

LEC: INORGANIC CHEMISTRY

DR. MC Rollyn Vallespin

1st Year 1st Semester | Academic Year 2026–2027

Module 1: Lesson 1

STATES AND CHARACTERISTICS OF MATTER

Why do states change?

- *The state of matter depends on the competition between (A) particle motion (kinetic energy) and (B) attractive forces.*

A Key Vocabulary

- **Intermolecular forces (IMF)**- attraction between molecules (not chemical bonds)
- **Kinetic energy**- energy of motion
- **Ionization**- removing electrons from atoms → ions + free electrons
- **Quantum behavior**- wave-like behavior at very low temperature

SOLID STATE OF MATTER

Particle Model:

- Particles are closely packed in a fixed arrangement (often a lattice)
- Vibrate in place; lowest kinetic energy among common states

Properties:

- Definite shape and definite volume
- High density (usually)
- Not easily compressible
- Very slow diffusion

Examples: Ice, metal, salt crystals, plastic

LIQUID STATE OF MATTER

Particle Model:

- Particles are close together but not fixed
- Slide past one another; medium kinetic energy

Properties:

- Definite volume, no definite shape (takes container shape)
- Slightly compressible (much less than gases)
- Flows; diffusion occurs but slower than in gases

Examples:

- Water, oil, alcohol, mercury

GASEOUS STATE OF MATTER

Particle Model:

- Particles are far apart, random motion, high kinetic energy

Properties:

- No definite shape or volume
- Highly compressible
- Low density
- Diffuses rapidly; fills container evenly

Examples:

- Air, oxygen, CO₂, helium

Common Misconception:

- "Gas has no mass."
-  Gas has mass and occupies space—just very low density.

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PLASMA STATE OF MATTER

What it is:

- Plasma is a gas so energized that electrons are stripped from atoms.
- It becomes a mixture of positive ions + free electrons

How it differs from gas:

- Conducts electricity
- Responds to electric and magnetic fields
- Often glows due to energy transitions (e.g., neon signs)

Where we see it:

- The Sun and stars, Lightning, Neon signs, fluorescent lamps, Auroras

Clarify the “fire” confusion:

- Fire is not purely plasma; it's a mix of hot gases, glowing soot, and sometimes partially ionized regions.
- Lightning and stars are better “clean” plasma examples.

Bose-Einstein Condensate (BEC)

What it is:

- At temperatures extremely close to absolute zero (0 K), atoms lose most kinetic energy.
- A group of atoms can behave like one single quantum entity, often described as a single ‘matter wave’.
- In a BEC, particles are so cold and slow that their wave-like nature overlaps, and the whole sample acts “as one.”

Notable Properties:

- Superfluidity (in some systems): can flow with almost no viscosity
- Strange quantum behaviors visible at a macroscopic scale (in lab conditions)

Where it happens:

- Superfluidity (in some systems): can flow with almost no viscosity
- Strange quantum behaviors visible at a macroscopic scale (in lab conditions)

SUMMARY

- **Solid**- fixed shape, fixed volume, low KE, strong attraction, not compressible
- **Liquid**: variable shape, fixed volume, medium KE, moderate attraction, slightly compressible
- **Gas**: variable shape, variable volume, high KE, weak attraction, very compressible
- **Plasma**: like gas but ionized, conducts electricity, influenced by fields
- **BEC**: ultracold, quantum “single wave,” unusual flow properties

B

Transitions Between States

ENDOTHERMIC (ABSORBS HEAT):

- **Melting**- Solid → Liquid
- **Evaporation**- Liquid → Gas
- **Sublimation**- Solid → Gas

EXOTHERMIC (RELEASES HEAT):

- **Condensation**- Gas → Liquid
- **Solidification**- Liquid → Solid
- **Deposition**- Gas → Solid

- **Gas → Plasma**- requires very high energy (or strong electric fields)
- **Plasma → Gases**- happens when ions recombine with electrons (energy released)
- **Gases → BEC**- requires extreme cooling and special conditions.

Common Misconceptions

- “Gas doesn’t have mass.” → It does (balloons, air has weight).
- “Plasma is just hot gas.” → It’s ionized; charges change behavior.
- “BEC is just a very cold solid.” → No; it’s a quantum state, not simply “colder solid.”
- “Phase changes always change temperature.” → During phase change, energy changes IMFs, not temperature (at constant pressure)

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Module 1: Lesson 2

Properties and Changes of Matter: The Physical and Chemical Nature of Our World

A NAVIGATING THE ARCHITECTURE OF MATTER AND ITS TRANSFORMATIONS

Step 1: Define

- Distinguish the nature of matter, mass, and volume.

Step 2: Categorize

- Identify physical vs. chemical properties (Extensive vs. Intensive).

Step 3: Differentiate

- Determine whether a change is physical or chemical based on mechanics.

Step 4: Apply

- Explore the 5 observable signs of chemical change and virtual lab evidence.

Step 5: Assess

- Complete the interactive knowledge check.

B PROPERTIES OF MATTER

Physical Properties

Core Rule:

- Characteristics observed without changing the substance into another substance

Insight:

- You can measure and see these traits without changing what the object fundamentally is.

