LINXON myRGA

THEORY AND OPERATION

Module 100:
Gas Theory

PURPOSE

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

OBJECTIVES

Upon completion of this module, you will be able to:

- List the subatomic particles that make up atoms
- Describe how the mass of an atom is defined
- Describe how the charge of a particle is defined
- Describe that an ion is a charged particle
- Describe the difference between the isotopes of an element
- Describe the relationship between molecules and atoms
- Describe the difference between partial and total pressure
- Describe how gas concentration is defined

OUTLINE

1. Three Basic States of Matter
2. Atoms and Subatomic Particles
3. Mass and Atomic Mass
4. Electric Charge and Ions
5. Elements, Atomic Number and Isotopes
6. Molecules
7. Total Pressure and Partial Pressure
8. Gas Concentration
9. Vacuum

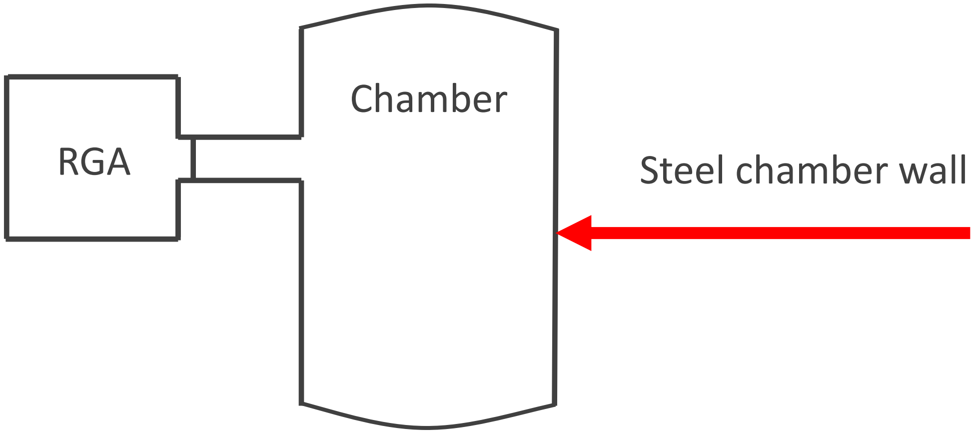
1 THREE BASIC STATES OF MATTER

THREE BASIC STATES OF MATTER

- Solid, liquid and gas
- Water, for example:
  - Solid form of water is “ice”
  - Liquid form of water is “liquid water” or “water”
  - Gas form of water is “water vapor” or “water”
  - State depends on temperature and pressure
- A key difference is how freely the particles can move

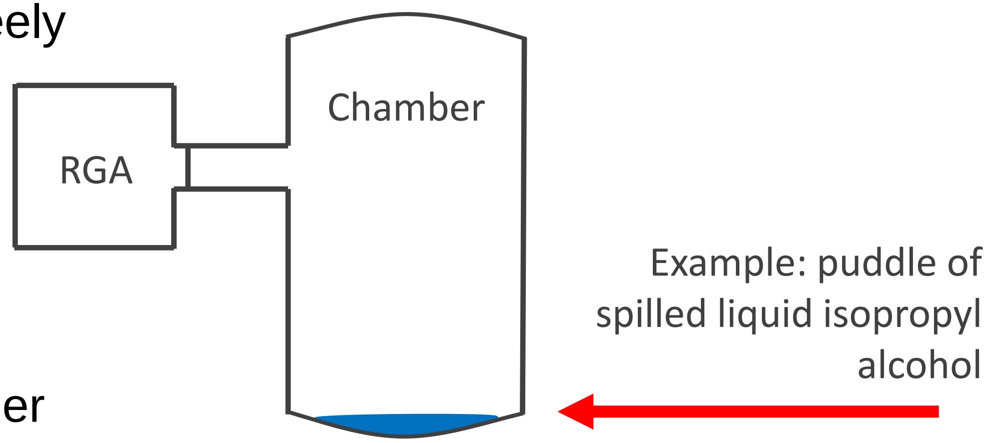
SOLID

- Particles of a solid object are confined in their arrangement
- A solid object will retain its shape
- Example: steel chamber wall



LIQUID

- Particles of a liquid move more freely than a solid
- Particles of a liquid can flow
- They can move in relation to each other
- Conform to the shape of a container
- Example: isopropyl alcohol spill, flows to bottom of chamber



