware and v10 software manual. Quick-connectors explained. OPUS OVP description added. CE compliance
3.11	August 2016	Added description for COM2 on the front panel. Changed N <sub>2</sub> flow rate to 0.08 LPM. Added some metal cell setup pics and description and sample temperature 35 °C. Referred to COM3 for TE Cooler and COM4 for Metal Cell heaters.
3.12	NA	Was mislabelled as 3.11
3.13	May 2021	Converted to Rackmount version without TE Cooler and revised Calibration section.
3.14	January 2022	Added TE Cooler option, CE compliance, strip interpretation and cell cleaning.
3.15	August 2024	Added a step in section 2.4.2: Chemical dryer and glass wool will be securely packaged within a Ziploc bag. Also, updated references from COM 1 to COM 6.

---

# 1. Introduction

---

## 1.1 Description

---

This document contains information about the operation, construction and technical details of the Acoem Australasia Trace Gas & Isotopes Analyser. This analyser has been developed by the Centre for Atmospheric Chemistry at the University of Wollongong and improved and manufactured by Acoem Australasia.

The analyser uses Fourier Transform Infrared (FTIR) spectroscopy to quantify the mole fractions of several trace gas species (including CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, CO, H<sub>2</sub>O, as well as δ<sup>13</sup>C and δ<sup>18</sup>O in CO<sub>2</sub> and optionally δD in H<sub>2</sub>O vapour). When used in conjunction with micrometeorological and chamber systems it can be used to estimate the fluxes of these gases to and from the atmosphere [Citation: Chapter 8, Point 3].

Throughout this document it is assumed that the user is familiar with basic principles of infrared spectroscopy, specifically FTIR spectroscopy, and if required, the methods used to determine trace gas exchange fluxes at the earth's surface. The primary purpose of this document is to provide a user guide and technical manual of the system components and their interconnection to facilitate the orientation of new users to system operation.

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## 1.2 Specifications

---

### 1.2.1 Measurement Metal Cell

Gases	Precision (5 min average)
CO <sub>2</sub> μmol mol <sup>-1</sup>	< 0.02
CH <sub>4</sub> nmol mol <sup>-1</sup>	< 0.15
N <sub>2</sub> O nmol mol <sup>-1</sup>	< 0.1
CO nmol mol <sup>-1</sup>	< 0.15
δ <sup>13</sup> C - CO <sub>2</sub> /‰	< 0.04*
δ <sup>18</sup> O - CO <sub>2</sub> /‰	0.4*
δD in water vapour/‰	1
δ <sup>18</sup> O in water vapour/‰	0.2

- δ<sup>13</sup>C and δ<sup>18</sup>O-in-CO<sub>2</sub> precision are compromised if sample airstream is not dried.
- < 1 - 60-minute time averaged measurement of all species simultaneously (trade precision for measurement time).
- Accuracy: 1 - 5% without reference to any calibration gases. Accuracy is comparable to precision if measurements are referenced to standard calibration gases (NIST, CMDL, GASLAB etc.) [Citation: Chapter 8, Point 5].

## Linearity

Better than 0.1%

## Sample Flow Rate

0.5 - 1.5 slpm, or static

## Calibration Drift

Typically, < precision figure per week [Citation: Chapter 8, Point 5]

### 1.2.2 Power



#### CAUTION

The user must ensure that the local mains power matches the power setting as indicated by the factory fitted label below the mains power inlet.

#### 1.2.2.1 Analyser Power (Spectronus Rack Mount Version)

### Operating Voltage

100 - 240 VAC ( $\pm 10\%$ )

50 - 60 Hz

Overvoltage Category II

### Fuse Rating

5 A 20x5 time delay 250 VAC

### Power Consumption

240 VA (max)

185 VA (nominal)

#### 1.2.2.2 TE Cooler Option Power

**Note:** The TE Cooler option is powered separately to the main Spectronus unit.

### Operating Voltage

100 - 240 VAC ( $\pm 10\%$ )

50 - 60 Hz

Overvoltage Category II

### Fuse Rating

5 A 20x5 time delay 250 VAC

### **Power Consumption**

390 VA (max)

260 VA (nominal)

#### **1.2.2.3 Pump Power (Pump Supplied with Spectronus)**

### **Operating Voltage**

The MV2 NT pump will be supplied as either 240 VAC or 110 VAC as per customer request. It cannot be changed between input voltages.

### **Power Consumption**

Maximum motor power (Model MV2 NT) is 250 W. This is a guide as per the manufacturer at the time of writing.

Nominal power consumption will vary depending on load and flow.

**Note:** Refer to the pump specifications plate/sticker on the pump, or the pump manufacturer or manual for details.

#### **1.2.3 Operating Conditions**

### **Ambient Temperature Range (Rack Mount Version without TE Cooler)**

15 - 25 °C and stable. In order to avoid condensation, consideration also needs to be given to maintaining temperature in sample lines external to the Spectronus, especially in humid environments.

### **Ambient Temperature Range (Rack Mount Version with TE Cooler)**

10 - 32 °C. In order to avoid condensation, consideration also needs to be given to maintaining temperature in sample lines external to the Spectronus, especially in humid environments.

### **Altitude**

Up to 3000 meters above sea level.

### **Sample Temperature (Rack Mount Version without TE Cooler)**

Metal Cell 38 °C factory configured.

When operating in higher or lower ambient temperatures, this default temperature may need to be changed.

**Note:** Changing the sample temperature may affect all background, calibration, cross sensitivities and measurements. It is recommended to leave this at the factory setting.

### **Sample Temperature (Rack Mount Version with TE Cooler)**

Metal Cell 35 °C factory configured. The TE Cooler controls the Optics enclosure to ~30 °C.

## Sample Inlet Pressure

Sample inlet pressure should not exceed 1080 mBar.

## Cell Pressure

The cell pressure should not exceed 1080 mBar, as this is the maximum inlet pressure of the vacuum pump.



### CAUTION

Under certain uses or manual mode, the sample inlet pressure could be passed through entirely to the cell pressure. The user should prevent this occurring, or use a maximum sample inlet pressure of 1080 mBar.

## 1.2.4 Physical Dimensions

### Case Dimensions - Rack mount version

The dimensions below are without tubing and cables attached. Extra clearance room will be required at the rear of the instrument once tubing is connected. Allow a minimum of 1110 mm installation length.

- Optical Module with case without TE Cooler 1034 mm (L) x 448 mm (W) x 403 mm (H).
- Optical Module with case with TE Cooler 1034 mm (L) x 448 mm (W) x 555 mm (H).
- Optical module dimensions include fittings and room temperature sensor on the rear and handles on the front. Case length is 920 mm.
- Auxiliary Module with case 1020 mm (L) x 448 mm (W) x 232 mm (H).
- Auxiliary Module dimensions include fittings and filter on the rear and handles on the front. Case length is 920 mm.

### Weight - Rack Mount Version without TE Cooler



### CAUTION

Owing to their weight, it is recommended that the modules, with or without cases, only be moved with the use of a mechanical aid, such as an appropriately rated and sized electric lift trolley.



### CAUTION

If no mechanical aid is available, multiple people are required to move the modules.

- |   |         |
|---|---------|
| • Optical Module Internals without TE Cooler  | 47.2 kg |
| • Optical Module Outer Case without TE Cooler | 9.6 kg  |
| • Optical Module Internals with TE Cooler     | 47.2 kg |
| • Optical Module Outer Case with TE Cooler    | 22.1 kg |
| • Auxiliary Module Internals                  | 26.8 kg |
| • Auxiliary Module Outer Case                 | 8.0 kg  |

- Pump 17 kg
- Accessories (Standard) 5 kg

### 1.2.5 External Connections

#### Computer Interface

3 x USB, 1 x TCP/IP, 2 x RS232. 1 x RS485\*, 1 x HDMI

\* RS485 port is shared with internal connections. For more details, refer to Section 2.3.4 - Internal and External Connections and the software manual / help in the Spectronus Software.

**Note:** COM port assignments may change without this manual being updated. Refer to the software setup in the Spectronus Software.

Additional connections are present to link the Optical and Auxiliary modules together and as such are unavailable to the user. If the optional TE Cooler is installed, one of the RS232 ports will be used by the TE Cooler. Refer also to Section 2.4 - Installation and Section 2.4.3 - Linking the Modules.

#### Analog Inputs

3 x Analog input sockets (AI6 - AI8)

Voltage range -5 V to +5 VDC

(Includes +24 V auxiliary supply. 500 mA per socket)

#### Analog Outputs

2 x Analog output sockets (AO3 - AO4)

Voltage range 0 - 5 VDC

Maximum load 20 mA

(Includes +24 V auxiliary supply. 500 mA per socket)

#### Digital Outputs

2 x Digital (relay) output sockets (DO11 & DO12).

Contact rating 30 VDC, 500 mA each

(Includes +24 V auxiliary supply. 500 mA per socket)

## 1.3 Instrument Subsystems

---

The Spectronus FTIR Trace Gas Analyser is used to determine simultaneously the concentrations of several trace gases in air or other gas streams by collecting and analysing the Fourier transform infrared (FTIR) spectrum of the gas sample. In the closed path trace gas analyser, the air is contained in a sample cell which is multi-passed by the IR beam.

The analyser consists of separate subsystems under the control of a single computer program:

- The sample handling subsystem, which carries out all sample handling, inlet sample stream selection, cell evacuation and flushing procedures. This includes a 12-channel digital IO switching capability for switching 12 (or optionally more) solenoid valves, and also 8 channel analog-digital converter for logging environmental variables such as temperatures, pressures and flows.
- The FTIR spectrometer, which produces and records the interferogram and then performs Fourier transformation in order to obtain the infrared spectrum of sampled air. This Spectrometer is a Bruker IRcube fitted with a thermoelectrically-cooled MCT (Mercury Cadmium Telluride) detector (wavenumber range 2000 - 7800  $\text{cm}^{-1}$ ). The IRcube is coupled to a 26-metre metal multipass gas cell that contains the air to be analysed.
- The spectrum analyser, which provides quantitative analysis of measured spectra immediately after collection, with real-time display.
- Logging of analysed concentrations, analysis parameters and analog input quantities to a SQLite database, optionally exported to a comma separated values (CSV) text file.

## 2. Hardware Reference

This chapter describes the hardware construction and set-up of the closed path analysers. Individual analyser systems may vary in minor detail.

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### 2.1 Instrument Externals Overview

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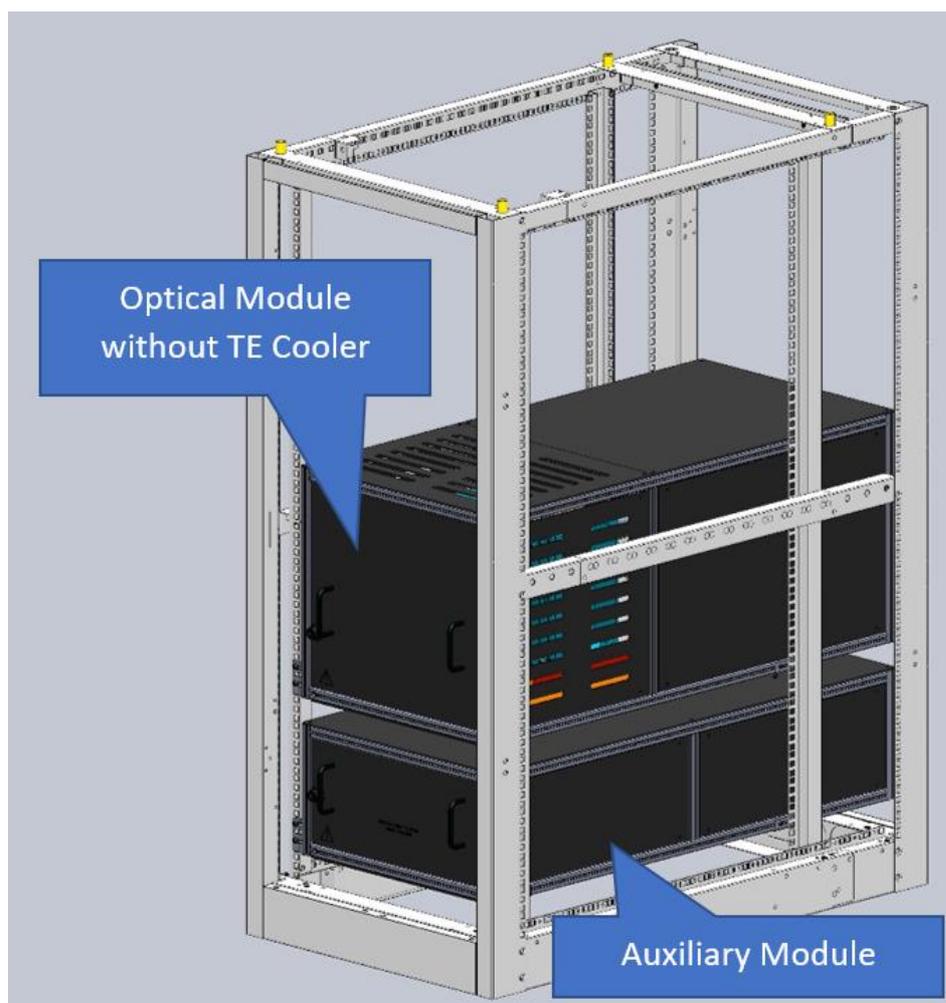
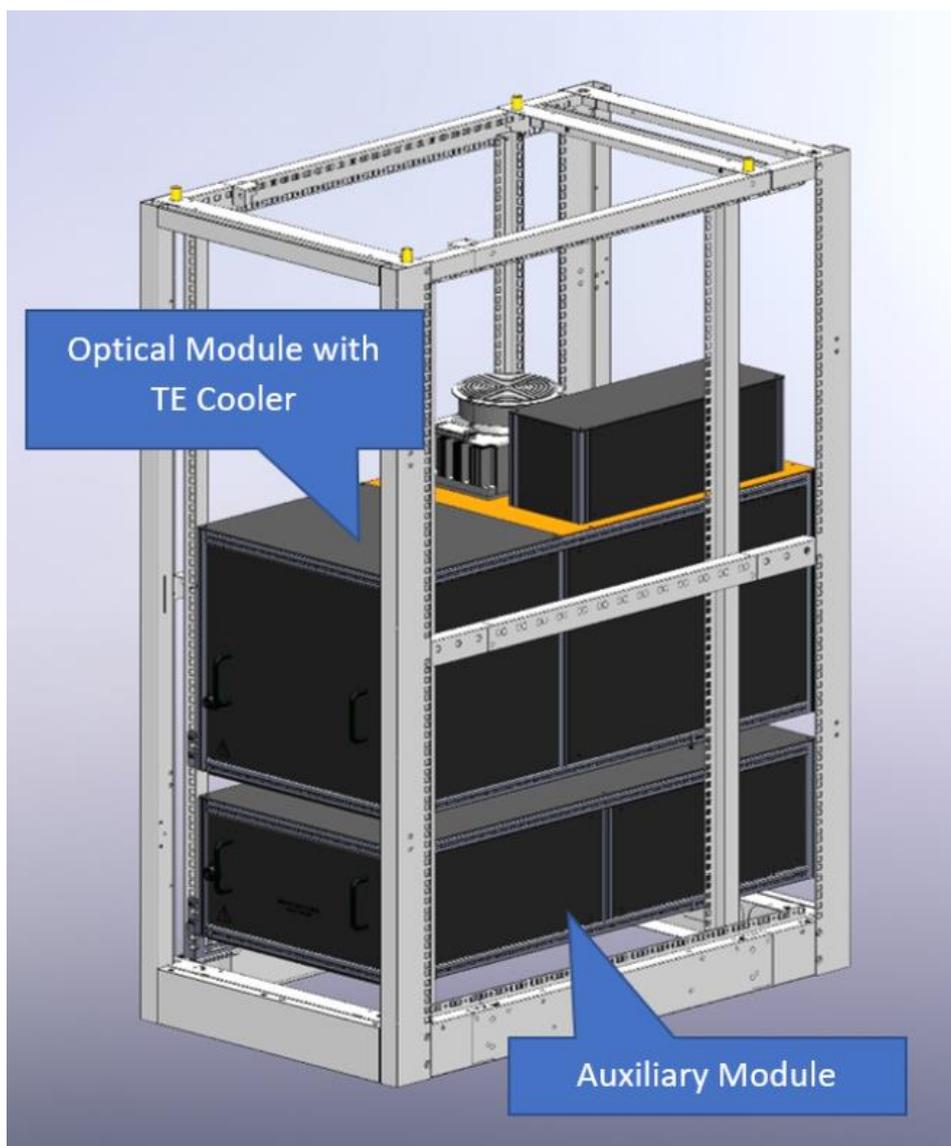


Figure 1 – Overview of the Analyser without TE Cooler



**Figure 2 – Overview of the Analyser with TE Cooler**

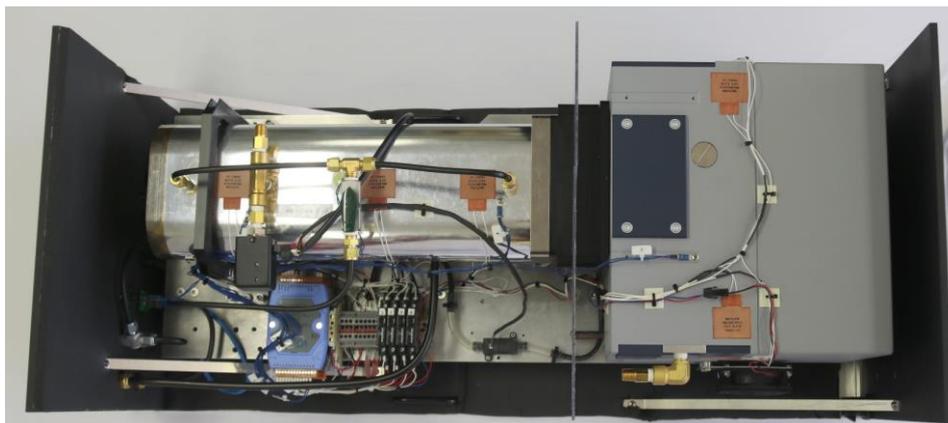
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## 2.2 Closed Path Analyser

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The closed path FTIR analyser can be divided into several sub-systems:

- The optical system, including FTIR spectrometer, White cell and detector.
- The gas handling system, including solenoid valves, Nafion and magnesium perchlorate dryers, flow meter and particle filter.
- The embedded computer running Spectronus and OPUS software on Windows.
- The analog input and digital output modules for data logging and solenoid control.
- The thermostat housing to keep the optical system at constant temperature.



**Figure 3 – FTIR - Spectrometer and Metal Cell (without TE Cooler)**

## 2.3 Components

### 2.3.1 Optics & Cell

The FTIR spectrometer (without TE Cooler), cell and optics are shown in Figure 3. If the TE Cooler option is installed, the baffle between the IRcube as well as the pair of heaters on the IRcube cell will not be present.

The spectrometer is a Matrix-M or Matrix-MGX IRcube supplied by Bruker Optics (Ettlingen, Germany), with a mid-IR globar source, CaF<sub>2</sub> beamsplitter and thermoelectrically (TE) cooled MCT detector operating above 2000 cm<sup>-1</sup>.

Unlike more commonly used InSb (Indium Antimonide) detectors in this wavelength range, the TE-cooled detector does not require liquid nitrogen cooling and operates at around -60 °C. The resolution is normally 1 cm<sup>-1</sup>, optionally 0.5 cm<sup>-1</sup>.

The modulated IR beam (f/6) exits the IRcube through a side window port, is focused into a permanently-aligned White cell with 26 m (Metal Cell) path length and returns through an adjacent window port to be re-focused onto the detector mounted inside the IRcube.

The transfer optics between the IRcube and the White cell consist of 4 flat mirrors which spread the parallel input and output beams from the window separation of the IRcube to that of the White cell. The transfer optics compartment is O-ring sealed to the IRcube and the cell endplate, so that the entire optical path is well sealed from the ambient atmosphere.

The usual windows in the IRcube have been removed. The IRcube and transfer optics are purged with a slow (0.8 - 0.2 LPM) flow of N<sub>2</sub>; additionally an absorption tube filled with molecular sieve removes traces of water vapour.

The cell pressure is monitored by an analog piezo-manometer (902 series, MKS Instruments, USA, or HPM-760s, Teledyne Hastings, USA).

The cell temperature is monitored by a high-precision thermistor.

### 2.3.2 Gas Handling System

The standard gas handling system is shown schematically in Figure 4 and Figure 5. Four equivalent inlet lines are available and are accessible via the front panel (refer to Figure 16).

- The drying system consists of a Nafion semi-permeable membrane dryer (Permapure, USA) followed by a  $Mg(ClO_4)_2$  drying tube and particle filter. By default the sample stream is dried. Solenoids 9a and 9b (ganged) can be switched on to bypass the Nafion dryer, or automatically bypassed via the software setup. Solenoids 10a and 10b are also ganged and allow the user to select between the default chemical dryer, or a second chemical dryer. This allows for faster and remote changeovers. Alternatively, one of the chemical dryers can be left empty so valves 9 & 10 when both switched will bypass all drying.
- During normal sample air measurements, dry air flows through the White cell, mass flow controllers (Kofloc, Japan), then at reduced pressure provides the back flush required for the Nafion dryer before exhausting through the vacuum/flow pump (model MV2, Vacuum brand, Germany) mounted externally.
- The cell can be evacuated by the pump (by activating valve 8) to  $< 1$  hPa for recording background spectra of the empty cell, or to evacuate in order to remove the current sample before filling with another sample or calibration gas for flow or static measurements.
- During background and static spectrum measurements, a flow of low-pressure dried sample air can be maintained through the inlets and Nafion dryer back flush via the cell bypass valve (5) to maintain consistent drying.

**Table 3 – Examples of Valve Switching States for Various Functions**

Solenoid valve	Sample flow from inlet 1, Nafion dried/undried Chem Dryer1/Dryer2	Evacuate cell	Fill cell from inlet 3	Measure static spectrum, bypass ON from inlet 1, dried	Measure static spectrum (bypass OFF)
1	ON	OFF	OFF	ON	OFF
2	OFF	OFF	OFF	OFF	OFF
3	OFF	OFF	ON	OFF	OFF
4	OFF	OFF	OFF	OFF	OFF
5	OFF	OFF	OFF	ON	OFF
6	ON	OFF	ON	OFF	OFF
7	ON	OFF	OFF	OFF	OFF
8*	OFF	ON	OFF	OFF	OFF
9 (Nafion)**	OFF/ON	OFF	OFF	OFF	OFF
10 (Chemical)***	OFF/ON	NA	User dependent	User dependent	User dependent

\* Valves 8, 9 and 10 are 3-way valves: in the “OFF” state the connections marked NO (normally open) are open.

\* \* Valve 9 bypasses the Nafion dryer only.

\* \* \* Valve 10 selects one of two chemical dryers.