Chemical Properties

Core Rule:

- Characteristics observed only as matter transforms into a completely new type of matter.

Insight:

- You cannot measure these traits without permanently altering the substance's chemical composition

Matter is anything that possesses mass and occupies volume

The diagram illustrates the definition of matter as the combination of mass and volume. On the left, a 'Mass' card (Amount of stuff) with a balance scale icon is added to a 'Volume' card (Space it takes up) with a cube icon. An equals sign leads to a 'MATTER' card featuring an atomic model. Below this, 'Core States' are shown: Solid (cube), Liquid (drop), and Gas (cloud). To the right, a large fingerprint graphic is shown with the text 'The Fingerprint Metaphor' and a note: 'Every element and compound is entirely unique. If you map a substance's specific properties, you can identify it with perfect accuracy—exactly like a forensic scientist matching a fingerprint.'

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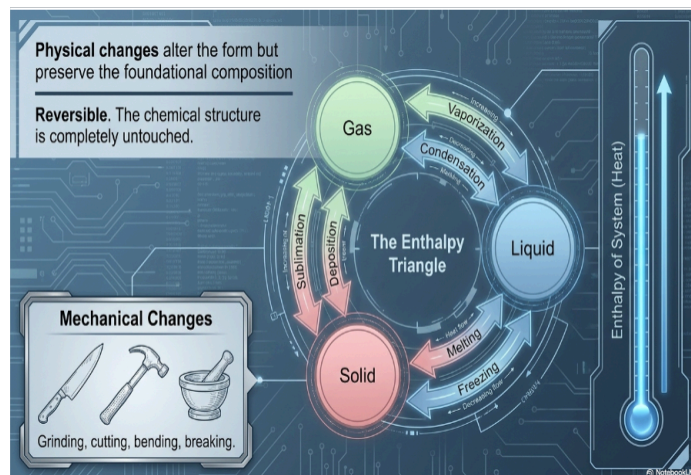
C

PHYSICAL PROPERTIES EXIST ON A SPECTRUM OF MASS-DEPENDENCY

Extensive Properties (Size Matters)	<i>These properties are strictly proportional to the amount of matter present.</i>	<i>Mass, Volume, Length, Weight</i>
Intensive Properties (Nature Matters)	<i>These properties remain identical regardless of how much of the substance is present.</i>	<i>Density, Color, Melting/Boiling Point, Hardness, Electrical Conductivity, Texture</i>

Properties describe what a substance CAN do. Changes describe what a substance IS doing.

Mass changes, but color and conductivity remain identical.



Mass changes, but color and conductivity remain identical.

Chemical properties dictate how substances interact, combine, or degrade

Reactivity	<i>The fundamental tendency of matter to chemically combine with other substances (eg. Potassium exploding when exposed to water).</i>
Flammability	<i>The tendency of matter to burn, which is a specific reaction requiring oxygen and emitting heat</i>
Toxicity	<i>The specific extent to which a chemical element or combination can biologically harm an organism.</i>
Acidity/Basicity	<i>A substance's ability to react with an acid or base to form water, neutralizing the original chemicals.</i>

Chemical Changes require the breaking and reforming of atomic bonds

- The substance is transformed into a completely different material. It is fundamentally irreversible..

- **The Mechanism:** A chemical reaction forces existing atomic bonds to snap and reform into an entirely new structural configuration.

1. Burning
2. Rusting
3. Biological Decomposition
4. Tarnishing

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D

5 OBSERVABLE SIGNS OF CHEMICAL TRANSFORMATION

PHYSICAL CHANGES

Color Change	Characteristics observed only as matter transforms into a completely new type of matter.
Gas Formed	Bubbles evolve spontaneously without the application of external boiling heat.
Precipitate	Mixing two clear liquids creates a sudden solid mass.
Odor Change	Production of a distinct new smell, often associated with rotting or sulfur.
Temperature Change	Endothermic (sudden cooling) or Exothermic (sudden heating) occurring without external heat sources.

Applying the evidence: Side-by-side scenario analysis

Physical Changes:

- **Scenario A:** Squishing an orange. Change in shape/form, but still an orange.
- **Scenario B:** Forging a steel knife. Tempering changes hardness and shape, but it is still steel.

Chemical Changes:

- **Scenario A:** An orange rotting. Odor change, color change,
- **Scenario B:** A rusting vintage car. Oxidation creates rust, a fundamentally new chemical structure. compounds.

Bridging theory and practice through modern virtual simulations

- **Hazard Safety**
 - Perform highly reactive experiments (acidity, toxicity, flammability) with zero physical risk.
- **Variable Manipulation**
 - Adjust temperature, concentration, and pressure to instantly observe cause-and-effect phase changes.
- **Instant Analytics**
 - Receive real-time data feedback on density, pH, and reaction kinetics.
- **Unlimited Iteration**
 - Repeat experiment between physical phase shifts and chemical evolution.

E

THE MASTER SYNTHESIS: PHYSICAL VS. CHEMICAL DYNAMICS

PHYSICAL

Core Definition:

- Form changes, composition remains.

