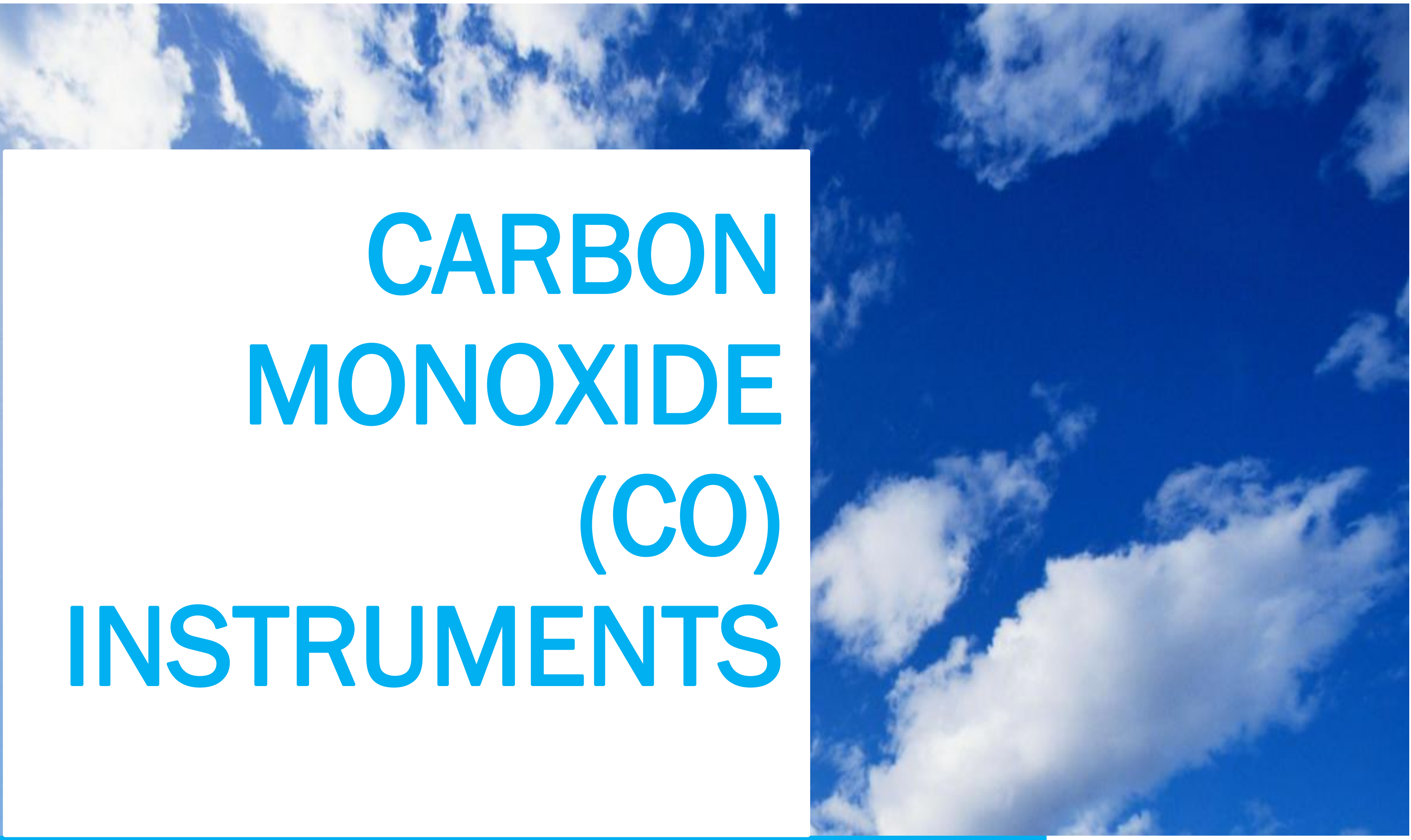


CARBON MONOXIDE (CO) INSTRUMENTS

Carbon Monoxide is a critical pollutant causing health risks and needs to be monitored using specialized instrumentation.

South African Weather Service

What is Carbon Monoxide

Carbon Monoxide is a colourless, odorous and tasteless flammable gas. CO is toxic to all animals that use haemoglobin as an oxygen carrier (body functions of red blood cells).

CO in the most abundant air pollutant found in the atmosphere. It is principally a man-made pollutant generated from the burning of coal and fuel oil burning, industrial processes and solid waste combustion.

Definition
Carbon monoxide is the chemical compound with the formula CO.

CO is a product of incomplete combustion and is most dangerous in enclosed spaces such as poorly ventilated rooms.

The chemical composition of Carbon Monoxide is written as CO which tells us that this gas consists of one Carbon molecule and one Oxygen molecules.

$$C + O \rightarrow CO$$

How do we measure CO?

The measurement of Carbon Monoxide (CO) in air is based on Non-Dispersive infrared spectrophotometry.

Definition
Non-Dispersive infrared spectrophotometry (NDIR); is a technique used where an infra-red beam is passed through a sampling chamber and each gas component in that sample absorbs some particular frequency of infra-red.

To enable us to measure trace levels of CO in ambient air we also make use of the principles of Non-Dispersive infrared spectrophotometry (NDIR) and certain components are required inside an instrument to do so. These basic components include:

- Electrical circuits to power the sensors and other circuits.
- Electronic circuits to measure voltages from sensors and circuits.
- Processor that can perform calculations and display data.
- Source that can emit Infra-red light.
- Measuring chamber for the infra-red absorption to take place without interference.
- Sensor that can measure the Infra-red light.

Although several different type of CO analysers are available on the market and they are all manufactured by different suppliers, most instruments make use of the same basic components and principle to measure CO in ambient air. To understand the principle of NDIR we first need to look at how infra-red light affects the CO molecules.

What is Infra-red light and how do we measure it?

Light is measured by its wavelength (in nanometers) or frequency (in Hertz). One wavelength equals the distance between two successive wave crests or troughs. Frequency (Hertz) equals the number of waves that passes a given point per second.

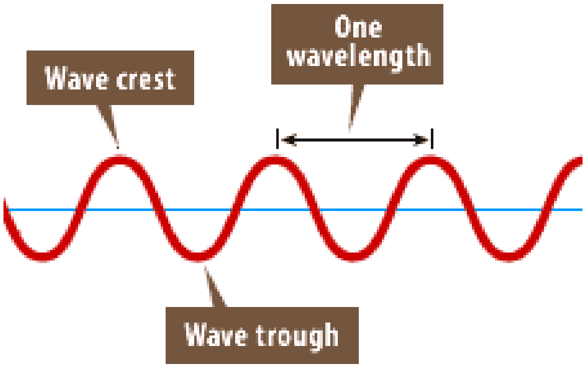


Figure 6.1: Light is measured in wavelength or frequency.

Definition
In physics, the wavelength is the spatial period of a periodic wave—the distance over which the wave's shape repeats.

Definition
Frequency is the number of occurrences of a repeating event per unit of time. It is also referred to as temporal frequency, which emphasizes the contrast to spatial frequency and angular frequency.