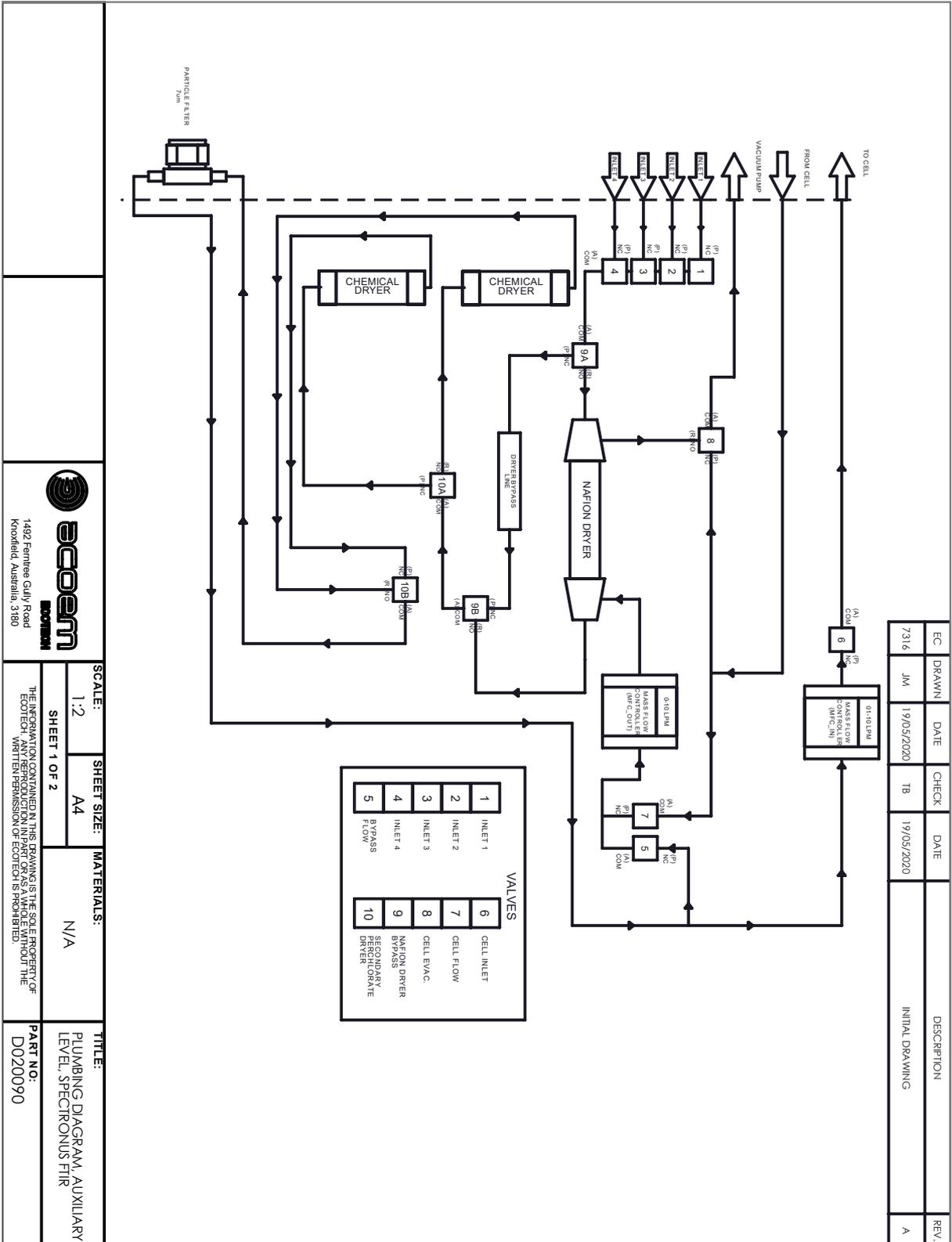


Figure 4 – Gas Handling System Flow Diagram Part 1

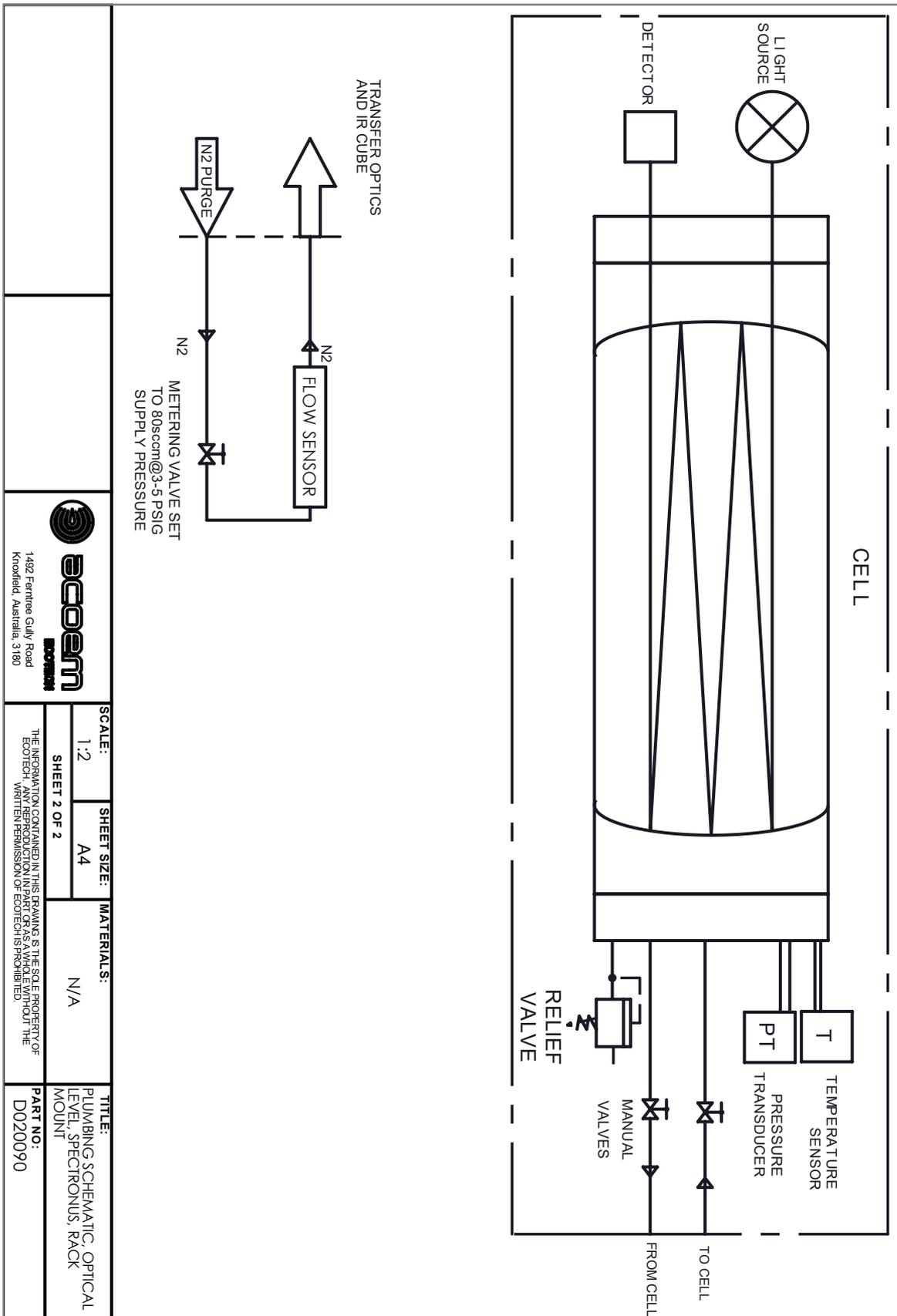


Figure 5 – Gas Handling System Flow Diagram Part 2

 <p>1492 Ferritree Gully Road Knoxfield, Australia, 3190</p>		SCALE:	SHEET SIZE:	MATERIALS:	TITLE:
		1:2	A4	N/A	PLUMBING SCHEMATIC, OPTICAL LEVEL, SPECTRONUS, RACK MOUNT
<p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ECOTECH. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ECOTECH IS PROHIBITED.</p>		SHEET 2 OF 2		PART NO. D020090	

### 2.3.3 Computer & Password

The computer is located in the front section of the auxiliary module.

It is an embedded industrial PC running Windows 10 Professional with external screen, keyboard and mouse.

Analog input and output modules are connected via an RS485 serial interface. Some of these are used by the machine and some are available to the user. The number of digital output modules used and seen on screen will vary depending on external valve control boxes that may or may not have been ordered as part of a custom set-up.

Your windows password will be on a sticker on the inside of the auxiliary module front panel. It is your Acoem Australasia Customer ID - Sales Order number. For example, if your Acoem Australasia customer ID is ABC123 and the sales order for your Spectronus FTIR is 123456, your windows password would be "ABC123-123456" - without the quotes. LogMeIn uses the windows password, so if the user changes the windows password and later requires Acoem Australasia to log in to the machine remotely, the user will need to advise Acoem Australasia of the current password.

A Windows 10 Product Key is on a sticker on the computer. It is unlikely that this will be needed.

For how to slide out the auxiliary module safely to view the windows password, refer to Section 5.1.11 - Sliding Out One of the Modules.



#### CAUTION

Mains AC voltage exists in the rear of the Auxiliary module. The unit must be powered OFF before opening the auxiliary module.

### 2.3.4 Internal and External Connections

**Note:** COM port assignments may change without this manual being updated. Refer to the Configuration menu in the Spectronus Software for an individual machine's setup.

The connections are sorted into modules. Refer to the online help / online software manual for setup details (refer to Section 3.1.2 - Spectronus Workspace and Software Manual).

There are several electrical connections internal to the FTIR enclosure.

- Cell Pressure, N2\_Flow, Flow\_Out and Flow\_In on module 7017 and Cell Temperature, Room Temperature\*, Optics Case Temperature and several thermistor inputs controlling the optical module heaters are on module 7005.

\* Room temperature dongle provided needs to be connected to the Optical module rear panel.

- Two internal analog outputs: MFC\_In and MFC\_Out are on module 7024. Refer to the online help/online software manual for setup details.
- Ten digital outputs (DO 1 - 10) are connected to control valves.

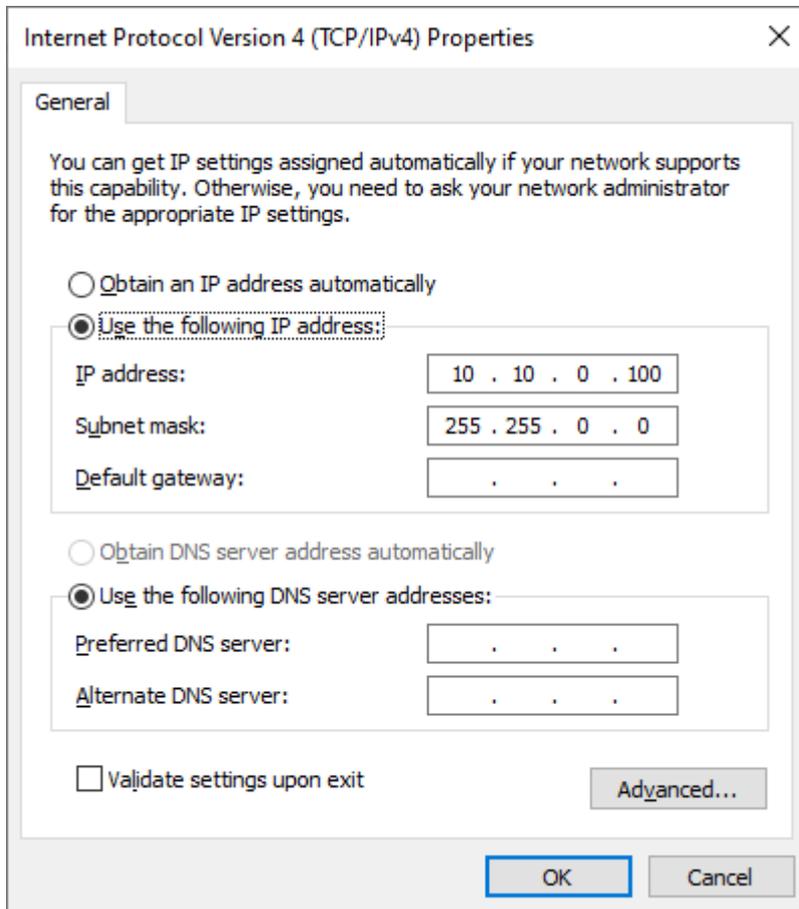
Digital output modules (DO, 12 channels, 4 per module) and analog input modules (AI, 8 inputs per module) are connected via an RS485 serial interface (on COM6). Refer to the online help/online software manual for additional setup details.

- RS485 (COM6) internal and external serial interface. Can be used to add more ICP DAS modules externally.
- RS485 (COM2) internal serial interface for Metal Cell temperature controller.
- There are several spare (unused) USB ports inside the lower compartment.

There are several electrical connections that link the Optical and Auxiliary modules. Refer to Section 2.4 - Installation for details.

- Cell Pressure, Heaters, Cube Power.
- TE Cooler RS232 where this option is installed.
- Cube Network.

The FTIR spectrometer is connected via one Ethernet port (called BrukerLAN). This internal LAN has a specific IP setup different to the external LAN. Refer to Figure 6.



**Figure 6 – Bruker LAN TCP/IP Properties**

The following connections are externally available to the user via the rear panel. Refer also to Section 2.4.6 - Rear Panel Connections.

- Three Analog inputs (AI 6 - 8) Amphenol sockets for additional sensors. Refer to Section 1.2.5 - External Connections for power limits.

- Two digital outputs (DO 7 - 8) via Amphenol sockets. Refer to Section 1.2.5 - External Connections for power limits.
- A second Ethernet port (RJ45 connector) for external network access.
- 3 USB ports.
- RS485 (COM6) serial interface (e.g., for external valve switching box boxes). This port is multi-dropped with the internal modules.
- RS232A (COM4) serial interface for connecting to external devices, such as TE Cooler (if installed), additional valve manifolds, Valco Valve or generic serial devices.
- RS232B (COM5) serial interface for connecting to external devices, such as additional valve manifolds, Valco Valve or generic serial devices.
- HDMI port for a monitor.

**Note:** The monitor must have a minimum resolution of 1440 x 900. 1920 x 1080 is preferred.

For further details on external connections, refer to Section 2.4.6 - Rear Panel Connections.

### 2.3.5 Measurement Cell Temperature Control

The metal measurement cell has been developed with improved temperature control features, resulting in much more consistent temperature throughout the measurement cell. The motivation for this was to reduce errors that were caused by thermal variations within the cell.

Low power surface heaters are distributed along the top and bottom lengths of the cell and IRcube. If the TE Cooler option has been fitted, there are no heaters on the IRcube. Feedback is obtained through the use of high precision thermistors which are mounted alongside the heaters. Supporting hardware and software is integrated into the system to drive the heaters and receive the input from thermistors. Additional hardware components included are relays, an ICP module and a communication channel (via COM2) which is set-up and configured to interface with these components (refer to Figure 3).

The latest Spectronus software has been developed to support this temperature control feature, including an updated user interface and all monitoring and control aspects of the program. All software improvements to the Spectronus program are documented in the electronic manual for the relevant builds of Spectronus software, and relevant sections of this manual.

### 2.3.6 TE Cooler Installed Option

The TE Cooler is a factory installed option mounted over the Optical Module. Heating and cooling of the enclosure is accomplished with a thermoelectric heater/cooler and controller (TE Technologies Inc., USA). Refer to Figure 2.

The TE Cooler option thermostatically controls the optical compartment, further enhancing stability of the analyser over a wider range of operating conditions. Refer also to Section 1.2.3 - Operating Conditions. The thermostat is programmed via the RS232 serial interface and the Spectronus program supports monitoring and control of the TE Cooler. The TE Cooler parameters and current temperatures can be logged in Spectronus via COM4. Refer to the Spectronus electronic online help manual for further details.

## 2.4 Installation

---

### 2.4.1 Un-packing and Shipping

On delivery, check that the analyser and all its accessories are not damaged. Be sure to keep shipping items in the event that the analyser is shipped to another location.



#### CAUTION - Heavy

The analyser modules are heavy and should not be manually lifted by a single person. It should only be lifted by an appropriate mechanical lifting aid, and/or an appropriate number of people.

Refer to the Quick Start Guide (TEC 0300) provided with the analyser for unpacking and installing into a rack.

### 2.4.2 Chemical Dryer Filling and Connections



#### CAUTION - Magnesium Perchlorate

The chemical dryer should be filled with magnesium perchlorate supplied by the user. Magnesium perchlorate is a hazardous substance that has particular safety and shipping requirements and is not allowed on an aircraft. The user must obtain and adhere to the directions from their magnesium perchlorate supplier's material safety data sheet, (MSDS) for magnesium perchlorate, including use of PPE and storage and disposal. The user must not ship magnesium perchlorate or a dryer with residual traces of that substance via aircraft.

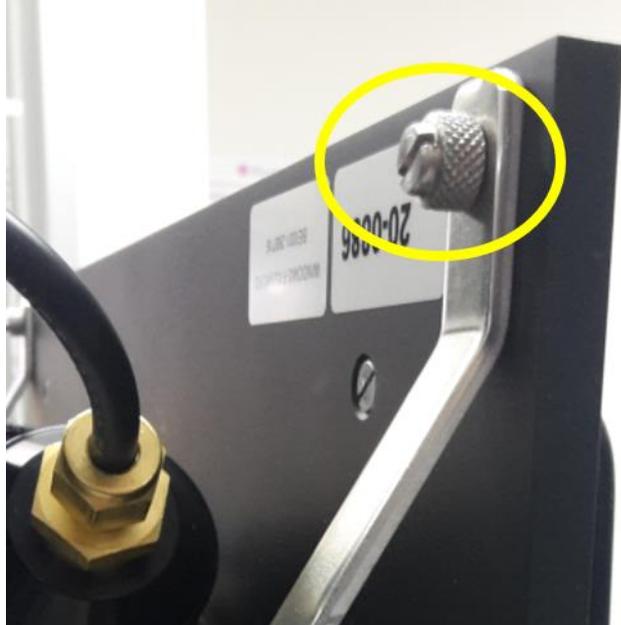
1. The Rack Mount Spectronus has two chemical dryer canisters. By default, the canister labelled Dryer1 will be used. Dryer2 can be used for remote changeovers, or as an empty canister as a chemical dryer bypass.

Unlock and then press the keyed button lock on the front of the Auxiliary Module, then gently slide the module out about 15 cm.



Figure 7 – Keyed Button Lock

- Using fingers or a flat screwdriver, undo the two screws (one each side) that hold the front panel to the stays. The module may need to be held up gently by the handles to keep the screws aligned. Use the handles to open the front panel by hinging-down.



**Figure 8 – Auxiliary Front Panel Thumbscrew**

- Looking from the front, Dryer1 is on the right. Using the release collars, remove the quick release connections for Dryer1 on the bulkhead above the PC.



**Figure 9 – Dryer1 Quick Release Fittings**

- Take note of the top of the dryer, which is on the left of the dryer as viewed from the front. Refer to Figure 9. Undo the Velcro straps, then the gray plastic clip and remove the dryer assembly.
- Remove the top end cap of the canister. Use of latex gloves can aid in gripping the tube. Use the provided glass wool to pack fully the tube at the bottom end.

**Note:** Do not use magnesium perchlorate powder as powder clogs too quickly and creates a greater restriction or blockage after much less use. It is essential to use granules.

6. Taking safety precautions (refer to the SDS from your Magnesium Perchlorate supplier),  $\frac{1}{4}$  fill the dryer with magnesium perchlorate granules (not powder), then tap the dryer gently to settle the media. Fill to  $\frac{1}{2}$  way full, gently tap, then fill to  $\frac{3}{4}$  full, then gently tap to settle the media. Fill the last  $\frac{1}{4}$  with magnesium perchlorate granules. Pack the top end with the provided glass wool. Be careful to ensure that no strands of glass wool protrude on to the sealing surface.
7. Replace the upper end cap tightly. If the Swagelok fitting was removed, carefully put it back in place by hand. Brass can easily be damaged by cross threading. Tighten with a spanner only after it has easily gone all fully by hand. It is recommended to vacuum leak test the dryer after re-assembly. A vacuum gauge, valve and pump can be used, or refer to Section 5.1.10 - Leak Check.
8. If Dryer2 is required, it can be filled in a similar manner.
9. Install the Dryer(s) back into the instrument being careful not to twist or kink the tubing. Double check that the Swagelok fittings are tight by trying to undo them by hand.
10. The chemical dryer and glass wool will be securely packaged within a Ziploc bag to ensure safe transport refer to Figure 10



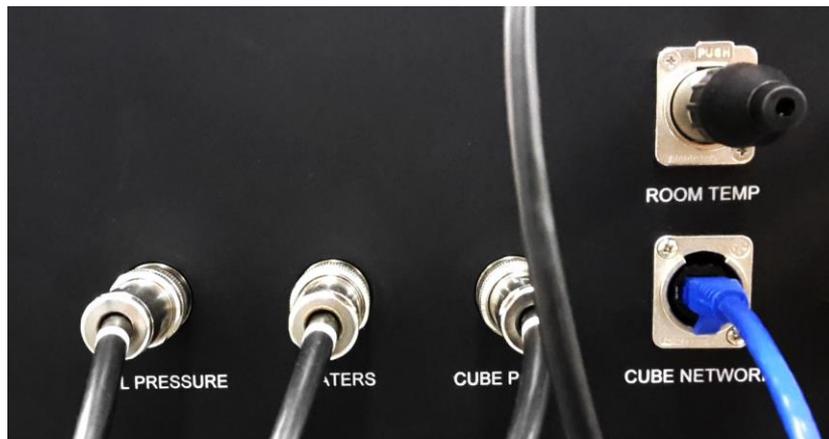
**Figure 10 – Empty Canister and Glass Wool**

### 2.4.3 Linking the Modules

1. Link the two modules (Optical & Auxiliary) with the 3 electrical link cables, Cell Pressure, Heaters and Cube Power. They are labelled and each link cable has a different number of pins. Take care to align each end whilst plugging it in.
2. Link the two units' "CUBE Network" ports with the supplied 1 metre network/ethernet cable.



**Figure 11 – Link Cables - Auxiliary Module**



**Figure 12 – Link Cables and Room Temp Sensor - Optical Module**

3. Plug in the room temperature sensor to the Optical module.
4. Taking care to align the fittings so as not to damage them, link the two units with the cell tubing. The ports are labelled “From Cell” and “To Cell”. Each fitting type is different, so they should all go on only one way.



Figure 13 – Link Tubing - Optical Module

5. If the TE Cooler option is installed, link the TE Cooler RS232 port to the Aux module RS232A port.



Figure 14 – TE Cooler to Auxiliary module RS232 link

#### 2.4.4 Power Connections



#### CAUTION

The user must ensure that the local mains power matches the power setting as indicated by the factory fitted label below the mains power inlet.

Rack mount versions of the Spectronus are auto ranging 100 - 240 VAC. The pump, however, must be purchased as either 240 VAC or 110 VAC operation. Without the TE Cooler option there is one mains power connection to the Auxiliary module. With the TE Cooler option there is a second mains power connection directly powering the TE Cooler option.

All subsystems within the Spectronus FTIR run from 24 VDC. There are 3 AC - DC converters. One is for the Bruker IRCube. One is for noisier electrical functions, such as switching valves and one is for quieter requirements such as analog and inputs and outputs and digital signals.

The mains power cord (or cords if TE Cooler option is installed) must be connected to a general-purpose power outlet of suitable voltage rating. This outlet should be protected using ELCB protection from the switchboard. The mains power outlet must have an earth connection for safety. The power cord must be in good condition and regularly tested. It should only be replaced with the same type of suitable rating.

There is a fuse located on the analyser power inlet. In the event that it blows, it should only be replaced with a fuse that is rated as per section 1.2.2 - Power. A spare fuse is provided in the fuse tray.

