LINXON myRGA

THEORY AND OPERATION

Module 200:
RGA Theory

PURPOSE

- Develop expertise with LINXON myRGA
- Understanding RGA theory is an essential part of learning how RGAs work and how they can be used to meet customer needs

OUTLINE

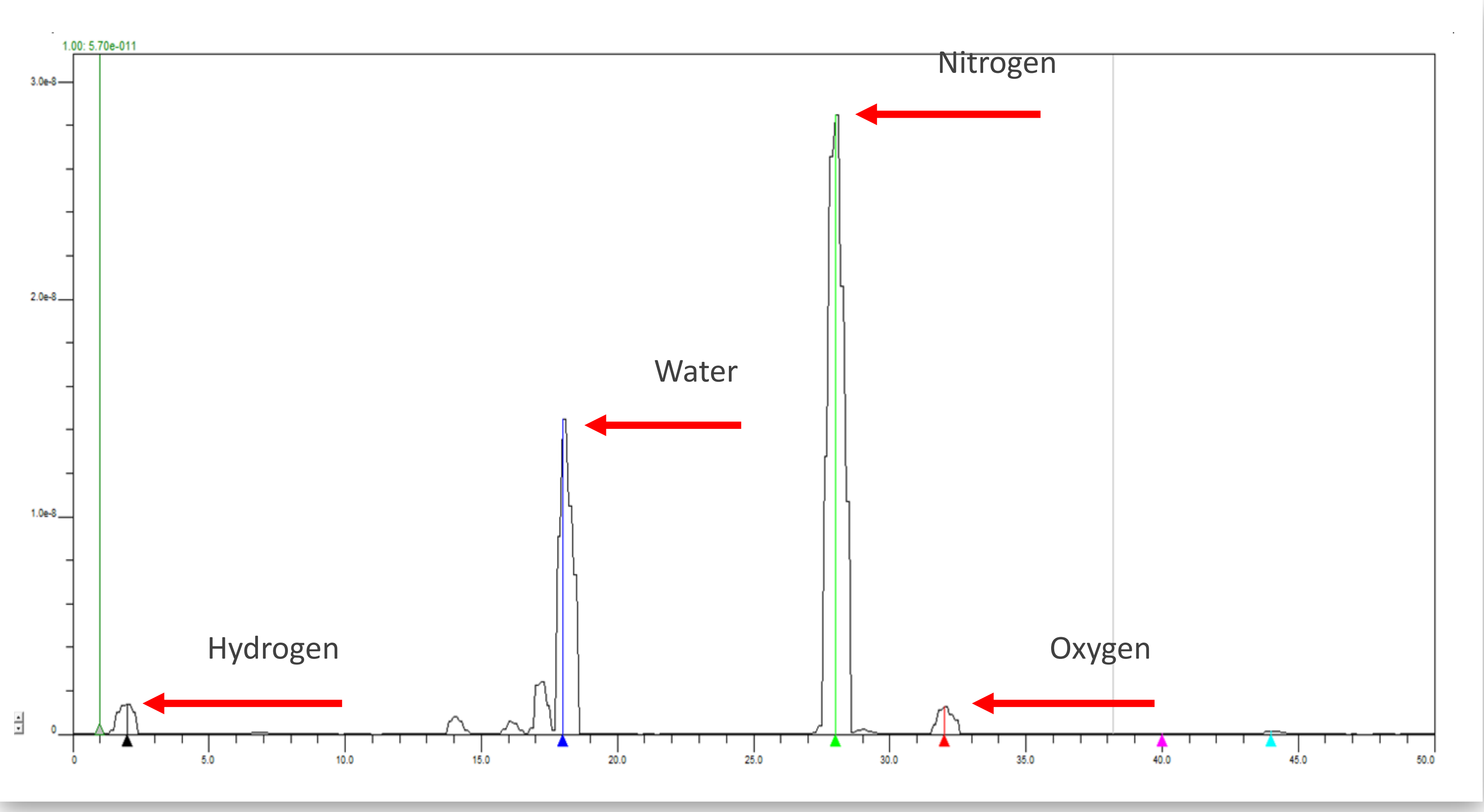
1. RGA Purpose and Applications Overview
2. Mass-to-Charge Ratio
3. RGA Sensor Overview
4. Mass Spectra

