Module #1

Mass spectrometer sensor

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Introduction:

A mass spectrometer is a device that can detect charged particles such as ions, protons, and electrons by separating them according to their mass-to-charge ratio using a magnetic field. Followed by a detector that receives these particles and transforms them into an electric signal. This signal is amplified by an amplifier circuit so that it can be recorded.

Objective:

To make a mass spectrometer to identify the composition of any gas for these molecules: HCl, HF, SO_2, and Hg, with their respective quantities.

Structure and roles

1. Analyzer:

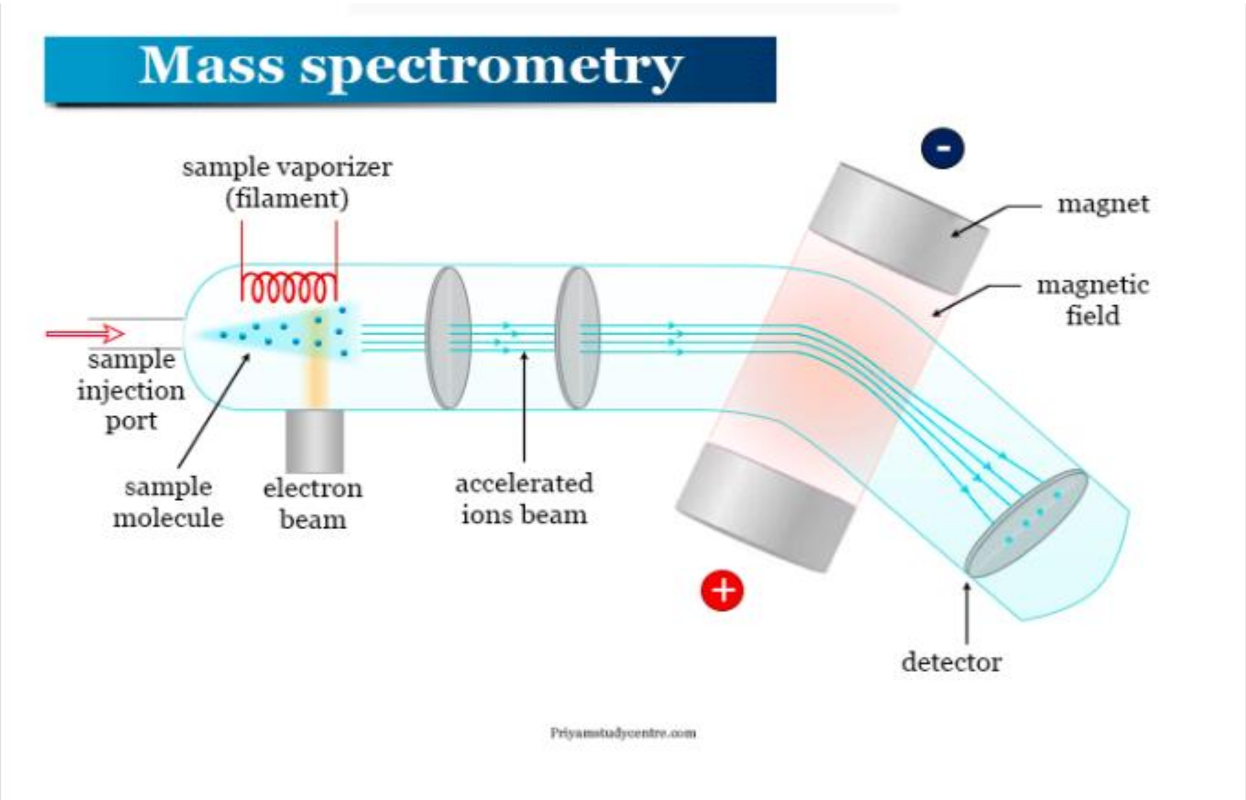


Fig. 1.1: The analyzer of the spectrometer

The analyzer is one of the three main parts of the mass spectrometer that has three essential stages:

Ionization, **Acceleration**, and **Separation**.

- **Ionization:** the sample of gas that needs a study is injected into a chamber that has a heat filament and electron gun that allow the gas to become charged (ionized).

- **Acceleration**: the sample is then accelerated using a magnetic field due to its charge.

- **Separation**: the accelerated ions go through another magnetic field but this time to change their direction, since all ions have the same charge, they will experience the same moving force. However, due to the different masses of each ion, they will move in a different directory i.e., the heavier the ion the longer the arc will take.