There is a fuse located on the TE Cooler power inlet (where that option is installed). In the event that it blows, it should only be replaced with a fuse that is rated as per section 1.2.2 - Power. A spare fuse is provided in the fuse tray.

#### 2.4.5 Pneumatic Connectors

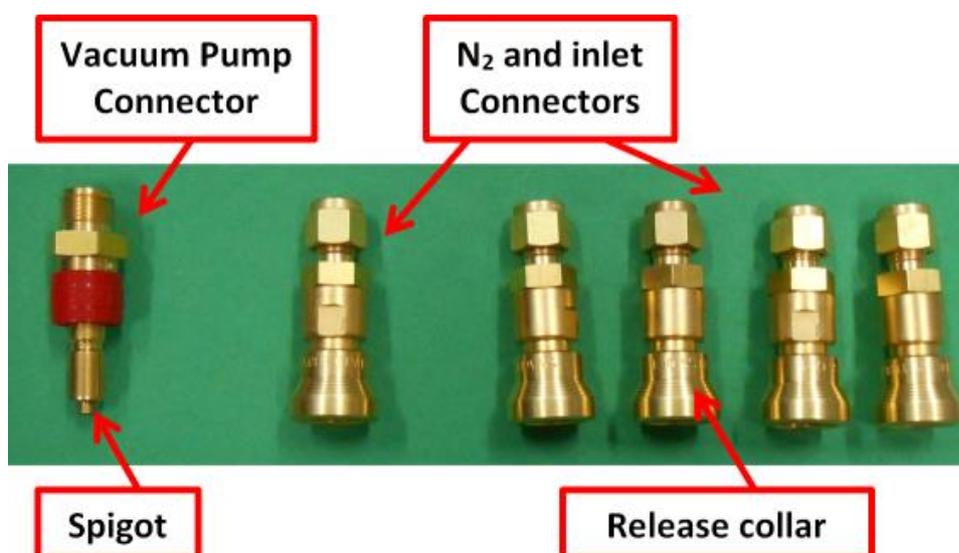


Figure 15 – Pneumatic Connectors

1. There is one male 1/4" quick-connect adaptor for connecting the analyser exhaust to the vacuum pump via the black 3/8" Synflex line. This will typically be shipped already attached to the 3/8" Synflex line.

2. There are 5 identical female 1/4" quick-connect adaptors for connecting to the analyser sample/cal inlets and also the nitrogen purge inlet.
3. These fittings are closed (sealed) when not connected. To connect, carefully align the two pieces and push all the way in until it clicks.
4. To separate, push on the release collar. It should click (it may or may not be audible) and then the two pieces should easily be able to be pulled apart.



**CAUTION**

Take care only to connect and separate with the two parts when properly aligned, or else damage to the spigot may occur.

**2.4.6 Rear Panel Connections**

For the rear panel auxiliary module connections, refer to Figure 16. For the optical module, refer to Figure 18. For basic pinouts of wiring, refer to Figure 17. For detailed wiring, refer to the A3 laminated wiring diagram D020141 supplied with the analyser.



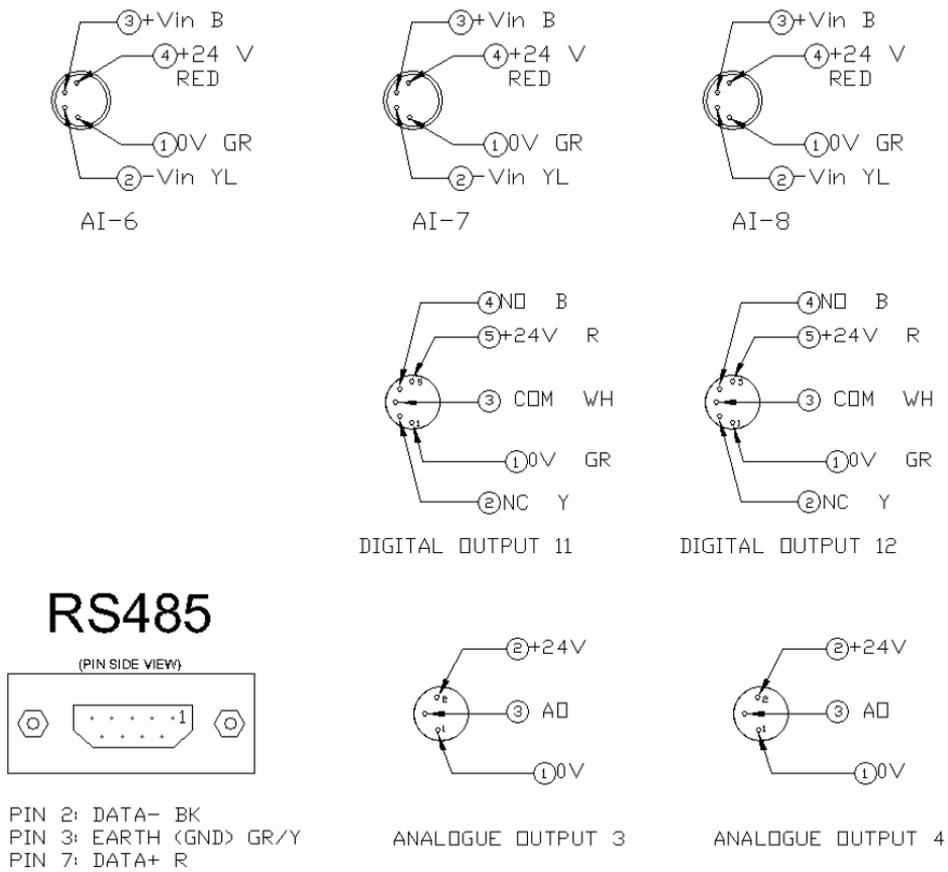
**Figure 16 – Rear Panel Auxiliary Module**

- 1 = Module-linking cables electrical connectors (x4 without TE Cooler, x5 with TE Cooler).
- 2 = Module-linking tubing pneumatic connectors (x2).
- 3 = Sample or Calibration inlets (x4).
- 4 = Particulate filter.

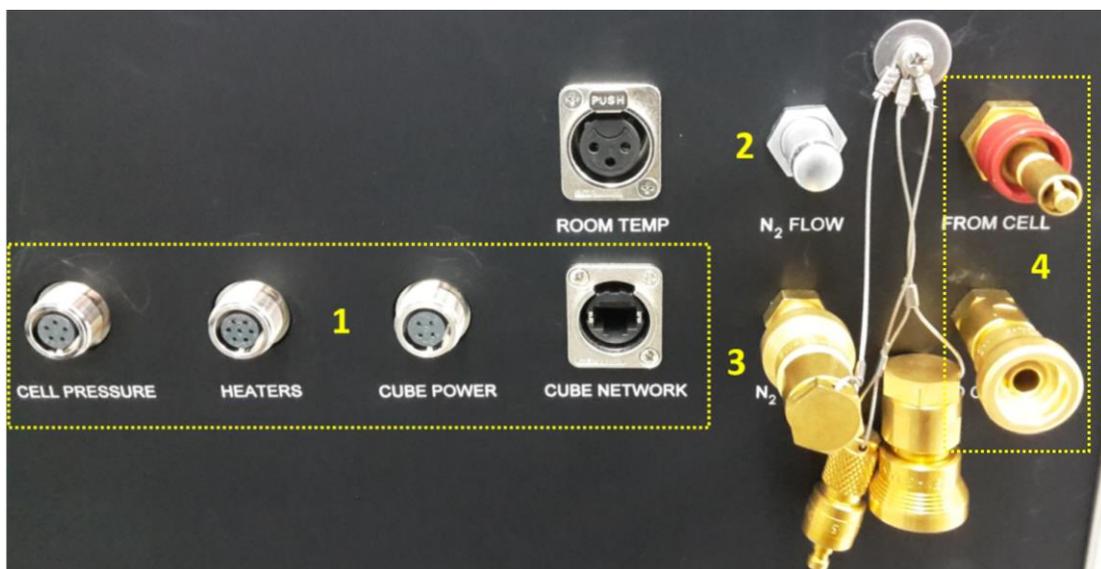


**CAUTION**

For analog and digital input and output power ratings, refer to Section 1.2.5 - External Connections.



**Figure 17 – Auxiliary Module Rear Panel Pin Out**



**Figure 18 – Optical Module Connections**

- 1 = Electrical Module linking cables connectors (x4).
- 2 = N<sub>2</sub> flow-adjusting needle valve.
- 3 = N<sub>2</sub> inlet.

4 = Module-linking tubing pneumatic connectors (x2).



Figure 19 – Room Temperature Assembly



Figure 20 – TE Cooler Option Connections

### 2.4.7 Connecting and Preparing for Startup

1. Ensure that the Analyser is installed in a clean and stable environment where the room temperature will remain within the specifications for this instrument.
2. Check that your local power supply and connections are appropriate . Connect a mains power cable to the rear panel of the Auxiliary Module, but do not power ON at this stage. If the TE Cooler option is installed, connect a mains power cable to the rear panel of the TE Cooler enclosure, but do not power ON at this stage. Refer also to Section 2.4.4 Power Connections.
3. Plug the Room temperature assembly into the rear panel of the Optical module.
4. Link the modules. Refer to Section 2.4.3 - Linking the Modules.
5. Connect the HDMI monitor and power cable, then the keyboard and mouse to the USB connectors.
6. Connect the vacuum pump to the vacuum pump port with the 3/8” quick connect and 3/8” Synflex tubing.
7. Ensure the N<sub>2</sub> needle valve is fully OFF (turned fully clockwise ☺). Connect the N<sub>2</sub> purge line. Inlet pressure should be set to 3 - 5 PSIG in order to be able to control the flow. Use of higher pressures can make flow adjustment difficult. Do not exceed an inlet pressure of 10 PSIG. Don't start N<sub>2</sub> flow at this point as you won't be able to see the flow rate. N<sub>2</sub> flow can be started after completion of these steps and power ON.



#### CAUTION

Do not exceed 10 PSIG at the purge flow inlet.

8. If you are using an external valve ICP-COM based RS485 manifold, connect it to the RS485 port (COM6).
9. If you are using a Valco valve manifold, or another generic serial device, connect it to RS232A or B port. If the TE Cooler option is installed, only RS232B will be available to connect a Valco valve or other serial device. Refer to the electronic manual under Help in the Spectronus Software.
10. Attach the filled chemical dryer as directed in Section 2.4.2 - Chemical Dryer Filling and Connections
11. Attach inlet sample lines via quick connects as required.

**Note:** These Quick Connects are closed when not connected, so no sample can flow if no connection is provided to the inlet.

12. Acoem Australasia recommends that all Quick Connects not in use be plugged with the supplied blank/cap to avoid damage to the spigot (and dirt/contamination and potential leaks).
13. Attach calibration and target tanks as required. Take all required purging steps for regulators and lines.
14. Attach any additional sensors (e.g., additional temperatures) to the AI sockets.
15. When all connections have been made, double check the front rail of each module is secured in place and that the modules are secured into the rack.

**Note:** From a cold start, it takes a minimum of 12 hours for the instrument to stabilise before meaningful readings can be taken. During stabilisation, there must be sample flow through the measurement cell, N<sub>2</sub> purge through the transfer optics, and all heating and cooling systems running to stabilise temperatures.

#### 2.4.8 Power-up

1. Before power up, be sure to check that all electrical and pneumatic connections have been made correctly.
2. Both modules must be in their outer case with all panels in place. Front rails must be secured.
3. Check that there is nothing obstructing the air flow around the optical module slotted vents.
4. Turn ON the mains power switch on the Auxiliary module rear panel. The PC and spectrometer will automatically power-up, but the cell heaters won't start until the Spectronus software is running.
5. If the TE Cooler option has been installed, turn ON the TE Cooler power.
6. Start OPUS and then Spectronus software. Refer to Section **Error! Reference source not found.** - **Error! Reference source not found.** It will take several hours for the system temperatures to stabilise. The time taken will vary depending on the temperature outside of the main enclosure. Precision measurements should not be taken until this temperature has stabilised.
7. Adjust the N<sub>2</sub> purge needle valve clockwise  until the desired flow is seen on the Spectronus software. Refer to Figure 21. It is recommended to flush the N<sub>2</sub> purge at 0.5 LPM for a few hours before taking measurements, e.g., while temperatures are stabilising, and then reduce then flow to 0.08 - 0.12 LPM for normal operation. Recommended flow is 0.10 - 0.12 LPM. The flow can take a while to settle, so after any adjustment, return a few minutes later to check that the flow is still correct. At low flows more H<sub>2</sub>O will accumulate in the transfer optics, resulting in slightly higher H<sub>2</sub>O readings. The N<sub>2</sub> flow rate can be seen in the Spectronus Standard Interface. Stability of this flow rate is dependent on the stability of the pressure supplied to the N<sub>2</sub> inlet. Alternatively, a user

may setup an additional MFC to control the N<sub>2</sub> flow. If using an external flow controller, set the Spectronus N<sub>2</sub> needle valve to fully open (fully anti-clockwise ⤴).



**Figure 21 – N<sub>2</sub> Flow Display**

8. Refer to Section **Error! Reference source not found.** - **Error! Reference source not found.** for further details on the software operation.
9. When a task/sequence in the software is ready to run, turn the external pump ON.
10. It may take a while for H<sub>2</sub>O levels to reach ultimate stability if the dryers have not had flow through them for a while.

### **2.4.9 Power-down**

If the user needs to turn OFF the analyser, the following steps should be completed:

1. Exit all open windows programs by selecting Exit or Quit from each File Menu, or by clicking the close (X) button in each program (the X may or may not be red).



**Figure 22 – Windows Close Button - X**

2. Select Shut Down from the Windows Menu and wait until the screen goes blank. The computer does not have a fan, so it is not possible to hear when it has shut down.
3. Refer to Figure 16. Switch OFF the mains Power button on the Auxiliary rear panel.
4. If the TE Cooler option is installed, switch OFF the TE Cooler power.

## 3. Software Quick Start Guide

A comprehensive user manual for software is part of the Help file in Spectronus. This section is a quick start guide only.

### 3.1.1 Software Start-up

In order to operate the analyser, two software applications must be started in the correct order. After power up the instrument, wait for windows to start-up.

#### Description of the Windows Task Bar shortcuts:

1. OPUS - Launch this first.
2. Spectronus - Launch this second.
3. Spectronus Task Builder. Only for Advanced Users writing their own tasks.
4. Igor pro - Demo version, can be used for post-measurement analysis.
5. Internet Explorer - To access the Bruker IRcube interface (as home page is to <http://10.10.0.1/>).
6. Firefox - For internet browsing.

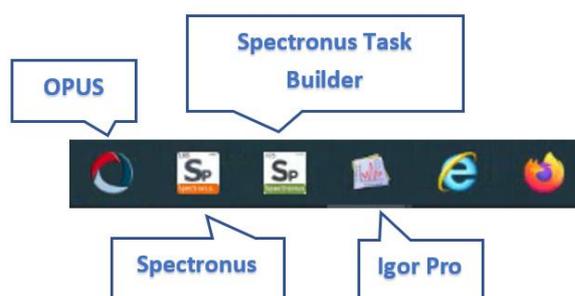


Figure 23 – Windows 10 Task Bar

#### Starting the Software:

1. OPUS 7 - This software must be started first. Either the shortcut on the desktop or on the task bar can be used. Refer to Figure 23. Both these shortcuts have switches on them to start OPUS in the correct mode.

```
/LANGUAGE=ENGLISH /directloginpassword=OPUS /OPUSPIPES=ON
```

2. After starting OPUS, there will be some messages displayed in green on the lower status bar. Wait until the message "No active task" appears. Refer to Figure 24.
3. The first time OPUS is started after turning ON the computer, it may take a couple of minutes to load. This is normal.



Figure 24 – OPUS No Active Task

- 4. Spectronus - Start this from the shortcut on the desktop or task bar (refer to Figure 23) after the “No active task” has appeared in OPUS. Failure to wait for the “No active tack” message may result in Spectronus reporting an error regarding being unable to talk to OPUS. Spectronus will attempt to start OPUS if the user has not started it. Either start OPUS and wait for “No active task”, or let Spectronus start OPUS.

### 3.1.2 Spectronus Workspace and Software Manual

After starting OPUS and then Spectronus, the user can set the workspace such that the OPUS scanning and health status are visible just above the task bar and below the Spectronus windows.

**Note:** The presence of the OPUS window at the bottom part of the screen allows the user to view the progress of spectrometer scanning and the green status light in the bottom right.

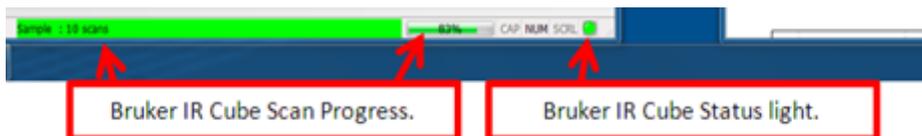


Figure 25 – OPUS Status

The user has several help and learning tools available to them. A tooltip will be displayed if the mouse pointer is hovered over an object. Pressing F1 or clicking the Help (?) button in the top right of the window will display help/online manual.



Figure 26 – Spectronus Help/Manual

### 3.1.3 Software Parts

Several software applications and processes are required to run the analyser. Refer to Figure 27 for a flow chart of how they relate. This is explained further in the online help/online software manual.

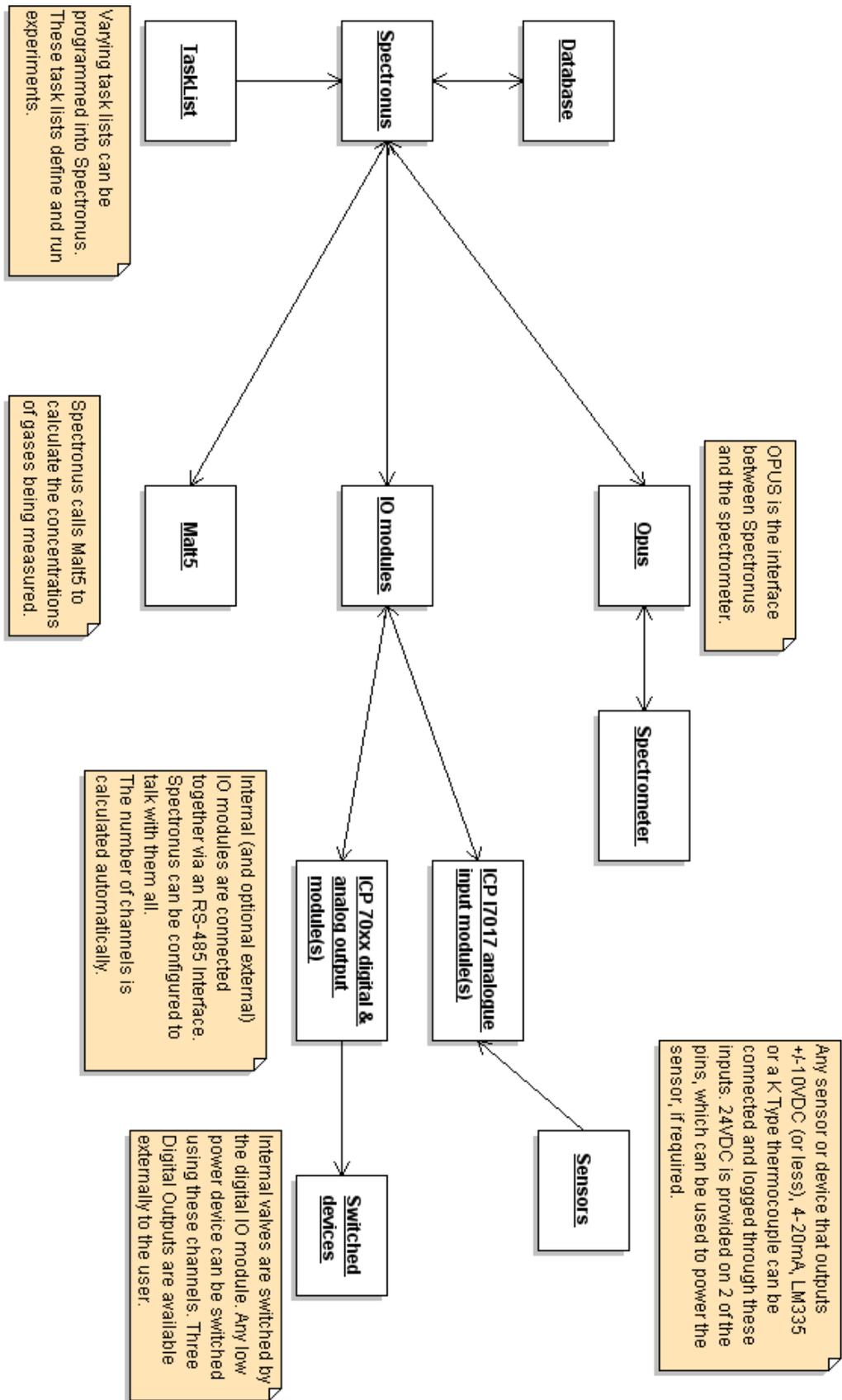


Figure 27 – Software Flow Diagram

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## 4. Sampling

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### 4.1 Starting Sampling

---

If the instrument and peripherals are supplied as factory standard, all software settings will already be setup.

In order to start sampling, the user will need to use an appropriate task list. The comprehensive online software manual in the help file in the Spectronus application details how to do this. Refer to Section 3.1.2 - Spectronus Workspace and Software Manual.

Once flow has been established through the dryers and cell, it may take several days for the water to decrease to below 10 ppm. It is recommended that accurate sampling is only performed once the cell has dried out to < 20 ppm.

Acoem Australasia recommends that calibration and sample measurements be performed at the same flow, or both in static mode and for the same measurement time. Acoem Australasia also recommends use of the same sample and calibration pressure (or similar if the user's unit only has one MFC). This helps eliminate cross sensitivities to flow and pressure, rather than having to compensate for them.

Target (non-calibrated) tanks (precision checks) may be performed at a different flow to sample, so long as the target tank is sampled at the same rate each time. For example, sample ambient flow might be 1 LPM, but in order to extend the life of the target tank, it may be sampled at 0.5 LPM. Calibration gas in this scenario would need to be sampled at 1 LPM - the same as ambient.

### 4.2 Background Spectrum

---

A user may choose to use the background that shipped with the instrument, or create their own using a background task list. The cell must have dried out completely, as per Section 4.1 - Starting Sampling, before performing a background, otherwise interference from water may influence measurements. The instrument is very stable and frequent backgrounds are not usually required. It is recommended, however, that a background be performed after shipment of the instrument and before and after a measurement campaign. The background is not expected to change for at least a month. The use of a target tank (such as a S.C.U.B.A. tank) can be used for precision checks. Refer to Section 5.1.2 - Precision Checks

If the user runs a background task, they should then check to see if the background has stripped correctly. The stripped spectrum is a \*.spc file, whereas the original is a \*.0 file. In OPUS, load both files and visually inspect them. For an example of a smooth, well-stripped background, refer to Section 6.3.5 - Stripping Water Vapour & CO<sub>2</sub> Absorption Features from Background Spectra.

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## 5. Maintenance

### 5.1.1 Safety



#### CAUTION

Mains AC voltages exists within the enclosed panels of this Instrument. Before removing any panels, or sliding out modules for servicing, disconnect the Mains Power. Maintenance should only be done by a suitably experienced and qualified technician

If any components are removed or replaced for maintenance and repair, or the analyser is dismantled in any form, before the mains power is reconnected, confirm the earth is connected to the chassis of the analyser using an approved appliance safety tester for your local region to ensure electrical safety of the analyser.

