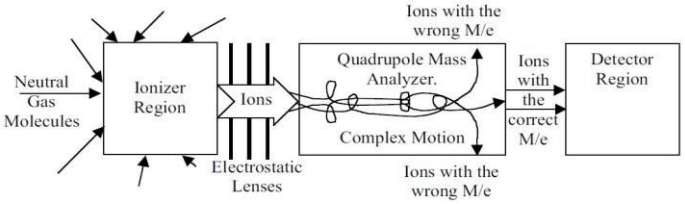
Residual Gas Analyzer

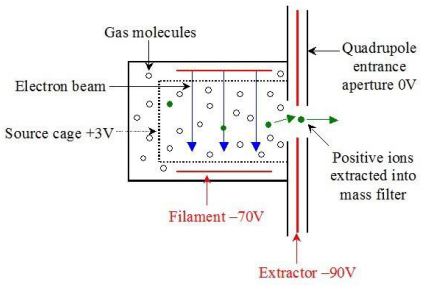


A **Residual gas analyzer** (RGA) is a spectrometer that effectively measure the chemical composition of a gas present in a low-pressure environment. The residual gas analyzer actually ionizes separate components of the gas to create various ions, and then detects and determines the mass-to-charge ratios. This process works better in vacuum, where quality is easier to monitor and impurities and inconsistencies are easier to detect because of the low pressure. Setups such as this can be found inside ion beam accelerators and electron/ion scanning microscopes.

Importance of RGA: (1) It allows one to analyze the various gas phase reactions; (2) It can monitor the changes occurring in any gas environment; (3) check for vacuum leak; (4) check the mass flow controllers; etc. These type of information may be difficult to determine by other methods, but can easily be found using a RGA attached to the low-pressure environment or chamber.

Operation of RGA : There are five main components of a RGA: (1) Ionizer; (2) Electrostatic Lens; (3) Mass Analyser and Filter; (4) Ion Detector; (5) Mass Spectrum.

1. Ionizer :



In the Ionizer, the neutral gas atoms or molecules are converted into positive ions. The Ionizer consists of the following parts: (a) two filaments for producing electrons; (b) source grid which is an electrostatic wire mesh for setting up a constant electrostatic potential inside the ionization region; and (c) insulating holders. There is also a Faraday shield "basket" around the entire assembly to keep external electrostatic potential from affecting the ionizer. Two wires, generally of Thoria coated Iridium at -70V, on passing current emit electrons by "thermionic emission" of energy 70 ev and a current of few milliamperes. These electrons are then accelerated toward the wire mesh because of the applied potential difference between the filaments and the wire mesh. The accelerated electrons then collide with neutral gas atoms or molecules in the mesh and ionize it.

When an electron collides with an atom or molecule M, it may not get ionized (elastic collision) or get ionized (inelastic collision) something like: $e^- + M \Rightarrow 2e^- + M^+$. This ionization reaction requires significant energy (the "ionization potential" of the molecule M) and that energy must be supplied by the electron. Table I gives the energy required to ionize a variety of molecules into specific ions. Other kinds of ionization reactions can also occur. For example a process called dissociative ionization can occur. The chemical equation for such a reaction would look something like: $e^- + MX \Rightarrow 2e^- + M^+ + X$ (or) $2e^- + M + X^+$. Clearly, things can get complex quickly. Indeed, an electron collision with a nitrogen molecule (N2) can have well over a dozen possible outcomes! We only measure two, using an RGA: The formation of $N2^+$ and N^+.

A concept called "cross-section" is used to describe the probability of an electron colliding or reacting with an atom or molecule. The simplest form of the idea is relatively simple: an electron has to collide with a molecule to initiate a reaction. Since the electrons move at least 100x faster than molecules, we can often treat those molecules as if they were standing still. If the molecule has a large radius (and therefore a large cross-section) the probability of an electron colliding with it is relatively large too. These cross-sections are generally measured as a function of ionization energy of the electron.

In the table below, ionization potential of some elements are given; all of the cross sections or ionization potentials tend to have a maximum value near 70 eV to 200 eV. That is why we use electrons of about 70eV to ionize molecules in the RGA. The ionization process is relatively efficient at that energy. Note also that the cross section for forming CF_3^+ is much larger than for forming other ions like CF^+ or C^+. Consequently, we should expect that the ionizer will produce, from CF_4 much more CF_3^+ than CF^+ or C^+ and that the CF_3^+ signal will be the largest as a result.

Table 1. The minimum Ionization Potentials (IP) of selected atoms and molecules.