GAS

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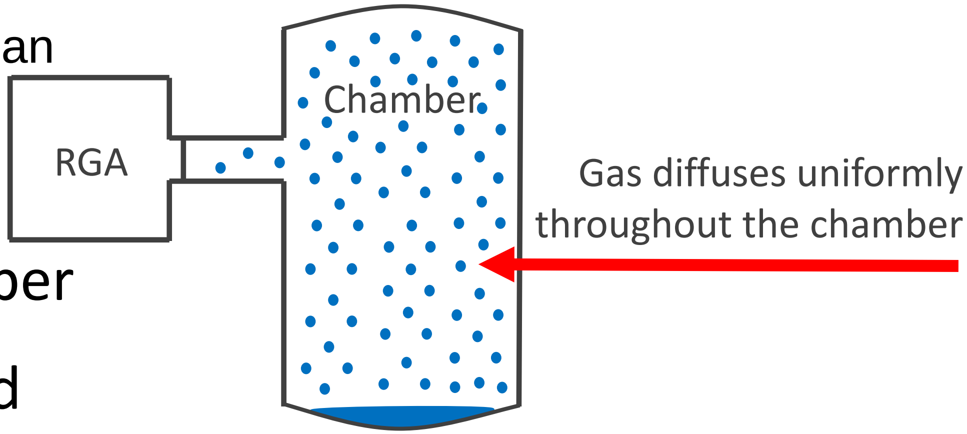
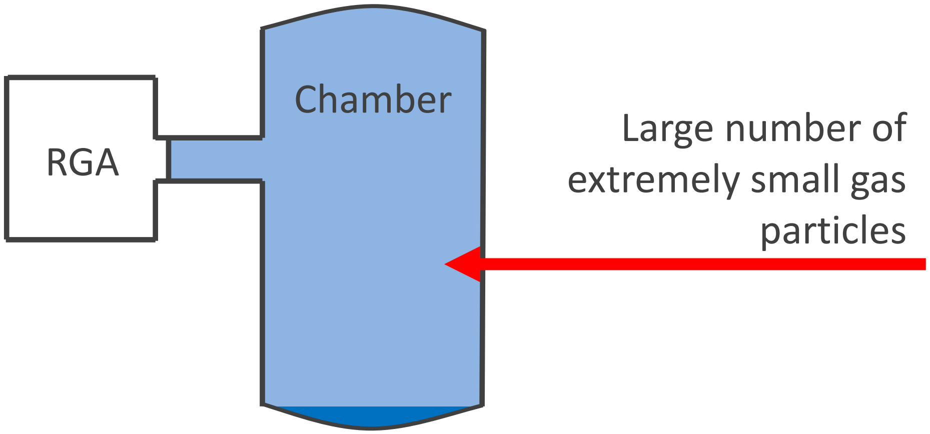
- Gas particles move more freely than a solid or a liquid
  - Gas spreads to fill the available space or chamber
  - Spreading process, called diffusion, produces a uniform distribution of the gas
- Example: Alcohol gas diffuses throughout the chamber



GAS NUMBERS ARE SMALL AND NUMEROUS

- Extremely small size
- Can be present in tremendously high quantities
- Could be more than one billion trillion gas particles in a chamber
- Measured sample can represent gas content of chamber



GAS - A MIXTURE OF GASES

- Any volume of gas is a mixture of different gases
- For example, air is a mixture of:
  - Nitrogen
  - Oxygen
  - Argon
  - Water
  - Other gases in trace amounts
- Each gas in a mixture will diffuse to produce a uniform distribution
- Gas intended to be pure typically will contain impurities

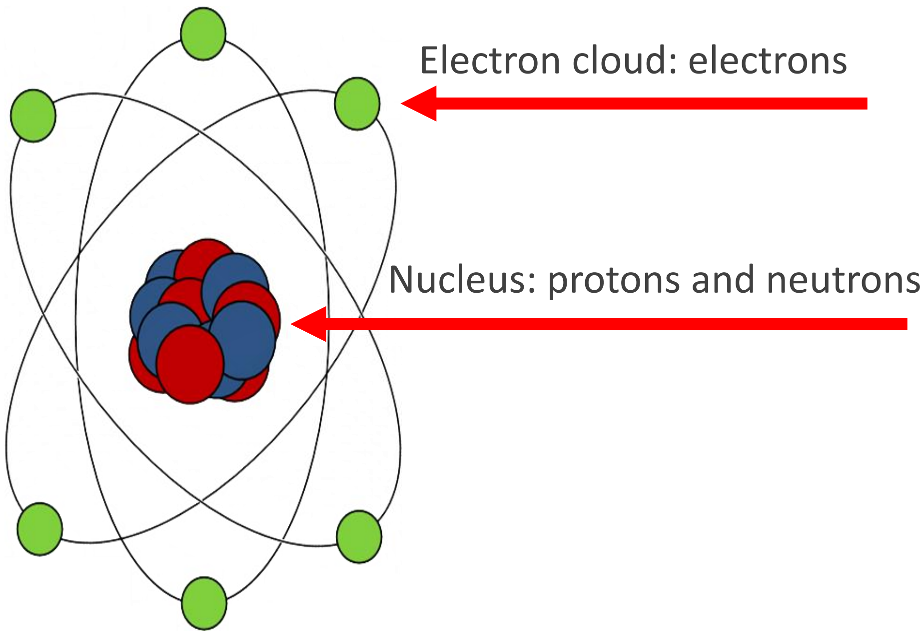
2 ATOMS AND SUBATOMIC PARTICLES

ATOMS

- Atoms are the particles that comprise all matter, including solids, liquids and gases
- Extremely small particles
- Highly abundant – present in tremendously high quantities
  - A 1 carat diamond, 1/5 gram of carbon, is comprised of 1×10^{22} carbon atoms, or ten billion trillion atoms
  - A 25 liter chamber containing argon gas at room temperature and 1 Torr pressure, contains approximately 1×10^{21} atoms, or one billion trillion atoms