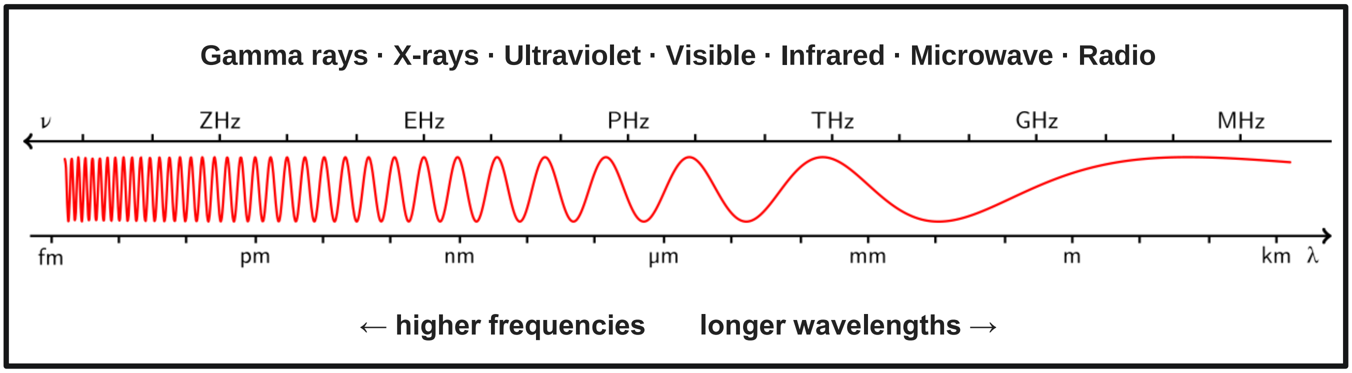


Figure 6.2: The full electromagnetic spectrum.

Light is measured at different wavelengths in nanometres, the electromagnetic spectrum for light is the available range of light that we can measure, the spectrum starts at a wavelength of 200 nM up to 20 µM.

Near infrared (NIR) is measured from 700 nM up to 2 µM and infrared light (IR) is measured from 2 µM up to 20 µM.

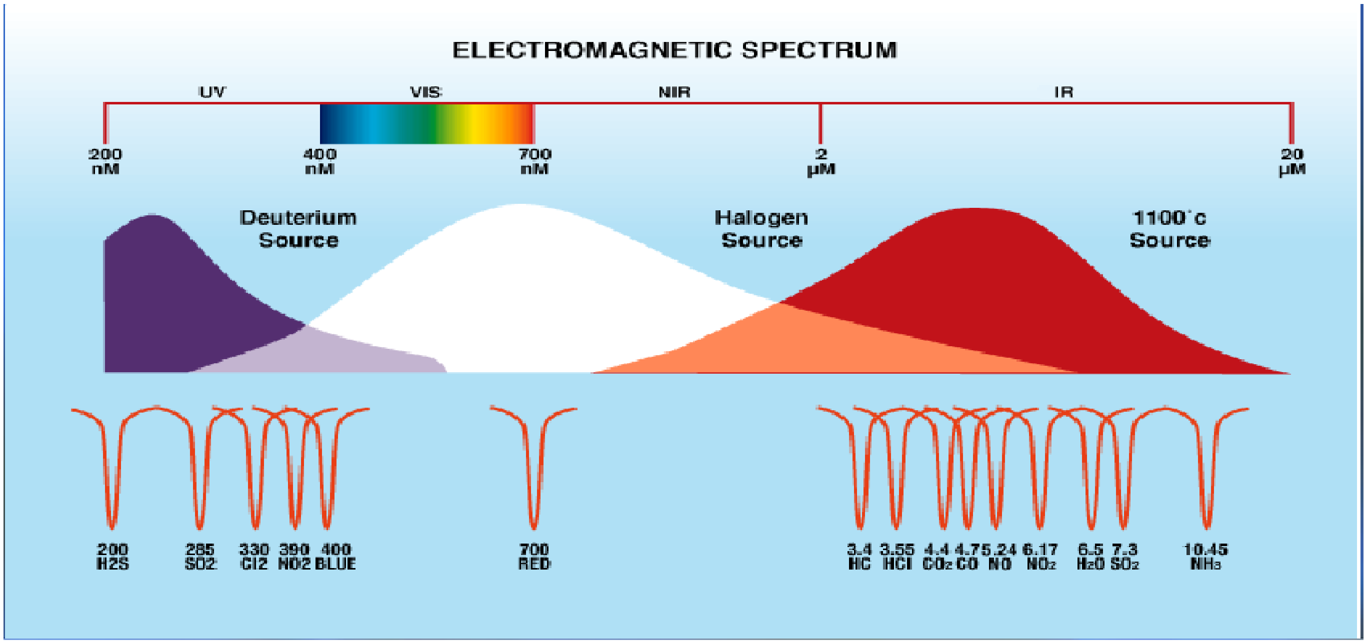


Figure 6.3: The electromagnetic spectrum of light.

Operation principles of CO instruments

Non-dispersive infrared spectroscopy (ND-IR) is used to detect gas and measure the concentration of carbon monoxide. An infra-red beam passes through the sampling chamber and each gas component in the sample absorbs some particular frequency of infra-red. In parallel a reference gas, typically nitrogen, is used in another chamber. By measuring the amount of absorbed infer red at the necessary frequency, the concentration of the gas component can be determined.

CO absorbs infrared radiation (IR) at a wavelength near 4.7 microns. The strength of the received will be proportional to the amount of CO in the sample being measured.