### 5.1.2 Precision Checks

A precision check can be done by sampling from a target tank, such as a S.C.U.B.A. tank. One method is to sample from the target tank immediately after sampling from a high accuracy reference cylinder. The (much less expensive) contents of the target tank can then be determined and/or recorded in order to create a second standard.

After this the user can build into their task list, or manually run a task that samples from the target tank at a frequency appropriate for their experiment. For example, in a 24-hour task list, the target tank might be sampled at midnight every night. It is not necessary to run frequent background measurements as the instrument is very stable. A S.C.U.B.A tank with all the appropriate adaptors and regulator for this purpose can be supplied by Acoem Australasia. Contact Acoem Australasia for details.

### 5.1.3 H<sub>2</sub>O levels and Interpreting Strip.log

If the H<sub>2</sub>O concentration is above the desired level, either the sample desiccant or IRcube desiccant or both may need to be replaced. Refer also to sections 2.4.8 Power-up, 5.1.4 FTIR Spectrometer and 5.1.7 Chemical Dryer Refill.

We can assess the distribution of H<sub>2</sub>O between IRcube and sample cell by looking at the strip.log file. Each time a background strip is performed, a log of the strip is created. This file is created or updated even if the “use as new” is not selected in the task method. It will only be created if “strip” is selected in the task. Refer to the online software manual for details of task methods. A file called strip.log will be created or added to in the following directory, assuming the selected user experiment directory is called “Background”:

C:\ProgramData\Ecotech\Spectronus\Data\Background\Spectra\strip.log

Strip.log is a txt file. The first few columns of a sample file are shown below:

**Table 4 – Strip.logs**

Bgnd Filename	region	CO2_L1	CO2_L2	H2O_L1	H2O_L2
		cell	optics	cell	optics
201008_075526bgnd.0	2300	0.000922	0.000422	0.000000	0.000000

Bgnd Filename	region	CO2_L1	CO2_L2	H2O_L1	H2O_L2
201008_075526bgnd.0	3000	0.000000	0.000000	0.005063	0.009201
201008_075526bgnd.0	3600	0.002194	-0.000302	0.003434	0.011987

The 2300 region is used to retrieve CO<sub>2</sub>, 3000 is used for CH<sub>4</sub> and 3600 is used for H<sub>2</sub>O (where H<sub>2</sub>O is the strongest). Reported numbers are partial pressures in hPa equivalents normalised to the cell pathlength of 26 m. The total amount of CO<sub>2</sub> (or H<sub>2</sub>O) present is the sum of the cell and optics partial pressures. The cell is evacuated and the IRcube is not. The lines are therefore broader in the IRcube than in the cell, allowing the MALT retrieval to roughly apportion the H<sub>2</sub>O or CO<sub>2</sub> between IRcube and cell.

Looking at the 3600 region in the above example (Refer to Table 4 – Strip.logs), there is 0.0034 hPa of H<sub>2</sub>O in column 5 and 0.01199 mB in column 6. We can convert this to approximate equivalent ppm at one atmosphere air in 26 m path by multiplying by 1000 (divide by 1000 hPa to convert to mole fraction, multiply by 10<sup>6</sup> to convert to ppm). 0.003 \* 1000 = approximately 3 ppm equivalent in the cell. 0.0119 \* 1000 = approximately 12 ppm equivalent in the IRcube. The total H<sub>2</sub>O amount would be approximately 15 ppm, the majority of which is in the IRcube. Sample readings in an air analysis will therefore not get below this value. If, say, the optics reading was 0.05, approximately equivalent to 50 ppm, that would indicate that the IRcube needs to be dried out. If the reported number in the Cell column was high, the cell needs to be dried out.

#### 5.1.4 FTIR Spectrometer Alignment, Desiccant and Laser

The spectrometer is permanently aligned and does not require optical alignment. Provided a flow of purge gas is maintained, maintenance required by the spectrometer should be minimal. The desiccant cartridge may require changing periodically if there are long periods without purge. Acoem Australasia recommends using Molesieve 4A spheres as the desiccant in the Spectrometer. The FTIR has an internal HeNe (Helium Neon) laser with a nominal and practical lifetime of 4 - 5 years. For details on desiccant exchange or regeneration, refer to the Bruker IRcube spectrometer manual. For HeNe laser replacement, contact Acoem Australasia for the Laser exchange instructions / tech note.

#### 5.1.5 Files

The system can generate a large number of files in a relatively short period of time. For example, the system might collect a spectrum every minute, or 60 files or around 1 Mbyte of storage per hour. Although there is a large amount of disk storage available, periodic back-up to another storage device and deletion of older data on the system is recommended.

#### 5.1.6 Gas Cell

A long-term (over several years) decrease in signal intensity may indicate gradual contamination of the mirror surfaces and increased losses due to scattering. In this case, usually there will be a proportionally larger energy loss in single beam spectra at higher wavenumbers relative to lower wavenumbers. If the gas cell mirrors need to be cleaned, First refer to Section 5.1.14 - Considerations when Working on Optical Module, then follow the below procedure:

##### 5.1.6.1 Metal Cell Cleaning Procedure

The following is an overview of how to clean the measurement cell and mirrors and doesn't include removal, disassembly or reassembly. Contact Acoem Australasia for further instructions as required.

The type of cell heater may change, as may the method used to affix the heater pads to the cell body. Contact Acoem Australasia for instructions on how to remove and re-stick the heaters in the cell cleaning process.

- The metal cell should not get very dirty as it is protected by a particulate filter and driers.
- In the case of accidental water ingress, the cell may need more thorough cleaning. Refer to Acoem Australasia for advice in such a situation.



#### CAUTION

The gold-plated mirrors are delicate and easy to scratch. Use extreme care. In general, do not wipe or touch the mirror surface.

- Remove the mirrors, O-rings and electronic fittings from the cell assembly. How the heater pads are to be removed and re-affixed may change. Contact Acoem Australasia for advice on an individual cell.
- When rebuilding the cell, if required to get O-rings to seat correctly, apply a little O-ring grease similar to Leybonol LVO810, using only the smallest quantity and wiping off excess once it sits and stays in the O-ring groove.
- Bathing of the cell body can be done manually, or in an ultrasonic cleaner:

**Note:** The detergent used should be a gentle/mild pH-neutral detergent compatible with electropolished Aluminium EN AW 6060.

**Note:** Acoem Australasia suggests using a detergent similar to Luminox by Alconox. (<https://www.alconox.com/product/luminox>). Acoem Australasia has not tried Luminox, but on paper it seems appropriate.

**Note:** Always first refer to the Safety Data Sheet and manufacturer instructions for the detergent prior to use.

**Note:** Don't use general household cleaners, as they may have impurities such as scents or hand moisturisers.

- o Bath the cell body only (not mirrors) with the detergent diluted in warm distilled or deionised water (40-50 °C) and agitate for a few minutes. Don't rub or scrape, just let the detergent do the work.
- o Drain and then thoroughly rinse with distilled or deionised water and immediately dry with dry-clean-oil-free-compressed air or nitrogen. Multiple rinses may be required.
- o Blind holes sometimes have to be dried with a clean cotton bud or similar, being careful not to leave behind any lint.
- If the mirrors need cleaning:
  - o Any dust should be removed using clean-dry-oil-free air, or pure N<sub>2</sub>, with the gas stream parallel to the mirror surface.
  - o If further cleaning is required, at first apply pure Ethanol (HPLC grade) using a touch-free applicator, then blow dry using clean-dry-oil-free air, or pure N<sub>2</sub>, with the gas stream parallel to the mirror surface.

- o If absolutely necessary (e.g. a fingerprint on the mirror) use the below technique (drag-wipe or drop-and-drag). Note that any friction on the coated mirror surface may create some scratching, so this should only be done if absolutely necessary. Use the drag-wipe technique described below with pure Ethanol (HPLC grade) (not Isopropyl Alcohol) and an optics-safe tissue.
- o Do NOT use Acetone or other chemicals on the mirrors.
- o If a fingerprint or similar oily residue is still present, the mirror surface may need to be cleaned with the same detergent as used on the cell body diluted in distilled water, then use the drag-wipe technique.

### The drag-wipe technique:

Drag-wiping can still scratch or damage the mirror, so should only be done if necessary and not done repeatedly.

Description taken from [https://www.thorlabs.com/newgrouppage9.cfm?objectgroup\\_id=9025](https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=9025)

The Drop and Drag Method can be used for cleaning flat optical surfaces that are elevated above any surrounding surfaces. First, inspect the optic to determine the location of the contaminants. This allows you to plan your drag so that the contaminant is lifted from the surface of the optic as soon as possible instead of being dragged across the surface of the optic. After inspection, place or hold the optic so that a weak lateral force on the surface will not cause the optic to move. Take a fresh, clean sheet of lens tissue and hold it above (not in contact) the optic so that as you pull the lens tissue it will be drawn across the optical surface. Next place one or two drops of an approved quick drying solvent on the lens tissue being held above the optic. The weight of the solvent will cause the lens tissue to come into contact with the optical surface. Slowly but steadily drag the damp lens tissue across the optic being careful not to lift the lens tissue off of the surface. Continue dragging the lens tissue until it is off of the optical surface.

The correct amount of solvent will keep the lens tissue damp for the entire drag but not leave any visible trace of solvent on the optical surface after the drag is finished. Inspect the optic and repeat, if necessary, but only use each sheet of lens tissue once. This cleaning method is preferred by many since the lens tissue is only in light contact with the optical surface. This method can be used successfully to remove small adhered particles and oils from an optical surface. Heavy concentrations of contaminants often require repeated treatments.

Video instructions can also be found at:

<https://www.edmundoptics.com/knowledge-center/application-notes/optics/cleaning-optics/>

### 5.1.7 Chemical Dryer Refill

The magnesium perchlorate in the chemical dryer should be replaced whenever H<sub>2</sub>O readings rise above the desired level, or when the dryer becomes too restrictive and the desired cell pressure cannot be met at the desired flow rate. The cell dries out best with a flow of 0.5 - 1.0 LPM with new magnesium perchlorate. It does not dry out well without flow (e.g. being under constant evacuation without flow). If the cell has not been well dried, H<sub>2</sub>O levels may rise if held in a constant evacuation without flow. The H<sub>2</sub>O readings can also rise above the desired level due to IRcube desiccant (or a combination of the IRcube desiccant and the magnesium perchlorate). Refer also to sections 5.1.3 H<sub>2</sub>O levels and Interpreting Strip.log.



#### CAUTION

The user must obtain and adhere to the directions from their magnesium perchlorate supplier's material safety data sheet, (MSDS) for magnesium perchlorate, including use of PPE and storage and disposal. It must not be just thrown in general rubbish.

#### Changeover using a single dryer

1. Stop any tasks running in Spectronus and make sure the cell inlet and evacuate valves are shut (this prevents 'wet' air getting into the measurement cell).
2. Remove the chemical dryer from the Spectronus by releasing the quick-connectors. Refer to Section 2.4.2 - Chemical Dryer Filling and Connections.
3. Remove the upper end cap of the chemical canister. Use of latex gloves can aid in gripping the tube. Refer to Section 2.4.2 - Chemical Dryer Filling and Connections.
4. Empty the used magnesium perchlorate into a suitable container. Refer to the magnesium perchlorate supplier's MSDS for correct storage and disposal.
5. Refer to Section 2.4.2 - Chemical Dryer Filling and Connections - for correct filling procedure.
6. Restart the desired Spectronus task.

#### Faster changeover using the second Dryer canister without modifying tasks

1. Have a pre-filled and leak tested Chemical dryer ready. This can be stored in the Dryer2 clip, or outside the instrument.
2. Stop any tasks running in Spectronus and make sure the cell inlet and evacuate valves are shut (this prevents 'wet' air getting into the measurement cell).
3. Remove the expired chemical dryer using the quick release connects (this blocks the lines and stops them getting wet). Refer to Section 2.4.2 - Chemical Dryer Filling and Connections.
4. Remove the tubes from the expired dryer by carefully undoing the brass Swagelok fittings.
5. Put the tubes onto the replacement Dryer. Be careful as brass fittings are soft and can be easily damaged if they are cross-threaded. Refer to Section 2.4.2 - Chemical Dryer Filling and Connections.
6. Install the replacement Dryer into the Dryer1 position.
7. Restart the Spectronus Task desired.
8. Empty and refill the expired dryer as per the changeover using a single dryer technique, then store it either in the Dyer2 clip, or outside the instrument.

## Remote or very rapid changeover using tasks and Valve 10

1. Have a duplicate set of tasks that are identical except for which chemical dryer is used. One set needs to have Valve10 (Dryer2) in default (not energised) state, which uses the Dryer1 position. The second set needs to have Valve10 (Dryer2) in the energised state, which uses the Dryer2 position. Alternatively, if only a few tasks are used, it may be simpler to have each task have a method with Dryer2 select and edit the task to enable or disable that method. Refer to the Spectronus software manual help. (Section 3.1.2 - Spectronus Workspace and Software Manual).
2. If using duplicate tasks, change the task in use to the relevant version.
3. If enabling/disabling by editing the task(s), edit and save in the Task Builder, then reload in Spectronus.
4. Start the relevant task.
5. The expired Dryer can then be refilled whilst the unit is still running.

### 5.1.8 Particle Filter Element Replacement

The particle filter element in the inlet line should be checked occasionally and replaced as required, especially in dusty or smoky environments. It is recommended that a spare filter element be kept on hand at all times. These can be purchased from Acoem Australasia (refer to Section 5.1.22 - Spare Parts List).

After reassembling the filter holder, the entire analyser should be checked for leaks (refer to Section 5.1.10 - Leak Check).

### 5.1.9 Pump

A loss of evacuating speed (and no other symptoms) may indicate a problem with the MV2 diaphragm pump; it is recommended that the user have a spare set of seals/diaphragms on hand (refer to the pump manual). These can be ordered from Acoem Australasia (refer to Section 5.1.22 - Spare Parts List). The pump manual says, “depending on individual cases, it may be efficient to check and clean the pump heads on a regular basis. In case of normal wear, the lifetime of the diaphragms and valves is > 10 000 operating hours.” (refer to the pump manual for details and replacement procedure).

### 5.1.10 Leak Check

A leak check should be performed periodically and also after any change to the plumbing system, such as after changing the dryer or particle filter. The user can use the Spectronus software to control manually the valves and MFCs. Refer to Figure 4 in conjunction with these instructions. Leak test task lists can (partly) automate the below processes. Sample leak test task lists are factory installed.

**Note:** Before starting any of the leak tests follow the steps below.

1. Connecting to the Spectronus software, click abort/reset on the main screen. This sets the system to a known idle state.
2. Ensure that the vacuum pump is ON and connected to the exhaust port.

**Note:** The entire system should leak at < 0.1 mB/minute.

### To leak test the entire system except for the pump

1. Block the 4 inlet ports with the protecting plugs provided.

2. Using Spectronus software, analog outputs, send 5 V to each of the MFCs.
3. Using Spectronus software, digital outputs, open up all the valves, except valve 9.
4. Wait about 5 minutes, until the cell pressure drops to about 1 mB.
5. Disconnect the vacuum pump from the Spectronus front panel (thus blocking the outlet).
6. Close Valve 8 only.
7. Pause for 60 seconds to let the cell pressure reading stabilise.
8. Record the cell pressure.
9. Wait 5 minutes.
10. Record the cell pressure.
11. The cell pressure should not increase at a rate more than 0.1 mB/minute.
12. In Spectronus software click abort/reset.
13. Reconnect the vacuum pump to the Spectronus front panel.

#### **To leak test just the cell**

1. Using Spectronus software, open Valve 8 only.
2. Wait about 5 minutes, until the cell pressure drops to about 1 mB.
3. Close valve 8 only.
4. Pause for 60 seconds to let the cell pressure reading stabilise.
5. Record the cell pressure.
6. Wait 5 minutes.
7. Record the cell pressure.
8. The cell pressure should not increase at a rate more than 0.1 mB/minute.

#### **To leak test the cell, MFC\_IN and particle filter (and valve 5 and valve 9b)**

1. Remove all connections from the inlets, leaving the spigots uncapped.
2. Release the in-use chemical dryer quick connect fittings from the bulkhead and leave the spigots uncapped. Refer to Section 2.4.2 - Chemical Dryer Filling and Connections for the location of the release collars.
3. Using Spectronus software, open Valves 6 and 8.
4. Using Spectronus software, send 5 V to MFC\_In.
5. Wait about 5 minutes, until the cell pressure drops to about 1 mB.
6. Close valve 8 only.
7. Pause for 60 seconds to let the cell pressure reading stabilise.
8. Record the cell pressure.
9. Wait 5 minutes.
10. Record the cell pressure.
11. The cell pressure should not increase at a rate more than 0.1 mB/minute.

### 5.1.11 Sliding Out One of the Modules



#### CAUTION

Make sure that the Quick Start guide rack installation has been correctly followed and that the rack is secured to the floor. Only ever slide out one module at a time.



#### CAUTION

Hazardous voltages exist within the auxiliary rack. Mains power must be switched OFF before sliding out the auxiliary rack either fully frontwards, or any amount rearwards.



#### CAUTION

Hazardous voltages exist within the TE Cooler upper section. Where the TE Cooler option is installed, mains power must be switched OFF before sliding out the optical rack either fully frontwards, or any amount rearwards.

After correct installation, the anti-tilt stoppers allow for each module (optical or auxiliary) to be slid out half way either to the front or the rear of the outer case. If the TE Cooler option is installed, the optical module has more limited movement.

Ensure all connections on the rear panel are long enough, or remove them.

Mains power exists in the rear of the auxiliary module. Mains power must be switched OFF before sliding it out to the rear. Mains power must also be switched OFF before removing the entire module from the outer case through the front. Where the TE Cooler option is installed, mains power to the TE Cooler must also be switched OFF and removed before removing the entire module from the outer case.

Release the keyed-button catch on the front panel, then use the handles to slide gently the module only as far as is needed to access the relevant part. If sliding out towards the front, the earth strap will be visible from the rear.

#### **The optical module needs to be slid out to the front to:**

1. Check the IRcube fan is still operational.
2. Replace the laser.
3. Check the desiccant indicator on the side of the IRcube.
4. Remove the module from the outer case.

#### **The optical module needs to be slid out to the rear to:**

1. Access the cell isolation manual valves.
2. Adjust the pressure transducer calibration (usually done in software). Refer to Section 6.2 Sensor Calibration.



**Figure 28 – Optical Module (without TE Cooler) Slid out to the Front**

**The auxiliary module needs to be slid out to the front to:**

1. View the Windows password or product key.
2. Access the chemical dryers.
3. Access the MFC zero adjust.
4. Remove the module entirely from the outer case.

The auxiliary module does not normally need to be slid out to the rear. If replacing a part in the rear, it may be easier to remove the module from the rack and work on a bench. Mains power should be removed before sliding the auxiliary module out to the rear.



**Figure 29 – Auxiliary Module Slid out to the Front**

#### **5.1.12 Sliding Back in One of the Modules**

When sliding back in, leave a 2 cm gap, then return to the rear and ensure that no cables, tubes or fittings (including blanking caps) are caught or going to be pinched. Move any such items out of the way, then slide the rest of the way. Be especially careful of the earth strap.

If the Optical Module has been slid out to the rear, the push button catch may need to be depressed mid-way when sliding it back in, to get past the upright.

### 5.1.13 Removing and Returning a Module from the Outer Case

Refer to the Quick Start Guide document TEC 0300 supplied with the instrument and follow the below. A front rail will need to be removed and at least two people are required for the lift. Refer to Section 1.2.4 - Physical Dimensions.



#### CAUTION

The modules are heavy and require more than one person to lift. Refer to Section 1.2.4 - Physical Dimensions for details.



#### CAUTION

Removing either the Optical or Auxiliary module requires undoing earth safety devices and should only be done if required and after power is removed from the entire instrument. Make sure the earth strap is replaced securely when the module is returned into the outer case.

#### Tools Required

- 3 mm Hex key (for older rack mount models only)
- 4 mm Hex key
- 7 mm spanner
- Container for safe-keeping of removed screws
- PH2 screw driver (TE Cooler option only)

#### Removing the Module from the Outer Case

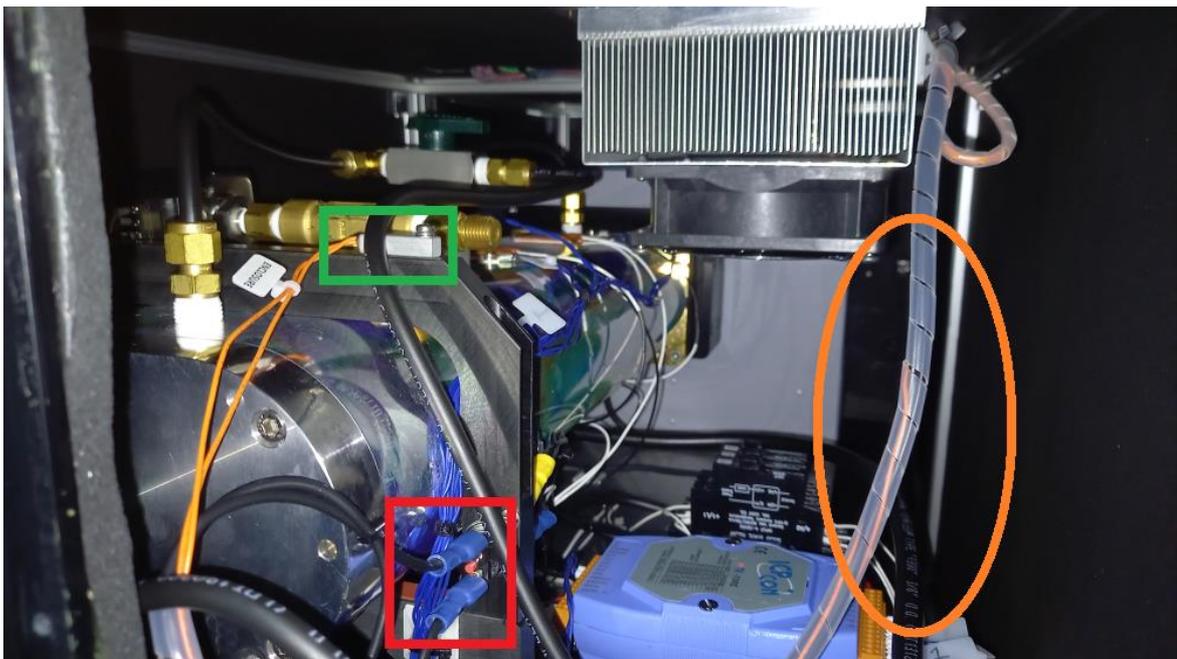
Before removing the entire module (either the Optical or the Auxiliary) from the outer case, the earth strap needs to be disconnected. For the TE Cooler installed option, two components also need to be disconnected.

1. Stop any tasks in Spectronus software, then safely shut down Windows Operating System.
2. Remove all mains AC power from the instrument (and TE Cooler option if installed).
3. Remove all connections from the rear panel.
4. For TE Cooler option, optical module.
  - a. Undo the 4 screws and remove the rear access panel. Refer to Figure 30 – Optical Module Rear Access panel (TE Cooler option).