Property Examples:

- Density, Mass, Melting Point.

Change Examples::

- Melting, Crushing, Dissolving.

Reversibility:

- Usually Reversible.

Visual Evidence:

- Change in state, size, or shape

CHEMICAL

Core

Definition:

- Bonds break, new substance forms.

Property Examples:

- Flammability, Reactivity, Toxicity.

Change Examples::

- Burning, Rusting, Digestion.

Reversibility:

- Fundamentally Irreversible.

Visual Evidence:

- Color, Gas, Precipitate, Odor, Temp.

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Module 1: Lesson 3

The Laws of Chemical Combination

A

MATTER

Elements

- Pure substances that cannot be decomposed by ordinary chemical change (e.g. Oxygen, Carbon)

Compounds

- Two or more elements chemically bonded with properties distinct from their individual elements.

The Mystery

- Before the 19th century, chemists did not know why elements formed compounds.
- They needed mathematics laws to predict the outcomes of reactions

Law 1: The Law of Conservation of Mass (Antoine Lavoisier 1789)

- Matter can neither created nor destroyed in ordinary chemical reaction
- **Total Mass of Reactants = Total Mass of Products** (Example: $2\text{g H}_2 + 16\text{g O}_2 = 18\text{g H}_2\text{O}$)

Law 2: The Law of Definite Proportions (Joseph Proust 1797)

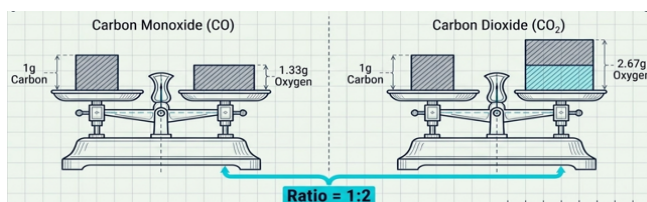
- No matter how a given chemical compound is prepared or sourced, it always contains the same elements in exact same proportions by mass.

Lab Evidence

- **1.25g** of Copper Oxide (**OuO**) always yields exactly 1.00g of Copper and **0.25g** of Oxygen when reduced.

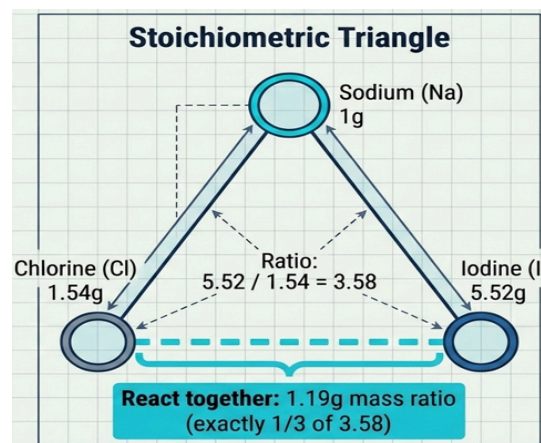
Law 3: The Law of Multiple Proportions (John Dalton 1804)

- If two elements form more than one compound, the masses of one element that combined with a fixed mass of the other are in ratio of small whole numbers.



Law 4: The Law of Reciprocal Proportions (Jeremias Richter 1791)

- The proportion by mass in which two elements combine is simply related to the mass in which they separately combine with a constant mass of a third element.

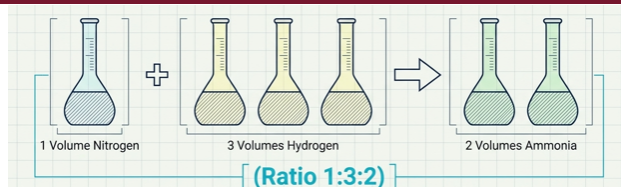


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B Expanding to Gases: Gay-Lussac & Avogadro



Gay-Lussac's Law (1802)

Gases combine in simple whole-number ratios by volume.
(if temperature and pressure are constant)

Avogadro's Law (1811)

Equal volumes of gases under identical conditions contain equal numbers of molecules. This perfectly bridges volumetric combinations with molecular formulas.

Dalton's Atomic Theory (1808)

1. Indestructible

- Matter is made of indestructible atoms.
 - Explains Conservation of Mass.

2. Identical Mass

- Atoms of a given element are identical in mass and properties.
 - Explains Definite Proportions.

3. Simple Ratios

- Atoms combine in simple, whole-number ratios.
 - Explains Multiple & Reciprocal Proportions.

Published in a New System of Chemical Philosophy, Dalton moved *chemistry* from qualitative observation to quantitative science by providing a physical reason for the math.

Law Name	Discoverer	Core Concept	Visual Mnemonic
Conservation of Mass	Lavoisier	Total Reactants = Total Products	
Definite Proportions	Proust	1 Compound = 1 Fixed Mass Ratio	
Multiple Proportions	Dalton	2 Elements, multiple compounds = Simple Ratios	
Reciprocal Proportions	Richter	A+B, A+C directly predicts B+C	

The Limits of the Laws (Modern Caveats)

Nuclear Chemistry & $E=mc^2$

- Energy and mass are related. In nuclear reactions, a tiny amount of mass is converted into energy, **slightly violating** strict mass conservation laws.