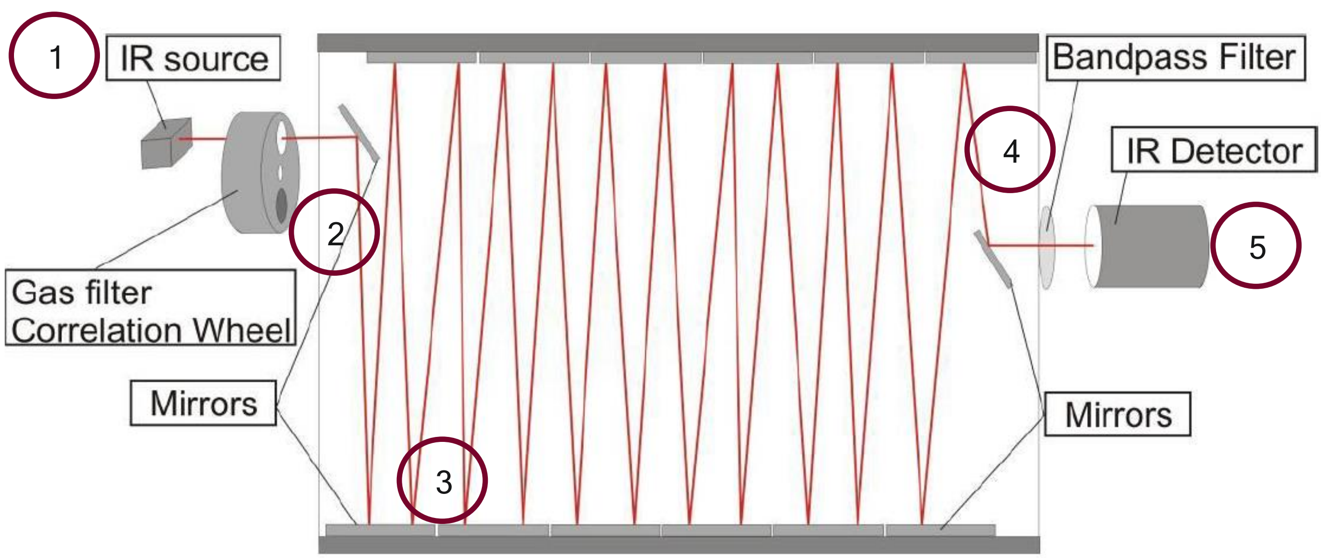
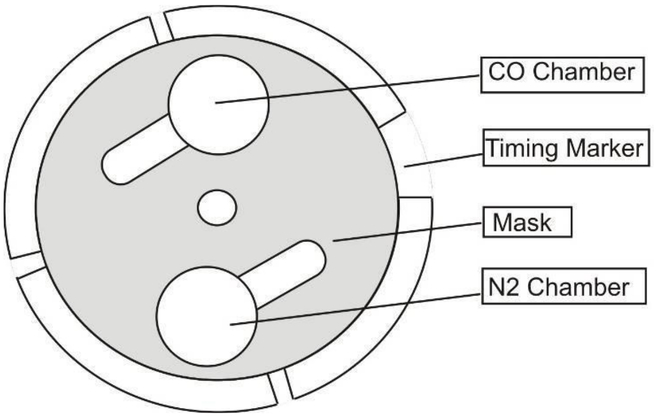


Figure 6.4: Optical cell measurement theory of a Carbon Monoxide gas analyser.

1. The IR source (light source) emits the infrared light. This light source will emit all wavelengths of IR light; thus, it is not specific to Carbon monoxide at this point.

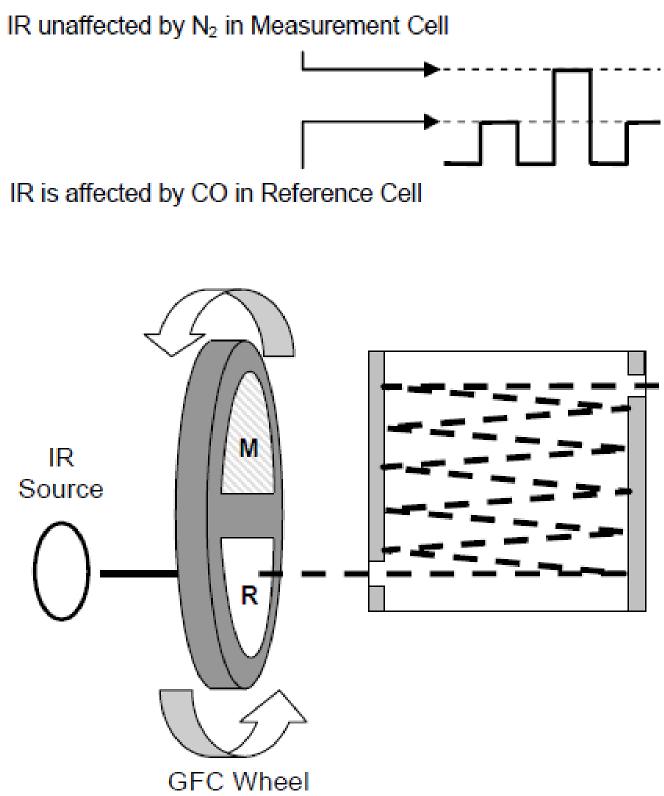
2. The IR source passes through a gas filter wheel which contains two filter, a CO filter and Nitrogen N_2 filter.



The CO filter absorbs IR at 4.7 microns, the frequency of light that CO absorbs. This filter is used as a **reference** point or zero measure.

The N_2 filter does not absorb any IR. This filter is used for normal CO **measurements**.

Figure 6.5: Filter wheel of a Carbon Monoxide gas analyser.



As the filter wheel turns the instrument alternates between measurement and reference.

Reference: The filter absorbs all the IR that can be absorbed by CO. When this light reaches the detector, this value is seen as a zero point, no CO is measured.

Measurement: This filter allows all IR through. As the IR enters the sample chamber the CO absorbs the IR and what is left of that light is sent to the detector.

Figure 6.6: Filter wheel of a Carbon Monoxide gas analyser

3. The IR enters the sample chamber and get bounced around the chamber with the use of mirrors. This technique is used to increase the path length to the IR light beam to interact with as much of the CO in the chamber as possible and allow to absorption.

4. The IR goes through a optical filter to remove all IR wavelengths of light except for the waveleng of light that is absorbed by CO.

5. The remaining IR is measured by a detector to determine the actual measurement of CO gas in the chamber. The detector is used to measure IR from the IR source which then translates it into a small voltage. The voltage produced is then measured by the microprocessor to generate a measurement that we can interpret.

