PARTICULATE MATTER (PM) INSTRUMENTS

Particulate Matter are suspended particles which are hazardous to human health and needs to be monitored using specialized instrumentation.

South African Weather Service

What is Particulate Matter

Particulate matter is classified by particle size. The key classifications are total suspended particulate matter (i.e., dust), PM10 (less than 10µm in diameter), PM2.5 (less than 2.5 µm in diameter), and ultrafine particles (less than 0.1 µm in diameter).

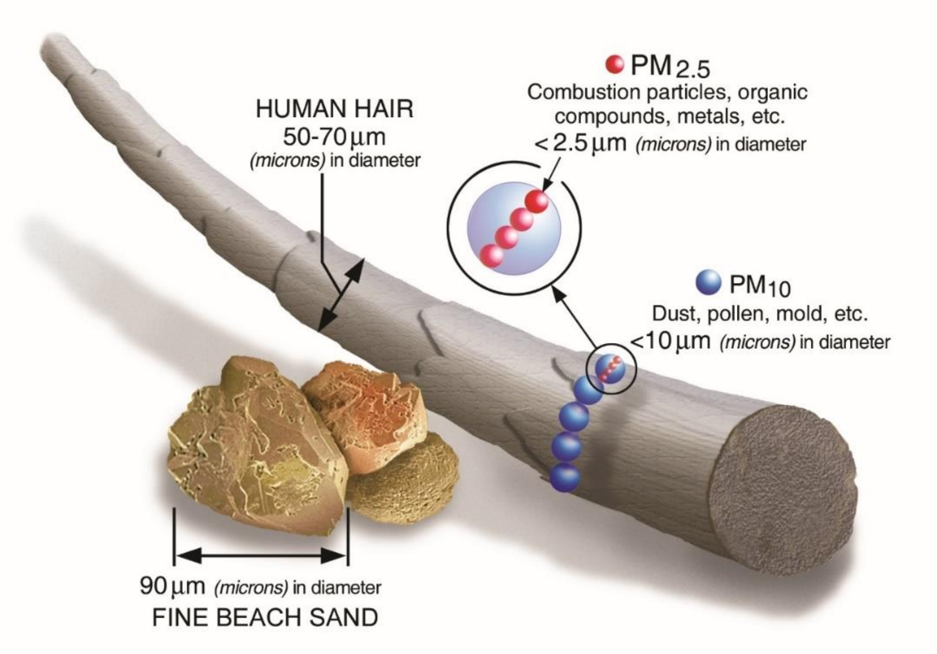


Figure 8.1: Size comparisons for PM particles.

Definition
Particulate matter is all solid and liquid particles that is suspended in the air. These include various particles, such as dust, pollen, smoke, soot and liquid droplets.

PM is referred to as "**primary**" if it is directly emitted into the air as solid particles and is called "**secondary**" if it is formed by chemical reactions of gases in the atmosphere. Sources of airborne particulate matter include road dust, agricultural activities, vehicle exhaust, wood burning, smoke from forest fires, and industrial activities. Secondary particulate matter is an important fraction of PM2.5 which can be created from NOx, SO2 and ammonia (NH3).

How do we measure PM?

There are several methods that are used to measure Particulate matter, hence there are several types of instruments that enable us to measure particulates from the air. The most common instrumentation for measuring particulate matter will do so by either measuring its **concentration** or the **size distribution** of particles.

Particulate concentrations are measured using technology that determine the **collected particle mass concentrations** in units of ug/m^3. This can be achieved by using one of two methods

- Beta ray attenuation method
- Gravimetric (weighing) method

Particulate sizes are measured using technology that determines the **particle count** and the individual size of each particle. This can be achieved using a method;

- Optical method

The average concentration for particulate matter is determined by dividing the particulate weight sampled over the total volume of air that was required to capture that sample. This allows us to determine the particle mass over a known volume of sampled air.

Operation principles of Beta ray attenuation instruments

Beta ray attenuation is a technique that uses the absorption of beta radiation by solid particles extracted from a sample of air. The instruments that use this principle to measure particulate matter is referred to as a **Beta Gauge particulate monitor**.

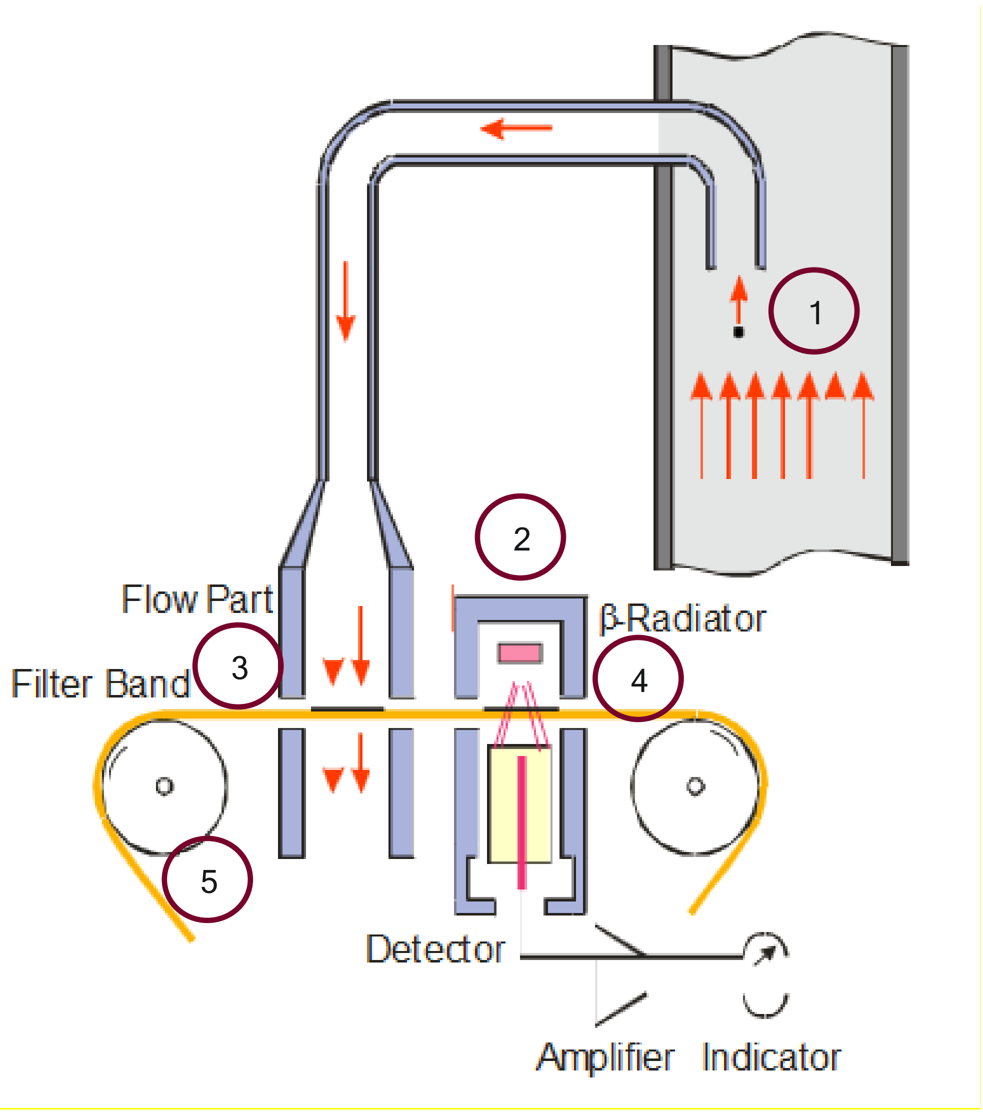


Figure 8.1: Beta ray attenuation theory of a Particulate Matter analyser.

The Beta Gauge instrument cycles every 60 minutes. During each sampling phase, the instrument deposits a sample onto the filter tape and simultaneously measures the previous sample that was taken from the previous 60 minute cycle.

The step of this process is demonstrated in Fig 8.1 with a description thereof below.