Atom	1st IP (eV)	2nd IP (eV)		Molecule	Ion formed	IP (eV)
H	13.598	--		CF_4	C^+	34.5
He	24.587	54.416			CF^+	27
B	8.298	25.154			CF_2^+	22
C	11.260	24.383			CF_3^+	16
N	14.534	29.601		N_2	N_2^+	15.6
O	13.618	35.116			N^+	24.3
F	17.422	34.970			N_2^{2+}	~ 43
Ne	21.564	40.962		Cl_2	Cl_2^+	11.5
Si	8.151	16.345			Cl^+	15.5
P	10.486	19.725		O_2	O_2^+	12.2
Cl	12.967	23.81			O^+	18.7
Ar	15.759	27.629		CO_2	CO_2^+	
Kr	13.999	24.359			CO^+	

RGAs come with similar tabular information on what ions are produced from various gases. RGAs also often come with a "Relative ionization sensitivity" table that describes the number of ions produced from a given molecule compared to an equal number of nitrogen molecules. For example: Argon produces 1.2 times as many ions as nitrogen and helium only 0.14. Consequently, one should expect smaller signals from helium at a given pressure than from either argon or nitrogen.

2. Electrostatic Lens Assembly:

The Electrostatic Lens assembly, through a series of electrostatic "lenses" focuses and accelerates the positive ions into a beam that has about 10-20eV of energy.

The ionizer wire mesh is generally set to 10 to 20 V above ground by the ionizer power supply. Setting this at a potential above ground ensures that all the ions produced have a significant potential energy of 10-20 eV {P.E.=K.E.= q x ($V_{ion\_region} - V_{mass\_filter}$)}. The mass filter region is usually kept at ground potential.

Thus, positive ions produced in the ion region basket having about 10-20eV of energy will accelerate into the grounded mass filter region and travel through it at a reasonably well-defined velocity (and KE) simply by setting the potential on the ionizer wire mesh. Each lens is a simple disk with a hole in the center (of donut structure). When a potential (negative potential with respect to the ionization region) is applied on such a donut structure, electric fields are formed that can accelerate ions through it as well as push them toward the center of the donut hole. The negative potentials placed on the successive lenses produce a potential gradient and hence determines the efficiency as well as the beam quality with which ions are accelerated into the mass filter.

The lens nearest to the ionizer wire mesh is usually called an "extractor" lens. Some RGAs have only the extractor lens. Others have more than one lens for focusing the ion beam and directing it into the mass filter.

3. Mass Filtering (Quadrupole):

The accelerated and focused positive ions are then sorted out according to their respective masses by employing electric and/or magnetic fields in the Mass Analyzer. This unit acts as a filter. It very nicely passes through the ions with mass to charge ratio (M/e) chosen by the user, and all the other ions get deflected aside into the walls where they neutralize and become undetectable.

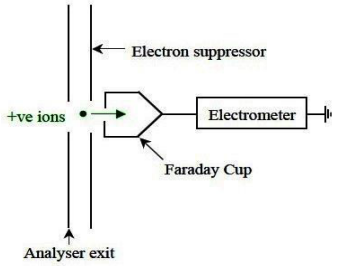
Quadrupole mass filters consist of 4 ("quad") rods that are electrically biased (poles). No magnetic fields are required to filter out different mass ions for this arrangement. These carefully placed rods, when biased with both - dc and rf voltages, produces electric fields of hyperbolic configuration in the centre, that confine very small ranges of M/e (mass to charge ratio) to the central region. All other M/e ions are accelerated right into the rods where they are neutralized and become undetectable.

4. Ion Detection System.

The Ion detector system detects and calculates the mass-to-charge ratio of the filtered ions as ion current either with a Faraday cup or an extended secondary electron multiplier (also known as a "channeltron").

By choosing a specific mass to charge ratio and making a measurement of the signal obtained, one can immediately find out the number of those molecules present in the ionizer region of the RGA. By sweeping through a whole range of M/e ratios, one can find a whole range of molecules that are present and begin to understand the full range of chemical components in the gas.

(a) The **Faraday cup** is simply a piece of metal biased at an appropriately negative potential (~ -50 V) so that the positive ions are attracted towards it and get neutralized. The current flowing through the Faraday cup is measured using a fast electrometer and this current is the relative signal recorded by the RGA. The larger the current, the larger the signal and hence greater the number of ions.