Examples of CO instruments

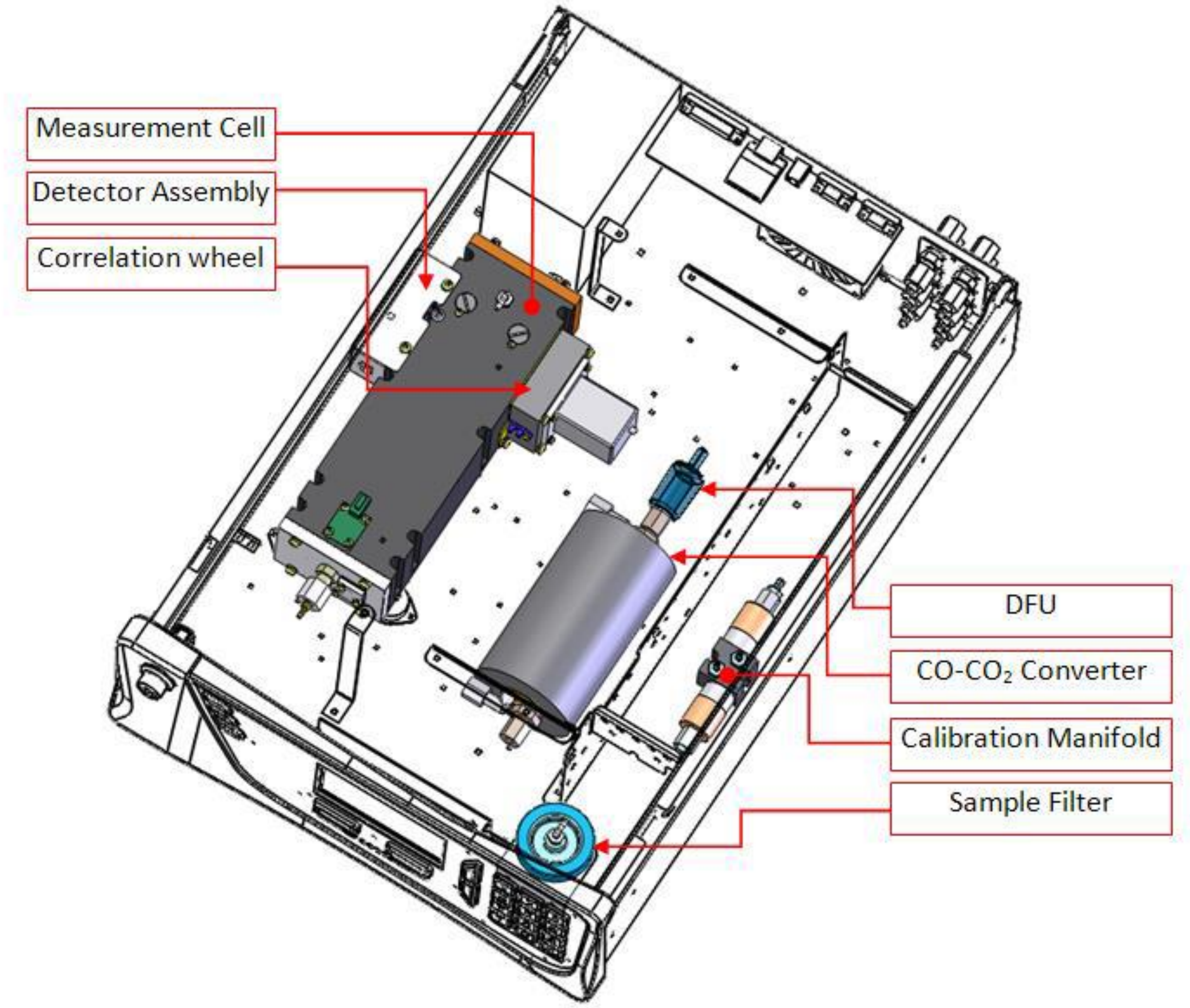


Figure 6.7: Example of the Ecotech Serinus 30 CO analyser.

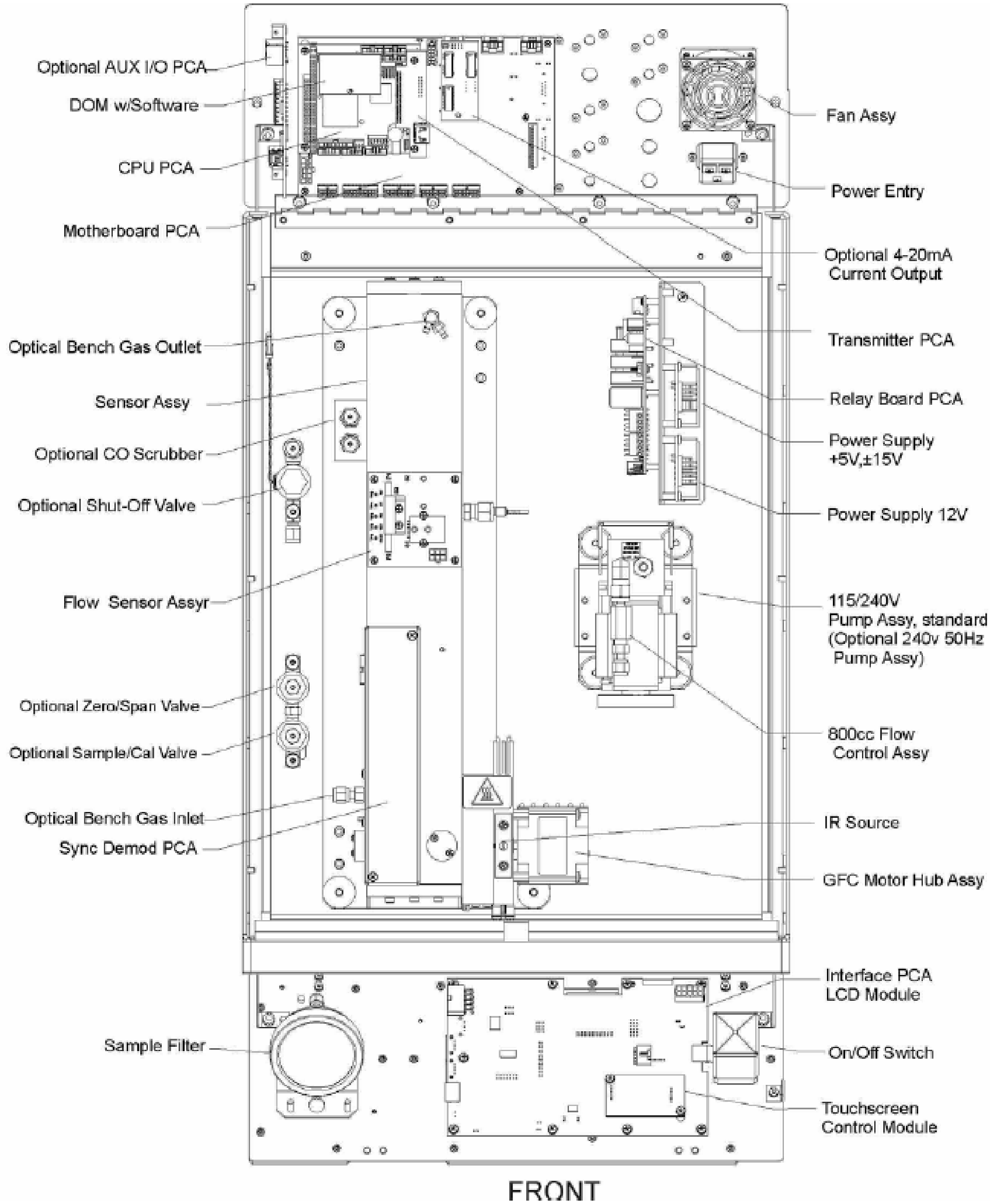


Figure 6.8: Example of API Teledyne T300 CO analyser.