**Figure 30 – Optical Module Rear Access panel (TE Cooler option)**

- b. Undo the screw retaining the enclosure thermistor and remove the screw, allowing the thermistor free movement. Refer to Figure 31 – Optical Module Thermistor and over-temperature switch (TE Cooler option).
- c. Carefully pull the 2 spade connector crimps of the overtemperature sensor. Refer to Figure 31 – Optical Module Thermistor and over-temperature switch (TE Cooler option).
- d. Move the thermistor and overtemperature cut-out switch cables so they hang out of the access panel. Refer to Figure 31 – Optical Module Thermistor and over-temperature switch (TE Cooler option).

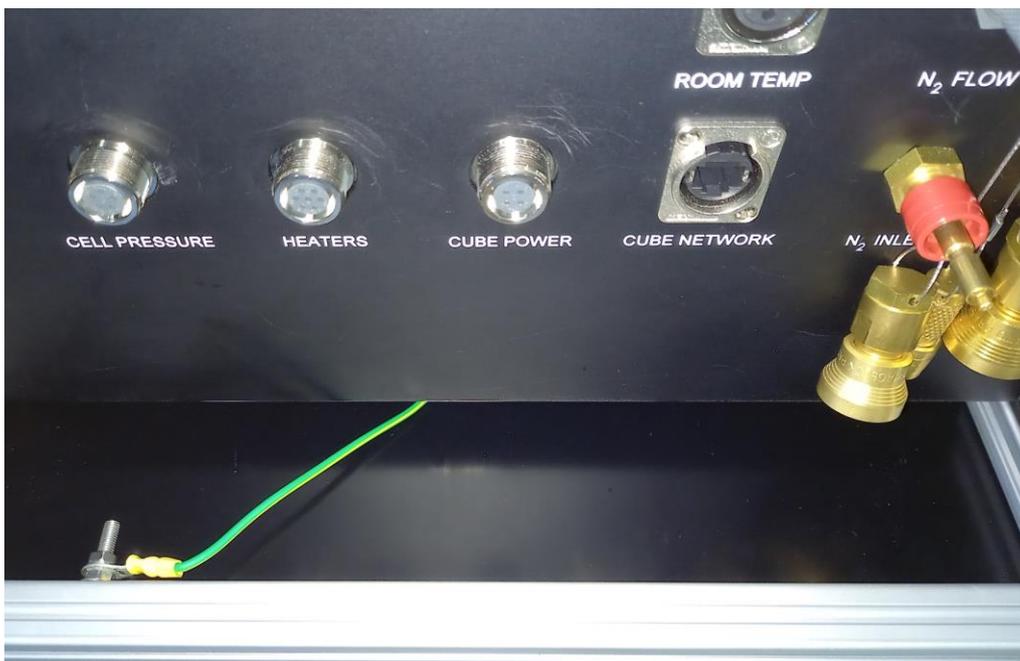


**Figure 31 – Optical Module Thermistor and over-temperature switch (TE Cooler option)**

- Slide out the module forwards about 10 cm. This is enough to access the earth strap.
- Locate the Earth strap at the rear of the module outer case. Refer to Figure 32 and Figure 33.



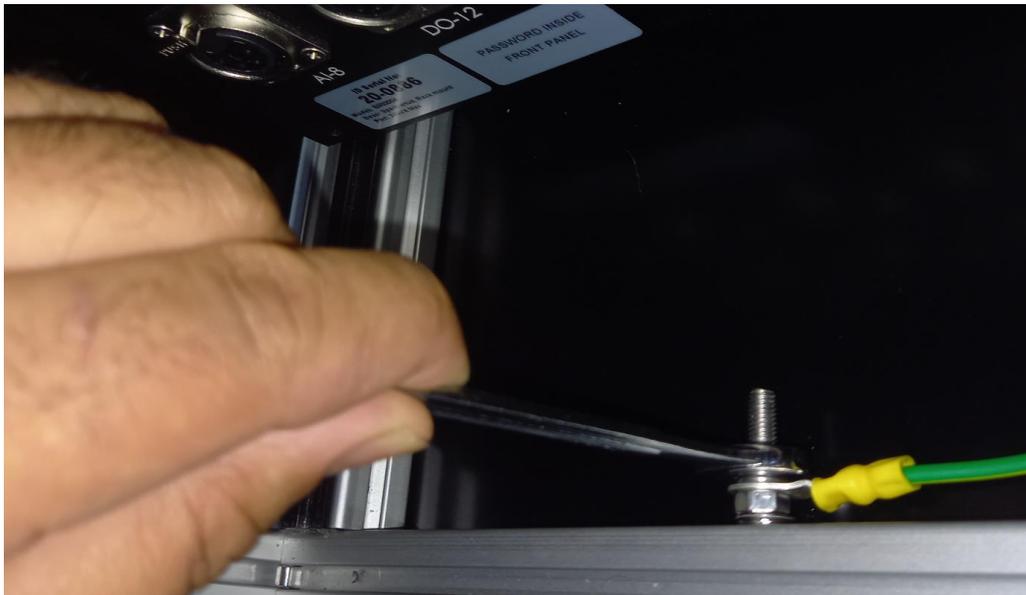
**Figure 32 – Location of the Earth Strap on the Auxiliary Module**



**Figure 33 – Location of the Earth Strap on the Optical Module**

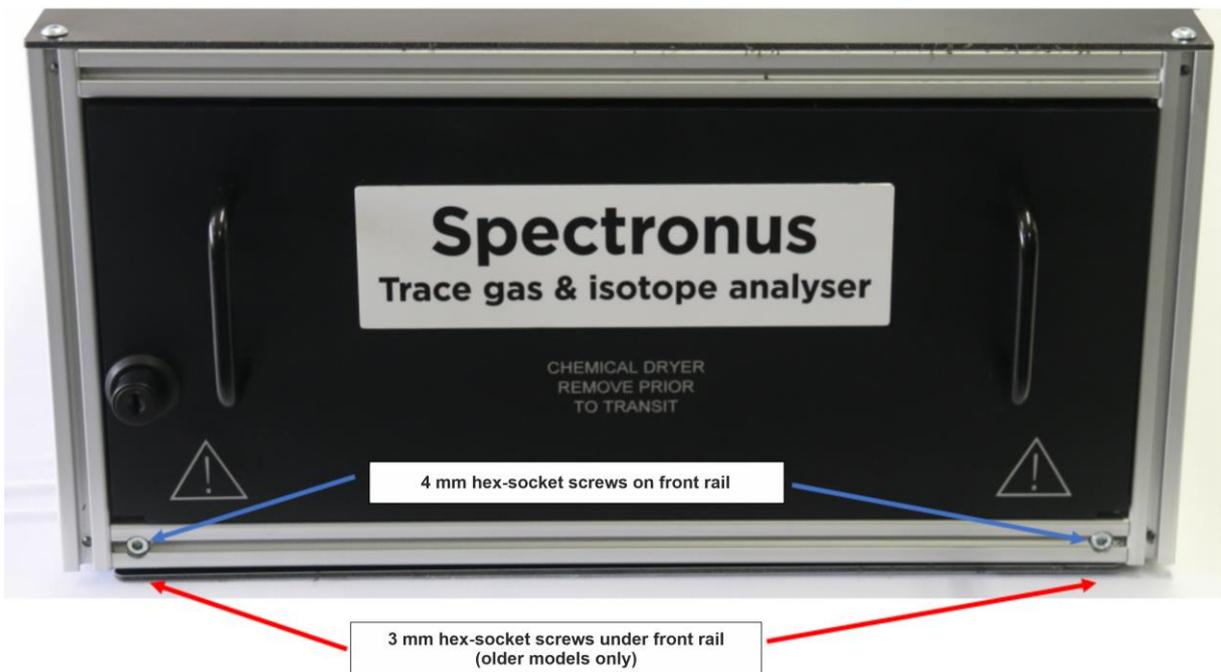
- Undo the earth strap by doing the following:
- Refer to Figure 34. There is a spring washer as well as the nut that must be caught and not allowed to fall into the instrument. Using a 7 mm spanner, undo only the first accessible nut on the outer case earth screw, then carefully remove the nut, spring washer and the ring terminal from the screw and place the earth strap on the outer case bottom panel, away from the edges (so it doesn't get caught). Do not undo the earth strap from the tray end. Do not undo the actual earth screw

from the outer case. Put the nut and spring washer back on the earth screw for safe-keeping until when the module is put back in.



**Figure 34 – Removing / Securing the Earth Strap**

9. Slide the module back in, then refer to the Quick Start guide for how to remove the front rail and module from the outer case.



**Figure 35 – Module Front Rail**

**Note:** Newer models have these screws (3 mm hex socket screws) set further back and do not need to be removed. Older models have the screws going into the front rail and do need to be removed.

## Returning the module to the Outer Case

1. Temporarily position the earth strap by hanging it over a fitting on the module rear panel, ensuring no slack so the strap won't get pinched underneath. Don't pull extremely tight, just tight enough to remove the slack.



Figure 36 – Temporarily Position Earth Strap

2. Carefully slide the module **partly** in, leaving about 10 cm still open. Do not push it all the way in as that will pinch the earth strap. Refer to Figure 37.

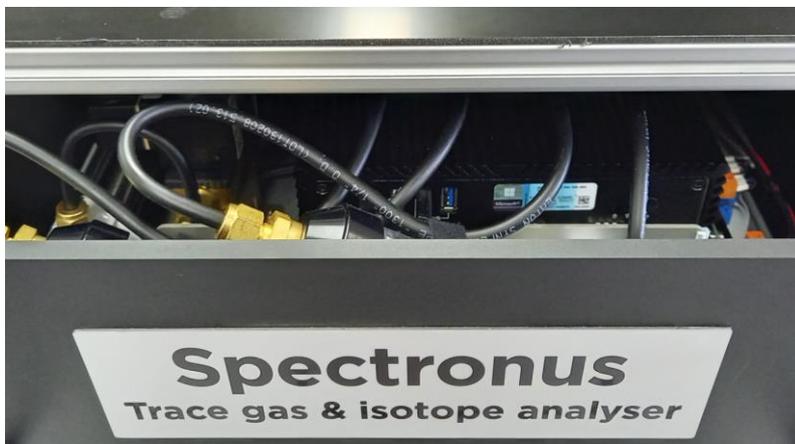


Figure 37 – Leave a Gap

3. Return to the rear of the module and then secure the earth strap back in place, by using the ring terminal, spring washer and nut with a 7 mm spanner. Refer to Figure 34.



### CAUTION

Failure to secure the earth strap will mean that the outer case will not be properly earthed.

4. Feed the slack of the earth strap onto the outer case bottom tray making sure it won't get pinched when the module is closed.

5. Carefully slide the module all the way in, making sure all cables and tubes are clear and don't get pinched.
6. For optical module TE Cooler option, reconnect the thermistor and over-temperature switch and rear access panel.
7. Re-attach the front rail.

#### 5.1.14 Considerations when Working on Optical Module

In order to clean the cell, or perform some of the sensor calibrations, the user may need to slide out or remove the optical enclosure. It is recommended that only an experienced technician perform such a procedure.

If the cell is dry and plumbing work needs to be done on the Optical Module, disconnect the To Cell and From Cell link tubes from the rear panel of the Optical Module.

This will ensure the tubing and cell are not exposed to wet and dusty ambient air. Secondly, turn the two cell-isolating valves to shut. This further protects the cell. Remember to reopen them when work is complete. Refer to Section 5.1.15 - Cell Isolation Valves and Section 5.1.11 - Sliding Out One of the Modules.

#### 5.1.15 Cell Isolation Valves

There are isolation valves on the inlet and outlet of the cell, in the optical module. These are useful for stopping the cell being exposed to wet (and dusty) ambient air when other parts of the plumbing need to be disconnected. They are best accessed by sliding the Optical Module part-way out rearwards. Refer to Section 5.1.11 - Sliding Out One of the Modules. The cell isolation valves are located above and below the cell. To isolate the cell, simply turn each of the green-handled valves 90° so that they are perpendicular to the plumbing line/flow path. The top of the cell has two inlets, both of which are fed from a single valve. The tubing is 1/4". The bottom of the cell is the outlet/exhaust and is connected to 3/8". Figure 38 shows the valves in the open (cell not isolated) position.

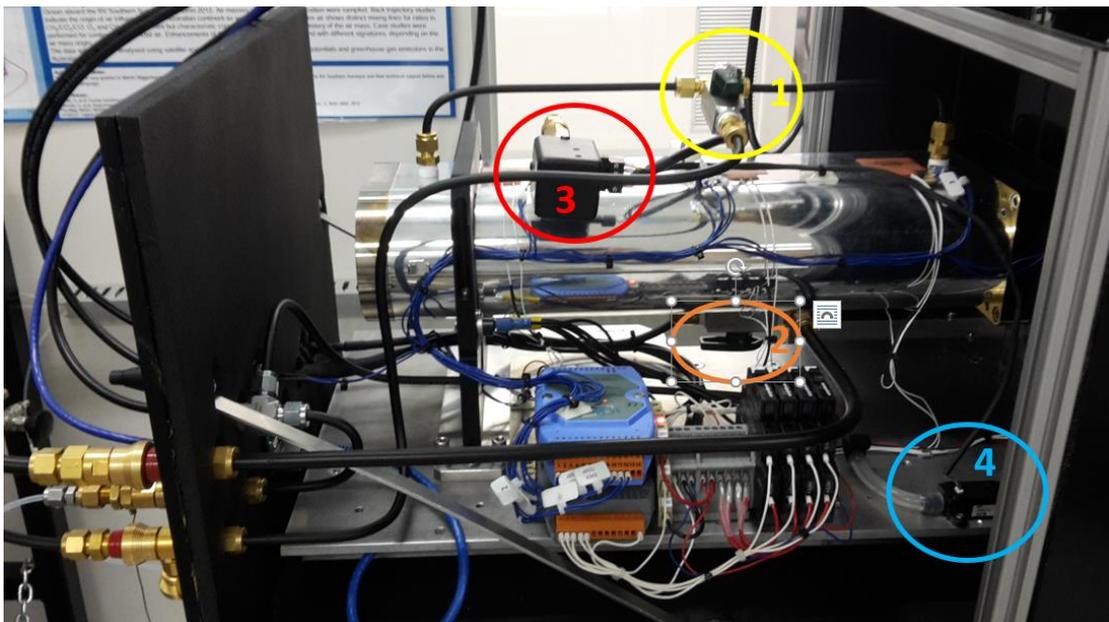


Figure 38 – Optical Module Rear Section (without TE Cooler)

1. Cell inlets isolation valve (shown in the open position)
2. Cell outlet isolation valve (shown in the open position)
3. Cell Pressure sensor
4. N<sub>2</sub> flow sensor

### 5.1.16 Auxiliary Section Overview

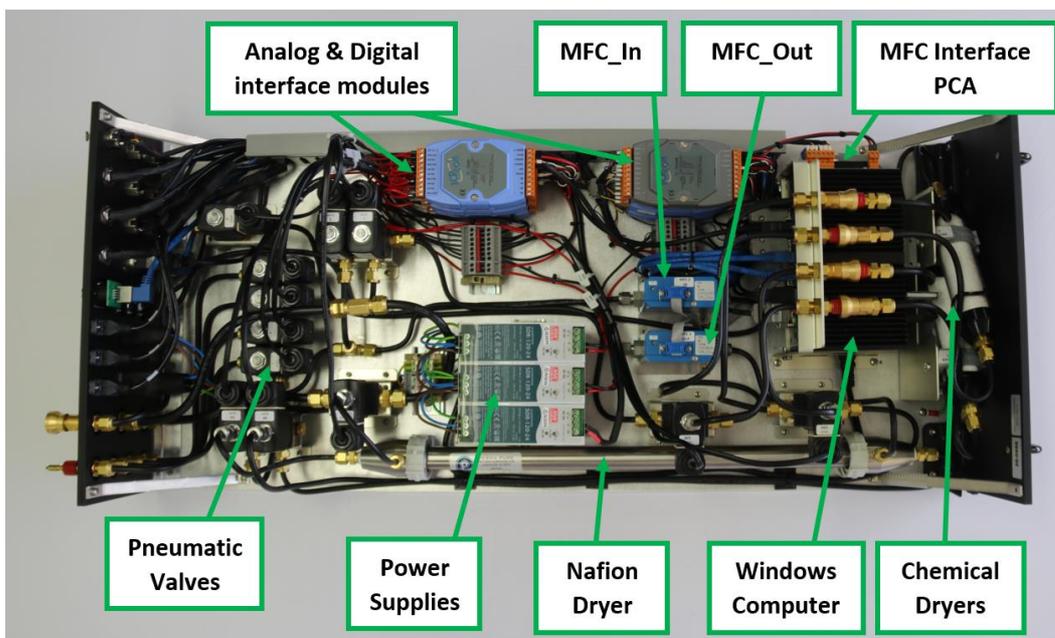


Figure 39 – Auxiliary Module Layout

### 5.1.17 Checking & Adjusting the MFC Zero Pots

The MFC zeroes can drift over time. It is suggested that the user monitors this drift over time. If the MFC is always drifting a significant amount in one direction, there may be a problem. Whilst this MFC ZERO drift doesn't affect most users, there is a hardware ZERO pot accessible to the user in the auxiliary module on each of the MFCs. Refer to Figure 40.

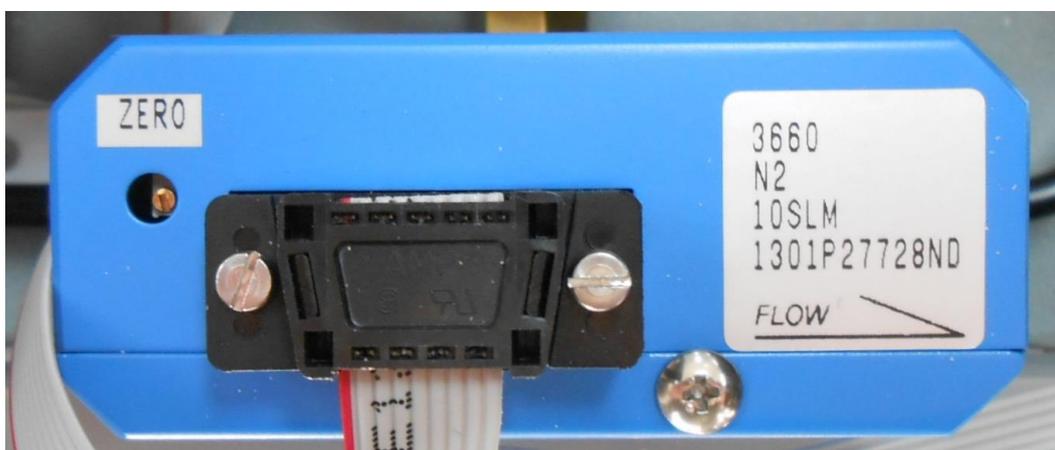


Figure 40 – MFC Zero Adjust Pot

## Tools Required

- Ceramic or shielded pot adjuster, short handled.

**Note:** Don't use an unshielded metal screwdriver as it can short to the case, causing interference on the reading.

## Checking the MFC Zeros

This is done with the analyser in its normal operating environment and fully up to temperature. It is not recommended to remove the auxiliary section to perform this procedure.

1. Using Spectronus software, click abort/reset and make sure that 0 V is being sent to each of the MFCs.
2. Wait 10 minutes. An MFC can take quite some time to settle to its final resting point.
3. Observe the Flow\_Out and Flow\_In values. They should be  $0 \pm 0.010$ , however, values of  $0 \pm 0.020$  are common. Values much larger than this may indicate a problem.

## Adjusting the MFC Zeros



### CAUTION

Mains AC exists in the rear of the Auxiliary section. This procedure outlines accessing only the front section. It should only be done by a suitably experienced and qualified technician. Ideally the Mains Power should be removed before opening the Auxiliary section.

It is not recommended to remove the Auxiliary Module from the rack to perform this procedure.

1. Mains AC voltage is present in the Auxiliary Module and therefore removal of all power is recommended. As such this procedure can take several attempts and quite some time due to equilibration time required by the MFCs. Alternatively, an experienced technician may leave the power ON and only access the front section of the auxiliary rack. The low voltage side of the power supplies is next to the MFC. Mains power exists on the other side and inside the power supply. Do not poke tools near the power supply.
2. Make a note of the MFC zeros as they appear on screen in Spectronus, including whether each one is positive or negative.
3. If using the mains-power-OFF method, shut down the system. Refer to Section 2.4.9 - Power-down.
4. Slide out the Auxiliary Module far enough to expose the MFCs. Refer to Section 5.1.11 - Sliding Out One of the Modules.
5. Refer to Figure 39 and locate the MFC needing adjustment.
6. Turn the ZERO adjust pot on the MFC clockwise  $\curvearrowright$  to increase the value and anti-clockwise  $\curvearrowleft$  to decrease the value.
7. If using the experienced technician method and mains power is still ON, monitor the Flow\_Out and Flow\_In values and adjust the pot until they read 0.000 to +0.006 LPM (not negative). It may fluctuate somewhat ( $\pm 0.004$  LPM), so observe the average. Once within correct range, carefully slide the module back in. Refer to Section 5.1.12 - Sliding Back in One of the Modules. If using this experienced technician method, the adjust procedure is complete.

8. If using the mains-power-OFF method, slide the module back in. Refer to Section 5.1.12 - Sliding Back in One of the Modules, then power the system back ON.
9. If the unit was OFF for only a couple of minutes, wait 15 minutes for everything to come back to temperature. If it was OFF for longer, wait 30 minutes or longer, depending on how much the system changed temperature.
10. Repeat steps 3 - 7 until the corresponding flow readings are 0.000 to +0.006 LPM (not negative). It may fluctuate somewhat ( $\pm 0.004$  LPM), so observe the average.

### 5.1.18 OPUS Status Indicators

In addition to performing precision checks, the user may also run the OPUS Verification Program. It is also recommended to perform these tests after cleaning the cell.

The files required to do this and the sub-tests to be performed are installed by Acoem Australasia and some of them are specific to the individual IRcube, matched up by the serial number.

After 365 days have elapsed since the program was last run, OPUS will change the status light from green to yellow. If the user clicks once on the status light (usually green under normal operation), the Instrument Status window will appear (refer to Figure 41).