SUBATOMIC PARTICLES

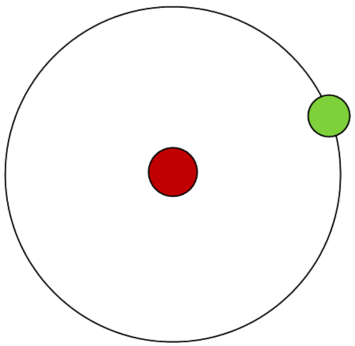
- Atoms are made of subatomic particles
- Protons and neutrons – in the nucleus
- Electrons – in the electron cloud



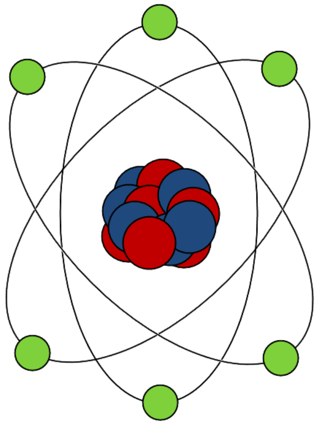
3 MASS AND ATOMIC MASS

MASS - AMOUNT OF MATERIAL

- Mass is a physical property of an object
- A measure of the amount of material
- More material will exhibit more mass
- Mass spectrometers identify different gases according to mass



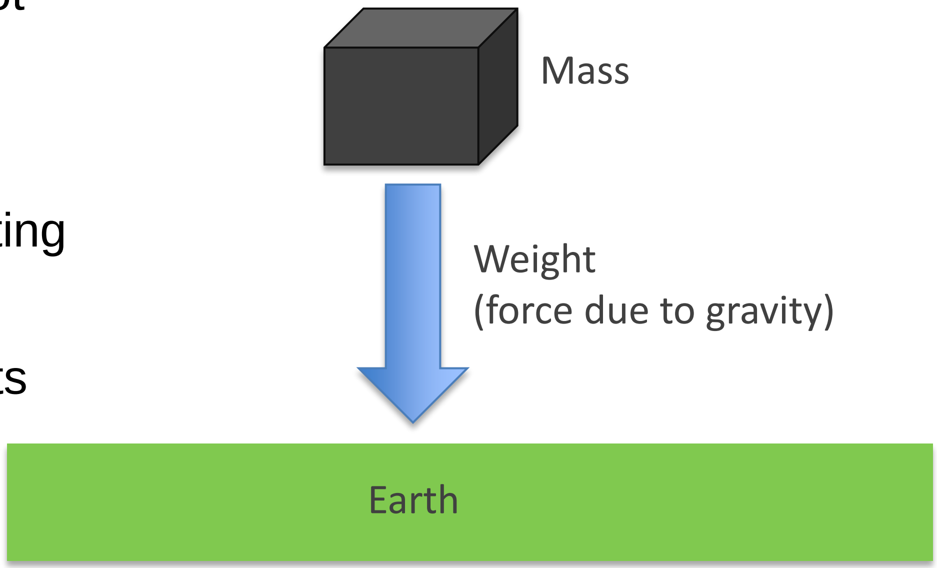
Hydrogen atom, less mass



Carbon atom, more mass

MASS AND WEIGHT

- Mass and weight are related, yet not the same
- Mass is the amount of material
- Weight is the force of gravity attracting that material
- The greater the mass, the greater its weight



MASS AND INERTIA

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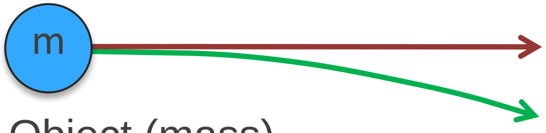
- Inertia is an object's resistance to change of motion due to a force
  - A mass will not change velocity until a force is applied
    - A mass at rest will remain at rest until a force is applied
    - A mass in motion will move at constant speed and direction until a force is applied
- An object's inertia is proportional to its mass
  - An object with more mass requires more force to change its motion



MASS AND RESONANT FREQUENCY

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- Different physical systems have different resonant frequencies
  - Frequency at which a system or object will oscillate or vibrate
- In many systems, mass affects resonant frequency
- Piano string example
  - The mass of a piano string is one of the factors that determines its frequency,
    the pitch of the note
- Mass spectrometer example
  - An ion’s mass is one of the factors that determines if that ion will resonate to pass through a mass filter

MASS AND SUBATOMIC PARTICLES – ATOMIC MASS UNIT

- The atomic mass unit (amu or u)
- 1 amu = mass of either 1 proton or 1 neutron
- 1 amu = 1.66 x 10^{-27} kg