Isotopes

- Atoms of the same element can have different masses (e.g. *Carbon-12* vs *Carbon-14*), **defying** Dalton's postulate of identical elemental mass.

Non-Stoichiometric Compounds

- Certain minerals and large biomacromolecules form complex fractions rather than simple whole-number ratios.

The Architecture is Predictable

- Chemical Reactions are not random occurrences; they are highly predictable, mathematical events governed by strict codes.
- By understanding how mass and volume combine, we can precisely calculate the outcomes of any chemical reaction.

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Module 2: Lesson 1

THE ARCHITECTURE OF MATTER: Elements, Compounds, and the Language of Chemistry

A NAVIGATING THE ARCHITECTURE ON MATTER REQUIRES A MASTERING FOUR CORE PRINCIPLES

CLASSIFY

- Differentiate between mixtures, elements and compounds using diagnostic physical and chemical tests.

DEFINE

- Understand the atomic makeup of the 118 elements and the fixed ratios of chemical compounds

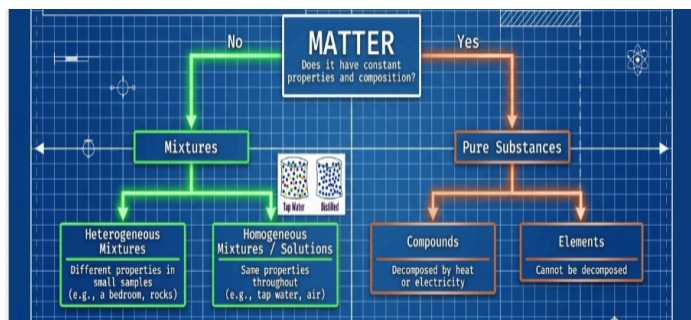
ANALYZE MECHANICS

- Contrast how atoms form ionic (transfer) versus covalent (sharing) bonds.

SPEAK THE LANGUAGE

- Apply IUPAC nomenclature rules to write precise chemical formulas for ionic molecules, molecular compounds, and acids.

B ISOLATING PURE SUBSTANCE FROM PHYSICAL MIXTURES IS THE FIRST STEP IN CHEMICAL CLASSIFICATION



Key insights: This empirical classification is based entirely on the methods used to separate matter in a laboratory settings

Pure substances possess definite chemical and physical properties that never vary

The Macro Definition

- A sample of matter with a uniform, constant composition Every molecule or atom is identical to the next

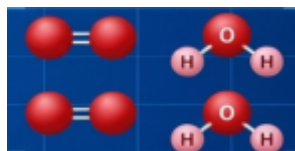
Elements

- Composed entirely of one kind of atom.
- Represented by a single symbol (e.g., O for oxygen)



Compounds

- Composed of two or more kinds of atoms in a definite fixed proportion (e.g., H₂O)



The Litmus Test

- Can the substance be separated by physical methods (like filtering or boiling)? If not, it is a pure substance.

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C ELEMENTS ARE THE FUNDAMENTAL, INDIVISIBLE BLOCKS OF THE UNIVERSE.

Indivisible

- A substance that cannot be separated into a simpler substance by physical or chemical means.

Atomic Identity

- Consists of an atom with a unique combination of protons, neutrons, and electrons. Distinguished by the atomic number (number of protons)

Scope and Sub-Classification

- There are 118 discovered elements (approximately 94 occurring naturally on earth). Broadly categorized by IUPAC into Metals, Nonmetals, and Semi-metals.

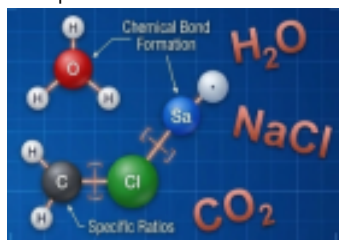
D COMPOUNDS FORM THROUGH THE CHEMICAL UNION OF TWO OR MORE DIFFERENT ELEMENTS IN FIXED PROPORTIONS.

The Three rules of a Compound

- Must be composed of two or more different elements.
- Elements must combine chemically (bonds are formed).
- The substance must have strictly consistent composition (specific ratio)

The Ozone Exception Ozone (O₃)

- A gas consisting of three oxygen atoms. Because it is made of only one element it is an element, not a compound.



The Scale

- While there are only 118 elements, scientific estimates suggest there could be as many as 10^{60} possible compounds.

E DIFFERENTIATING ELEMENTS AND COMPOUNDS AT A GLANCE.

	ELEMENTS	COMPOUNDS
Composition	Once type of atom.	Two or more different types of elements chemically united.
Breakdown Ability	Cannot be broken down by chemical reactions.	Can be separated into simpler substances by chemical reactions.
Representation	Symbols and numbers (e.g., Na, Au)	Chemical formulas (e.g., NaCl H ₂ O)
Properties	Atoms retain all properties of the element.	New molecules possess entirely different properties from their constituent elements.