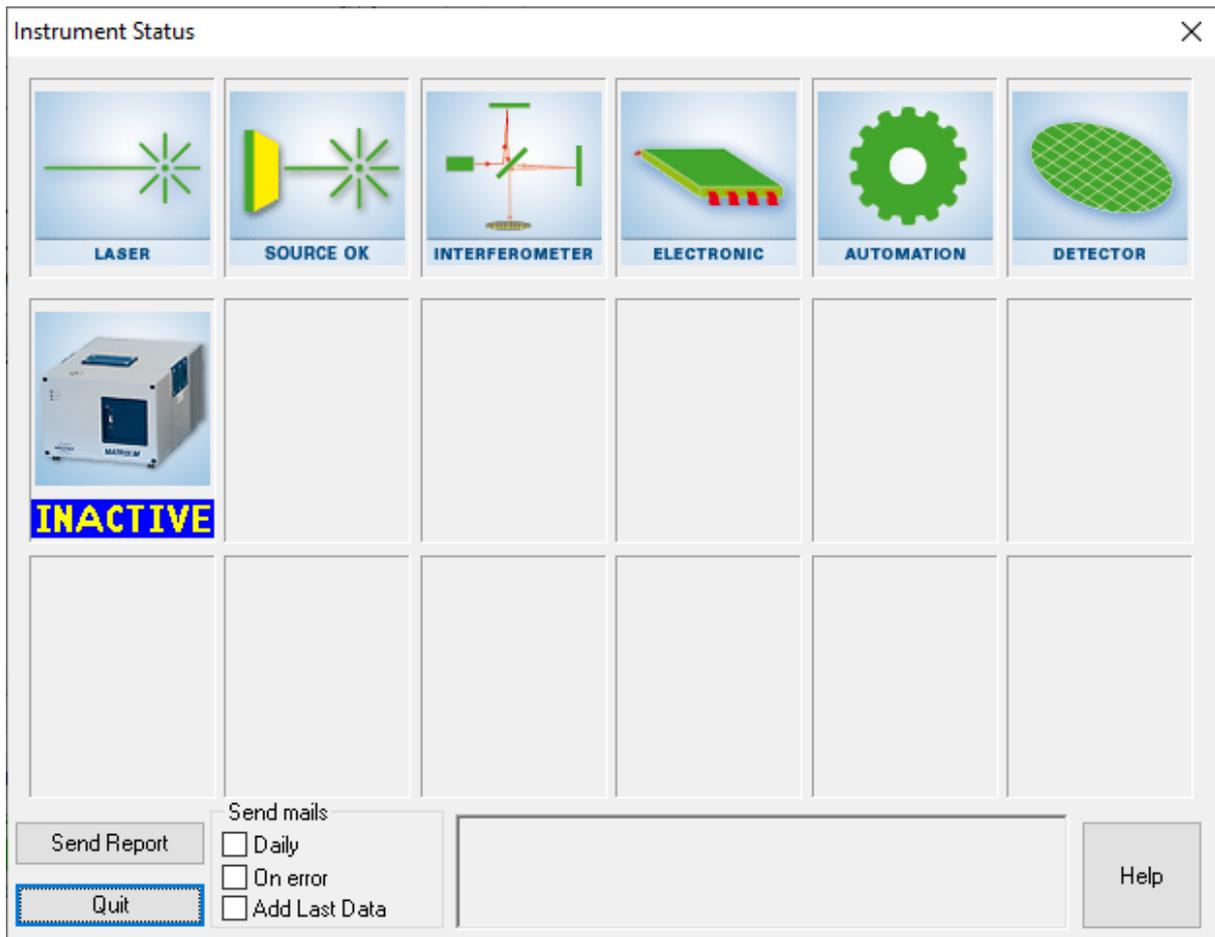
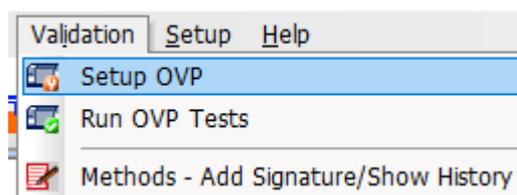


Figure 41 – OPUS - Instrument Status

Refer to Figure 41. All functions are showing as green/okay. The CUBE shows as INACTIVE when the OVP is disabled, which it will be for most of the time. If the cube shows as EXPIRED, the user can run the OVP program.

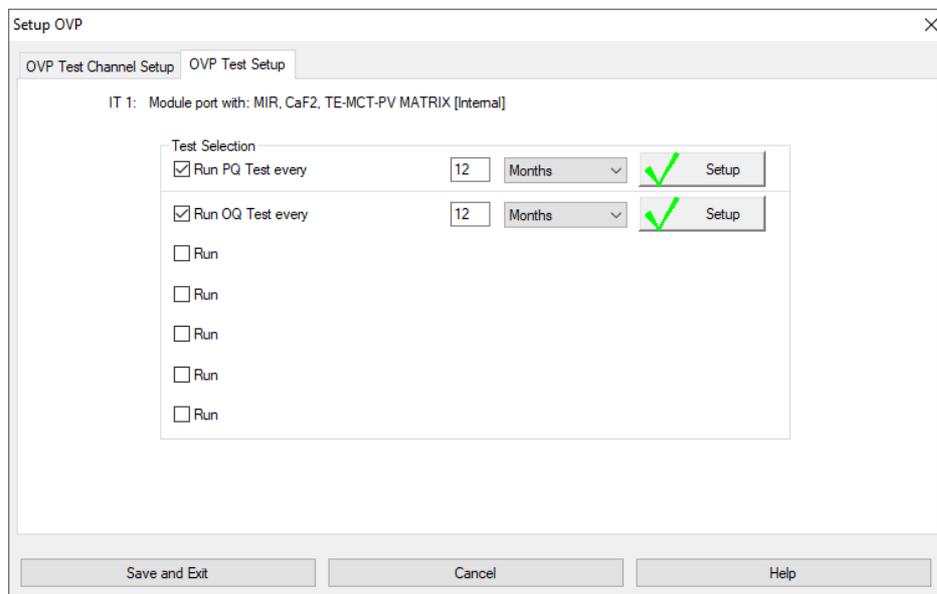
### 5.1.19 Running the OPUS OVP

1. Stop any task running from Spectronus with abort/reset.
2. Ensure all valves are de-activated.
3. Click on valve 8 to evacuate the cell, then wait 5 minutes, or until the cell pressure is around 1hPa.
4. If OPUS is not already running, open OPUS.
5. From the validation menu, select Setup OVP (refer to Figure 42).



**Figure 42 – OPUS - Setup OVP**

6. From the validation menu, select Setup OVP. Select “Run PQ Test every” and “Run OQ test every”, then click save and exit (refer to Figure 43). Do not change the sub-tests to be performed under the Setup button. Some of those tests are for the cube in isolation at the factory under different test conditions and will therefore not pass once built into a Spectronus analyser.
7. Click on the Setup button of PQ then OQ tests, the tests selected should match Figure 44 and Figure 45. Click exit, then the Icon will change to a green tick as shown in Figure 43.



**Figure 43 – OPUS - OVP Test Setup**

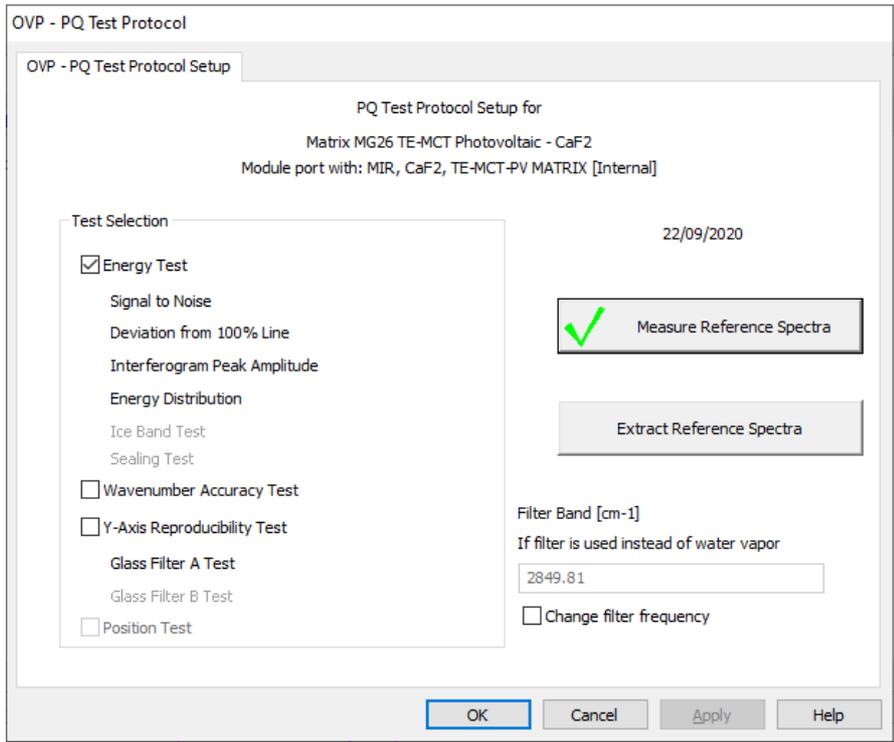


Figure 44 – OPUS - PQ Test Protocol

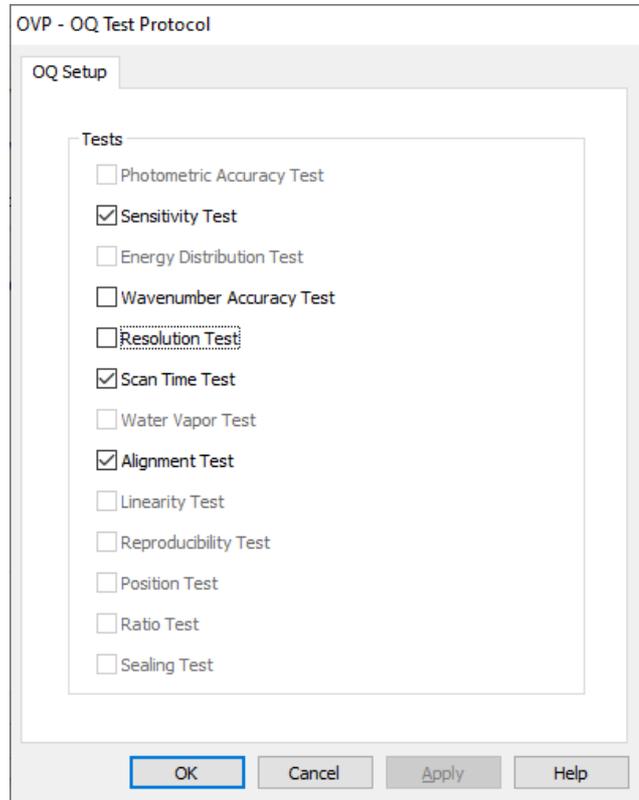
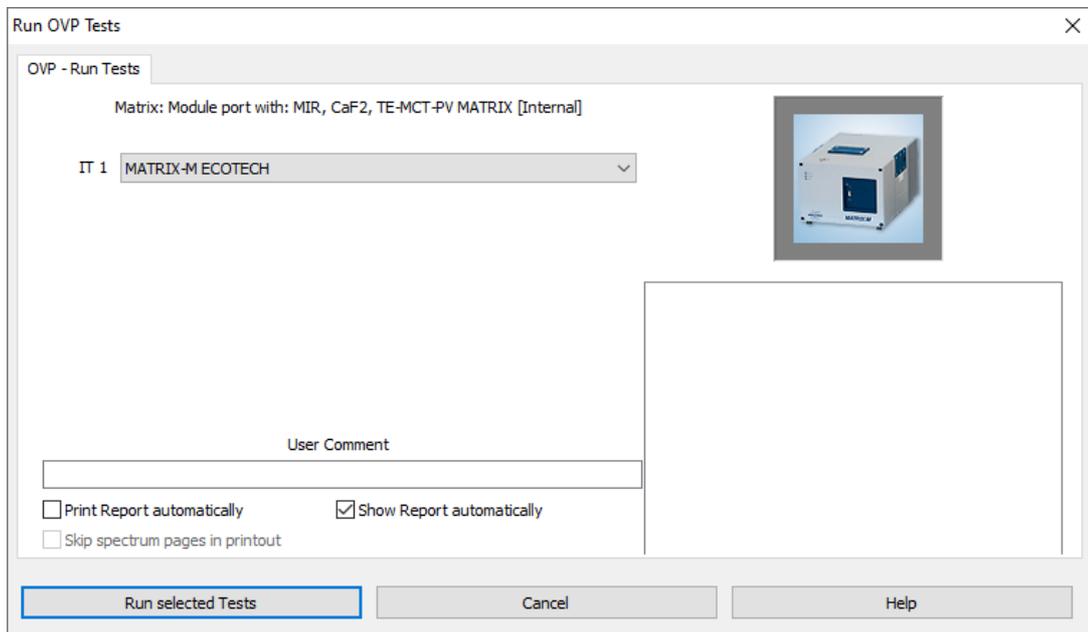


Figure 45 – OPUS - OQ Test Protocol

8. From the Validation Menu, select Run OVP Tests. Make sure “Print Report automatically” is NOT selected and that “Show Report automatically” IS selected (refer to Figure 46).



**Figure 46 – OPUS - Run OVP Tests**

9. Click “Run selected Tests”. This will take several minutes.
10. When each report pops up, the user may print to pdf to save a copy of the results. Ensure that all tests pass. If any test fails, send a pdf of the results to Acoem Australasia via email with details of how the test was performed. If all tests passed, click on the green status light and note that the CUBE now shows as okay rather than inactive. It will change back to inactive once the tests are again disabled.
11. Once the test has passed, the user must deactivate the tests. Failure to deactivate the tests will result in a yellow status light and an EXPIRED message on the cube. From the OPUS Validation menu, select Setup OVP tests.
12. Deselect “Run PQ Test every” and “Run OQ test every”, the click save and exit.



**Figure 47 – OPUS - Deactivate OVP Tests**

### 5.1.20 OPUS - Abort Task

1. If the user aborts a task in Spectronus and OPUS is still scanning, the OPUS task can be aborted manually.
2. In OPUS, right click on the status bar and then select Abort Task from the pop-up menu. Refer to Figure 48.

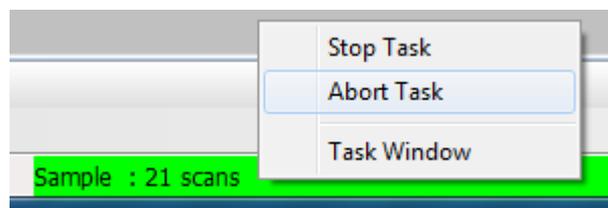


Figure 48 – OPUS - Abort Task

3. Note that if Spectronus triggered the scan, it will try to scan 3 times, so any Abort will need also to be done 3 times.

### 5.1.21 Cleaning

The analyser enclosure is made from mostly aluminium which is resistant to most forms of contamination. In order to keep the enclosure looking clean, use a microfiber cleaning cloth or a lightly dampened cloth. Be sure to turn the power OFF when doing so. The analyser is not water proof so large volumes of water may damage the analyser.

### 5.1.22 Spare Parts List

Table 5 – Spare Parts List

Part Number	Description
F010011-01	Filter, Element 7 micron, Swagelok
H010045	Hardware glass wool
H080118-50	HeNe Laser, Suit Bruker FTIR, Spectronus, Spare Part
F010060-50	Scrubber Assembly, Tested, Suit Spectronus Rack Mount - includes glass wool.
H080204	Kit, diaphragm and valves for MV 2 NT, FTIR pump
FUS-1156	Fuse, 5 A 20 X 5 time delay 250 VAC
E080101	Computer, PC, Programmed, without Dongle
O010112	O-ring Cell Body to Transfer Optics, Metric, 121.5 X 1.20 mm, Viton, VI564, Green
O010113	O-ring Cell Mirror to Cell Body, Metric, 110.0 X 3.0 mm, NBR, Nitrile, Black

## 6. Calibration

### 6.1 Calibration of FTIR Mole Fraction Measurements

Optical techniques such as FTIR spectrometry determine the absolute concentrations of individual trace gas species from the quantitative analysis of selected absorption bands or lines in the measured spectrum. The FTIR spectrometer records a broadband mid-IR spectrum which can be analysed in selected spectral regions for several trace gases. For CH<sub>4</sub>, CO and N<sub>2</sub>O the low resolution FTIR spectrometer does not resolve individual isotopic species, (or the absorptions of the minor isotopologues are too weak), and the relevant whole absorption bands are fitted assuming that all isotopologues are present in natural abundance.

For these gases the determinations natural variations in isotopic abundances do not significantly affect the FTIR mole fraction measurements. In for the case of CO<sub>2</sub> isotopologues such as <sup>12</sup>CO<sub>2</sub> and <sup>13</sup>CO<sub>2</sub> individual isotopologue concentrations can be determined independently from the spectrum, allowing the accurate determination of isotopic ratios.

This section outlines the procedures to correct and calibrate raw measurements to reference trace gas mole fraction and isotope ratio scales. For underlying details see [Citation: Chapter 8, Point 4 & Point 5].

#### 6.1.1 Quantitative Spectrum Analysis: MALT

The quantitative analysis of measured IR absorption spectra uses a computational approach to best-fit regions of the measured spectrum with a calculated spectrum based on knowledge of the sample conditions (pressure, temperature, pathlength), the HITRAN database of spectral line parameters [Citation: Chapter 8, Point 6 & Point 7] and a model of the FTIR instrument lineshape. Trace gas concentrations and instrument parameters are iteratively adjusted in the calculation to achieve best fit. This approach uses the program MALT (Multiple Atmospheric Layer Transmission, [Citation: Chapter 8, Point 2] to calculate spectra and is described in more detail in [Citation: Chapter 8, Point 4] and the MALT user's manual.

From each measured spectrum, MALT retrieves the concentration of each target gas and converts to a mole fraction scale by ratioing to total atmospheric gas concentration determined from the measured total pressure and temperature of the sample. The raw FTIR scale depends on the accuracy of HITRAN parameters, the MALT spectrum model, the optical pathlength, temperature, pressure and other parameters. It is usually within a few percent of established standard reference scales, [Citation: Chapter 8, Point 8], but for accurate mole fractions required calibration against reference gases.

#### 6.1.2 Calibration Nomenclature

**Table 6 – Calibration Nomenclature and Units**

Name	Symbol	Description	Unit (example)
Concentration	C	Amount of a species per unit volume	mol m <sup>-3</sup>
Mole fraction in air	y	(Concentration of species)/ (concentration of air)	mol mol <sup>-1</sup>

Name	Symbol	Description	Unit (example)
Isotope or isotopologue abundance	$x$	(Amount of isotope or isotopologue)/ (amount of all isotopes or isotopologues)	mol mol <sup>-1</sup>
Isotope ratio	$r$	Ratio of heavy: light atoms of an element in a sample, e.g. $^{13}r = ^{13}C/^{12}C$	mol mol <sup>-1</sup>

For CO<sub>2</sub> isotopologues we adopt the Hitran shorthand notation: 626 = <sup>12</sup>C<sup>16</sup>O<sub>2</sub>, 636 = <sup>13</sup>C<sup>16</sup>O<sub>2</sub> and 628 = <sup>12</sup>C<sup>16</sup>O<sup>18</sup>O.

### 6.1.3 Calibration Overview

There are several steps required to calculate calibrated dry air mole fractions of trace gases and isotopic  $\delta$  values from measured FTIR spectra:

1. The FTIR spectrum fit provides the raw (uncalibrated) concentration ( $C$ , mol m<sup>-3</sup>) of each trace gas species (CH<sub>4</sub>, N<sub>2</sub>O, CO, H<sub>2</sub>O) and isotopologue (<sup>12</sup>C<sup>16</sup>O<sub>2</sub>, <sup>13</sup>C<sup>16</sup>O<sub>2</sub>, <sup>12</sup>C<sup>16</sup>O<sup>18</sup>O).
2. The concentrations are converted to whole air mole fractions ( $y$ , mol mol<sup>-1</sup>) using the temperature and pressure of the sample in the cell.
3. Whole air mole fractions are adjusted to dry air mole fractions (DMFs) using the water vapour amount retrieved from the FTIR spectrum.
4. DMFs are corrected to standard conditions of pressure, temperature, flow, water vapour and CO<sub>2</sub> amounts to account for any small cross sensitivities of the measurements to changes in these variables.
5. A 2-parameter linear calibration is applied to the corrected DMFs to bring them onto the chosen calibration scale.
6. For CO<sub>2</sub>, total CO<sub>2</sub> mole fraction and isotopic  $\delta$  values are calculated from the individual isotopologue amounts, which are retrieved independently from the FTIR spectrum following steps 1 - 5 above.

### 6.1.4 Spectrum Fitting

Each measured spectrum is automatically fitted in Spectronus immediately after measurement to provide the raw species and isotopologue concentrations. The spectrum fitting is defined by the PRM files, specified in the Configure - Analysis Parameters menu. For standard measurements of ambient air, this step is automatic and does not require user input.

### 6.1.5 Calculation of Mole Fractions

The total concentration of air in the cell is calculated from  $C_{air} = n/V = P/RT$  where  $P$  and  $T$  are the pressure and temperature measured in the sample cell. The mole fraction of a species  $x$  is  $y_x = C_x / C_{air}$ .

For standard measurements of ambient air, this step is automatic and does not require user input.

### 6.1.6 Conversion to Dry Air Mole Fraction (DMF)

Water vapour amount in air is highly variable and dilutes other trace gas species in the sample. It is normal practice to remove this variable dilution effect by converting mole fractions to dry air. The water vapour amount  $y_{H_2O}$  is retrieved directly from the FTIR spectrum.

$$y_{dry} = \frac{y_{wet}}{(1 - y_{H_2O})} \quad (1)$$

If not otherwise stated, all mole fractions are assumed to be dry air mole fractions. In dried air samples the water vapour amount is low and this correction is small.

### 6.1.7 Correction to Standard Conditions

Raw measured dry mole fractions have small cross-sensitivities to cell pressure, cell temperature, sample flowrate and water vapour and CO<sub>2</sub> amount [Citation: Chapter 8, Point 4, Point 5 & Point 12]. These corrections are mostly negligible for the normal variations in pressure, temperature and flow in the cell, but water vapour and CO<sub>2</sub> amounts may vary sufficiently to require correction. For each cross-sensitivity, a linear correction factor is determined in testing and provided with the analyser - the demanding user may wish to re-determine these factors in their own lab environment. For each species the mole fraction  $y$  is corrected to standard conditions following:

$$y_{corr} = y_{dry} - dydQ \cdot (y_{H_2O} - y_{H_2O_0}) - dydP \cdot (P - P_0) - dydT \cdot (T - T_0) - dydF \cdot (F - F_0) - dydCO_2 \cdot (y_{CO_2} - y_{CO_2_0}) \quad (2)$$

where  $dydQ$ ,  $dydP$  etc are the linear correction factors. Eq. (2) corrects  $y$  to standard values of  $P_0$ ,  $T_0$  and  $F_0$  which are usually set to the standard measurement conditions.  $y_{H_2O_0}$  and  $y_{CO_2_0}$  are typically taken as 0 and 400 ppm respectively.

### 6.1.8 Calibration to a Reference Scale

Raw FTIR mole fractions are dependent on the accuracy of the Hitran line parameters, MALT model and FTIR instrument response. They may be interpreted as a general "instrument response", but their values are typically within a few percent of SI-traceable mole fraction calibration scales such as those of WMO-GAW. For comparability, they must be calibrated against standards with known mole fractions on the relevant reference scales. For each species, a linear regression of measured, corrected FTIR response or mole fractions ( $y_{meas}$ ) against reference values ( $y_{ref}$ ) from two or preferably more standards in the mole fraction range of interest generates the calibration coefficients  $a$  and  $b$  in Eq. (3):

$$y_{meas} = a \cdot y_{ref} + b \quad (3)$$

Once the instrument is calibrated (i.e.  $a$  and  $b$  are known), calibrated mole fractions  $y_{cal}$  for measured air samples are calculated from  $y_{meas}$  in the inversion of Eq. (3):

$$y_{cal} = (y_{meas} - b) / a \quad (4)$$

### 6.1.9 Isotopic Calculations and Calibration

FTIR spectroscopy fundamentally determines the amounts of individual isotopologues of each chemical species in a sample independently. The amounts of individual isotopologues  $^{12}\text{C}^{16}\text{O}_2$ ,  $^{13}\text{C}^{16}\text{O}_2$  and  $^{12}\text{C}^{16}\text{O}^{18}\text{O}$  can be retrieved from the FTIR spectra with sufficient accuracy (< 0.1%) to provide useful measurements of total  $\text{CO}_2$ ,  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  in  $\text{CO}_2$  in air. For  $\text{CH}_4$ ,  $\text{CO}$  and  $\text{N}_2\text{O}$  the minor isotopologues absorb too weakly to discriminate them with sufficient accuracy in ambient air and the spectrum analysis assumes fixed isotope ratios in all samples.