Proton and Neutron

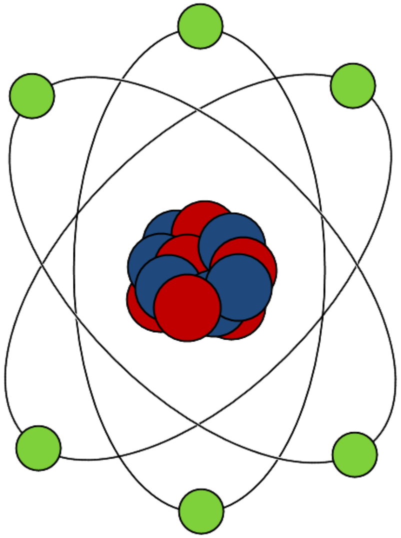
	Mass
Proton	1 amu
Neutron	1 amu

Electron

	Mass
Electron	0 amu

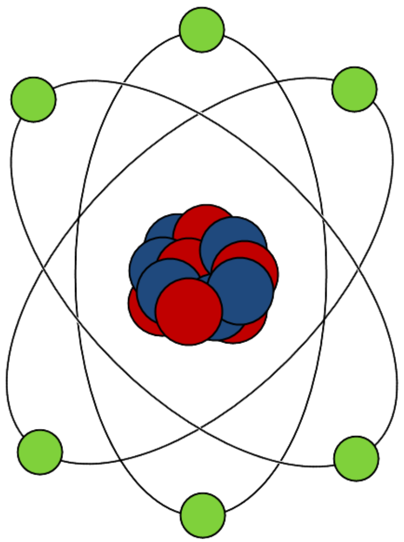
ATOMIC MASS

- Atomic mass is the mass of an atom
- Unit of measure is the atomic mass unit (amu or u)
- Equal to the total number of protons and neutrons in the atom
- For example, carbon-12 atom:
  - 6 protons and 6 neutrons
  - 6 + 6 = 12
  - Atomic mass is 12 amu



MASS NUMBER

- Mass number is equal to atomic mass, except that mass number is shown with no unit of measure (dimensionless)
- For example, carbon-12 atom:
  - Atomic mass is 12 amu
  - Mass number is 12



4 ELECTRIC CHARGE AND IONS

ELECTRIC CHARGE

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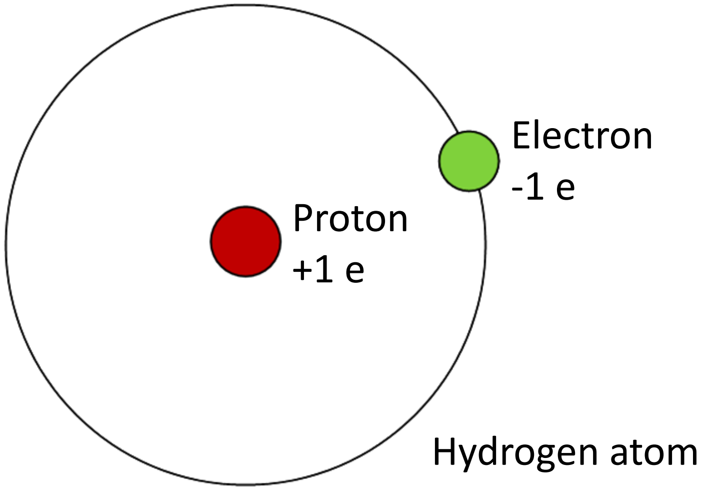
- Positive, negative or zero (neutral)
- Opposite charges, positive and negative, attract one another

- Charges of the same sign, positive and positive, for example, repel one another

ELECTRIC CHARGE OF SUBATOMIC PARTICLES

- The elementary charge unit (e) is defined as the magnitude of the electric charge of 1 electron
- Electrons have negative charge, protons have positive charge
- An electron has 1 unit of negative charge (-1 e)
- A proton has 1 unit of positive charge (+1 e)
- Neutrons are neutral
- 1 e = 1.6×10^{-19} C
- 1 Ampere is a stream of 6 billion billion electrons per second



ELECTRIC CHARGE OF SUBATOMIC PARTICLES

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Proton and Neutron

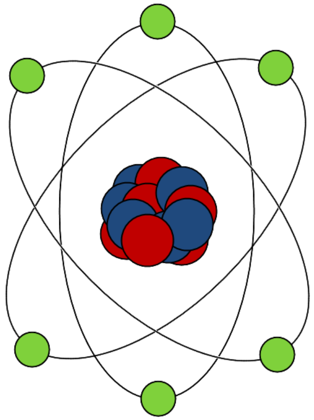
	Mass	Charge
Proton	1 amu	+1 e
Neutron	1 amu	0 e

Electron

	Mass	Charge
Electron	0 amu	-1 e

NET CHARGE OF A PARTICLE

- Net charge is the sum of the electric charges
  - Protons are positive (+1 e)
  - Electrons are negative (-1 e)
  - Neutrons are neutral (0)
  - Particle's net charge is equal to number of protons minus number of electrons
  - When number of protons and number of electrons are equal, net charge is neutral
  - Atoms are neutral
  - Atoms have equal numbers of protons and electrons

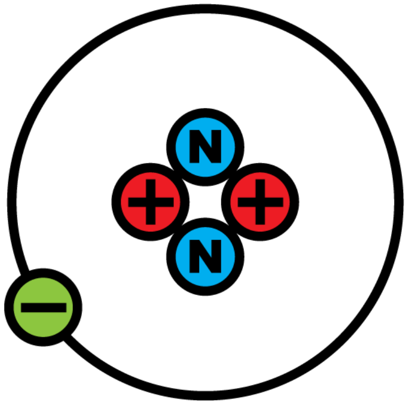


CHARGE NUMBER (z)

- Charge number is equal to the net charge of a particle shown with no unit of measure (dimensionless)
- Charge number is a dimensionless integer
- -2, -1, 0, 1, 2,…
- Commonly used to show the charge of a particle
- Simplifies the units displayed for mass-to-charge ratio
  - Mass-to-charge ratio = mass divided by charge (or charge number)
  - Allows display of mass-to-charge ratio in units of amu, as an alternative to amu/e
  - Integer value is not affected
  - Convenient option to simplify the display of measurement units