1

RGA PURPOSE AND APPLICATIONS OVERVIEW

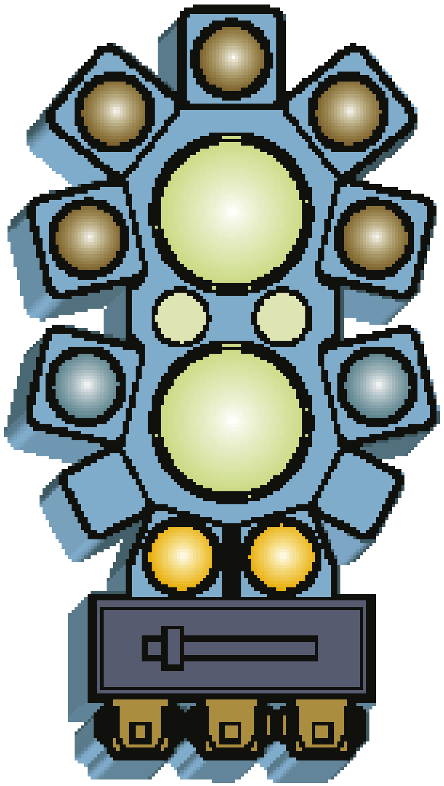
RGA PURPOSE

Determine types and quantities of gases in a system



RGA OVERVIEW OF APPLICATIONS

- Leak detection
- Gas or contaminant identification
- Vacuum system diagnostics
- Process monitoring and control
- Research and development
- Manufacturing
- Quality assurance
- Process efficiency improvement
- Scrap reduction / cost reduction



MASS SPECTROMETRY

- Analytical technique used to identify and measure gases
- Sampled gas pressure can range from ultra-high vacuum to above atmospheric pressure
  - LINXON myRGA can operate at pressure up to 5×10^{-4} Torr
- High sensitivity to detect extremely small gas concentrations or partial pressures

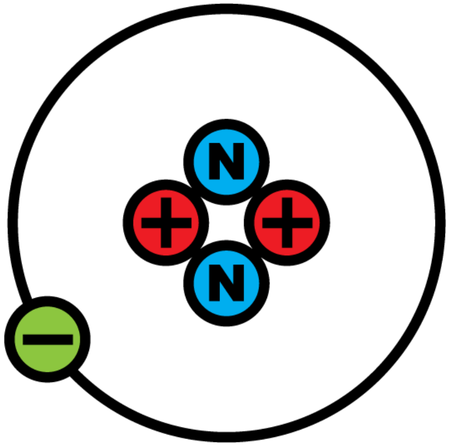
2 MASS-TO-CHARGE RATIO

REQUIREMENT TO IONIZE THE GAS

- RGA needs to:
  - Filter gas particles according to their mass
  - Detect and measure the filtered particle stream
- However, gas particles are neutral
  - Difficult to filter
  - Difficult to measure
- Solution is to ionize the gas
  - Ions have electric charge
  - RGA can filter ions by exerting electric forces on them
  - RGA can measure ion stream by measuring electric current

ION'S CHARGE NUMBER

- An ion is similar to an atom or a molecule, except it has a net charge
- Atom or molecule that loses 1 electron
  - Singly ionized
  - Positive ion
  - Charge number is +1
- Atom or molecule that loses 2 electrons
  - Doubly ionized
  - Positive ion
  - Charge number is +2



Helium ion (He^{+})
z = +1

Mass-to-Charge Ratio (m/z)

- Essential to a mass spectrometer's ability to independently measure different gas species
- Equal to an ion's mass (m) divided by its charge number (z)
- Basis for filtering ions in an RGA
  - Separate, identify and quantify each gas species in a sample
- Mass-to-charge ratio often shortened to "mass" for convenience
  - Ion's charge number often equal to 1
  - When z = 1, mass-to-charge ratio = mass

MEASUREMENT UNITS FOR M/Z

MASS-TO-CHARGE RATIO

- amu/e
  - Clearly shows mass divided by charge
  - Mass (amu) divided by charge (e)
- amu
  - Most common
  - Mass (amu) divided by charge number
- No unit of measure (dimensionless)
  - Integer value with no unit of measure
  - Mass number divided by charge number
- Mass-to-charge ratio usually involves integer values
  - Integer values not affected by choice of measurement unit