1. Particles are extracted from ambient air via the use of a pump to draw a sample through a sample probe.

2. Before particles are deposited, the blank tape is measured to determine the baseline or zero point of that measurement. At the beginning of the hour the C14 element emits beta rays through a clean spot of filter tape to determine the zero reading

3. The instrument advances this exact spot to the sample nozzle where air containing particulate is sampled onto the filter tape. The filer tape is exposed to air flow and particles are deposited onto a filter tape. Most beta attenuation instruments measure particulates over a one (1) hour average period. The instrument will continue to extract a sample onto a single point for the 60-minute period.

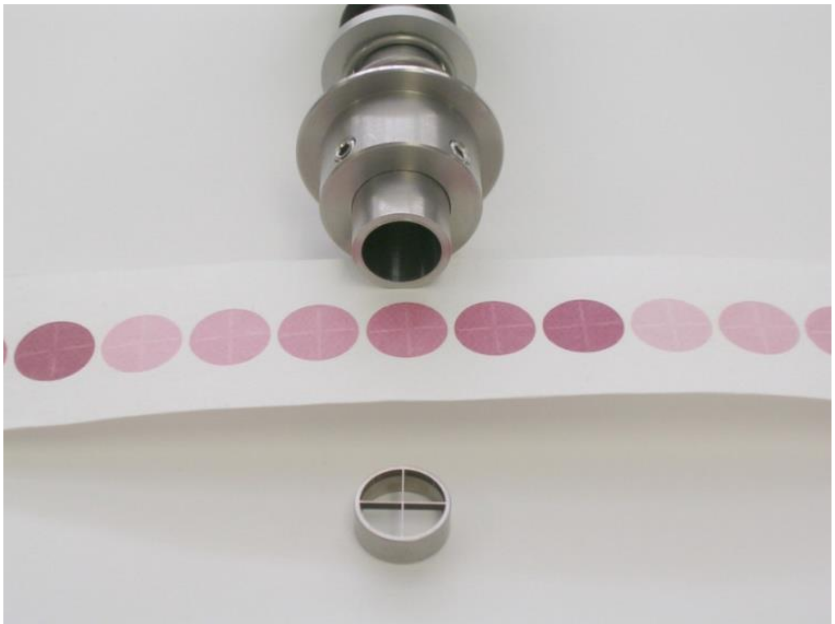


Figure 8.2: Particulates deposited onto filter tape.

4. At the end of the hour, the dirty spot is placed back at the source where it is re-measured with beta rays. The section of tape with the deposited particulates are moved over the radiation source and detector for measure. A small Carbon14 (C14) element emits a constant source of low-energy electrons, also known as **beta particles**. The beta rays are attenuated as they collide with particles collected on a filter tape. The dust spot attenuates the beta rays more than the clean spot did. The difference between the two measurements is related to the mass of the particulate by a variation of Beer's Law.

> **Definition**
> **Attenuation** is the process by which the number of **particles** or photons entering a body of matter is reduced by absorption and scattering.
>
> **Beer's Law** is the calculation concerning the absorption of radiant energy by an absorbing medium.

5. This cycle repeats itself every hour to give an output of a continuous hourly average of particulate concentrations.

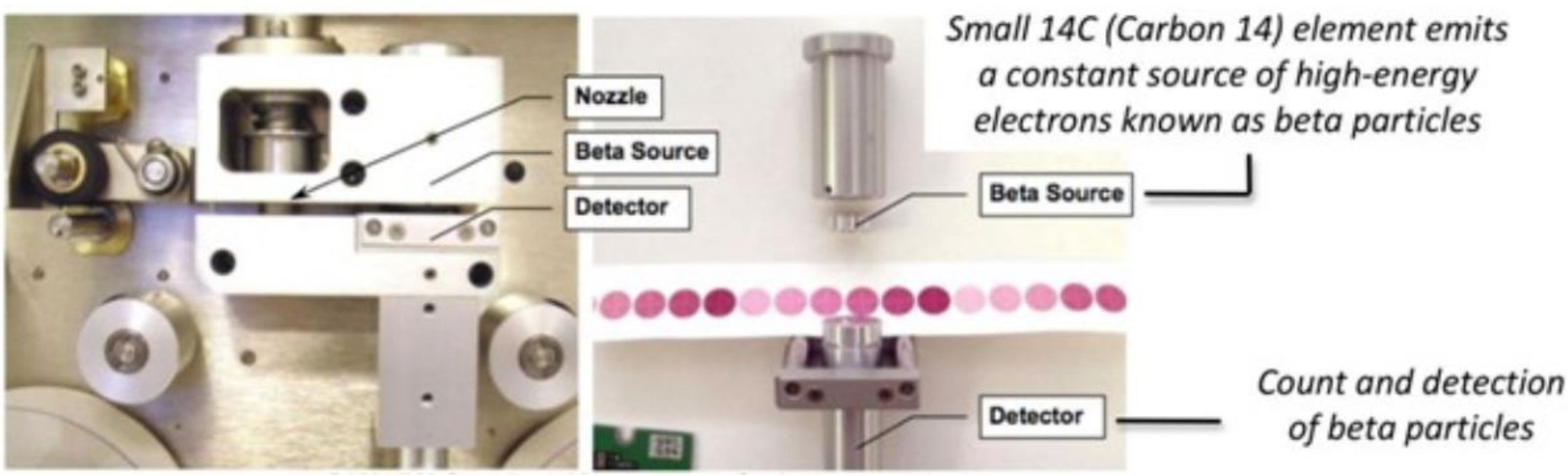


Figure 8.3: Internals of a Beta Gauge analyser.

Components of Beta gauge instruments

Unlike gas monitoring instruments, particulate instruments have an independent inlet from which a sample is extracted from the ambient air.