This treatment of isotopic composition follows that presented at the WMO-GAW Greenhouse Gas Measurement Techniques (GGMT) meeting in Duebendorf, Switzerland, Sept 2017 [Citation: Chapter 8, Point 12 & Point 13]. Refer to these papers for background and full details of isotopic calculations.

#### 6.1.9.1 Actual and Normalized Isotopologue Mole Fractions

The analysis output variables "CO2\_1", "CO2\_2" and "CO2\_3", in Spectronus refer respectively to the isotopologues  $^{12}\text{C}^{16}\text{O}_2$ ,  $^{13}\text{C}^{16}\text{O}_2$  and  $^{12}\text{C}^{16}\text{O}^{18}\text{O}$ . The analysis output variable "CO2" refers to total  $\text{CO}_2$  mole fraction retrieved ignoring isotopic variability. This quantity is in principle not as accurate as the total  $\text{CO}_2$  mole fraction retrieved via the isotopologues, but can be used when isotopic information for reference standards is not available and constant isotopic composition must be assumed.

The reported  $\text{CO}_2$  isotopologue mole fractions derived from the MALT fit using Hitran line parameters are implicitly normalized by reference isotopologue abundances implicit in Hitran and shown in Table 7. They are reported as the normalized mole fractions  $CO2\_1$ ,  $CO2\_2$  and  $CO2\_3$  (Eq. (5)):

$$\begin{aligned} CO2\_1 &= y_{626} / x_{626,ref} \\ CO2\_2 &= y_{636} / x_{636,ref} \\ CO2\_3 &= y_{628} / x_{628,ref} \end{aligned} \quad (5)$$

where  $y_{626} \dots$  are the actual isotopologue mole fractions in air and  $x_{626,ref} \dots$  are the Hitran reference isotopologue abundances given in Table 7.  $CO2\_1$ ,  $CO2\_2$  and  $CO2\_3$  are referred to as  $y'_{626}$ ,  $y'_{636}$  and  $y'_{628}$  in [Citation: Chapter 8, Point 13].

Actual and normalised mole fractions can be interconverted using Eqs.(5) if the user prefers to work with actual mole fractions.

**Table 7 –  $\text{CO}_2$  Isotopologue abundances and conversion factors. Abundances are taken from [Citation: Chapter 8, Point 6] for [Citation: Chapter 8, Point 14] for VPDB- $\text{CO}_2$ . The Werner & Brand values supersede earlier values given by [Citation: Chapter 8, Point 10].**

Isotopologue	Notation	Abundance $X_{\text{HITRAN}}$	Abundance $X_{\text{VPDB-CO}_2}$	Rescaling factor (Hitran - VPDB- $\text{CO}_2$ )
$^{16}\text{O}^{12}\text{C}^{16}\text{O}$	626	0.98420	0.984054	1.000150
$^{16}\text{O}^{13}\text{C}^{16}\text{O}$	636	0.01106	0.0110019	1.005280
$^{16}\text{O}^{12}\text{C}^{18}\text{O}$	628	0.0039471	0.00411009	0.960319

Isotopologue	Notation	Abundance $X_{\text{Hitran}}$	Abundance $X_{\text{VPDB-CO}_2}$	Rescaling factor (Hitran - VPDB-CO <sub>2</sub> )
<sup>16</sup> O <sup>12</sup> C <sup>17</sup> O	627	0.000734	0.00077366	0.948734
$R_{\text{sum}}$	-	1.016205	1.016053	-

In Table 7,  $R_{\text{sum}} = (1 + {}^{13}r) \cdot (1 + {}^{17}r + {}^{18}r)^2$  is a sum over all 18 possible isotopologues of CO<sub>2</sub> as described below (Eq. **Error! Reference source not found.**).  $R_{\text{sum}}$  is most easily interpreted as the ratio of the mole fraction of total CO<sub>2</sub> to that of the major isotopologue, 626 (<sup>12</sup>C<sup>16</sup>O<sub>2</sub>) (Eq. **Error! Reference source not found.**).

The Hitran reference scale is referenced to VPDB for carbon, and SMOW for oxygen. For CO<sub>2</sub> in air, however, the scale conventionally adopted is VPDP-CO<sub>2</sub>, which is the same as VPDB for C but 41.5‰ lower than SMOW for O [Citation: Chapter 8, Point 10, Point 14 & Point 11]. To convert Hitran-normalised mole fractions to mole fractions normalized to VPDB-CO<sub>2</sub>, multiply the Hitran-normalised mole fractions by the ratio of the VPDB-CO<sub>2</sub> and Hitran reference values, also given in Table 7).

$$\begin{aligned}
 \text{CO}_2\text{-1}_{\text{VPDB-CO}_2} &= \text{CO}_2\text{-1}_{\text{Hitran}} \cdot x_{626,\text{Hitran}} / x_{626,\text{VPDB-CO}_2} \\
 \text{CO}_2\text{-2}_{\text{VPDB-CO}_2} &= \text{CO}_2\text{-2}_{\text{Hitran}} \cdot x_{636,\text{Hitran}} / x_{636,\text{VPDB-CO}_2} \\
 \text{CO}_2\text{-3}_{\text{VPDB-CO}_2} &= \text{CO}_2\text{-3}_{\text{Hitran}} \cdot x_{628,\text{Hitran}} / x_{628,\text{VPDB-CO}_2}
 \end{aligned} \tag{6}$$

### 6.1.9.2 Converting between $y_{\text{CO}_2}$ , $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ and isotopologue mole fractions

The total amount and isotopic composition of CO<sub>2</sub> in an air sample is usually specified by the total CO<sub>2</sub> mole fraction and delta values, CO<sub>2</sub>,  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  rather than the three isotopologue mole fractions retrieved from the measurement,  $y_{626}$ ,  $y_{636}$  and  $y_{628}$ .  $\delta$  values can be calculated from the isotopologue mole fractions following Eq. (7):

$$\begin{aligned}
 \delta^{13}\text{C} &= \left( \frac{y_{636} / y_{626}}{x_{636,\text{ref}} / x_{626,\text{ref}}} - 1 \right) = \left( \frac{y_{636} / x_{636,\text{ref}}}{y_{626} / x_{626,\text{ref}}} - 1 \right) = \left( \frac{\text{CO}_2\text{-2}}{\text{CO}_2\text{-1}} - 1 \right) \\
 \delta^{18}\text{O} &= \left( \frac{y_{628} / y_{626}}{x_{628,\text{ref}} / x_{626,\text{ref}}} - 1 \right) = \left( \frac{y_{628} / x_{628,\text{ref}}}{y_{626} / x_{626,\text{ref}}} - 1 \right) = \left( \frac{\text{CO}_2\text{-3}}{\text{CO}_2\text{-1}} - 1 \right)
 \end{aligned} \tag{7}$$

Recognizing that  $y_{636} / y_{626} = {}^{13}r_{\text{sample}}$  and  $x_{636,\text{ref}} / x_{626,\text{ref}} = {}^{13}r_{\text{reference}}$  (and similarly for <sup>18</sup>O) the isotopologue definitions are equivalent to the conventional definition in terms of atomic ratios <sup>13</sup> $r$  and <sup>18</sup> $r$  in the chosen reference scale.

<sup>1</sup>  $\delta$  values are usually multiplied by 1000 and quoted in ‰. For convenience 1000‰ is omitted from equations.

The total CO<sub>2</sub> mole fraction  $y_{\text{CO}_2}$  is the sum over all CO<sub>2</sub> isotopologues, which can be calculated from Eq. **Error! Reference source not found.** once  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O}$  (or equivalently the atomic isotope ratios <sup>13</sup> $r$ , <sup>17</sup> $r$  and <sup>18</sup> $r$ ) are known:

$$y_{CO_2} = y_{626} \cdot R_{sum} = CO2\_1 \cdot x_{626,ref} \cdot R_{sum} \quad (8)$$

where  $R_{sum}$  is a sum over all possible CO<sub>2</sub> isotopologues:

$$R_{sum} = (1 + {}^{13}r) \cdot (1 + {}^{17}r + {}^{17}r) \cdot (1 + {}^{17}r + {}^{18}r) \quad (9)$$

Note that to calculate  $R_{sum}$  all three  $\delta$  (or  $r$ ) values should be known to account for all isotopologues in the sum.  $\delta^{13}C$  and  $\delta^{18}O$  are retrieved from the measurements (Eq. (7) **Error! Reference source not found.**) and to a good approximation  $\delta^{17}O = 0.528 \times \delta^{18}O$  or  ${}^{17}r = {}^{17}r_{ref}({}^{18}r/{}^{18}r_{ref})^{0.528}$ . See [Citation: Chapter 8, Point 13] for further details.

### 6.1.9.3 Calibration procedure: CO<sub>2</sub> standards with specified isotopic composition

A CO<sub>2</sub> sample or standard from a central calibration lab is typically specified by the total CO<sub>2</sub> dry mole fraction  $y_{CO_2}$ , plus  $\delta^{13}C$  and  $\delta^{18}O$ , while the FTIR measurement determines  $CO2\_1$ ,  $CO2\_2$  and  $CO2\_3$ . (Other optical instruments may specify unnormalised mole fractions  $y_{626}$ ,  $y_{636}$  and  $y_{628}$  instead of the normalized mole fractions.) To calibrate the analyser for each isotopologue individually, first calculate the individual isotopologue mole fractions in the reference gas using Eq. (10) or (11) below, then use Eq. (3) to calculate isotopologue-specific calibration coefficients for each isotopologue. For an unknown sample, calibrate the raw measurements of  $CO2\_1$ ,  $CO2\_2$  and  $CO2\_3$ , which can then be used to calculate  $y_{CO_2}$ ,  $\delta^{13}C$  and  $\delta^{18}O$  directly using Eq. **Error! Reference source not found.**(7) and Eq. (8) **Error! Reference source not found.**.

### 6.1.9.4 Calibration procedure: CO<sub>2</sub> standards without specified isotopic composition

In some cases, reference gases may be available with only total CO<sub>2</sub> specified and without isotopic information. In this case the retrieved amount  $y_{626}$ , or  $CO2\_1$  may be used as a proxy for total CO<sub>2</sub> in the calibration. (The quantity  $CO_2$  is retrieved in Spectronus from fitting the spectrum for CO<sub>2</sub> assuming the fixed isotopic abundances assumed by Hitran.) This may lead to a small but potentially significant error in determining total CO<sub>2</sub> in a sample of different isotopic composition from the calibration gases, because references and samples may have different but unknown values of  $R_{sum}$  in Eq. (10). If  $R_{sum}$  is constant, it is absorbed into the calibration slope  $a$  in Eq. (3) and there is no error. Over a realistic maximum range of  $\delta^{13}C$  of 0‰ to -40‰, variation in  $R_{sum}$  induces an apparent error of up to ~0.2 ppm in total CO<sub>2</sub> calculated from inverting Eq. (10) for  $y_{CO_2}$ . Potential errors are discussed in detail in [Citation: Chapter 8, Point 13].

### 6.1.9.5 Determination of isotopologue mole fractions in calibration reference tanks

Reference tank composition is usually defined by the total CO<sub>2</sub> mole fraction and isotopic  $\delta$  values  $y_{CO_2}$ ,  $\delta^{13}C$  and  $\delta^{18}O$  in a given reference scale. To calculate the reference isotopologue mole fractions required for calibration following Eq. (3), determine the normalized ( $CO2\_1$ ,  $CO2\_2$ ,  $CO2\_3$ ) or actual ( $y_{626}$ ,  $y_{636}$ ,  $y_{628}$ ) mole fractions for the calibration gases following Eq. (10) or (11) after calculating  $R_{sum}$  (Eq. **Error! Reference source not found.** for each reference gas:

$$\begin{aligned} CO2\_1 &= y_{CO_2} / (R_{sum} \cdot x_{626,ref}) \\ CO2\_2 &= (1 + \delta^{13}C) \cdot y_{CO_2} / (R_{sum} \cdot x_{626,ref}) \\ CO2\_3 &= (1 + \delta^{18}O) \cdot y_{CO_2} / (R_{sum} \cdot x_{626,ref}) \end{aligned} \quad (10)$$

$$\begin{aligned}
 y_{626} &= CO2\_1 \cdot x_{626,ref} \\
 y_{636} &= CO2\_2 \cdot x_{636,ref} \\
 y_{628} &= CO2\_3 \cdot x_{628,ref}
 \end{aligned}
 \tag{11}$$

### 6.1.10 Implementation of Calibration in Spectronus Software

In the inbuilt Spectronus Calculated Values scheme the raw mole fractions of the three CO<sub>2</sub> isotopologues are corrected and calibrated in several steps:

1. renormalize to VPDB-CO<sub>2</sub> following Eq. **Error! Reference source not found.** using the data in Table 7.
2. correct to dry air (Eq. (1)).
3. correct to standard values of P<sub>0</sub>, T<sub>0</sub>, F<sub>0</sub>, water vapour and CO<sub>2</sub> (Eq. (2)). These corrected values are written into the database as CV\_CO<sub>2</sub>\_1\_corr, CV\_CH<sub>4</sub>\_corr, etc
4. Apply calibration Eq. (4), the calibrated values are written to the database as CV\_Y626, CV\_YCO<sub>2</sub>, CV\_CH<sub>4</sub>\_cal etc. For CO<sub>2</sub>, the calculations are carried through using normalized mole fractions and actual mole fractions are calculated calibration.

In Spectronus Software, the calibration coefficients need to be entered. These values are used by the calculated values equations. Refer to the software manual for details on how the various configuration forms specify the correction and calibration equations applied to the measured data.

### 6.1.11 Implementation of Calibration in Post-processing

Real time calibration and correction as in section 6.1.10 - Implementation of Calibration in Spectronus Software can only use coefficients known in advance and stored in the Spectronus calibration tables. Final calibrated data may require adjustments to calibration coefficients determined after the sample measurement. Post-processing of the raw data with updated corrections and calibrations may thus be necessary, following the same calculations as illustrated in section 6.1.10 - Implementation of Calibration in Spectronus Software in a data processing code of the user's choice. Post-calibration may be based on the raw measured amounts, corrected amounts, or pre-calibrated amounts of each trace gas or isotopologue.

### 6.1.12 Calibration Revision History

0	Oct 2016	Isotope ratios and scale factors to follow Brand et al. 2010
1	Nov 2016	Minor edits.
2	Jan 2017	Small change to <sup>17</sup> r isotope ratio and scale factors to follow [Citation: Chapter 8, Point 12]
3	Nov 2018	Nomenclature, symbols and isotope calculations consistent with AMT reference paper [Citation: Chapter 8, Point 13]

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## 6.2 Sensor Calibration

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Sensor calibration is best carried out with the instrument in its normal operating environment.

The logged values of an analog input quantity such as cell pressure depend on the scaling employed by the software between sensor signals (usually in Volts) and the quantity being measured. We use as an example a pressure transducer with 0 - 10 V output nominally corresponding to 0 - 1000 torr, or 0 - 1333 mbar. Factory calibration is achieved by using a transfer standard to adjust the sensor itself. No further adjustment is usually required in the Spectronus software at that stage.

To calibrate the sensor, two known reference states will need to be established (e.g., pressures in the cell). For example, for pressure by pumping the cell down to a known low pressure (preferably less than 1 mb) and filling it to atmospheric pressure with an independent atmospheric pressure measurement. The Spectronus heated-metal-cell thermistors are precision calibrated and do not require adjustment. Contact Acoem Australasia if there is a cell temperature problem. After changing plumbing, a leak check should be performed. Refer to Section 5.1.10 - Leak Check.

### Example: Cell pressure sensor calibration

1. Run the software and **View** the **Analog Input Values** panel.
2. Open the **Configure/IO/Analog** Inputs form and select the pressure channel.
3. Set the **Scaling** values equal to the min and max values of the sensor voltage range (for the example  $V_{min} = 0$  and  $V_{max} = 10$  volts). The values reported in the **Analog Input Values** panel will now read volts from the pressure sensor directly.
4. Pump the cell to  $< 1$  mb and record the actual pressure ( $P_1$ , near 0) and actual sensor voltage ( $V_1$ , should be near 0).
5. Open the cell inlet and allow pressure to equalise with atmospheric pressure,  $P_2$ . Measure atmospheric pressure with an independent, calibrated manometer. Record the corresponding sensor voltage,  $V_2$ .
6. Assuming a linear calibration,  $P = a + b.V$ , calculate the calibration parameters a and b:  
$$b = (P_2 - P_1)/(V_2 - V_1)$$
$$a = P_2 - b.V_2 = P_1 - b.V_1$$
7. Calculate the scaling values of P corresponding to  $V_{min}$  and  $V_{max}$  and enter these in the Min and Max fields in the Scaling box:  
$$P_{min} = a + b.V_{min} \text{ ( = a for the example)}$$
$$P_{max} = a + b.V_{max} \text{ ( = a + 10b for the example)}$$
8. Click apply to save changes.
9. The analog input values panel should now read pressure correctly in the selected units.

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## 6.3 Determining Cross Sensitivities

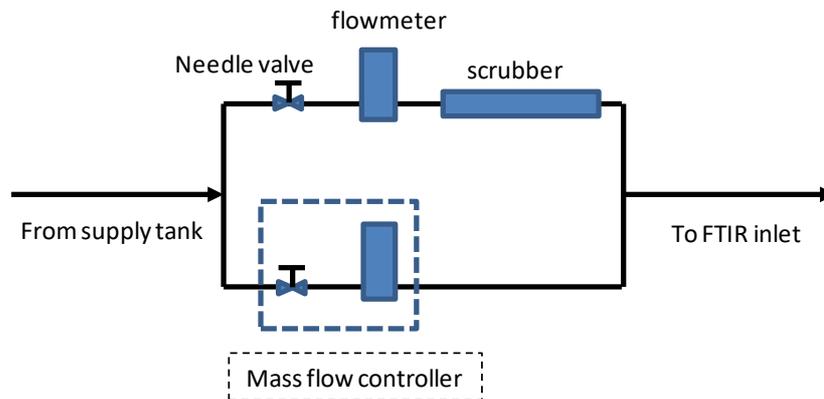
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Cross sensitivity coefficients are determined at the factory and provided with each analyser. The following outlines methods to re-determine cross sensitivity coefficients if required.

### 6.3.1 Water Vapour & CO<sub>2</sub>

To determine cross-sensitivities to residual water vapour and CO<sub>2</sub> concentration, a manifold such as that shown schematically in Figure 49 can be used. Air flow from a cylinder (preferably aluminium) is split into two streams, each with a flow meter and flow control valve (or mass flow controller). One

stream is scrubbed (magnesium perchlorate for water vapour, Ascarite or equivalent for CO<sub>2</sub>), the other remains unmodified. (In the case of water vapour a dry tank supply may need to be humidified. Alternatively, the scrubber could be replaced by a humidifier such as type ME Nafion, or a dew point generator.) The two streams are recombined and directed to the FTIR analyser inlet. By slowly stepwise changing the proportions of scrubbed and unscrubbed air in the outlet stream, concentration of water vapour or CO<sub>2</sub> can be varied from the original cylinder value to near zero.



**Figure 49 – Flow Splitter for Determining Cross-Sensitivities to Water Vapour and CO<sub>2</sub>**

For CO<sub>2</sub>, a compressed air cylinder can be conveniently spiked with CO<sub>2</sub> by pre-evacuating the cylinder, adding approximately 2L pure CO<sub>2</sub> from a balloon to a 15L cylinder before compressing ambient air into the cylinder to 200 bar. This will provide CO<sub>2</sub> mole fractions around 1000 ppm. (CO<sub>2</sub> from a soda-water maker and a 15L S.C.U.B.A. tank is convenient for this purpose). Figure 50 illustrates typical data from stepwise stripping of CO<sub>2</sub> from a flowing tank sample.

For water vapour, start with a cylinder with ideally 100 - 200 ppm water vapour. Alternatively, start with a dry air flow through the analyser's dryer, then bypass the dryer and allow the water vapour content to slowly rise.

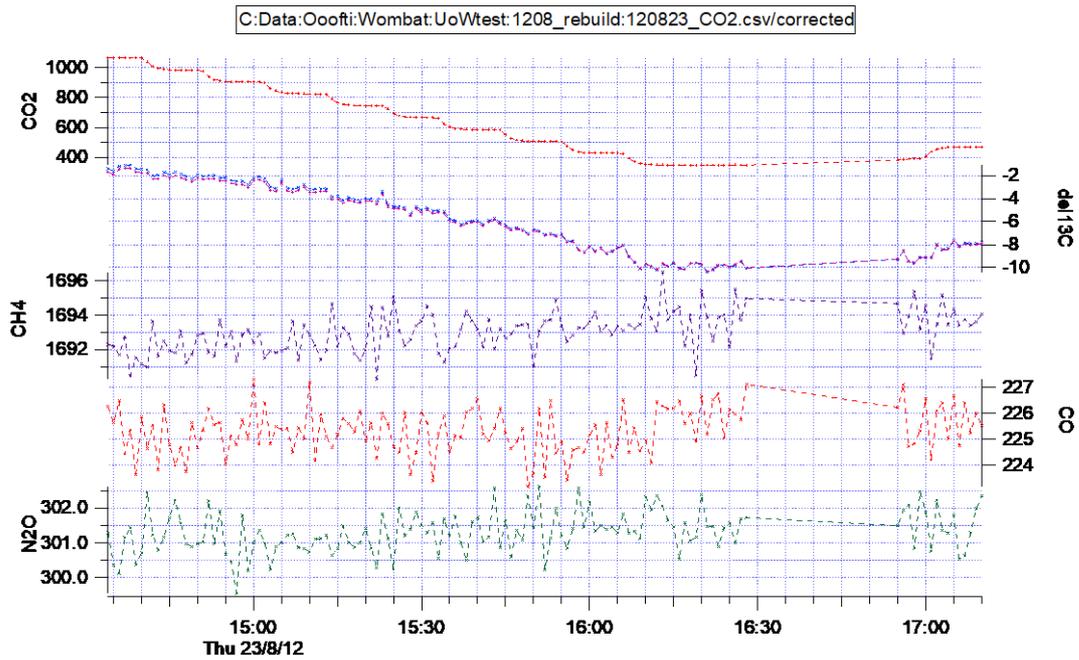


Figure 50 – Measurement: Stepwise Stripping of CO<sub>2</sub> for CO<sub>2</sub> Cross-Sensitivity - Time Series of Raw Retrieved Mole Fractions

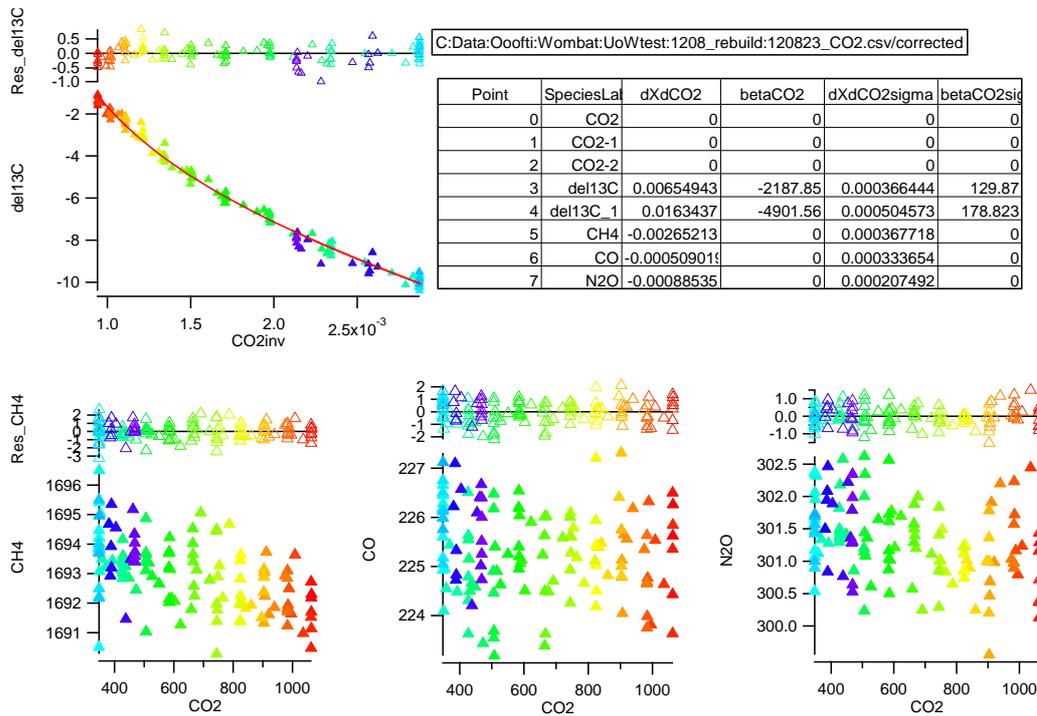


Figure 51 – Measurement: Stepwise Stripping of CO<sub>2</sub> for CO<sub>2</sub> Cross-Sensitivity - Regressions of Trace Gas Mole Fractions and  $\delta^{13}\text{C}$  Against CO<sub>2</sub> Mole Fraction

### 6.3.2 Pressure

To determine pressure cross sensitivity, vary the sample cell pressure with a sample gas from a target tank of constant composition (such as a S.C.U.B.A. tank). This can be static or pressure and flow controlled. Ensure that the target tank pressure regulator is set to higher than the highest pressure needing to be tested, but no higher than the instrument limits. Create a cycle list where each cycle samples from the target tank at different pressures and the same flow. A sample cycle of this nature is provided with the instrument and is called dXdP.