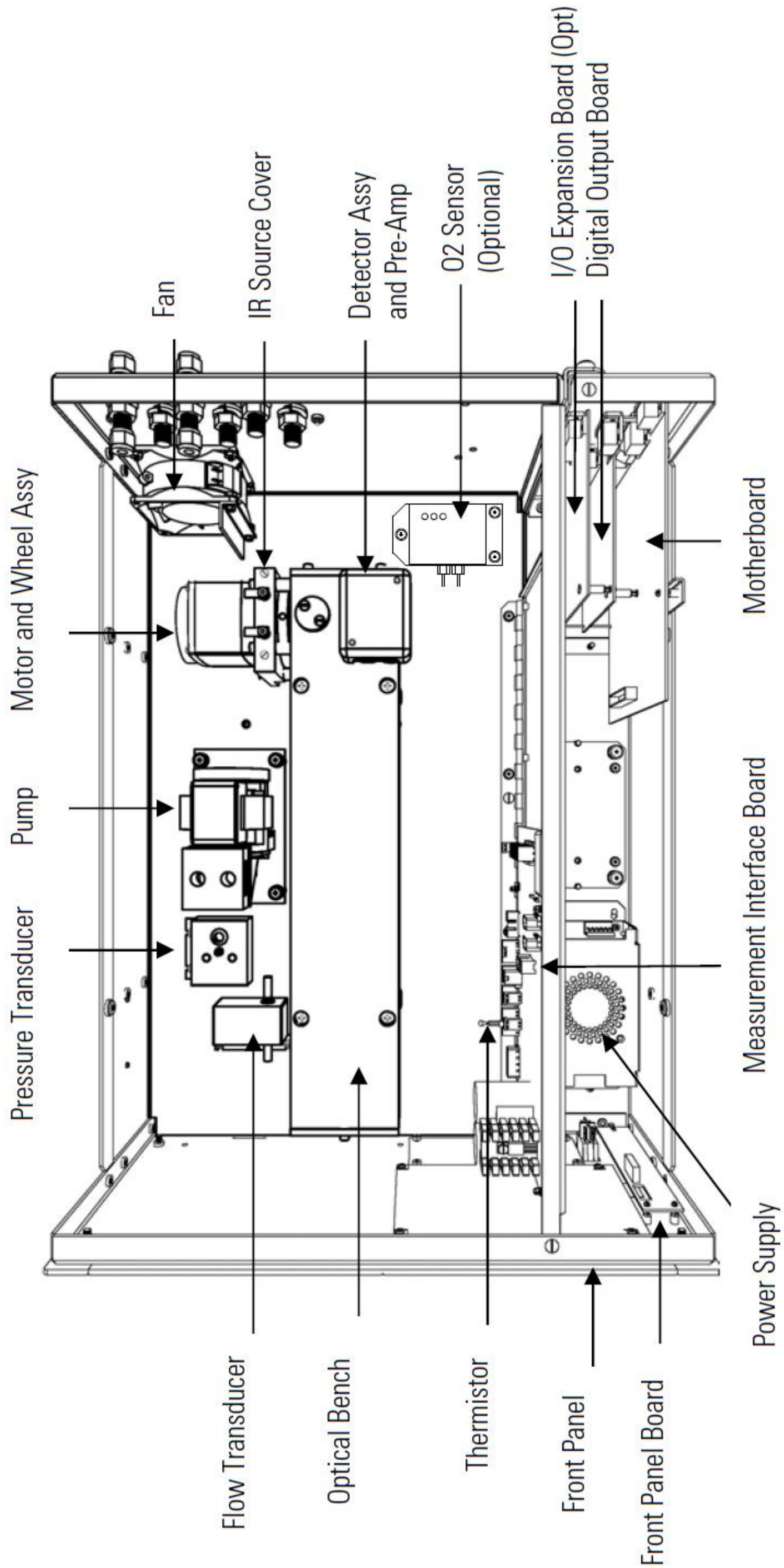


Figure 6.9: Example of Thermo Scientific CO analyser.

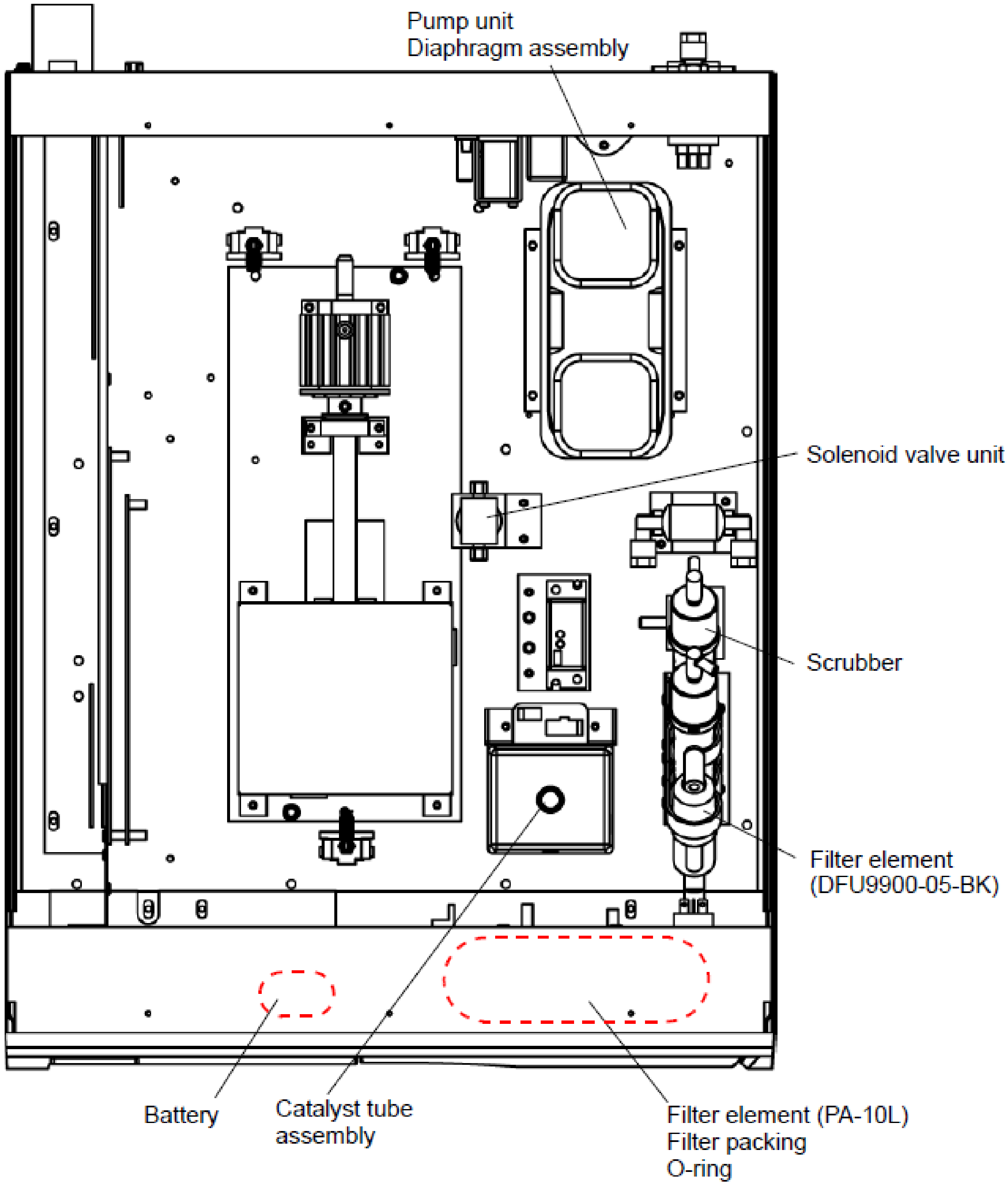
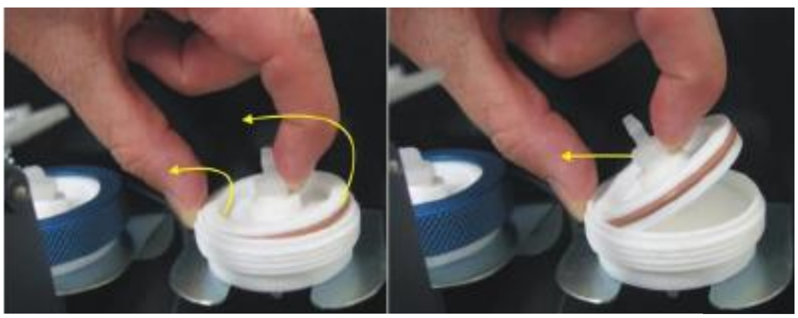