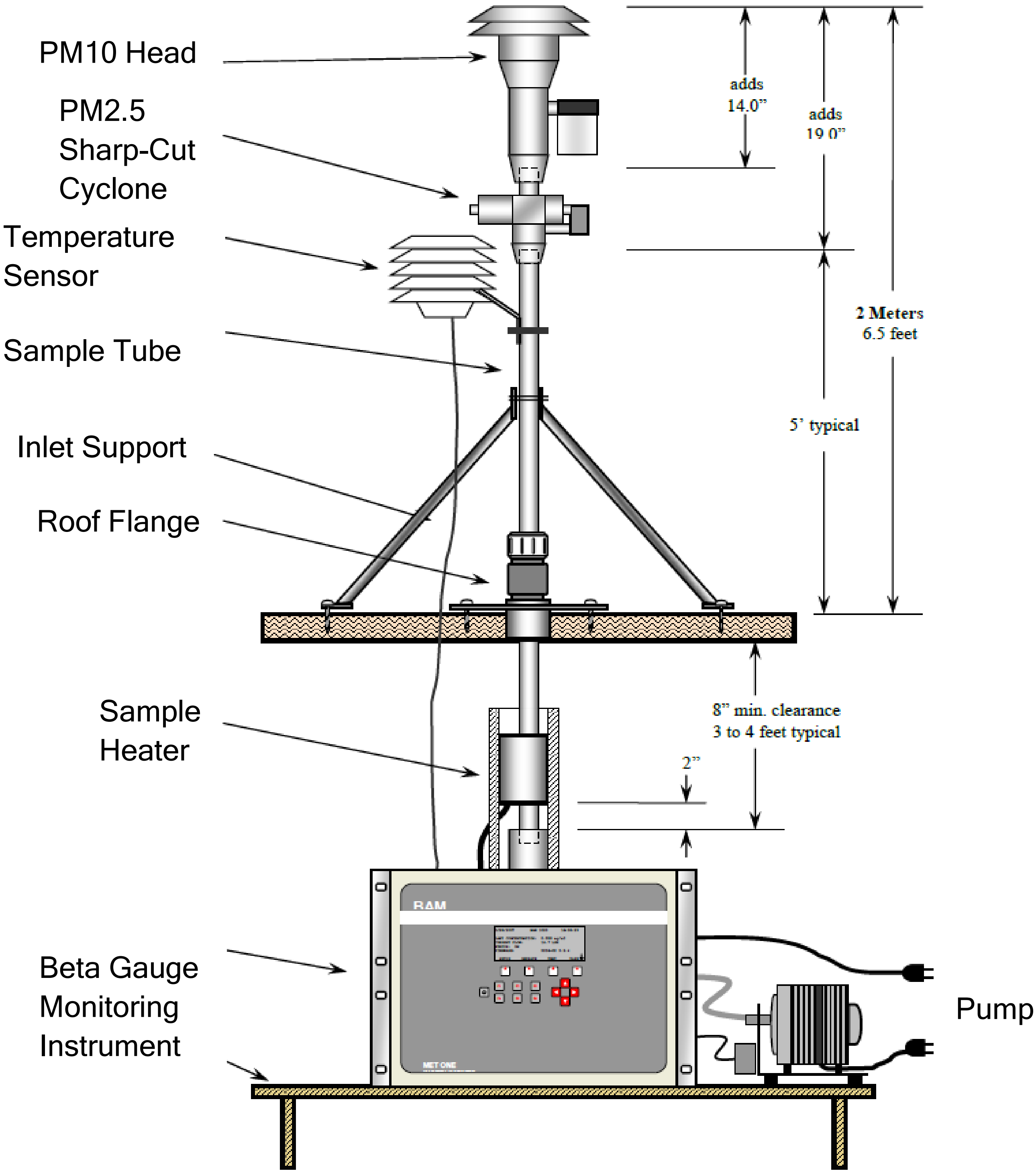


Figure 8.4: BAM Beta Gauge instrument.

Sample inlet (PM10 Head)

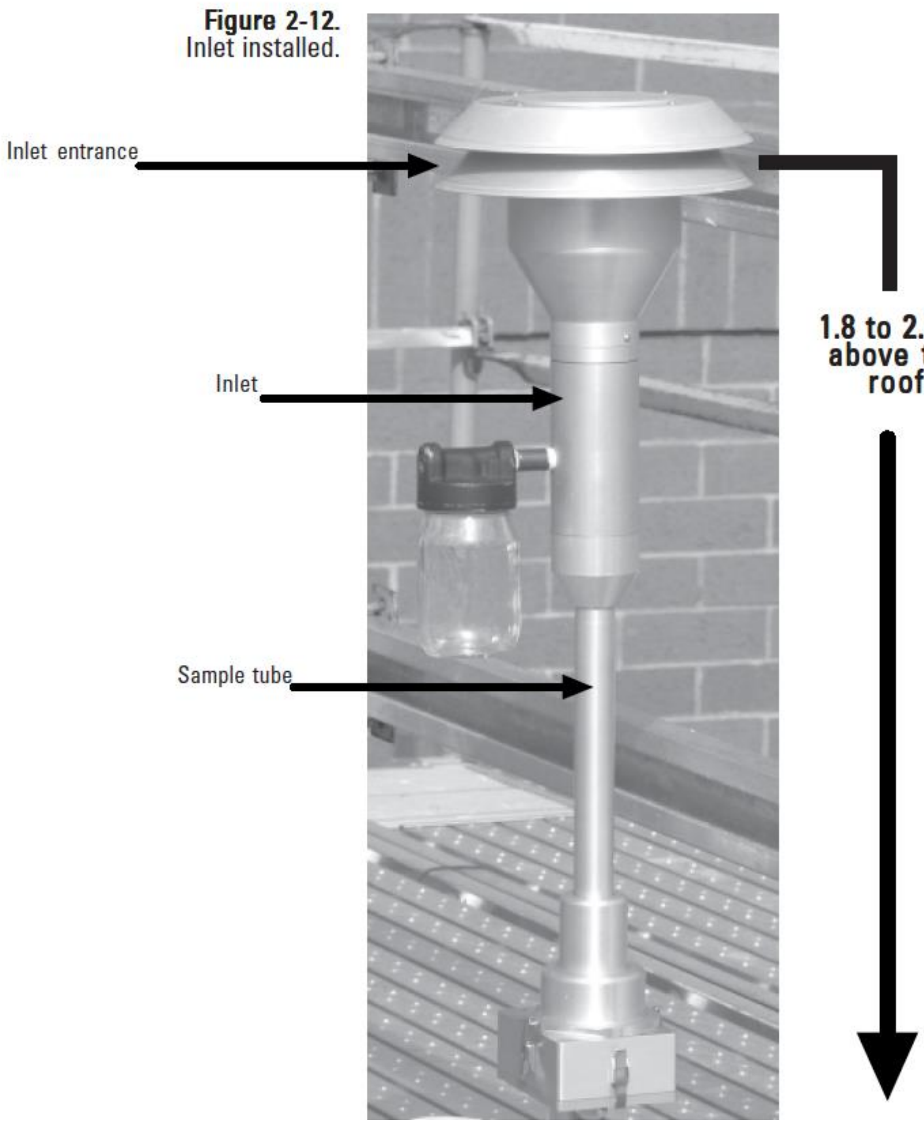


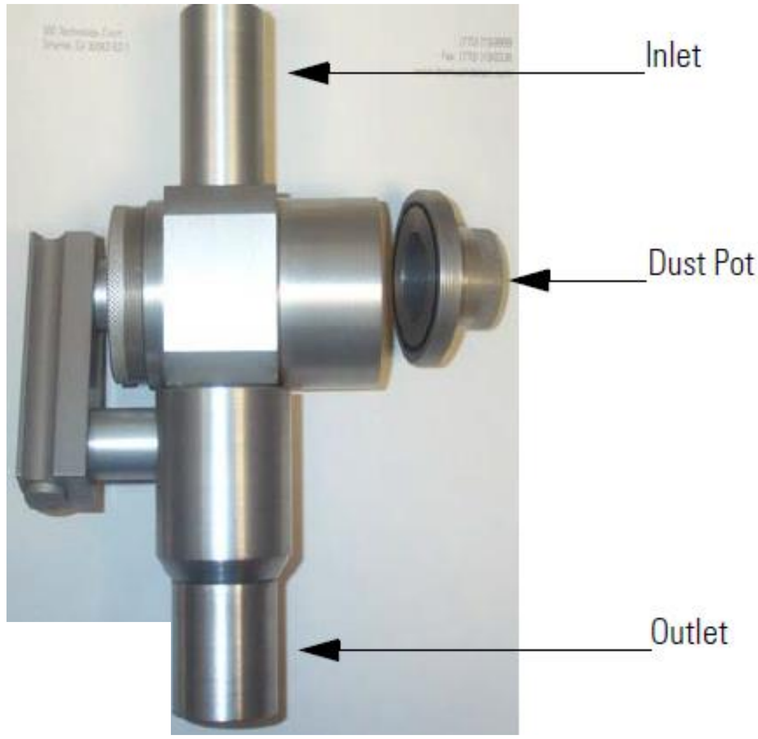
Figure 8.5: PM10 sample inlet head for a particulate instrument.

The sample inlet is where the sample gets drawn in from the ambient environment. The sample inlet contains a filter that only allows particles through that are 10 microns or smaller to pass through.

Sharp-Cut Cyclone (PM2.5)

To measure PM2.5 a separate device is required to further remove any particle that is greater than 2.5 microns.

The Sharp cut is designed to create a cyclone in the center that pushes out the heavier PM10 partials and only allows the lighter PM2.5 particles to pass.



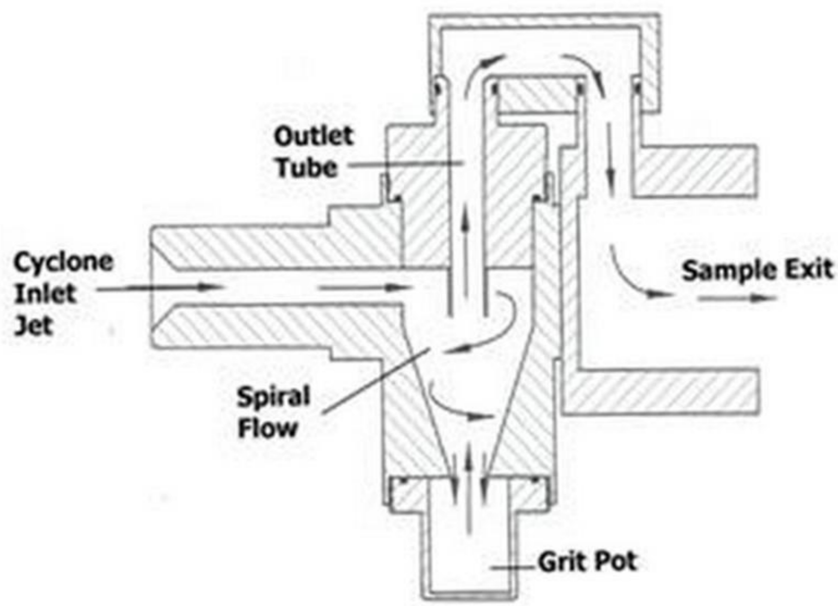


Figure 8.6: Cyclone cutter used to sperate PM2.5 particles from a sample.