40 amu/e

40 amu

40

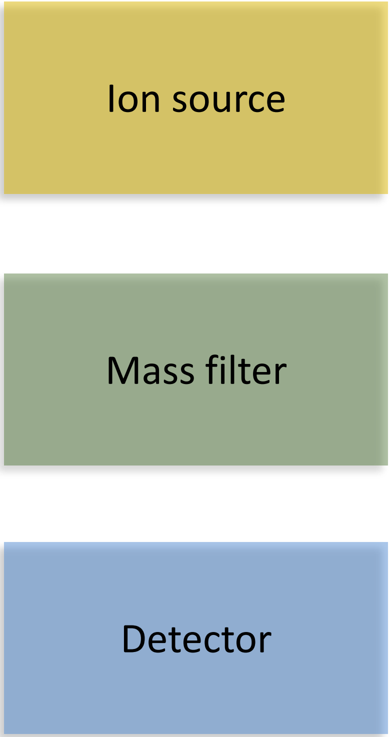
EXAMPLES OF MASS-TO-CHARGE RATIO

- Singly ionized helium (He^+)
  - Mass = 4 amu
  - Charge number = +1
  - 4 amu / 1 = 4 amu
  - Measurement signal at mass 4 indicates helium
- Singly ionized argon-40 ($^{40}Ar^+$)
  - Mass = 40 amu
  - Charge number = +1
  - 40 amu / 1 = 40 amu
  - Measurement signal at mass 40 typically indicates argon

3 RGA SENSOR OVERVIEW

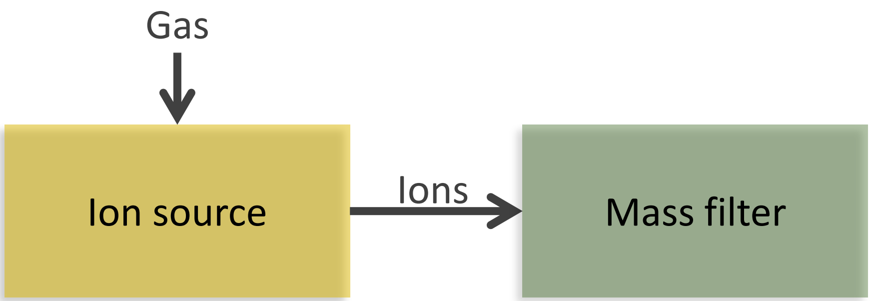
RGA SENSOR – FUNCTIONAL BLOCKS

- Ion source
- Mass filter
- Detector



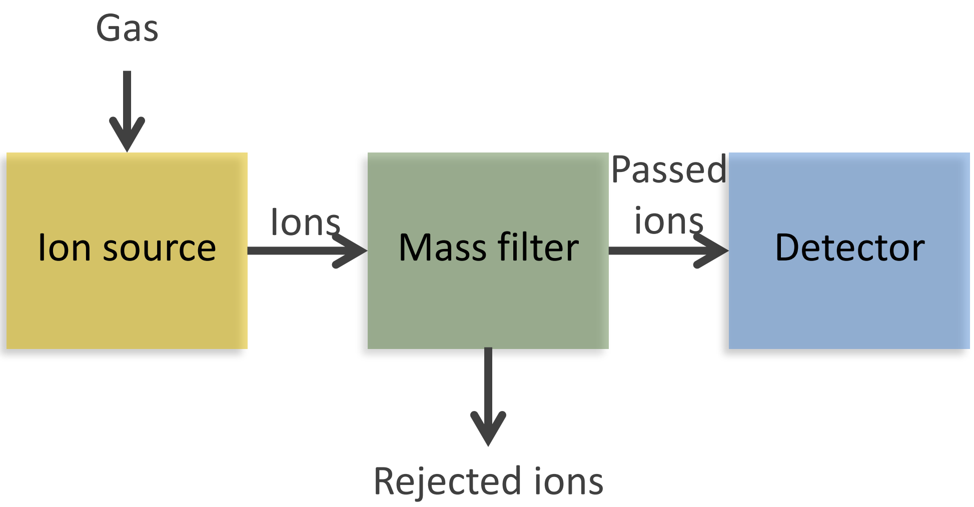
ION SOURCE – IONIZES THE GAS

- Gas enters the ion source
- Atoms and molecules inside the ion source are ionized
- Ions are guided out of the ion source and into the mass filter