### 6.3.3 Temperature

Temperature dependence of retrieved concentrations is due to both the error in measuring the sample temperature and changes in optical alignment of the FTIR interferometer and optics. Temperature dependence is thus very difficult to quantify because retrieved concentrations depend not only on temperature but on the rate of change and recent history of temperature changes. For these reasons the best approach is to maintain close temperature control with the supplied thermostat system, typically near 30 °C (for Glass Cell).

**Note:** It can be difficult to vary one parameter while keeping others constant. For example, changing pressure can change water vapour due to changing wall interactions.

In cases when more than one parameter (i.e., Q, P, T, C) varies during an experiment, one parameter can be pre-corrected (if its cross-sensitivity coefficients are known) before determining the cross sensitivity to the others. Alternatively, two or more can be determined simultaneously from a multi-linear regression with more than one independent variable, provided the variations in the parameters are not correlated during the measurements.

### 6.3.4 Typical Cross Sensitivity Coefficients

Most cross-sensitivity coefficients are small or negligible. To give an idea of scale, [Citation: Chapter 8, Point 5], Table 8 gives typical values for one analyser.

**Table 8 – Typical Cross-Sensitivities for Target Gases to Water Vapour and Pressure**

$\frac{dx}{d(\text{quantity})}$	CO <sub>2</sub> μmol mol <sup>-1</sup>	δ <sup>13</sup> C - CO <sub>2</sub> ‰	CH <sub>4</sub> nmol mol <sup>-1</sup>	CO nmol mol <sup>-1</sup>	N <sub>2</sub> O nmol mol <sup>-1</sup>
Pressure hPa	0.0085	0.005	0.031	0.006	0.007
Equil. Temp. °C	< 0.8	0.6	< 1.6	< 1	0.6
Disequil. Temp. °C	2.07	4.1	-4.6	10.2	3.2
Flow LPM	0.15	-0.9	< 4	< 2	< -0.8
Residual H <sub>2</sub> O μmol mol <sup>-1</sup>	.01	-	< 0.2	< 0.2	-
CO <sub>2</sub> μmol mol <sup>-1</sup>	-	0.006*	-	0.006	0.008

### 6.3.5 Stripping Water Vapour & CO<sub>2</sub> Absorption Features from Background Spectra

Retrieved raw concentrations from the Spectronus FTIR trace gas analyser can depend on the background spectrum to which the sample air spectrum is ratioed before MALT fitting. This manifests itself most clearly as small changes in retrieved concentrations after recording a new background. It is most obvious in CO<sub>2</sub> and CO<sub>2</sub>\_1 retrieved from the 3600 cm<sup>-1</sup> window (and in δ<sup>13</sup>C, which may be derived from it).

This band is heavily overlapped by water vapour absorptions which, if variable, can lead to variable retrievals of CO<sub>2</sub> due to imperfect spectral water cancellation between sample and background spectra.

### 6.3.6 Analysis of the Problem

Sample and background spectra always contain some remnant water vapour absorption in the 3600 cm<sup>-1</sup> region (as well as CO<sub>2</sub> absorption near 2350 cm<sup>-1</sup>). This water vapour absorption does not “ratio out” simply or linearly when calculating a transmission spectrum to be fitted by MALT, for two reasons:

1. The background water vapour spectrum actually has two components: Water vapour at ~1 mb total pressure in the sample cell, and water vapour at ~1030 mb total pressure in the IRcube optics compartment. The low-pressure lines are narrower than those at 1030 mb, the spectral line shapes are not identical and do not subtract cleanly from water vapour at ~1000 mb in the sample spectrum.
2. Because the sample and background spectra are recorded and apodised by the FTIR to 1 cm<sup>-1</sup> before being divided to calculate transmission, cancellation is not complete. This is related to the well-known breakdown of Beer’s Law at low resolution.

The result is that the calculated transmission spectrum actually has three water components, which do not cancel linearly, and a single layer MALT calculation does not represent the resultant composite residual line shape correctly. To account for this behaviour, MALT must emulate it, in which case the water vapour amounts (in both 1 mb (cell) and 1030 mb (IRcube) layers) in the background must also be known or fitted independently - MALT can do this (see the manual) but it gives unstable solutions because of the strong correlations between the sample and background components of the composite water spectrum.

A better alternative, described here, is to remove the water vapour absorptions from the background spectrum altogether before ratioing with the sample to form the transmission spectrum, so that water vapour absorption in the background spectrum is effectively zero and only sample water vapour needs to be fitted.

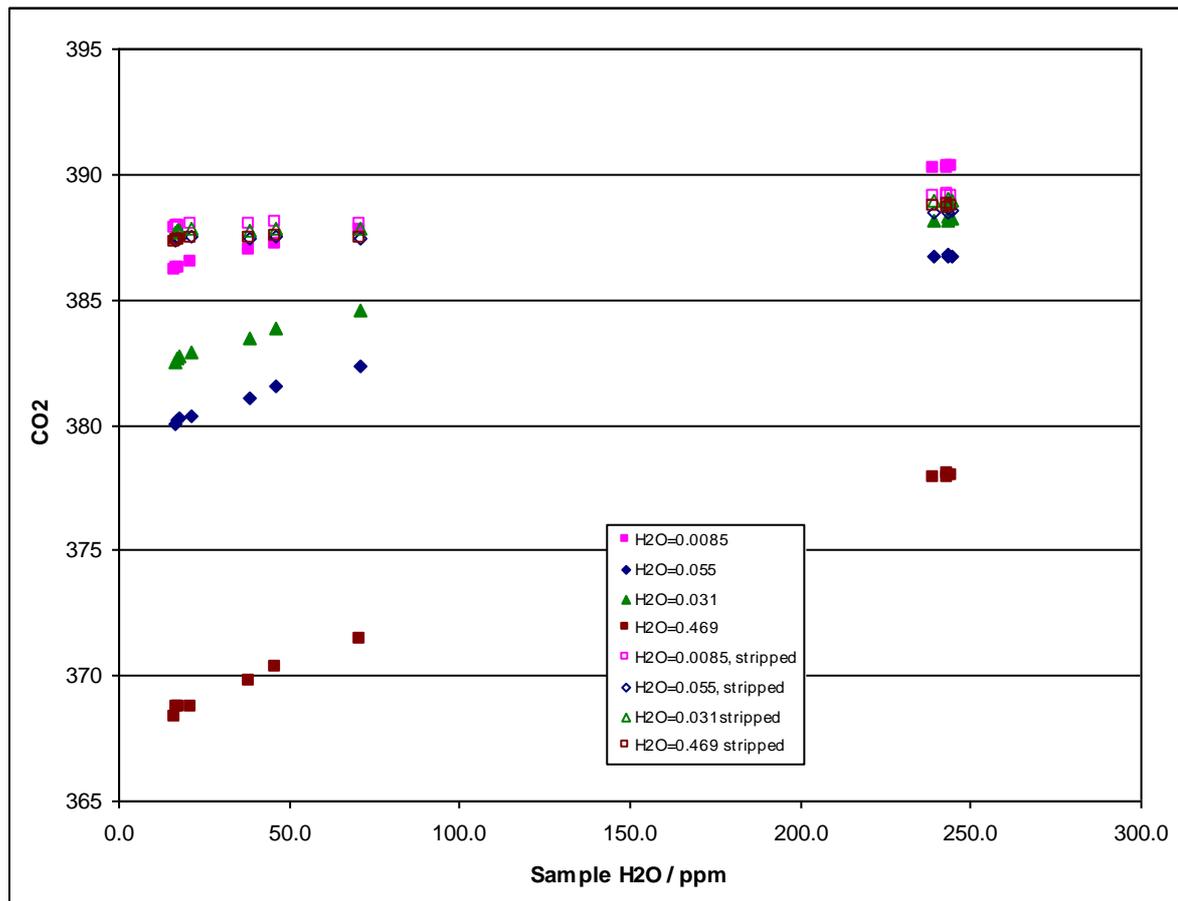
### 6.3.7 Procedure Outline

1. Fit the background single beam spectrum with a 2-layer MALT model, one layer at 1 mb total pressure (representing the cell), and one layer at 1030 mb (representing the optics). It is impossible to get a good fit with a single layer model, in a reasonably dry system there is approximately equal amounts of water vapour in each layer - typically 0.2 mb-m. The 2-layer fit is reliable, with consistent partitioning of the total water between the 2 layers.

2. Use the concentrations and Instrument Line Shape (ILS) parameters from this fit as input to MALT in simulation mode to simulate the transmission spectrum of water vapour (2 layers) at the levels in the selected background spectrum with the retrieved ILS, over the full range of the water vapour bands.
3. Divide the measured (wet) background spectrum by this simulated water transmission spectrum. The result is a water-absorption free background spectrum.
4. Use the dried, or stripped, background to calculate transmittance when fitting sample spectra. The retrieved water vapour is now only that of the sample, and the fits are generally good with negligible residuals in the H<sub>2</sub>O lines.
5. Use this procedure wherever there are residual absorptions in the background spectrum - usually water vapour around 3500 - 3700 cm<sup>-1</sup> and CO<sub>2</sub> near 2350 cm<sup>-1</sup>.

### 6.3.8 Example

Figure 52 shows an illustrative result for the worst case of CO<sub>2</sub> retrieval near 3600 cm<sup>-1</sup>, where there is strong water vapour absorption.



**Figure 52 – CO<sub>2</sub> Retrieval - Strong Water Vapour Absorption**

The levels given for water vapour in the legend are the amount of retrieved water vapour in the 24 m cell in hPa (assumed at 1 hPa total pressure) in the background spectrum. The water vapour amounts retrieved in the optics were of similar magnitude in each background spectrum and similar to the driest cell spectrum – equivalent to 0.007 hPa over an equivalent 24 m path.

The measurements are of 11 spectra of a single tank of air, made over 8 days and having variable amounts of water vapour (10 - 250 ppm) in the sample (due to variable pre-conditioning of inlet lines and cell). The 11 spectra were ratioed to eight background spectra, four with water vapour at different levels (see legend, filled symbols), and the same four backgrounds with water stripped out by the procedure described above (open symbols).

There are two main observations:

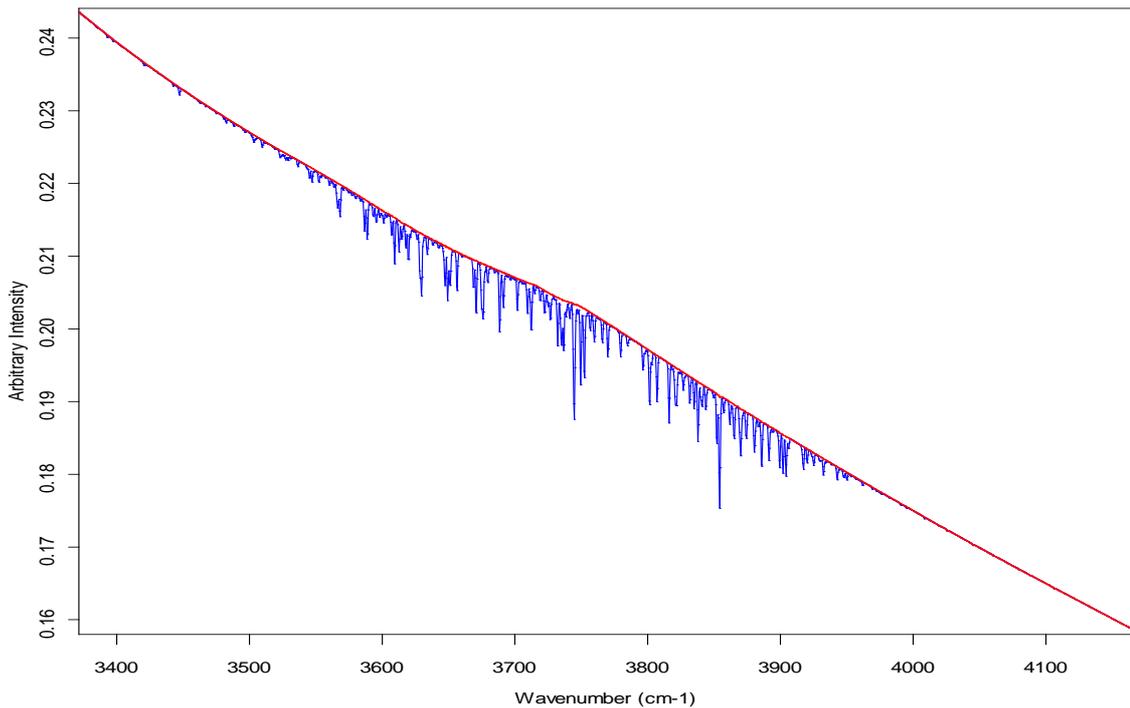
1. For unstripped backgrounds, there is a strong dependence of retrieved concentration of CO<sub>2</sub> on both the amount of water vapour in the sample (X axis) and background water vapour (as given in the legend).
2. For stripped backgrounds, the dependence on water vapour in the background is reduced substantially, and all four retrievals agree within 0.5 ppm. The dependence of CO<sub>2</sub> on sample water vapour is reduced by more than a factor of ten relative to the wet backgrounds (approximately 0.0055 ppmCO<sub>2</sub>/ppmH<sub>2</sub>O in this case).

The latter is somewhat surprising – it seems to be the inaccurate fitting of the composite water vapour spectrum when using unstripped backgrounds that leads to the sample water vapour dependence of CO<sub>2</sub> retrieval. With only sample water vapour to be fitted, MALT can do a good fit and there is little cross-sensitivity.

The differences between the four stripped backgrounds reflect small changes in the overall response of the Spectronus, probably due mainly to temperature stability.

### 6.3.9 In Practice

The background stripping procedure is implemented in the programme strip.exe and batch file autostrip.bat, which fits and calculates the spectra of water vapour and CO<sub>2</sub> in the 3600, 3000 and 2300 cm<sup>-1</sup> regions, creates a transmission spectrum of the fitted H<sub>2</sub>O and CO<sub>2</sub> amounts and ratios it from the measured background. The result is illustrated in **Error! Reference source not found.**



C:\Programs\Strip\work\090616_1400bgnd.spc	00/00/ 0
C:\Programs\Strip\work\090616_1400bgnd.0 Emma@CapeGrim	

Page 1/1

**Figure 53 – Original Background Spectrum of an Evacuated Cell (Blue) and the Stripped Spectrum (Red) in the 3600 cm<sup>-1</sup> Region Where There is Strong Water Vapour Absorption**

### 6.3.10 Imperfect Cancellation of Water Vapour Absorption Features

The imperfect cancellation of water vapour features in the sample/background transmission spectra is related to the breakdown of Beer's Law at low resolution. Let  $\tau_S$  and  $\tau_B$  be the optical depth of the sample and background spectra at some frequency due to water vapour concentrations in the sample and background:  $\tau$  is proportional to the water vapour concentration  $\tau_S = \alpha C_S$  and  $\tau_B = \alpha C_B$ . The true sample and background spectra are:

$$I_S = I_0 \exp(-\tau_S) \text{ and } I_B = I_0 \exp(-\tau_B)$$

The true, or monochromatic, transmission is:

$$T_{\text{true}} = I_S/I_B = \exp(-(\tau_S - \tau_B)) = \exp(-\alpha C_S - C_B)$$

This is exactly the same as the spectrum of a net water concentration  $C_S - C_B$ , the difference in concentrations between sample and background. This would also be true for measured spectra if the spectra were measured with infinite resolution. But in reality, the spectra  $I_S$  and  $I_B$  are each apodised and convolved with an instrument line shape (ILS) of 1 cm<sup>-1</sup> resolution, significantly wider than the lines themselves, before being divided:

$$I_{S, \text{measured}} = I_S \otimes ILS$$

$$I_{B, \text{measured}} = I_B \otimes ILS$$

The convolution is not linear with respect to  $\tau$  and

$$T_{measured} = I_{S,measured}/I_{B,measured} \neq I_S/I_B \neq T_{true}$$

$T_{measured} \approx T_{true}$  only when absorption is weak and/or the spectral resolution is sufficient to fully resolve the observed line widths.

## 7. Signal to Noise Ratios and Allan Variance

### 7.1 Signal to Noise Ratio (SNR)

A simple measure of SNR of the FTIR spectrometer is to ratio two consecutive spectra of an evacuated sample cell and measure the rms or peak-peak noise  $N$  on the 100% continuum line. The SNR is then  $1/N$ . OPUS provides a convenient tool to determine this SNR.

Typical conditions: 2 x 1-minute spectra at  $1\text{ cm}^{-1}$  resolution, determine noise from  $2500 - 2600\text{ cm}^{-1}$ . Typical SNR by this method is typically 50:000:1 -  $\$80,000:1$  RMS, and depends mainly on detector noise. Allan variance studies (below) show that this SNR is the major factor determining repeatability of retrieved trace gas concentration measurements.

### 7.2 Allan Variance

Precision or repeatability of trace gas analyses with the Spectronus is determined from replicate measurements of a gas sample of constant composition, for example a set of measurements of a constant air sample in the sample cell. Figure 54 and Figure 55 illustrate two examples of such measures of precision with typical time series (upper panels) and Allan deviation (lower panels) of consecutive 12-second measurements of  $\text{N}_2\text{O}$  and  $\text{CO}$  in air over a 13-hour period, where  $\text{N}_2\text{O}$  was stable in the cell and  $\text{CO}$  slowly increased.

For these measurements the cell was filled with dried ambient air, closed, and spectra were collected continuously overnight for approximately 13 hours. Each measurement consists of 16 coadded scans over 12 seconds. In this case the spectrum analysis (approximately 10 seconds required per spectrum) was carried out after the data collection period to allow maximum time resolution.

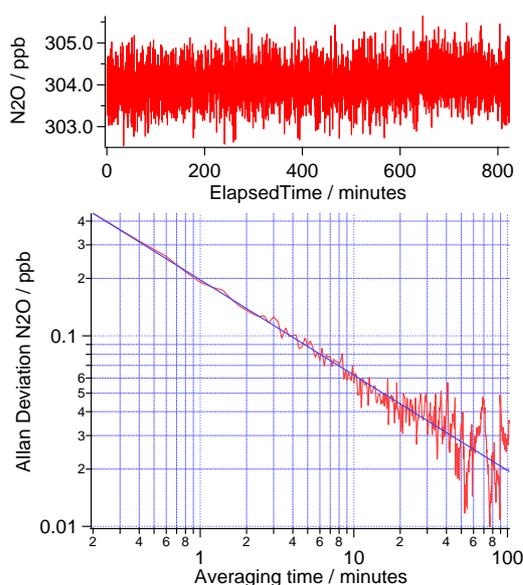
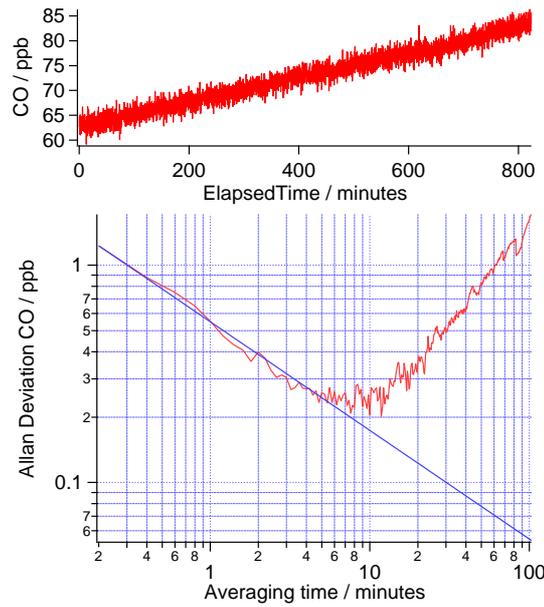


Figure 54 – Allan-Variance Plot of  $\text{N}_2\text{O}$



**Figure 55 – Allan-Variance Plot of CO**

Allan variance is commonly used to characterise noise in repeated measurements [Citation: Chapter 8, Point 9 & Point 1] and describes the precision of a measurement as a function of the averaging time or number of averaged measurements. It is defined for a variable  $y$  as:

$$\sigma_y^2(\tau) = \frac{1}{2} \langle (\Delta y)^2 \rangle$$

**Equation 18**

Where  $\tau$  is the averaging time,  $\Delta y$  is the difference between mean values of  $y$  taken over consecutive periods of length  $\tau$ , and the brackets  $\langle \rangle$  indicate the mean or expectation value. If the variability is dominated by white (Gaussian) noise, as should occur in the ideal detector-noise-limited case, the Allan variance should decrease linearly with averaging time and the log-log plots of Allan deviation (i.e., the square root of the Allan variance) in Figure 54 should have slope of -0.5, as indicated by the blue lines. Figure 54 displays the ideal case for  $N_2O$ , where there is no drift over the 13-hour measurement period and the Allan deviation continues to decrease with  $\sqrt{time}$ . Figure 55 displays a case for CO, which drifted upward at ca.  $1.5 \text{ nmol mol}^{-1} \text{ h}^{-1}$ ; in this case the Allan deviation ceases to decrease once the drift becomes significant relative to the noise, in this case after approximately 10 minutes.

For Allan deviation limits in a new analyser, refer to Section 1.2 - Specifications.

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