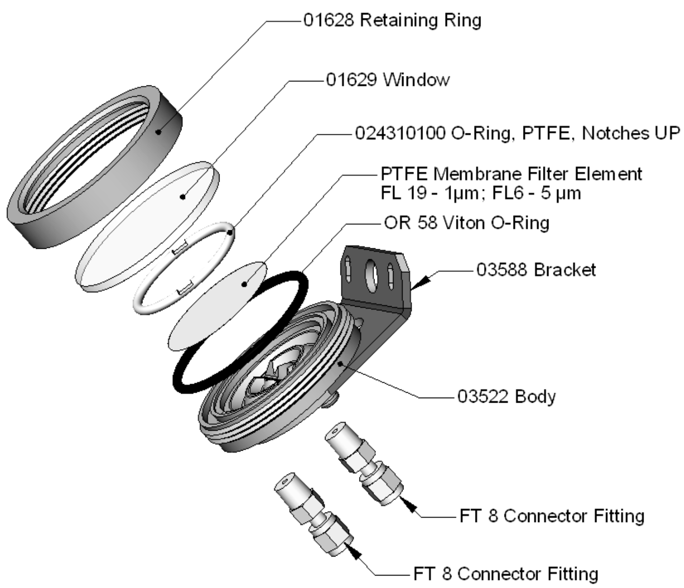
Figure 6.10: Example of Horiba APMA-370 CO analyser.

Internal components of CO instruments

From the above examples several different internal components of the CO instruments are shown, these internal components are used to ensure that the sample is delivered to the reaction chamber and that any impurities is scrubbed from the sample. Some of the internal components are discussed in further detail below.

Particulate filter





- All instruments will have a particulate filter. The filter is used to prevent contamination of the internal components of the instrument.
- Contamination of the filter can result in degrading of the instrument performance, including
  - Slow response time (Lower flow)
  - Erroneous readings (Cell contamination)
  - Temperature drift

Figure 6.11: Examples of particulate filters used in an CO analyser.

Valve block (Manifold)

During sampling or calibration of the instrument the flow of air needs to be redirected for a specific mode of operation. Valve blocks fitted with small electronic valves are used to control the flow of air as indicated by the user. The valve block can also be referred to as the zero/span/sample control block.

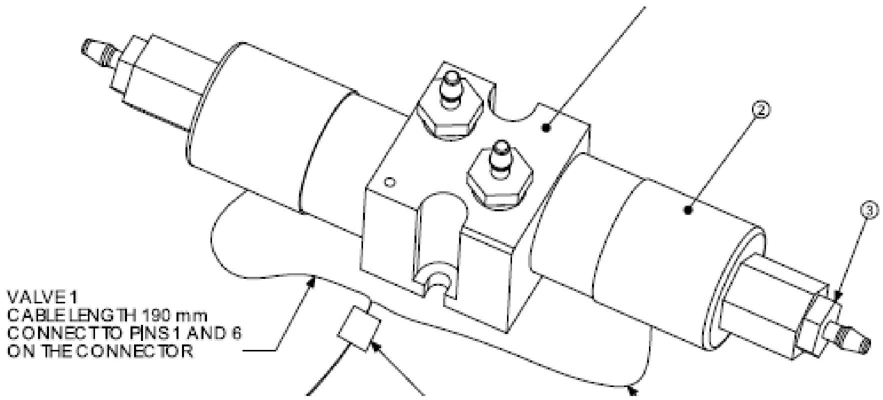
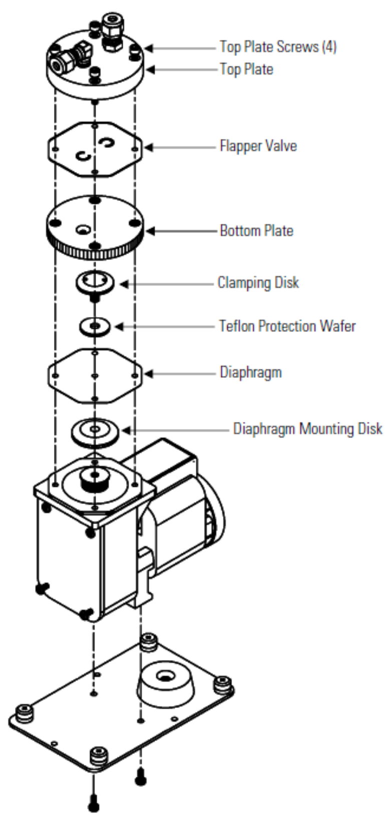


Figure 4.16: Example of valve block used in an CO analyser.

Pump



- All instruments require a source of flow to provide a sample to the reaction chamber. For this purpose a pump is used to draw a sample through the instrument.
- A pump can either be built into the instrument or be external and connected to the exhaust port.
- All gas instrument pumps are diaphragm pumps. Meaning a small piston pushes against a diaphragm creating a vacuum thus generating suction.

Figure 6.12: Example of a pump used to draw air through an CO analyser.