Physical blends do not equal chemical bonds.

MIXTURES

Mechanism: Substance held together by physical forces, not chemical bonds.

Results: Each item retains its original properties. Variable composition.

Example: Saltwater. The water molecules and salt molecules exist together but aren't chemically combined. Easily separated by evaporation.

COMPOUNDS

Mechanism: Elements are chemically joined together

Results: The compound has properties entirely different from the elements it contains. Definite composition.

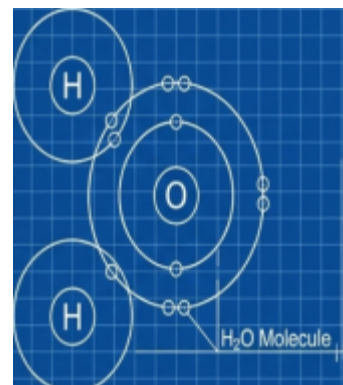
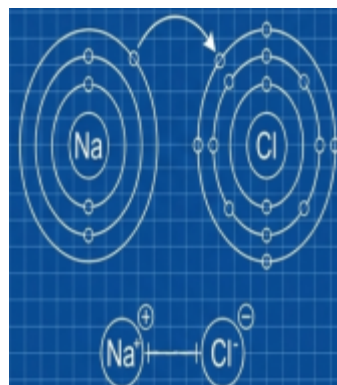
Example: Pure water (H₂O). Cannot vary the amount of hydrogen or Oxygen. Only separated by chemical reactions (electrolysis).

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	MIXTURE	COMPOUND
Composition	Variable composition – you can vary the amount of each substance in a mixture	Definite compositions – you cannot vary the amount of each element in a compound.
Joined or Not	The different substances are not chemically joined together.	The different elements are chemically joined together.
Properties	Each substance in the mixture keeps its own properties.	The compound has properties different from the elements it contains.
Separation	Each substance is easily separated from the mixtures.	It can only be separated into its elements using chemical reactions.
Examples	Air, sea water, most rocks	Water, carbon dioxide, magnesium oxide, sodium chloride



F

PURE COMPOUNDS ARE CLASSIFIED EMPIRICALLY BY THEIR BEHAVIOR IN WATER.

Atoms unite by either sharing or transferring electrons to achieve stability

Ionic Bond (The Transfer)

Mechanism: Formed when atoms transfer electrons.

Result: Created charged particles (ions) held together by the attraction of opposite charges.

Typical pairing: Metal + Nonmetals (e.g., Sodium chloride / NaCl)

Covalent/Molecular Bonds (The Share)

Mechanism: Formed when atoms share electrons.

Results: Created distinct entities called molecules.

Typical pairing: Nonmetals (e.g., Water/H₂O)

Ionic Compounds	Molecular Compounds	Acids and Bases
(Metal + Nonmetal)	(Nonmetals)	A special class
All are solids at SATP (Standard Ambient Temperature and Pressure) When dissolved in water, they form solutions that conduct electricity.	Can be solids, liquids, or gases at SATP When dissolved in water, solutions generally do not conduct electricity.	Acids turn blue litmus paper red; bases turn red litmus paper blue. Both form electrically conductive solutions in water.

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G

THE LANGUAGE OF CHEMISTRY: DECODING IONIC NONMENCLATURE

Rule 1: Binary Compounds Name the cation (metal) first, then the anion (nonmetal) ending with the suffix “-ide”	AlCl_3 = Aluminium Chloride
Rule 2: Multivalent Metals Use Roman numerals in brackets to indicate the specific charge of the ion. Not the number of ions.	AlCl_3 = Aluminium Chloride
Rule 3: Polyatomic Ions Groups of atoms with a net charge. Predict formulas by finding the ratio that yields a net charge of zero. Use parentheses when indicating more than one polyatomic ion.	$\text{Cu}(\text{NO}_3)_2$ = Copper (II) nitrate

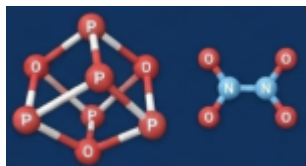
Rule 1: Prefix System

Used only for binary molecular compounds (two different nonmetals)

Visual Example:

P_4O_{10} = Tetraphosphorus decaoxide

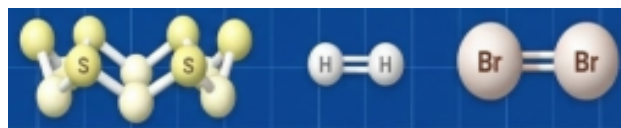
N_2O_4 = Dinitrogen tetraoxide.



Rule 2: Diatomic Elements

Elements ending in “-gen” (hydrogen, nitrogen, oxygen, halogens) naturally form two-atom molecules.

Exception: The prefix system is generally not used for hydrogen compounds. (e.g., H_2S is hydrogen sulfide, not dihydrogen sulfide).