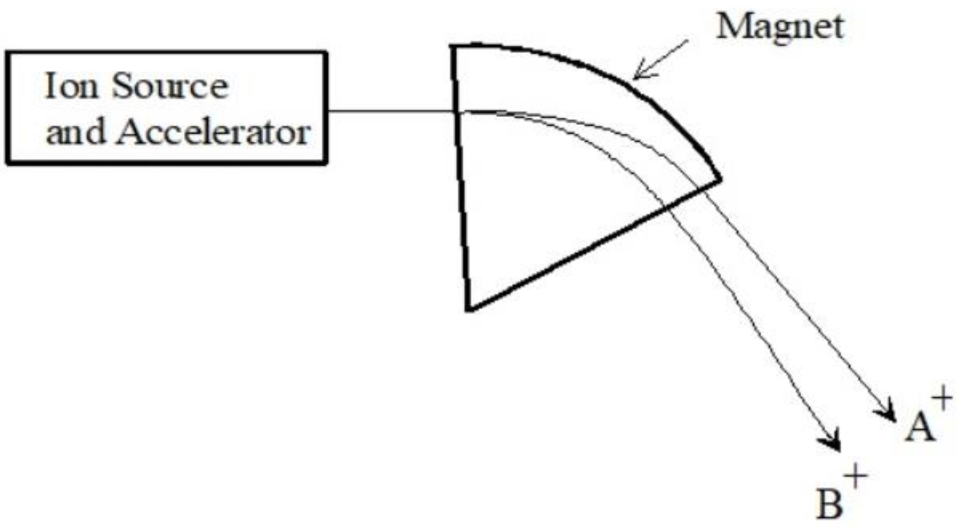


Fig.1.2: ion A^+ and B^+ separated using a magnet.

For the wanted sample:

1.4 Measurement of physical quantities

We have $R = (m * 2 * U / q * B^2)^{1/2}$, and $v = (2 * q * U / m)^{1/2}$; For a magnetic field $B = 20 * 10^{-2}$ T, and a potential difference U=300 v, we obtain the values of the radius and the velocity as below:

Gaz type	Masse m (kg)	Radius R (m)	Velocity v (cm/s)
HCl	$5.76 * 10^{-26}$	0.073	408
HF	$3.2 * 10^{-26}$	0.056	547
SO_2	$10.24 * 10^{-26}$	0.098	306
Hg	$32 * 10^{-26}$	0.173	173

2. Detector:

The detector is the second main part of the mass spectrometer that allows us to know the location of ions when they exit the analyzer and thus know their masses. There are several types of detectors out there, but it was chosen to use “Faraday’s Cup “as a detector.

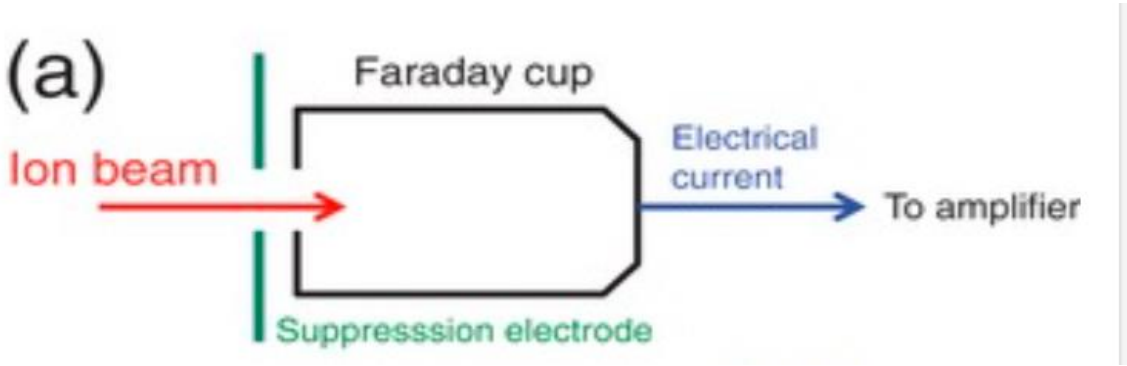


Fig. 2.1: Faraday's Cup

Faraday Cup works for large ion currents since 1 ion (+1) has: 1.6×10^{-19} Coulombs, and that means 1 ion/second is 1.6×10^{-19} A or 1.6×10^{-4} fA

When the ions collide with the plate it induces a current equal to its charge, therefore the more ions the higher the current and thus the bigger the signal allowing us to know the quantity.

When designing a Faraday's Cup, a few considerations should be considered:

1. Material Selection:

A conductive material with high thermal and electrical conductivity. Commonly used materials are stainless steel and brass.

2. Cup Geometry:

The cup's geometry is critical for efficient ion collection and minimizing losses due to scattering.

3. Aperture Size:

The aperture size should be optimized to allow ions of interest to pass through while minimizing the passage of unwanted neutral particles or larger molecular clusters.

4. Electric Isolation:

The Cup must be electrically isolated from the analyzer to prevent interference with the magnetic fields used in it.

5. Collection Efficiency:

The design should aim to maximize the collection efficiency of ions like optimizing the cup's shape for a smooth interior surface and minimizing the distance between the aperture and the collector surface.