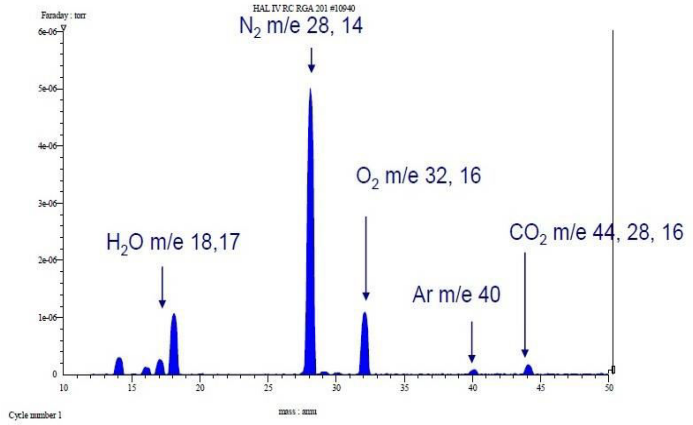


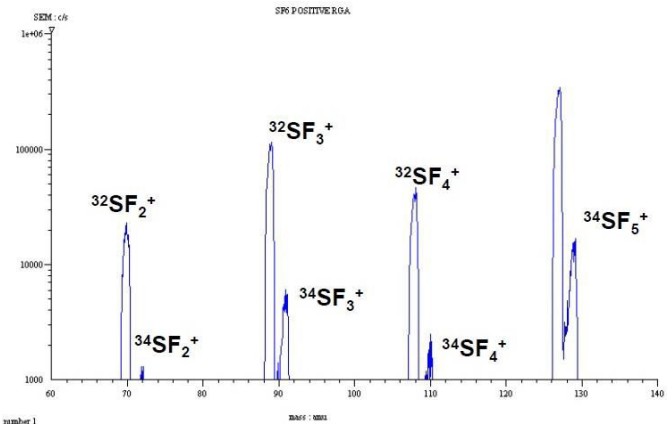
Since current is simply the net flow of charge across a unit area plane per unit time, and since a multiple ionized molecule carries more charge than a singly ionized molecule, one should expect multiple ionized molecules to produce a larger signal for a given number of ions. For example: each Ar^{++} ion carries twice the charge of an Ar^{+} ion; consequently the Ar^{++} signal should be twice as large as the Ar^{+} signal if there are the exact same numbers of ions. This can cause the signal of multiple charged ions to be larger than that predicted by just using the ionization cross section.

(b) Secondary electron multiplier or channeltron are simply bent glass tubes with a special interior coating (usually an oxidized metal such as Pb or Bi) that emits several electrons ("secondary electron emission") every time it is hit by either an ion or an electron. The back end has a Faraday cup installed on the tube that collects the electrons produced inside the tube. The front wide "mouth" end has a collar that is connected to a low current power supply and is biased to a very large negative voltage (~ -2 kV). The back end is kept very close to ground potential and connected to a fast electrometer again. In some cases, the back-end can be connected to a pulse counting circuit instead so that the current pulse from each individual ion is counted rather than the time integrated current measured. Most often, the current is simply measured. The advantage of a channeltron is that it amplifies (M) the current of each ion by a very large factor. The value of the amplification factor, M, can be on the order of 10^4 to 10^9 depending upon the construction of the multiplier, the voltage used and the age of the device. This allows one to measure trace gases with much improved signals. This enhances the sensitivity of the RGA.

5. RGA spectrum or Mass Scan Spectrum :

The spectrum depicts peaks of ions with mass to charge ratios in amu unit. An "amu" is an "atomic mass unit" and corresponds roughly to the mass of one proton. These M/e ratios are characteristic of all elements. For example, peaks in the spectrum at 14 amu is N^{+}, 20 amu is Ar^{2+}, 28 amu is N_2^{+}, and 40 amu is Ar^{+}. The peak at 28 amu corresponds to molecular nitrogen in this case, but other molecules might also have contributed to this signal (or any other signal for that matter). In particular, carbon monoxide, CO^{+}, has the same M/e ratio as N_2^{+} to within the detection capability of any ordinary RGA and consequently is always detected at 28 amu with nitrogen. The differences between N_2 and CO come in the total spectrum of CO versus N_2. N_2 will produce signal peaks at primaily 28 and 14 amu while CO will produce peaks at 28 (CO), 16(O) and 12(C) amu along with lesser peaks at 29($C_{13}O$ and COH) and 13 (C_{13}) amu..





Types of RGA : (1) Open ion source RGA and (2) Closed ion source RGA.

(1) Open Ion Source RGAs: These RGAs can only handle a maximum pressure of 1E-4 Torr. If chamber pressure falls below this value, these RGA's can usually be attached directly to the vacuum chamber. They measure the gas present without changing the gas composition or altering the vacuum environment.

(2) Closed Ion Source RGAs: Generally speaking, closed ion source RGAs operate between 1E-2 and 1E-11 Torr. A closed ion source RGA, has a small ionizer, attached to a quadrupole filter and has a tube with two openings: one for the electrons to enter and one for the electrons to exit. Alumina rings seal the tube, and the majority of the quadrupole is comprised of electrodes. As soon as the process begins and electron contact is intitated, the ions are formed. However, the rest of the mass analyzer is under high pressure.

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