ION – A CHARGED PARTICLE

- An ion is a particle with a net charge not equal to zero (not neutral)
- Atom loses 1 electron
  - Loses 1 unit of negative charge
  - Becomes a positive ion with a charge of +1 e
- Atom loses 2 electrons
  - Loses 2 units of negative charge
  - Becomes a doubly ionized positive ion with a charge of +2 e
- Often show charge as a charge number
  - Show integer value without the unit symbol e
  - Still commonly called charge



Helium ion (He^+)

5

ELEMENTS, ATOMIC NUMBER, AND ISOTOPES

ELEMENTS

- Elements are different types of atoms
- More than 100 known elements
- Organized in the Periodic Table of Elements
- Some elements have similar properties
  - For example: copper, silver and gold
    - Soft metals, good electrical conductors, relatively inert
- Some elements have very different properties
  - For example: helium and chlorine
    - Helium: odorless, inert, non-toxic
    - Chlorine: strong odor, highly reactive, poisonous

ATOMIC NUMBER

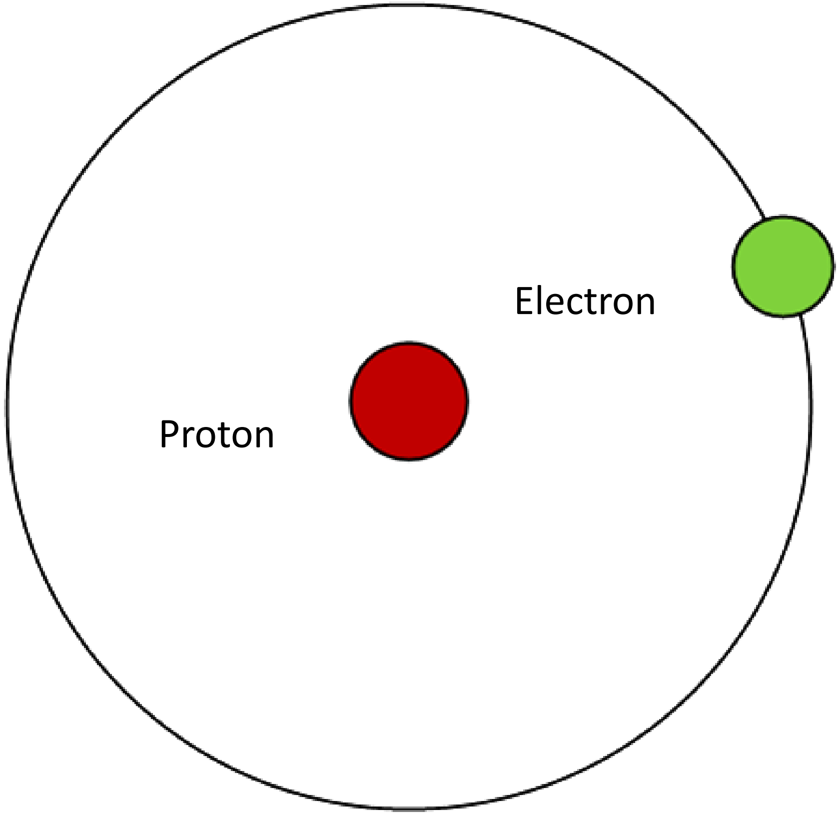
- Atomic number is the number of protons in the nucleus of an atom
- Characteristic that defines each chemical element
  - All atoms of an element have the same number of protons (atomic number)
    - Carbon has 6 protons, atomic number 6
    - Nitrogen has 7 protons, atomic number 7
    - Oxygen has 8 protons, atomic number 8
- Chemical properties of elements depend on atomic number
  - Chemical properties of atoms depend on the number of electrons they contain
  - Atoms are neutral, so atomic number indicates:
    - Number of protons
    - Equivalent number of electrons
    - Chemical properties of the element due to that number of electrons

ATOMIC NUMBER – DIFFERENT FROM ATOMIC MASS AND MASS NUMBER

- Atomic number
  - Number of protons
  - Defines each element in the Periodic Table
  - Chemical properties of the elements depend on atomic number
- Atomic mass
  - Total number of protons and neutrons
  - Units of amu
  - Basis for an RGA (mass spectrometer) to independently measure different gases
    - Mass number is the same as atomic mass, just shown with no unit of measure

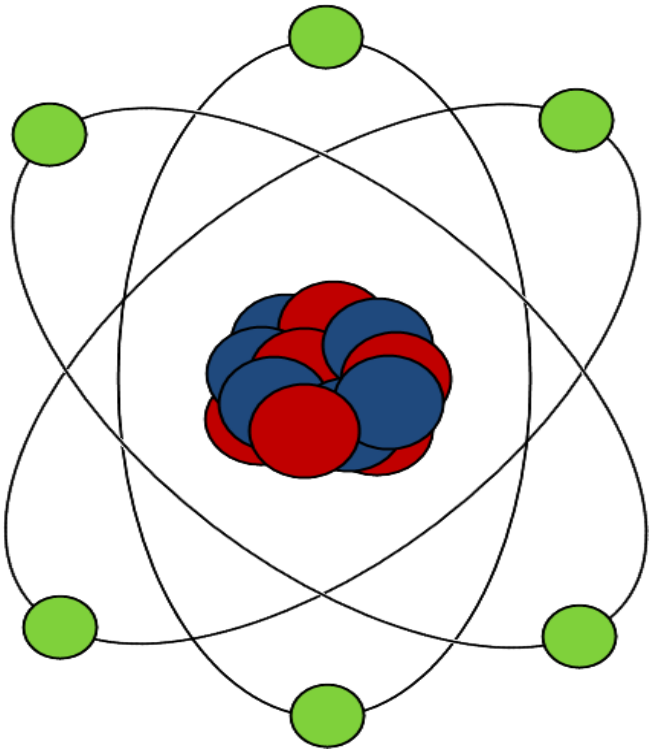
HYDROGEN-1 ATOM (PROTIUM)