Temperature and pressure Sensor

Ambient temperature and barometric pressure measurements are used to convert the measured mass flow into volumetric flow (LPM). As the measured temperature and barometric pressure change, the mass flow controller will adjust its output to maintain constant volumetric flow.

Figure 8.7: Temperature and Pressure sensor.

The instrument uses the volume of air sampled to determine the particulate concentration, mass over a know volume, it is therefore important that the volume of air being measured is know and accurate.

Sample Heater

Figure 8.8: Inlet sample heater.

The inlet heater is installed just above the inlet of the Beta gauge monitor. The heater is used to control the humidity of the incoming sample to a 35% set point.

This is to prevent any moisture from being deposited onto the filter tape during the sampling process.

Beta Gauge Instrument

The beta gauge instrument is made up of four main components;

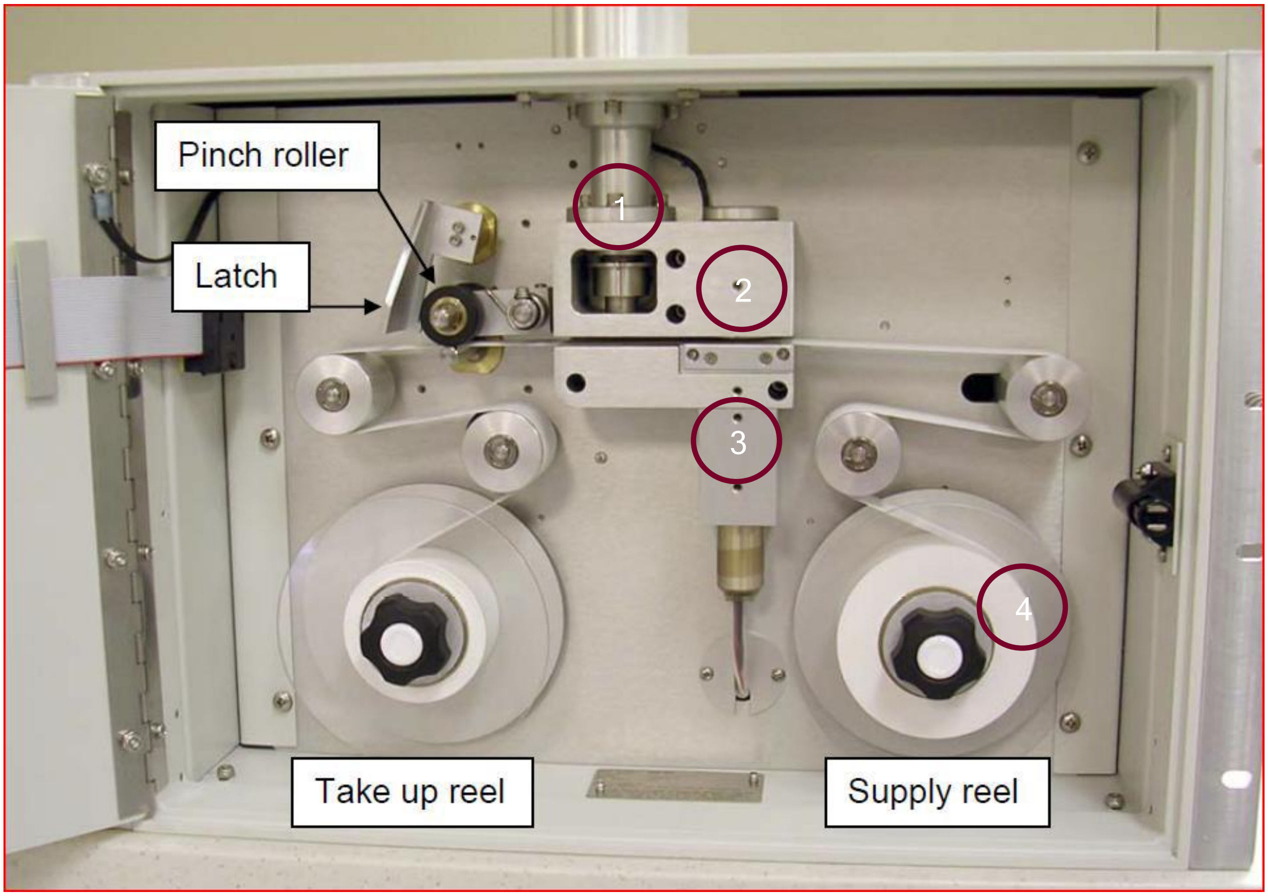


Figure 8.9: Beta gauge instrument.

1. Sample Nozzle
2. Beta Source
3. Detector
4. Filter Tape

Sample nozzle

Figure 810: Sampling nozzle.

The sample nozzle focuses the sampling point of the particulate matter onto a single point.

The nozzles seal against the filter tape is important for proper airflow regulations.

The nozzle needs to be cleaned as often as the tape is changed.

Beta Source

The Beta source is a small Carbon14 (C14) element that emits a constant source of low-energy electrons, also known as **beta particles**. **Beta** particles are nothing more then fast moving electrons, emitted from certain radioactive isotopes, called **sources**.

Detector

The detector is a photomultiplier tube (PMT) detector that measures the difference in beta particles between the measured (dust spot) and zero (clean spot) on the filter tape.

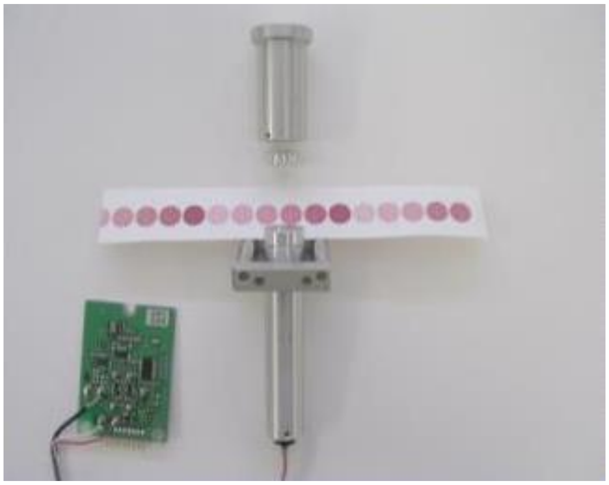


Figure 811: Beta gauge PMT detector.

Filter Tape

The filter tape is a continuous glass fiber filter on which the particulates are deposited for measure.

Figure 812: Roll of glass fiber filter tape.

Vacuum pump assembly

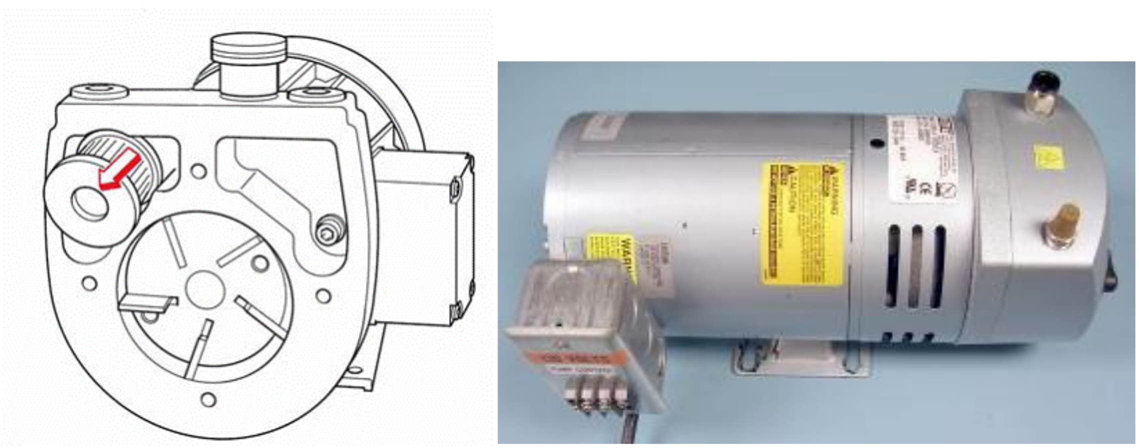


Figure 812: Roll of glass fiber filter tape.