IUPAC GREEK PREFIXES

1 = mono
2 = di
3 = tri
4 = tetra
5 = penta
6 = hexa
7 = septa
8 = octa
9 = nona
10 = deca

Acid Naming Matrix	Classical Rules based on anions:
Row 1	If an ion ends in ‘-ide’ -> hydro __ic acid (e.g., HCO = hydrochloric acid)
Row 2	If an ion ends in ‘-ate’ -> __ic acid (e.g., H_2SO_4 = Sulfuric acid)
Row 3	If an ion ends in ‘-ite’ -> __ous acid (e.g., H_2SO_3 = Sulfuro

- **IUPAC Acid Rule:** Name as aqueous hydrogen compounds (e.g., H_2SO_4) = aqueous hydrogen sulfate)
- **Base Naming Rule:** Named as ionic hydroxides (e.g., NaOH = aqueous hydrogen sulfate)

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Module 2: Lesson 2

THE ARCHITECTURE OF MATTER

Deconstructing Fundamental Particles, Atomic Mass, and Atomic Number

A DECONSTRUCTING THE FUNDAMENTAL PARTICLES

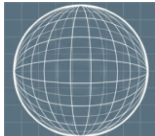
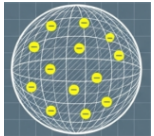
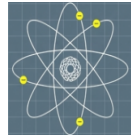
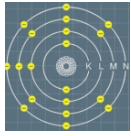
Proton (p)	Electron (e-)	Neutron (n)
Positively charged (+1).	Negatively charged (-1).	Neutral charge (0).
Located inside the nucleus	Orbits the nucleus	Located inside the nucleus.
Named by Ernest Rutherford.	Discovered by J.J. Thomson (cathode ray experiment).	Discovered by J. Chadwick.
Categorized as a Baryon (a composite particle built of 2 Up Quarks and 1 down Quark).	Categorized as a lepton (a true elementary particle).	Categorized as a Baryon (built of 1 Up Quark and 2 Down Quarks).



The Particle Property Matrix

Particle	Relative Mass	Relative Charge	Charge in Coulombs
Proton, p	1 amu	+1	$+1.6 \times 10^{-19} \text{ C}$
Neutron, n	1 amu	0	0 C
Electron, e ⁻	1/1836 amu (Negligible)	-1	$-1.6 \times 10^{-19} \text{ C}$

The Evolution of Atomic Architecture

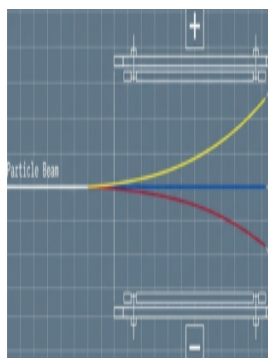
			
Dalton (Solid Sphere) The atom is proposed as the ultimate, indivisible building blocks of matter.	Thomson (Plum Pudding) The discovery of the electrons proves divisibility; negative charges are embedded in a positive sphere.	Rutherford (Nuclear Model) The gold foil alpha-ray experiment proves atoms are mostly empty space with a microscopic, dense, positive nucleus.	Bohr (Planetary Model) Electrons do not roam randomly; they are restricted to specific, stable energy shells (K, L, M, N) determined by the formula $2n^2$.

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PROVIDING CHARGE VIA ELECTRIC FIELD



Elections.
Bend sharply towards the positive plate. The extreme angle of deflection occurs because they are 1,836 times lighter than protons.

Neutrons.
Passed straight through. Completely unaffected by electric fields due to their neutral charge.

Protons.
Bends gently toward the negative plate. The deflection is slight due to their high relative mass.

THE ATOMS HEAVY CORE: MASS NUMBER (A)



The Mass Number (A) (or Nucleon Number) is the absolute sum of protons and neutrons packed into the nucleus.

A = Z + N
(Mass Number = Protons + Neutrons)

- Deducting Neutrons: To find the hidden number of neutron, simply subtract the atomic number from the mass number $N = A - Z$.

- Crucial Note: Because an electrons mass is 1/1836 amu, they are entirely excluded from this calculation.

THE ATOMS IMMUTABLE IDENTITY: ATOMIC NUMBER (Z)

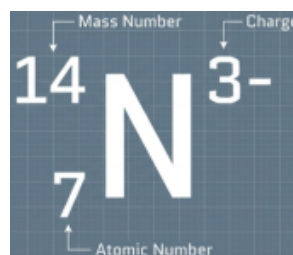


The Atomic Number (Z) is the total number of protons in the nucleus of an atom.

The rule of identity:
The proton number NEVER changes for a given element. It is the atoms unique fingerprint. Every atom in the universe with exactly 6 protons is Carbon.

The rule of Neutrality:
In a purely neutral atom, the number of positive protons always perfectly balances the number of negative electrons ($p = e^-$)

DECODING STANDARD ATOMIC SYMBOLISM



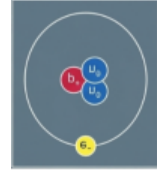
Symbols				Neutrons		Electrons
35 CL 17	+	17	-	18 (35-17)	=	17
14 N 3- 7	+	7	-	7 (14-7)	=	10 (7+3)
63 Cu+29	+	29	-	34 (63-29)	=	28 (29-1)

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ISOTOPES: SAME IDENTITY, DIFFERENT MASS

Isotopes atoms of the same element (identical Z) that contain different numbers of neutrons (different A).	Protium (1H) 1p, 0n (Stable)	Deuterium (2H) 1p, 1n (Stable)	Tritium (3H) 1p, 2n (Radioactive)
			

Key insights: Isotopes have identical chemical properties (because electrons arrangements are identical) but different physical properties (mass, density, and radioactivity).