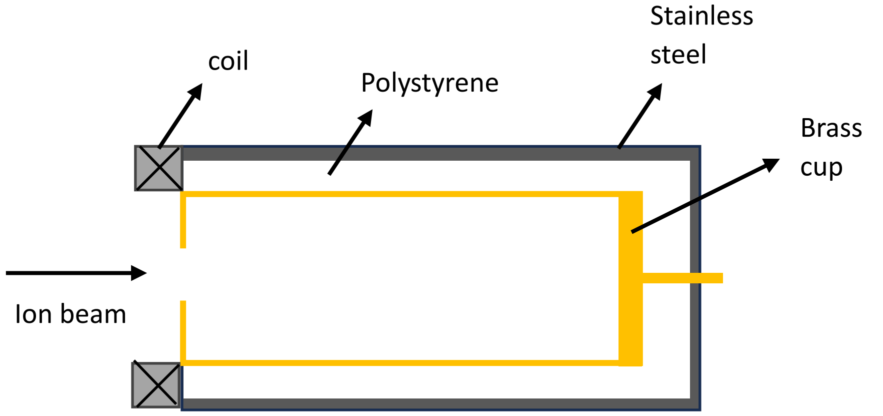


Fig 2.2: model #1 of Faraday's cup module #1

In the above fig., the brass cup is the collector; Polystyrene is not only an electric insulator, but also a shield against outside noise. The stainless steel is a protective casing, and finally, the coil, when electrified is going to induce a magnetic field that will prevent unwanted charged particles from interfering with the signal (protecting from potential inside noise).

The dimensions are yet to be determined since further consulting from the project coordinator is required.

In addition, this module is more for testing purposes and is not to be implemented in the project.

3. Amplifier

The last part of the spectrometer is the amplifier circuit, since as mentioned above the current induced is too small (1.6×10^{-19} A per ion) and is impossible to record directly.

The job of the amplifier circuit is to amplify the upcoming signal so it can be recorded and studied.

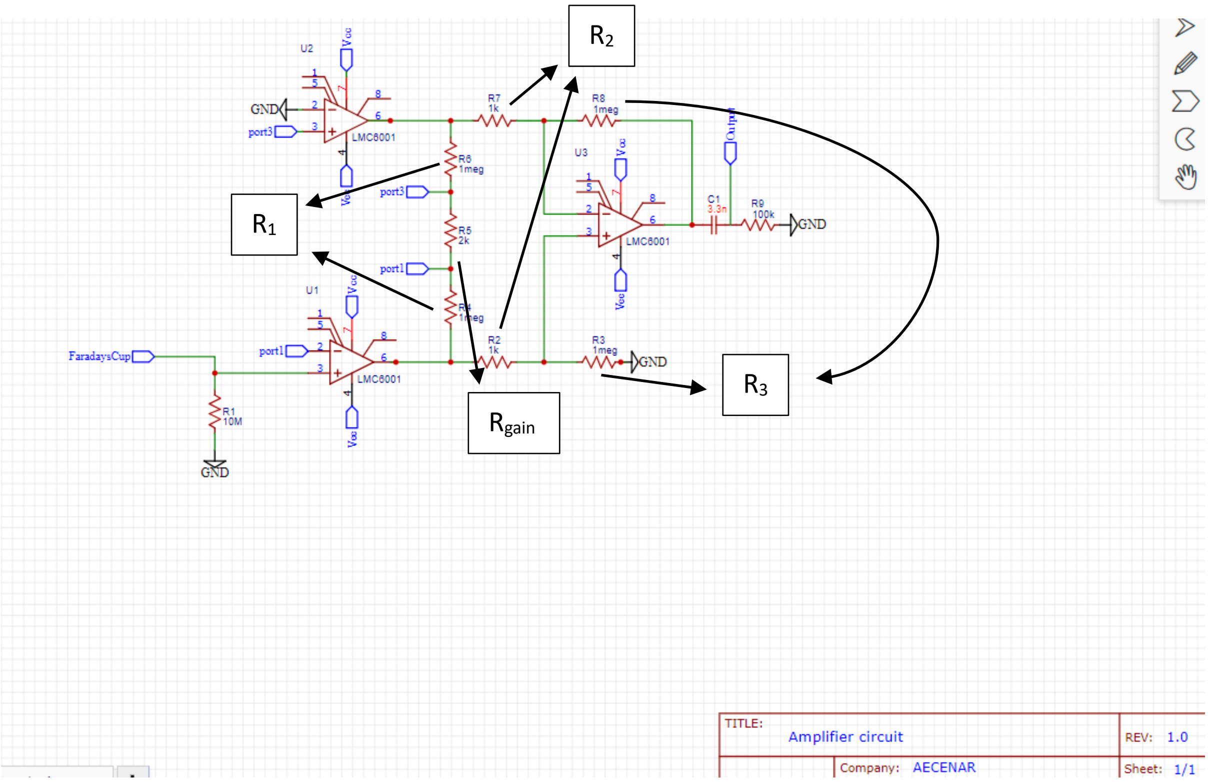


Fig. 3: amplifier circuit module #1

The amplification factor of the circuit can be determined by this equation:

$$A_v = \frac{Vout}{V2-V1} = \left(1 + \frac{2R1}{Rgain}\right) \times \frac{R3}{R2}$$

Where A_v is the amplification factor.