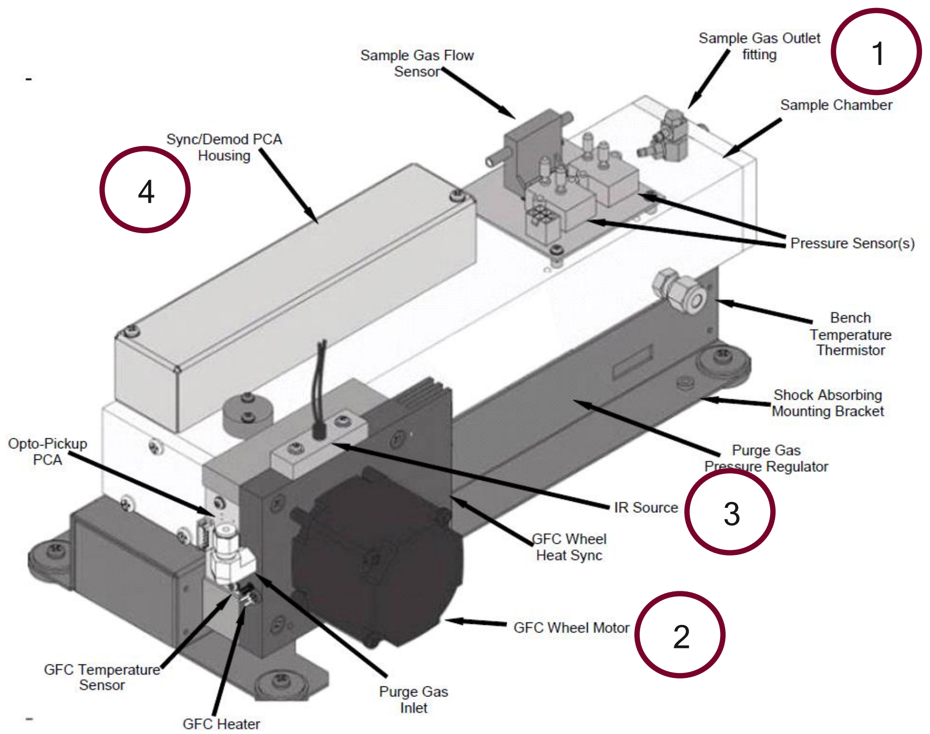
CO – CO_2 Converter

Some CO analysers will have a CO – CO2 converter. This device provides a source of CO free air for the instruments own auto-zero functions. The converter is a heated catalyst at 90ºC that converts any CO in the sample to less than 0.1ppm. This function is used as a zero reference for the measurement instrument.

Note: Not all CO analysers will have a CO converter and will rely on external zero verifications.

Optical Cell

The optical cell is the heart of a CO anaylser as it contains all the major components of the instrument. The optical cell is made up of four main components;



1. Measurement Cell (Sample Chamber
2. Gas filter correlation wheel
3. Infra radiation (IR) source
4. IR Detector

Figure 6.13: Example of the optical cell on an CO analyser.

Measurement Cell (Sample Chamber)

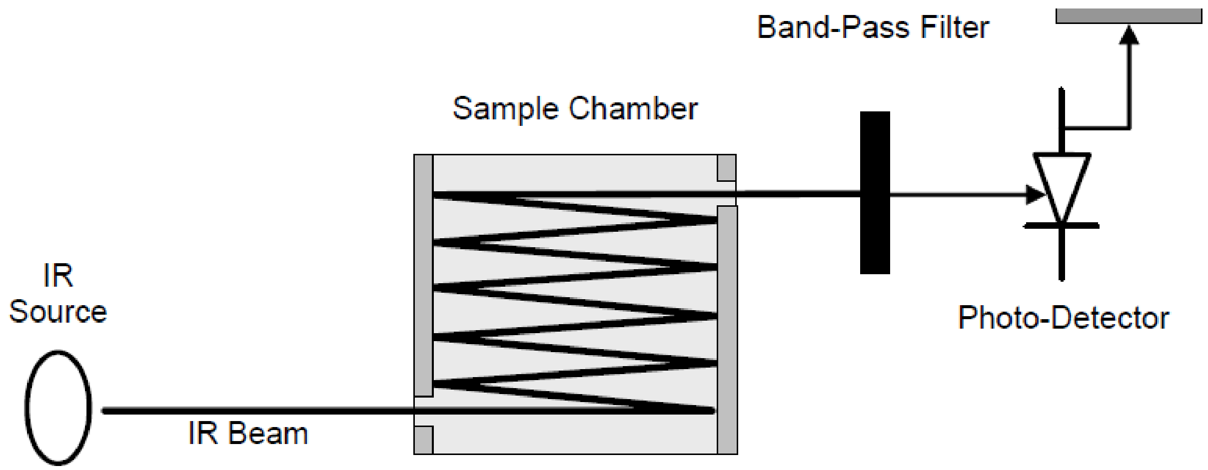


Figure 4.21: Example of the measurement cell on an CO analyser.

This measurement cell contains mirrors that form a five (5) meter folded path length through the cell. The sample gas fills the sample chamber and the IR light travels through the sample. The CO that is in the sample chamber then absorbs IR light at the 4.7-micron wavelength.

Gas filter correlation wheel

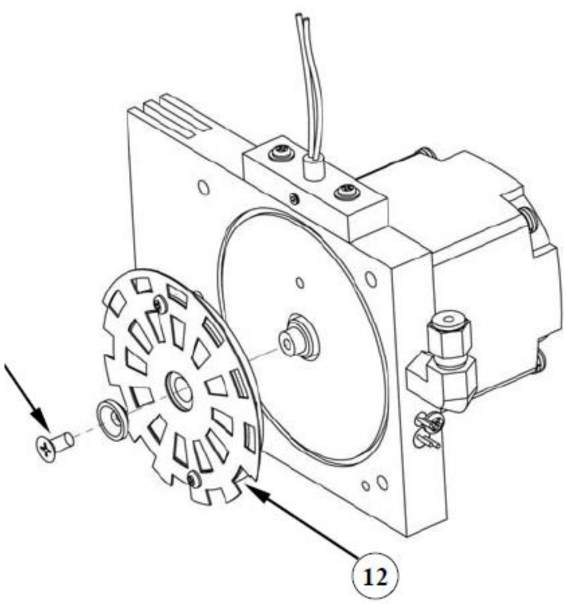


Figure 6.14: Example of filter wheel on an CO analyser.

The correlation wheel contains three filter elements

- N2 chamber
- CO filled chamber
- Mask

N2 chamber: Allows all IR radiation to pass to be absorbed by the CO
CO filled chamber: Absorbs wavelengths sensitive to CO. Thus, the only signals received by the detector will be potential interference.
Mask: Block all IR light entering the Cell

Infrared Light source (IR-lamp)

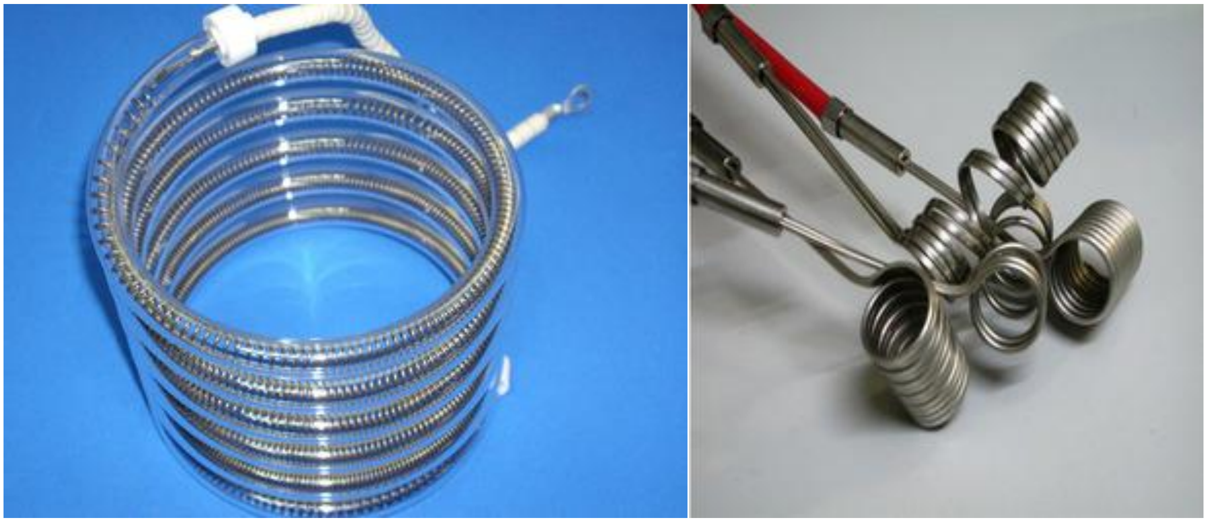


Figure 6.15: Example of the IR-lamp sources used in an CO analyser.