The pumps used in particulate instruments are much larger compared to gas analysers. PM instrument require much larger flow to draw in heavy materials - 16 l/m. Thus, a rotary pump is used.

Flow of air through a Beta Gauge instrument

With the knowledge of the principles of operation and all the internal components used inside a Beta gauge analyser we can piece together the flow process.

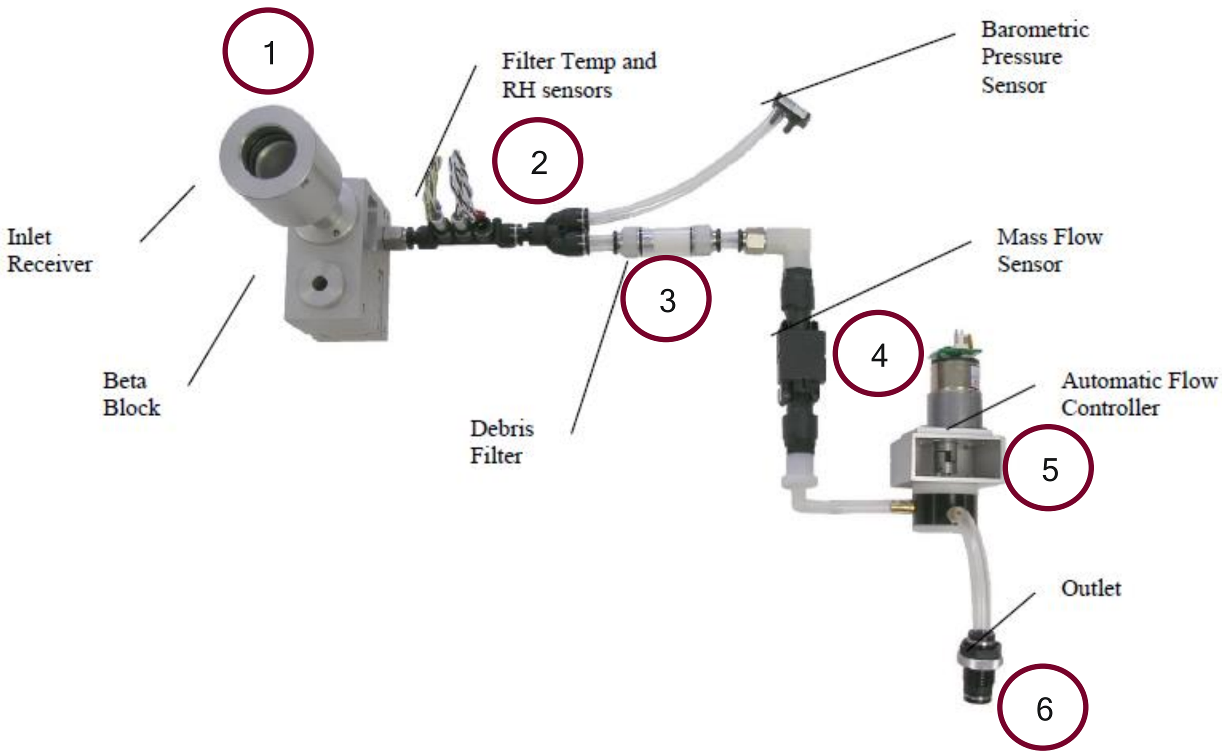


Figure 8.13: Flow process inside an Beta Gauge analyser.

The airflow system of a beta gauge consists of a few simple components;

1. Inlet/Nozzle: Where the particulate sample in deposited onto the filter tape

2. Temperature/Relative humidity/Pressure sensor: are used to convert the measured mass flow into volumetric flow (LPM). As the measured temperature and barometric pressure change, the mass flow controller will adjust its output to maintain constant volumetric flow.

3. Debris filter: To capture any particles or debris from the filter tape.

4. Mass flow sensor: To measure the flow.

5. Flow controller: Mass flow controller that adjusts and regulates the flow.

6. Outlet: Connector to which the vacuum pump is connected.

Operation principles of Gravimetric instruments

FDSM TEOM – Filter Dynamics Measurement System Tapered Element Oscillation Microbalance is what referred to as a True Gravimetric instrument. TEOM is a technique used to continuously measure concentrations of air particles.

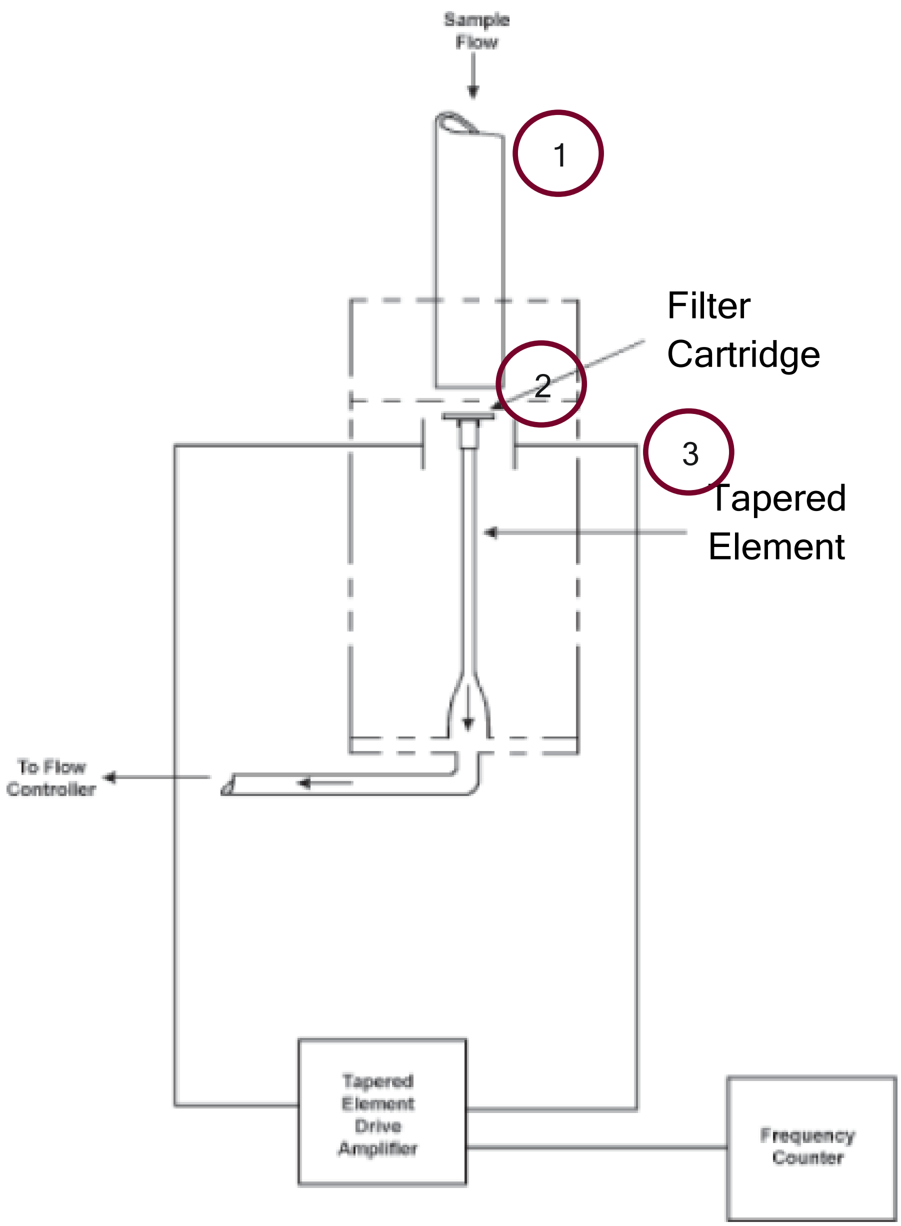


Figure 8.14: TEOM theory of a Particulate Matter analyser.