- Atomic number: 1
  - 1 proton
- Atomic mass: 1 amu
  - 1 proton, 0 neutrons
- Charge: neutral
  - Atom
  - 1 proton, 1 electron



CARBON-12 ATOM

- Atomic number: 6
  - 6 protons (red)
- Atomic mass: 12 amu
  - 6 protons, 6 neutrons (blue)
- Charge is neutral
  - Atom
  - 6 protons, 6 electrons (green)



ISOTOPES

- Atoms of the same element that have different masses
  - Same element, same number of protons
  - Different masses, different numbers of neutrons
  - Same chemical properties, same number of electrons
- Argon example

Argon Isotope	Mass	Protons	Neutrons
Argon-40	40	18	22
Argon-38	38	18	20
Argon-36	36	18	18

ISOTOPE RELATIVE ABUNDANCE

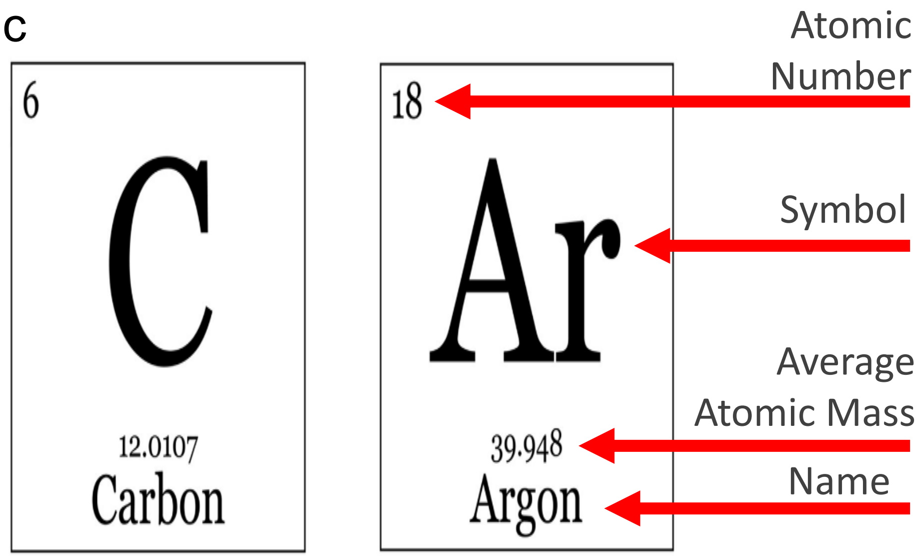
- Each isotope has its own natural relative abundance
- Carbon and argon isotope abundances are listed below

Isotope	Abundance
Carbon-12	98.90%
Carbon-13	1.10%
Carbon-14	<0.01%

Isotope	Abundance
Argon-40	99.60%
Argon-36	0.34%
Argon-38	0.06%

PERIODIC TABLE OF ELEMENTS

- Each element's name, symbol, atomic number and average mass
  - Average mass is the weighted-average per the isotope abundance
- Elements listed on Periodic Table by ascending atomic numbers



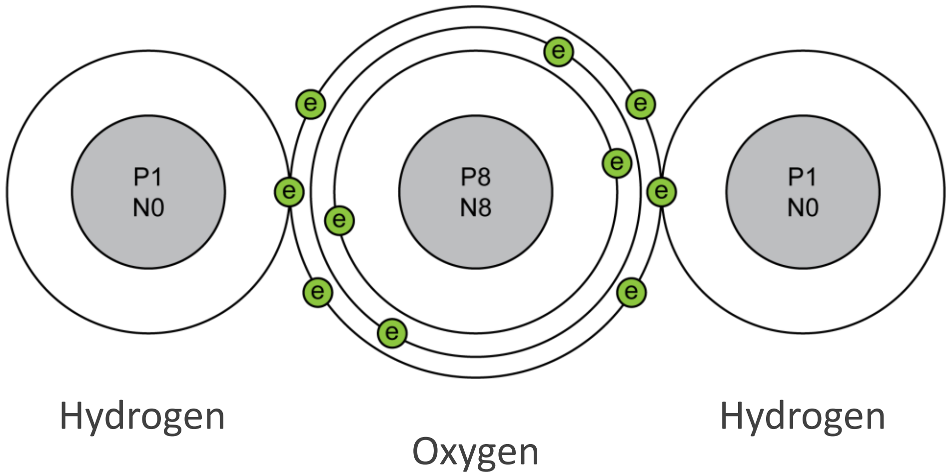
6 MOLECULES

WHAT IS A MOLECULE?