The chosen resistances are as follows:

R_1=1meg ohm

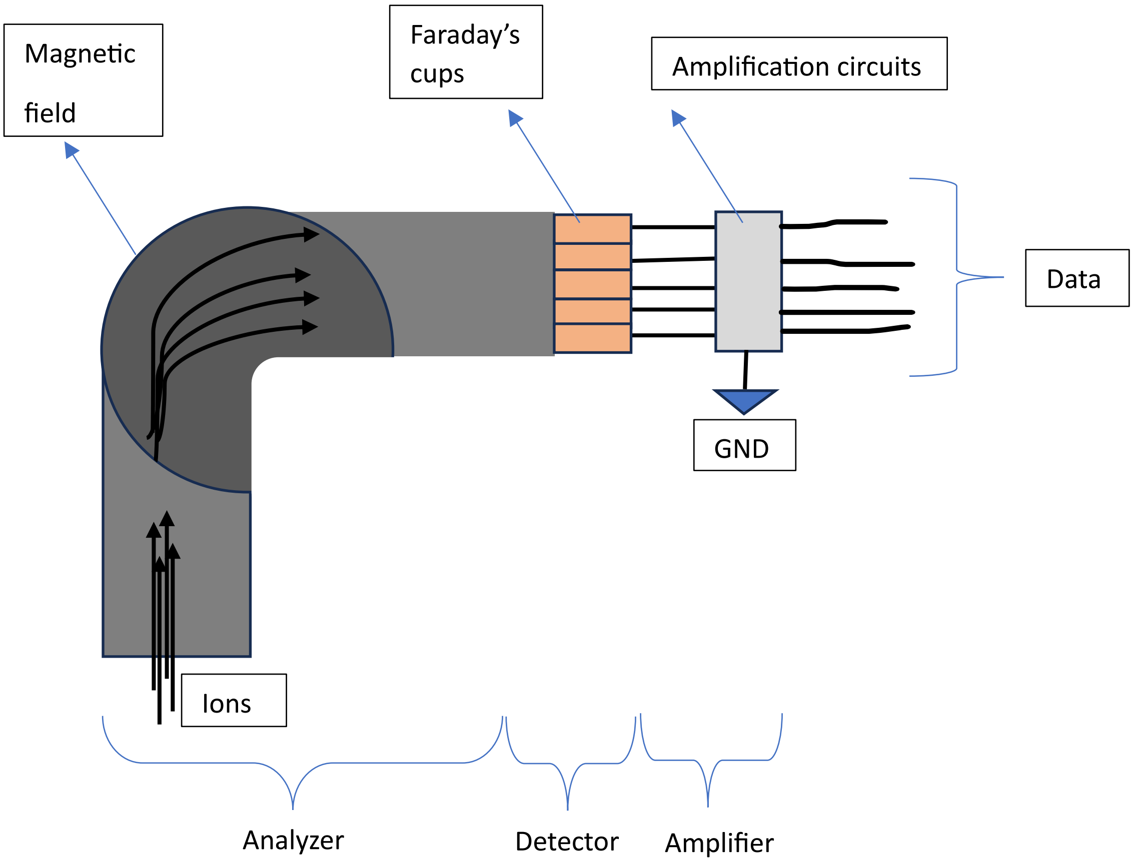
R_2= 1000 ohm

R_3= 1meg ohm

R_{gain}= 2000 ohm

This will make A_v= 1000000.

For example, if $3*10^{10}$ ions collide with the detector, it will generate roughly 5nA which will be amplified 1 million times to become 5mA which is recordable.



4. Places for improvement

a- Faraday's cup collector shape can be optimized for efficient ion collection and minimizing losses due to scattering, but it needs simulations and testing.

b- Using only one Faraday cup instead of 4, or more, by implementing a flight time analysis for ions, since each one has its velocity and thus a time of flight, but it needs testing.

c- Optimization of the amplifier circuit using more efficient and sensitive amplifiers.

d- The use of one amplification circuit instead of 4 or more by implementing a mechanism that transfers the signal to the amplifier in series format and not parallel.

e- Changing the amplification factor of the circuit by changing the resistance in case it is needed since the number of ions entering the mass spectrometer is still in the study.