The TEOM instrument is a continuous measuring instrument providing a particulate measurement every six (6) seconds. The instrument draws ambient air through two filters at a constant flow rate, continuously weighing the filters and calculating the real-time mass concentrations of the particulates being sampled.

The step of this process is demonstrated in Fig 8.14 with a description thereof below.

1. A pump draws a sample into the instrument at 16.7 litres per minute (L/min) through an inlet designed to allow only particles of the required size range to pass through.

2. Sample is directed onto a filter cartridge which is placed on top of a tapered element.

3. The tapered element consists of a filter cartridge mounted on the tip of a hollow glass tube. The base of the tube cannot move, but the tip is free to vibrate at its natural frequency (in a similar way to a tuning fork).

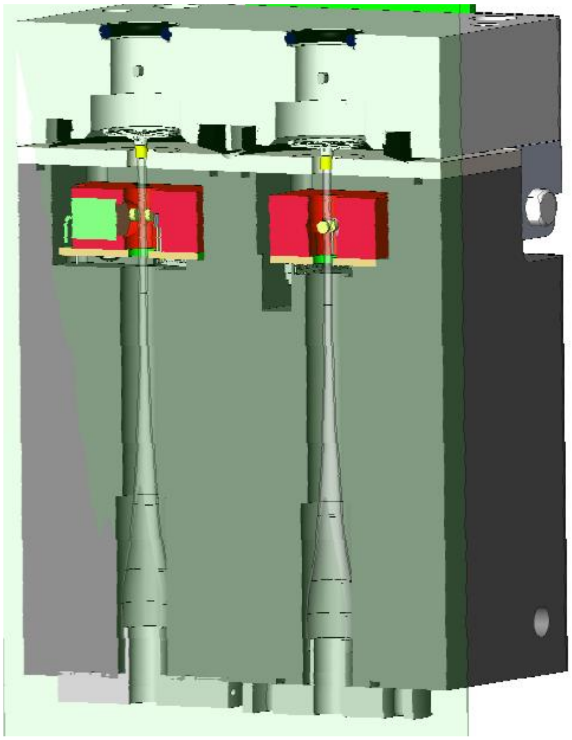


Figure 8.15: TEOM tapered elements.

Any additional weight from particles that collect on the filter changes the frequency at which the tube oscillates. The electronic circuitry senses this change and calculates the particle mass rate from the magnitude of the frequency change.

- As the frequency increased you will see a loss in mass on the filter
- As the frequency decreases you will see an increase in mass on the filter

Dividing the mass rate by the flow rate provides a continuous output of the particle mass concentration.

Components of TEOM instruments

Unlike gas monitoring instruments, particulate instruments have an independent inlet from which a sample is extracted from the ambient air.

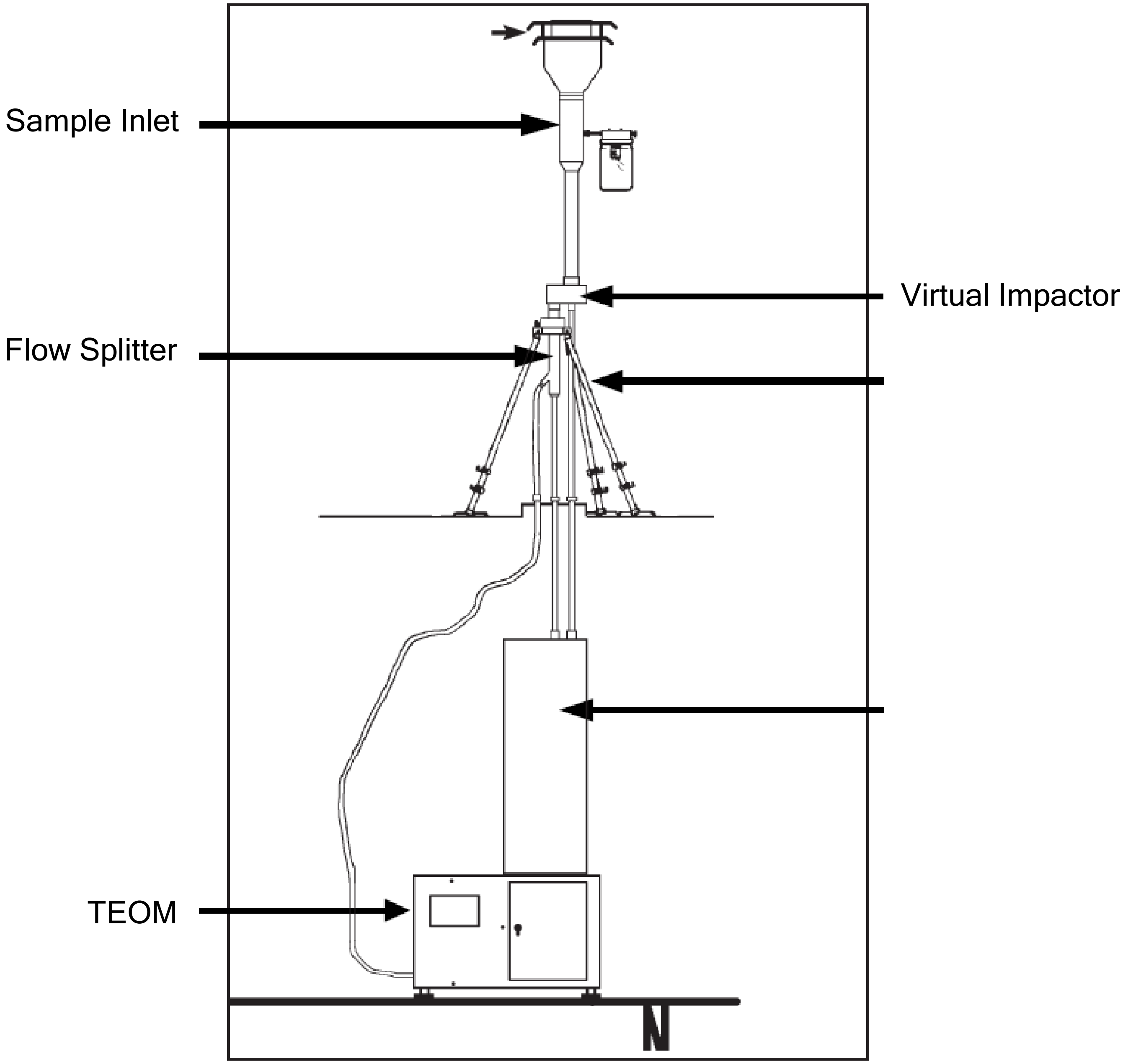


Figure 8.16: Basic components of a TEOM analyser.

Sample inlet (PM10 Head)