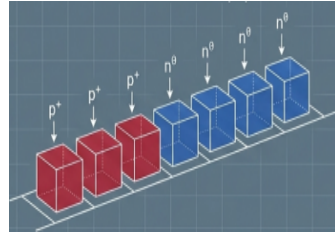
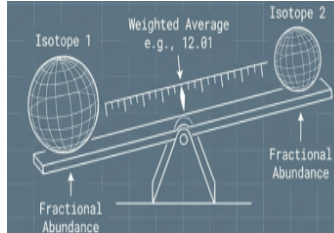
ISOBARS: DIFFERENT IDENTITY, IDENTICAL MASS

Isobars are atoms of completely different elements having the same mass number but different atomic numbers,

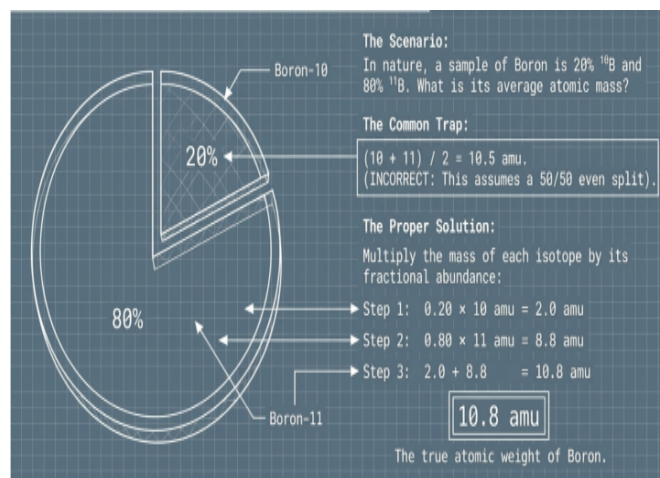
	Argon-40 18 Protons + 22 Neutrons = Mass 40		Calcium-40 20 Protons + 20 Neutrons = Mass 40
--	---	---	---

Key insights: Unlike isotopes, isobars possess entirely different chemical properties because they are fundamentally different elements with different electron configurations.

THE DISTINCTION: MASS NUMBER VC. ATOMIC WEIGHT

Mass Number (A)	Atomic Weight
	
- Always a discrete whole number. - Applies to one single, specific isotope at a time. - Derived by simply counting physical particles: Proton + Neutrons	- Rarely a whole number (e.g., Carbon is 12.01) - Represents the weighted average of all naturally occurring isotopes of an element. - Accounts for the fractional abundance of isotopes found in nature.

CALCULATING ATOMIC WEIGHT: THE BORON DILEMMA



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Module 2: Lesson 3

Isotopes

Why are masses on the periodic table decimals?

- If protons and neutrons both weigh approximately 1 atomic mass unit (amu), and an atom contains whole numbers of these particles, why does Carbon weigh 12.011 amu instead of exactly 12?

A THE SUBATOMIC INVENTORY

Particle	Charge	Mass	Location
Proton (+)	+1	~1 amu	Nucleus
Neutron (0)	0	~1 amu	Nucleus
Electron (-)	-1	~0.0005 amu	Electron Cloud

KEY INSIGHT: Protons define the IDENTITY (atomic number). Neutrons define the MASS VARIANCE. Electrons define the CHEMISTRY.
Because electrons are so light, nearly 100% of an atom's mass resides in the nucleus.

B THE ISOTOPE: SAME IDENTITY, DIFFERENT MASS

Carbon-12

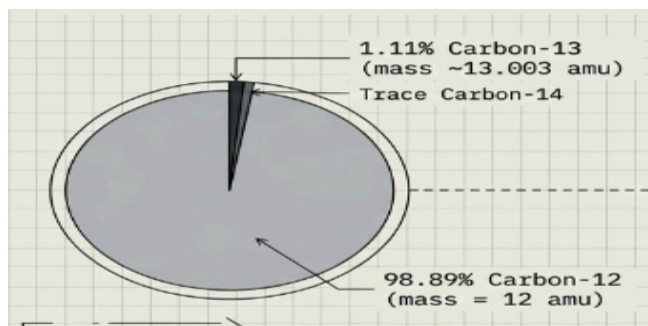
- 6 Protons + 6 Neutrons
- Mass = 12 amu

Carbon-13

- 6 Protons + 7 Neutrons
- Mass = 13 amu

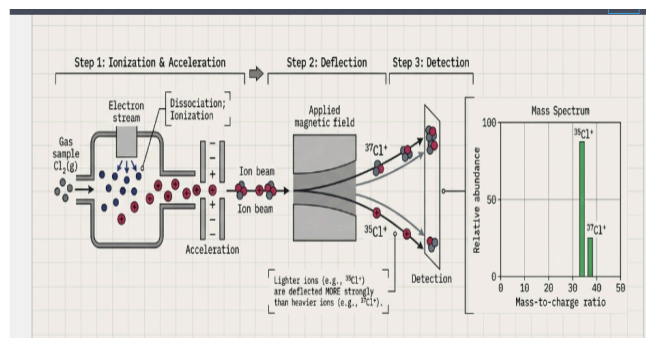
Isotopes are atoms of the same element (identical protons) that contain different numbers of neutrons. Because they share the same number of protons and electrons, isotopes exhibit the exact same chemical behavior. They differ only in mass.