- A particle comprised of two or more atoms that are bonded together
- Structures that are larger than individual atoms
- Examples of molecules:
  - Oxygen (O_2)
  - Isopropyl alcohol (C_3H_7OH)
- Mass of a molecule is the total number of protons and neutrons
- Electric charge of a molecule is neutral
- Gases can be comprised of atoms and molecules

WATER MOLECULE

- Water example: 2 hydrogen atoms bonded to 1 oxygen atom
- Chemical formula H_2O
- Mass is 18 amu (10 protons plus 8 neutrons)



IONS FORMED FROM MOLECULES

- Ions can be formed from molecules
- Similar to how ions are formed from atoms
- When a molecule acquires a net charge, it becomes an ion
- Molecule loses 1 electron:
  - Loses 1 unit of negative charge
  - Becomes a positive ion with a charge of +1
- Molecule loses 2 electrons:
  - Loses 2 units of negative charge
  - Becomes a doubly ionized positive ion with a charge of +2

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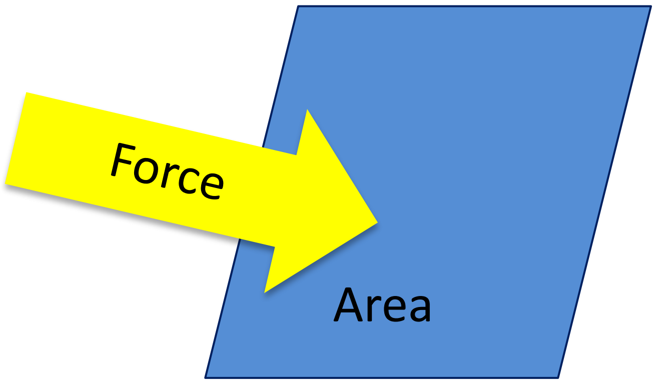
7

TOTAL PRESSURE AND PARTIAL PRESSURE

GAS PRESSURE – FORCE PER UNIT AREA

- Gas pressure is the force per unit area that gas exerts on the walls or surfaces of its container
- Units of measure for pressure include:
  - Pounds per square inch (psi)
  - Newtons per square meter (N/m^2), equal to Pascal (Pa)
  - Atmosphere (atm)
  - Bar
  - Torr



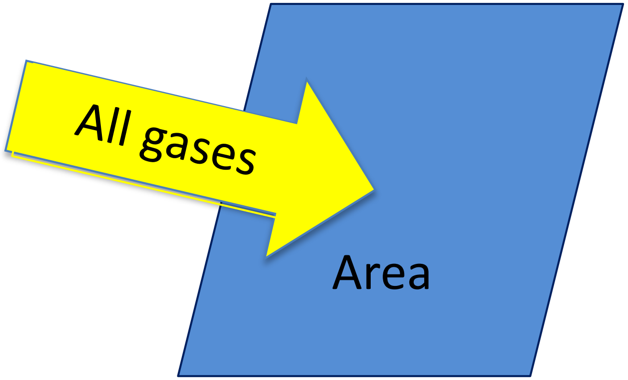
GAS PRESSURE – AMOUNT OF GAS

- Gas Pressure (P)
  - Proportional to the number of gas molecules in a chamber (n)
  - Proportional to the temperature of the gas (T)
  - Inversely proportional to the volume of the chamber (V)
- When temperature and volume are constant, the pressure is proportional to the amount of gas ($P \propto n$)
- Gas pressure indicates the amount of gas in the chamber

$$P \propto \frac{nT}{V}$$

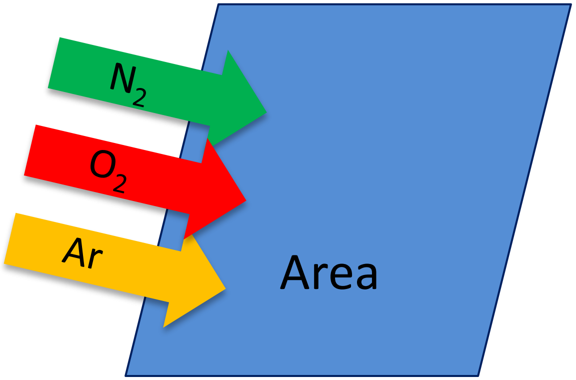
TOTAL PRESSURE

- Total pressure is the pressure that a gas mixture, the total gas, exerts on the walls of a chamber
- A variety of pressure gauges are available, including:
  - Capacitance diaphragm gauge (CDG)
  - Cold cathode ionization gauge
  - Hot cathode ionization gauge
  - Pirani (thermal conductivity) gauge