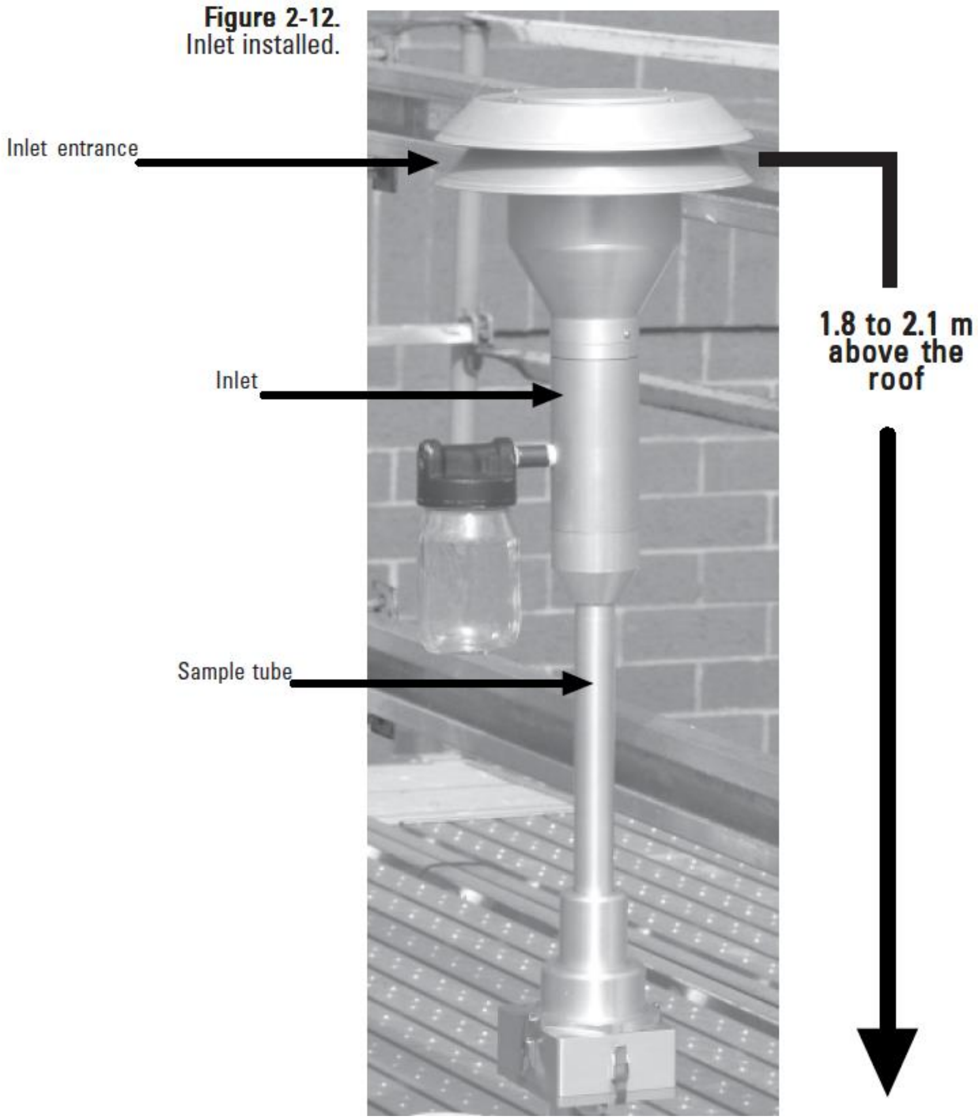
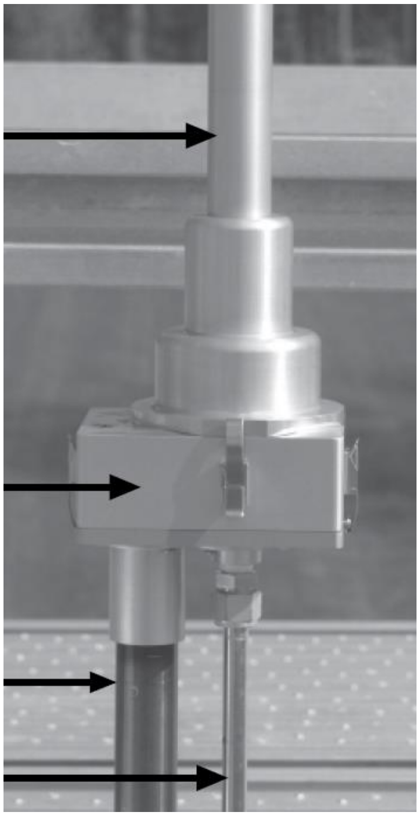


Figure 8.17: PM10 sample inlet head for a particulate instrument.

The sample inlet is where the sample gets drawn in from the ambient environment. The sample inlet contains a filter that only allows particles through that are 10 microns or smaller to pass through.

Virtual Impactor (PM2.5)



To measure PM2.5 and PM10 simultaneously a separate device is required to separate particles that are 2.5 microns and smaller from the

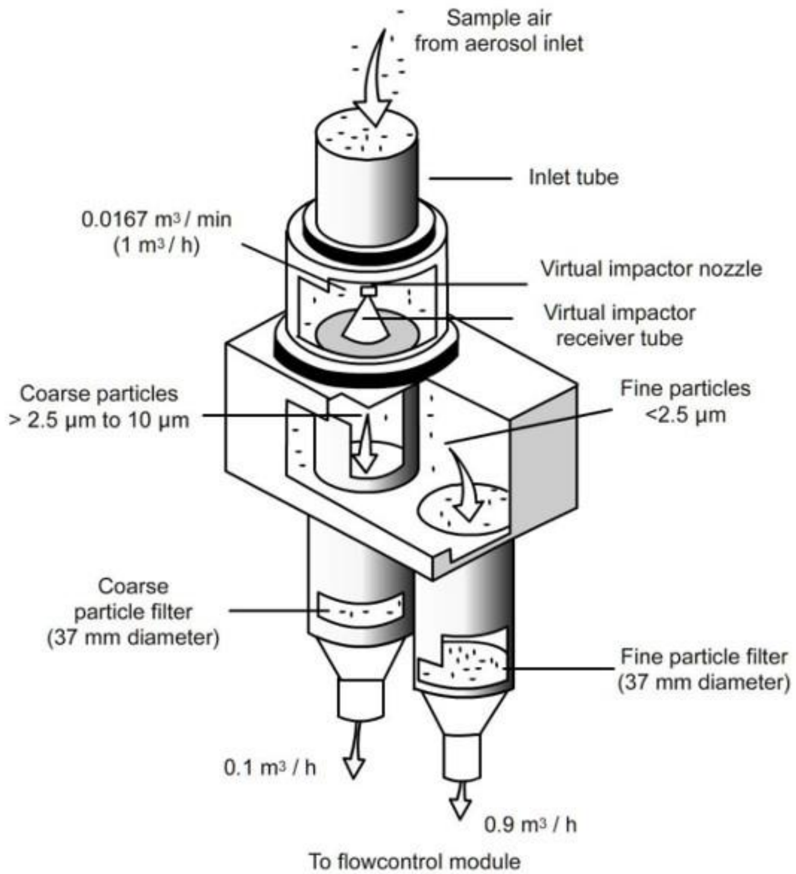


Figure 8.18: Virtual impactor device used to separate PM2.5 from PM10 particulates.

The virtual impactor separated the PM10 sample into a PM Course sample stream and into a PM fine sample stream.

- PM Course = Particles that are larger than 2.5 µm but smaller than 10 µm
- PM Fine = Particles that are smaller than 2.5 µm

Mass Transducer – Sample filters

The measurements of particles are all performed within the mass transducer of the TEOM.

The particulates that are being measured are continuously being deposited onto filter cartridges and measured using frequency oscillation.

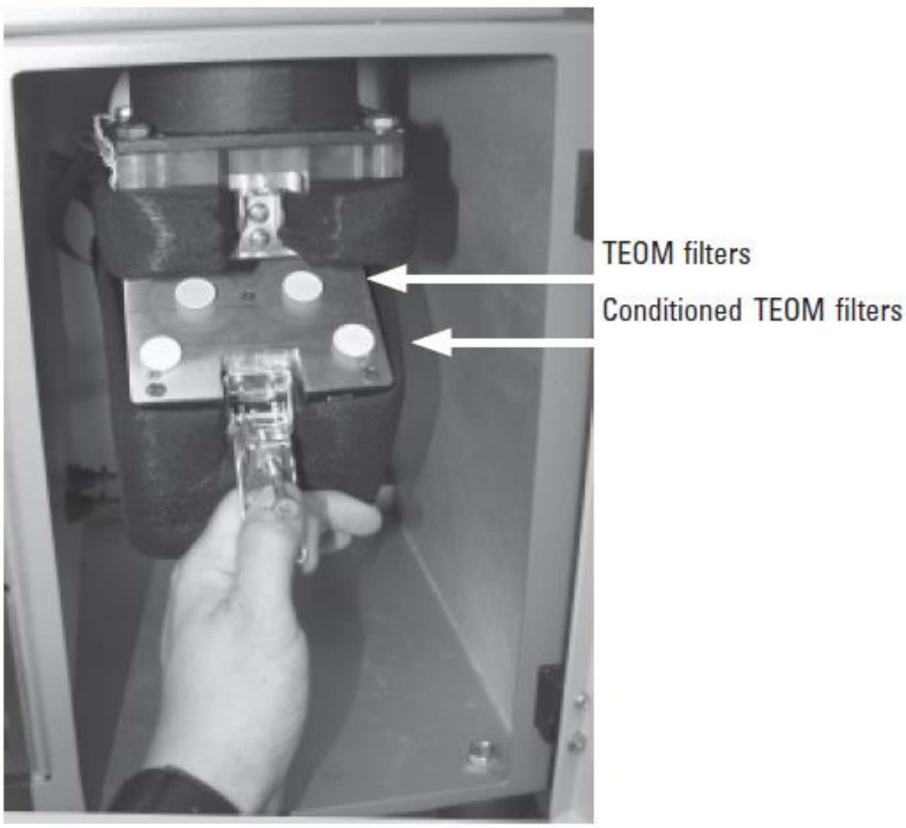


Figure 8.19: Filters and filter placement for TEOM instruments.