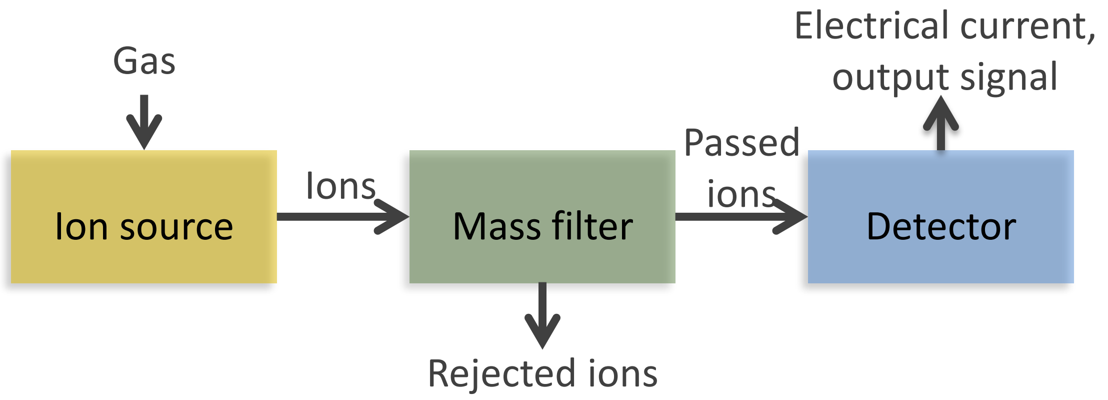
MASS FILTER -FILTERS THE IONS

- Mass filter
  - Filters ions according to their mass-to-charge ratio
  - Ions with m/z within a specific pass band are passed to the detector
  - Ions with m/z not within the pass band are rejected



DETECTOR – DETECTS THE IONS

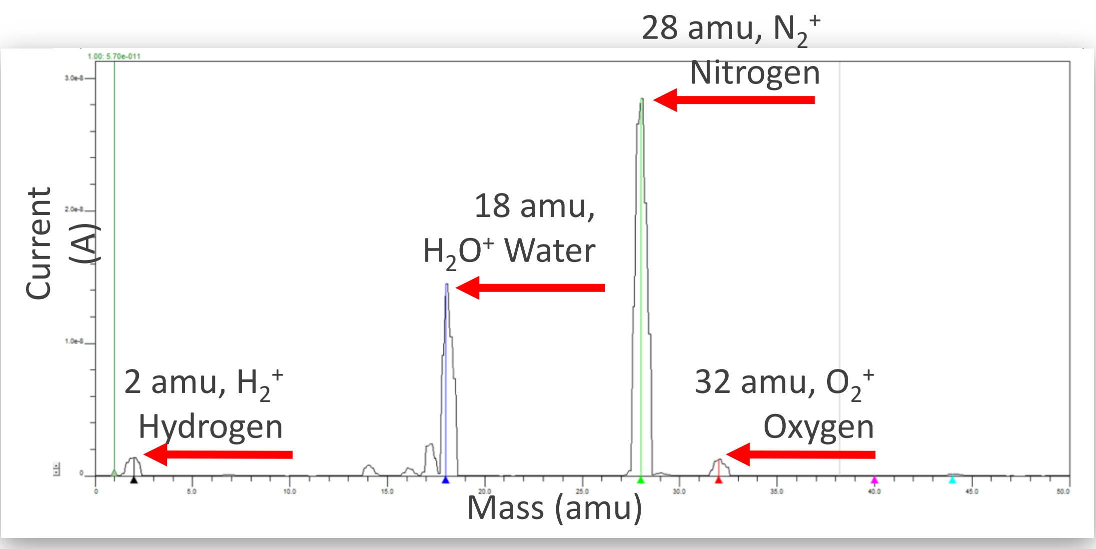
- Ion current arrives at the detector
- Detector produces output current proportional to the ion current
- Output signal represents the gas being measured at that time



4 MASS SPECTRA

MASS SPECTRUM

- Graph of current vs. mass-to-charge ratio ("mass")
  - Mass scale (horizontal axis) identifies different ions being detected
  - Current scale (vertical axis) indicates relative amounts



COMMON PEAKS

Gas	Primary ion	Mass
Hydrogen (H_2)	H_2^+	2 amu
Helium (He)	He^+	4 amu
Water (H_2O)	H_2O^+	18 amu
Nitrogen (N_2)	N_2^+	28 amu
Oxygen (O_2)	O_2^+	32 amu
Argon (Ar)	Ar^+	40 amu