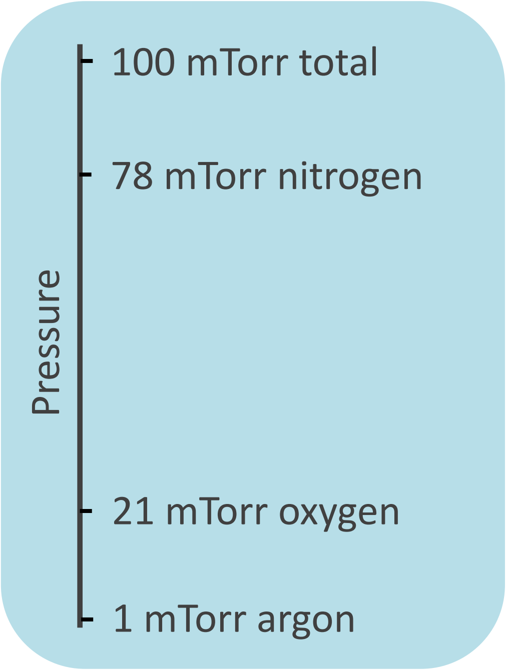
PARTIAL PRESSURE

- Pressure that one gas species in a mixture would exert if it was the only gas in the chamber
- Partial pressure of each gas species is proportional to the amount of that gas species
- Partial pressure is used to independently analyze gas species
- RGAs can measure gas species separately, so RGAs are used to measure partial pressure



TOTAL PRESSURE AND PARTIAL PRESSURE

- Total pressure is equal to the sum of the partial pressures
- Adding the partial pressures of all gases present will equal the total pressure
- 100 mTorr of air comprised of:
  - 78 mTorr nitrogen (78%)
  - 21 mTorr oxygen (21%)
  - 1 mTorr argon (1%)
  - Other gases (< 1%)



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8 GAS CONNECTION

GAS CONNECTION

- Concentration is a ratio
  - Gas concentration ratio = partial pressure divided by total pressure
  - A measurement of the amount of one gas species with respect to the total amount of gas present
- Calculating concentration in three units of measure
  - Percent: Multiply ratio times 100 (%)
  - Parts per million: Multiply ratio times 1,000,000 (ppm)
  - Parts per billion: Multiply ratio times 1,000,000,000 (ppb)
- Example for concentration, in units of ppm
  - Concentration = (Partial Pressure / Total Pressure) x 1,000,000 ppm

9 VACUUM

VACUUM

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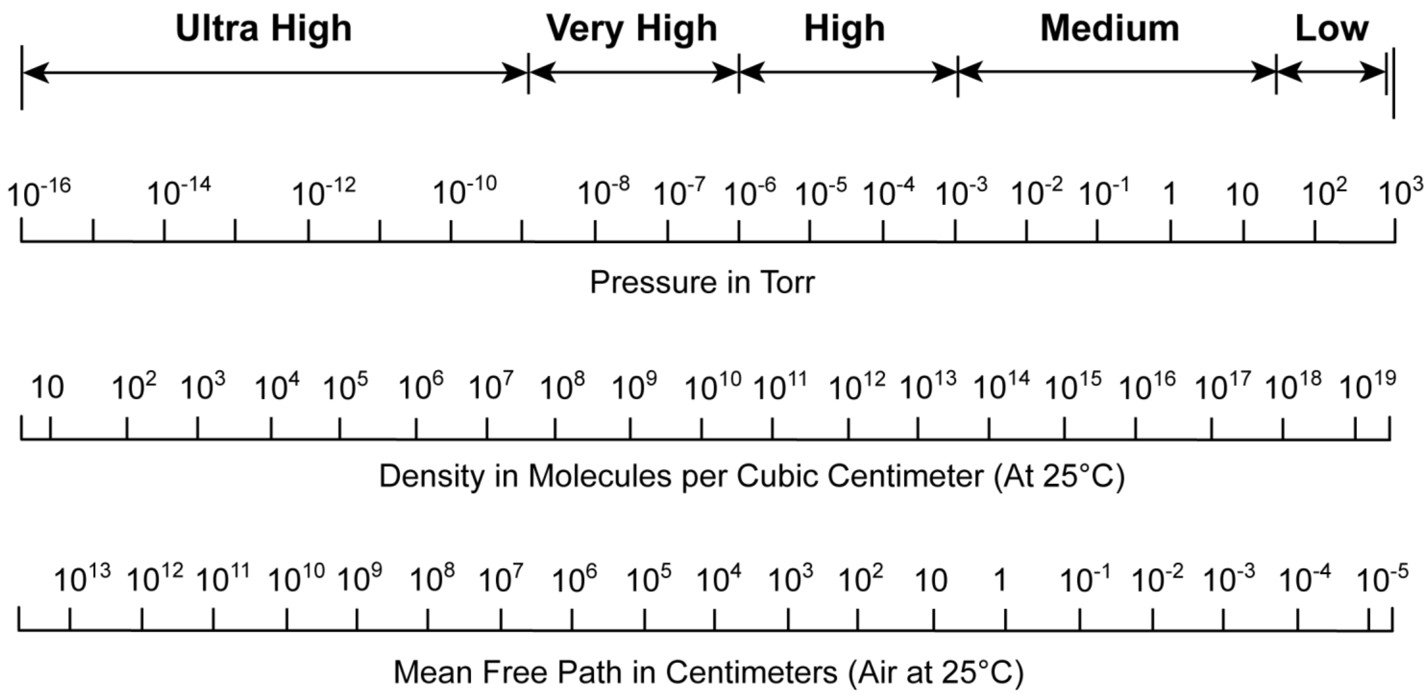
Gas pressure that is less than the pressure of the local ambient atmosphere



Harland G. Tompkins; An introduction to the Fundamentals of Vacuum Technology, 1984

THANK YOU!

You have completed the

Gas Theory module!

You may come back and review

the content of this module at any time.