The IR source is usually a small looped coil, similar to the coil that can be found in light bulbs. The IR source emits a broadband infrared radiation that irradiates the filters in the correlation wheel.

Infrared (IR) detector

The IR dector is a photoconductive IR detector. It creates an electrical signal when wavelenths centered at 4.7 microns reach it.

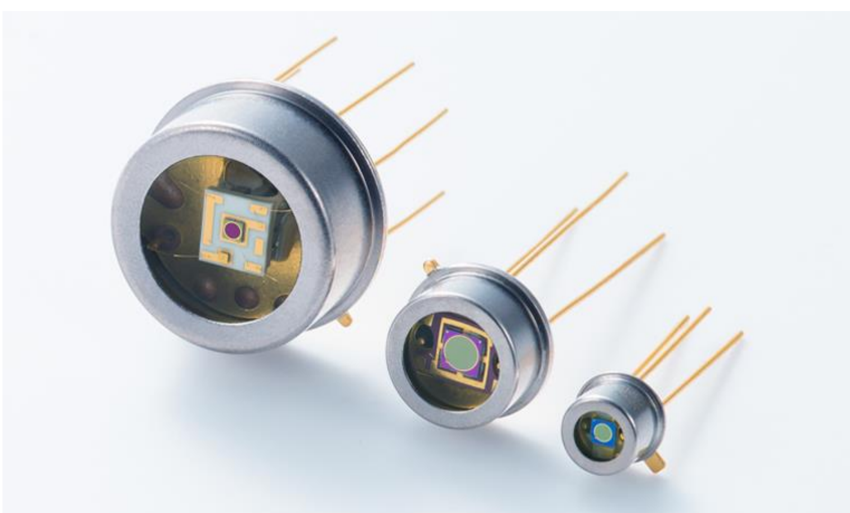


Figure 6.16: Example of the IR detector.

Flow of CO gas inside the instrument

With the knowledge of the principles of operation and all the internal components used inside an CO analyser we can piece together the flow of how CO gas is measured.

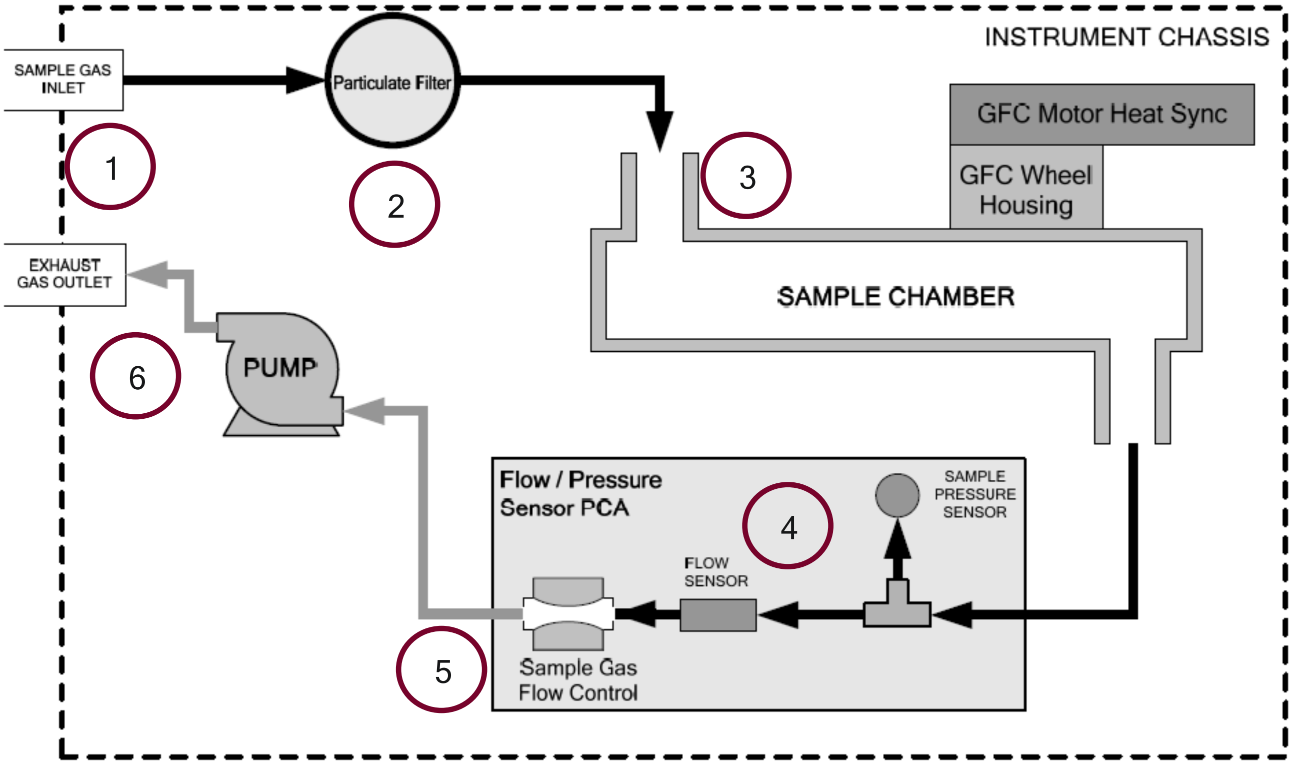


Figure 4.27: Flow process inside an SO_2 analyser.

1. The sample enters the sample inlet due to the suction created by the pump on the opposite side of the process. The pump is always the final component in the flow process as the pump needs to create a flow of air through the instrument.

2. Once the sample has entered the inlet the sample filter first removes any small dust particles that can influence or contaminate the operation of the instrument.

3. The sample now enters the sample chamber where the CO gas can reacts with the IR created by the IR source. The IR at a wavelength of 4.7 microns gets absorbed by the CO. The IR source not absorbed then gets measured by the IR detector.

4. The sample can now exits the reaction cell and passes through a flow sensor or pressure sensor to measure the flow of air through the instrument.

5. The next step can sometimes also be introduced between steps 2 and 3, the critical orifice inside the manifold is used to allow the correct amount of air to pass through the instrument. – Flow control device.

6. Finally the sample will exit the instrument by the suction created by the pump exiting the instrument via the pump or exhaust outlet.