ARGON EXAMPLES, ISOTOPE PEAKS

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- Argon has isotopes ^{40}Ar, ^{38}Ar and ^{36}Ar
- Spectrum can be normalized
  - Scale highest peak, $^{40}Ar^+$, to 100%
  - $^{36}Ar^+$ peak height is 0.3% of the peak height at mass 40
  - Allows user to monitor argon at mass 36 to reduce ion current striking detector

Ion	m/z	Normalized Amplitude
$^{40}Ar^+$	40	100%
$^{36}Ar^+$	36	0.3%
$^{38}Ar^+$	38	< 0.1%

ARGON EXAMPLES, DOUBLY IONIZED PEAKS

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- Doubly ionized, charge number = 2
  - 3 isotopes x 2 ionization states = 6 peaks
  - Argon peak at m/z 18 can interfere with water peak at m/z 18
  - Argon peak at m/z 19 can interfere with fluorine peak at m/z 19

Ion	m	z	m/z	Normalized Amplitude
$^{40}Ar^{+}$	40	1	40	100%
$^{40}Ar^{++}$	40	2	20	14.6%
$^{36}Ar^{+}$	36	1	36	0.3%
$^{36}Ar^{++}$	36	2	18	< 0.1%
$^{38}Ar^{+}$	38	1	38	< 0.1%
$^{38}Ar^{++}$	38	2	19	< 0.1%

CRACKING PATTERS – WATER EXAMPLE

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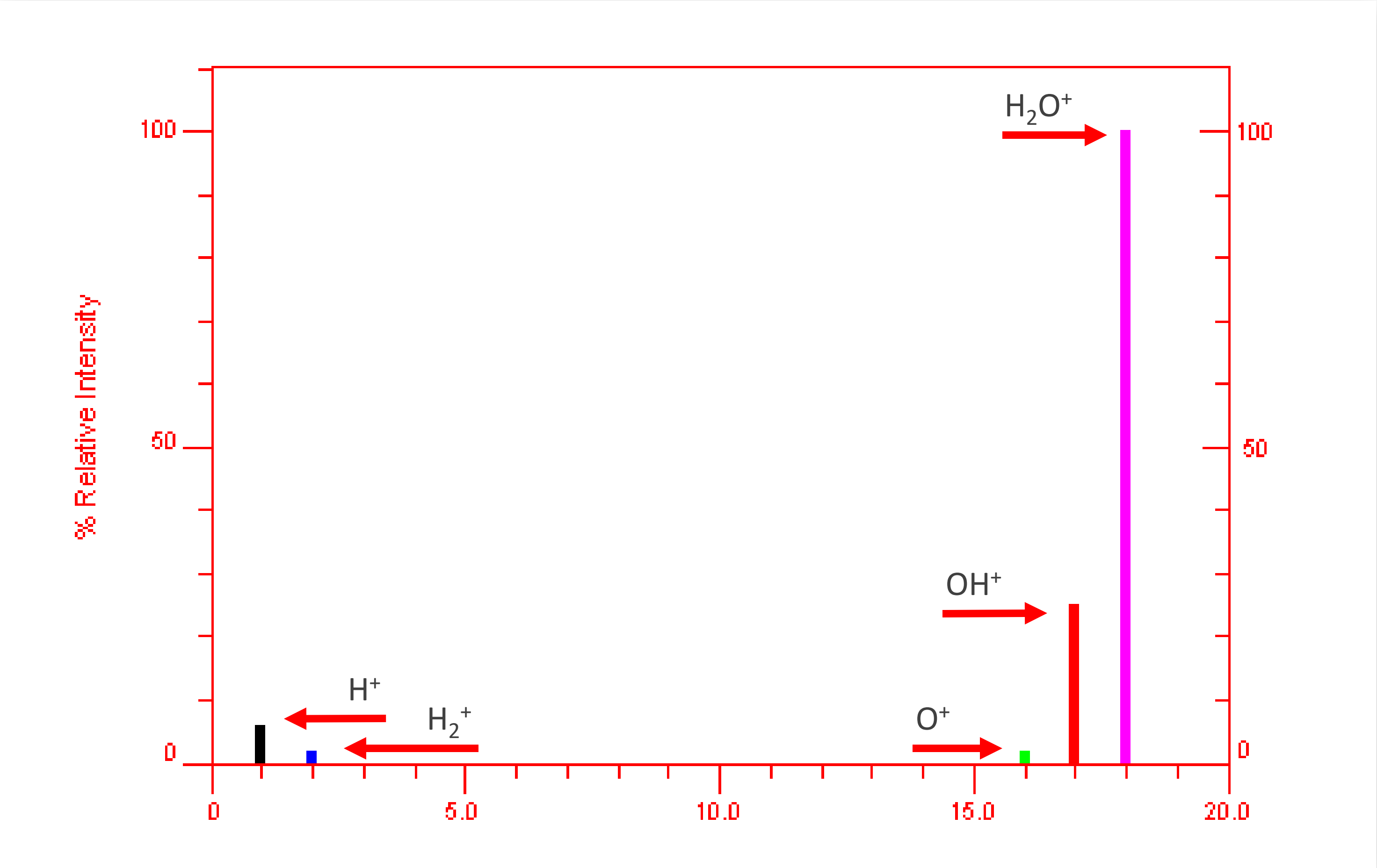
- Molecules can break into smaller fragments during ionization
- For example, water molecules can break into smaller fragments
- Typical mass spectrum for water