Flow of air through a TEOM instrument

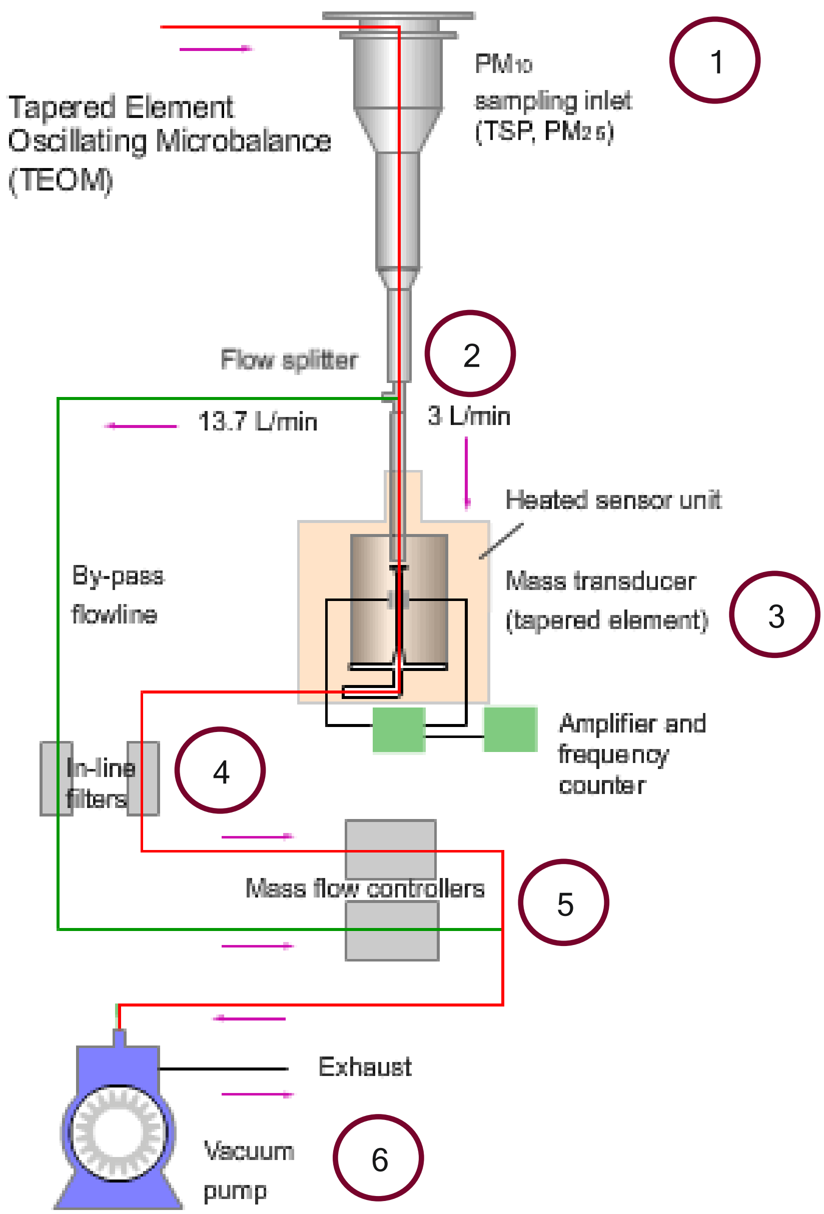


Figure 8.20: Flow process of a TEOM analyser.

The airflow system of a TEOM consists of a few simple components;

1. Sample inlet: A pump draws a sample into the instrument at 16.7 litres per minute (L/min) through an inlet designed to allow only particles of the required size range to pass through.

2. This air stream is then split so that 3L/min of sample is directed to the tapered element while the remainder is sent to exhaust.

3. The air stream passed through the mass tranducer where the particles are deposited onto the filter elements and continuously measured.

4. The flow of air passes through filters to prevent any particles or debris from the filters contaminating the mass flow controllers.

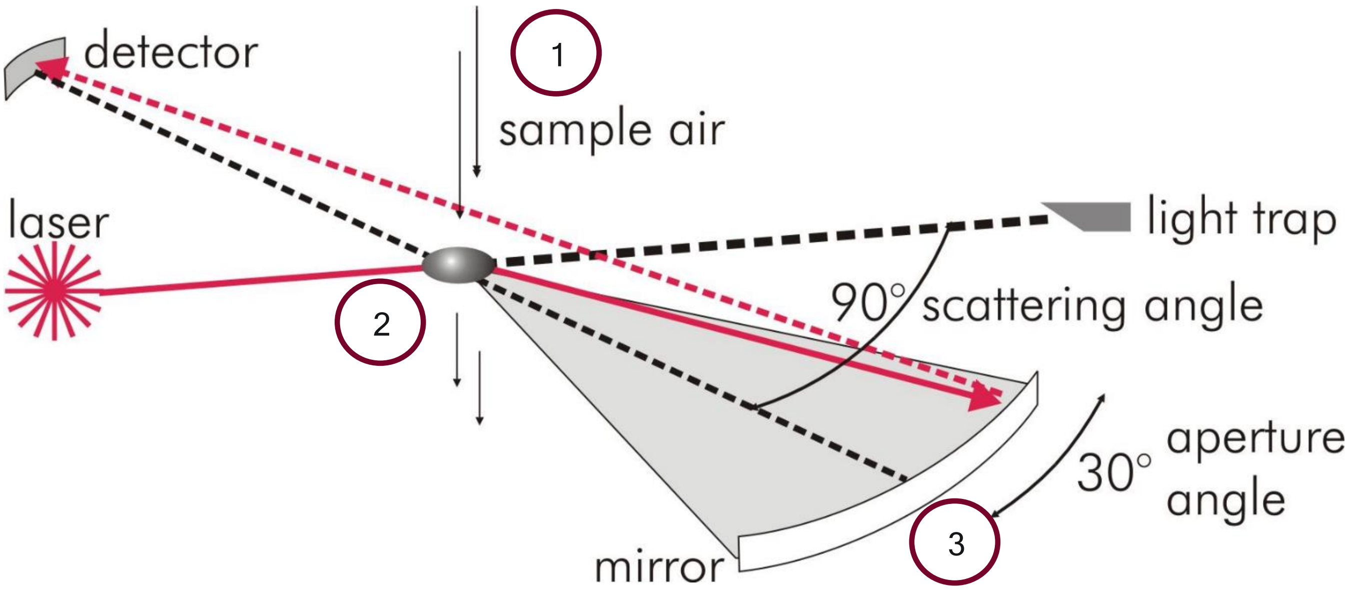
5. The flow them passes through Mass flow controllers that adjusts and regulates the flow.

6. The instrument is connected to a vacuum pump for the source of flow.

Operational principles of Optical instruments

Optical instruments are used to detect and physically count the particles from a drawn sample. Optical instruments are a continuous measuring instrument providing a particulate measurement every six (6) seconds. The instrument draws ambient air through focused point at a constant flow rate.

The step of this process is demonstrated in Fig 8.21 with a description thereof below.



1. The particles are drawn into the measurement cell through a sample probe.

2. The particles pass through a laser source. Every time a partial obstructs or scatters the light source that particle is counted allowing the instrument to physically count the number of particles being sampled.

3. By using the light scatter, the angel at which the laser light is reflected, the size of that particle can be determined.

Using this technique Optical instruments can determine the mass being measured by counting the particles and distinguishing their size simultaneously.