Ion	Mass/Charge	Normalized Amplitude
H_2O^+	18	100%
OH^+	17	25%
O^+	16	2%
H_2^+	2	2%
H^+	1	6%

WATER SPECTRUM – RELATIVE INTENSITY VS. M/Z



SPECTRA LIBRARY

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- Library of substances and their mass spectra
- Peak locations (amu) and normalized relative peak heights (%)

Substance	Formula	1	2	3	4	5	6
Acetic acid	$C_6H_{12}O_2$	43/100	56/44	61/15	41/15	73/14	55/7
Acetone	C_3H_6O	43/100	15/42	58/20	14/10	27/9	42/8
Acetylene	C_2H_2	26/100	25/20	13/6	27/3	12/3	
Air		28/100	32/27	14/14	16/3	40/1	
Ammonia	NH_3	17/100	16/80	15/8	14/2		
Argon	Ar	40/100	20/10				
Arsine	H_3As	76/100	78/92	75/39	77/29		
Benzene	C_6H_6	78/100	77/22	51/18	50/17	52/15	39/10
Benzene, chloro	C_6H_5Cl	77/100	112/89	51/57	50/48	38/31	114/25
Borane, trichloro	BCl_3	81/100	83/63	35/30	80/25	116/23	118/23
Borane, trifluoro	BF_3	49/100	11/6	19/4	30/3	68/2	20/1
Butane	C_4H_{10}	43/100	29/44	27/37	28/33	41/28	39/13
Carbon dioxide	CO_2	44/100	28/15	12/14	16/9	22/3	45/1

SPECTRUM GUIDE

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Possible source gases are shown for each m/z listed

AMU	ION(S)	SOURCE(S)
1	H	Hydrogen, Water, Acids, HY
2	H_2	Hydrogen
	D	Deuterium
3	HD	Hydrogen – Deuterium
	He	^{3}Helium
4	He	Helium
6	C	DI Carbon
7	N	DI Nitrogen
8	O	DI Oxygen
10	Ne	DI Neon
11	Ne	DI^{22}Neon
12	C	Carbon dioxide or monoxide, HY, HL
13	CH	Methane, HY
14	CH_2	Methane, HY
	N	Nitrogen, Ammonia
15	CH_3	Methane, HY
	NH	Ammonia

AMU	ION(S)	SOURCE(S)
19	F	Fluorine, Hydrofluoric acid, HL, Silicon tetrafluoride, PFK, PFTBA
20	HF	Hydrofluoric acid
	Ar	DI Argon
	Ne	Neon
22	Ne	^{22}Neon
	CO_2	DI Carbon dioxide
24	C_2	HL, HY
25	C_2H	HY
	CF_2	HL, DI CF_2
26	C_2H_2	HY
	CN	Hydrogen cyanide
27	C_2H_3	HY
	HCN	Hydrogen cyanide
28	C_2H_4	HY
	CO	Carbon dioxide or monoxide
	N_2	Nitrogen, Air

SUMMARY

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- Vacuum diagnostics are important for quality and efficiency in both manufacturing and research
- LINXON contributes by providing RGAs that measure gases with high sensitivity to detect extremely small partial pressures
- Within the RGA, gas is ionized and the measured quantity is the ion current as a function of ion mass-to-charge ratio
- Basic analysis of gas composition commonly is performed by examining peaks at masses such as 2, 4, 18, 28, 32 and 40
- For a more precise analysis, one should consider the detailed mass spectrum of each substance present

THANK YOU!

You have completed the

RGA Theory module!

You may come back and review

the content of this module at any time.