Solving the Decimal Discrepancy



- The atomic mass on the periodic table is NOT the mass of a single atom. It is the **WEIGHTED AVERAGE** of all naturally occurring isotopes in a typical sample.
- Conclusion: There is no single carbon atom that weighs exactly 12.011 amu. The decimal reflects the natural blend of isotopes found on Earth.

C HOW WE MEASURE MASS: THE MASS SPECTROMETER



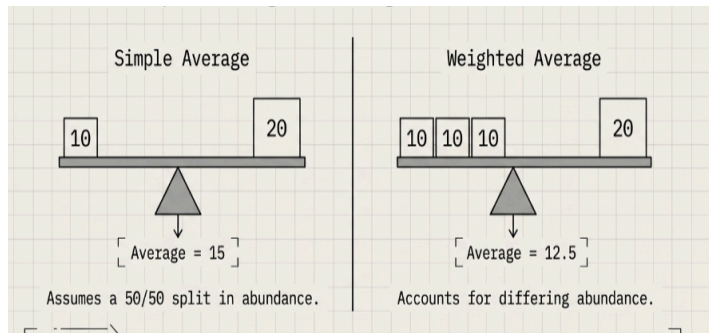
Instrument Output: Provides two critical data points-the exact mass of each isotope and its relative abundance in nature.

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The Math: Simple vs. Weighted Averages



Connecting to Chemistry: Because Carbon-12 is 98.89% abundant, the 'fulcrum' carbon's mass rests extremely close to 12.000, pulling it only slightly up to 12.011 due to the rare presence of Carbon-13.

The Weighted Average Formula

$$\text{Atomic Mass} = (\text{Mass}_1 \times \%_1) + (\text{Mass}_2 \times \%_2) + \dots$$

Exact mass of the isotope

Percent abundance expressed as a decimal fraction

Execution Rules

Execution Rules:

1. Convert Percentages Always divide the percent Always divide the percent abundance by 100 to yield a decimal fraction (e.g., 75.76% becomes 0.7576).
2. Multiply Calculate the mass contribution of each individual isotope by multiplying its exact mass by its decimal fraction.
3. Sum Add the weighted contributions together to find the overall average atomic mass.

Calculating the Mass of Chlorine

Mass Spectrometry Data		
	1	2
1 Isotope 1: Chlorine-35	Mass: 34.969 amu	Abundance: 75.76%
2 Isotope 2: Chlorine-37	Mass: 36.966 amu	Abundance: 24.24%

Step 1 (Decimals):
75.76% → 0.7576 | 24.24% → 0.2424

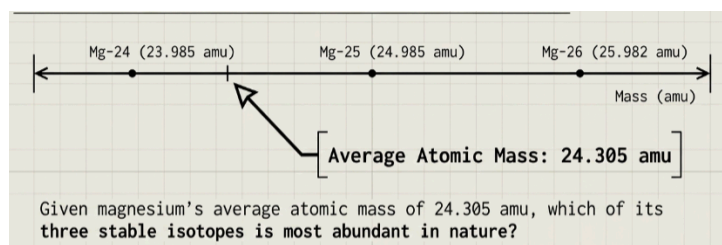
Step 2 (Multiply):
(34.969 × 0.7576) + (36.966 × 0.2424)

Step 3 (Calculate):
(26.492) + (8.960)

Final Result: 35.45 amu

D

PREDICTING ISOTOPIC ABUNDANCE



The Shortcut Rule: The average atomic mass will always skew closest to the mass of the most abundant isotope. Because 24.305 is heavily weighted toward 24, Mg-24 is overwhelmingly the most abundant isotope (approx 79%).

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Advanced Application: Finding the Unknowns

Nitrogen weighs 14.007 amu. It consists of N-14 (14.003 amu) and N-15 (15.000 amu). What is the % abundance of each?

- **The Algebraic Trick**
Because total abundance must equal 100% (or 1.00), if
 $N-14 = x$, then
 $N-15 = (1 - x)$.
- **The Setup:**
 $14.007 = (14.003)(x) + (15.000)(1 - x)$
- **The Solution:**
 $14.007 = 14.003x + 15.000 - 15.000x$
 $-0.993 = -0.997x$
 $x = 0.996$
- **The Result:**
Nitrogen-14 is 99.6% abundant, and Nitrogen-15 is 0.4% abundant.

E

SYNTHESIS: THE ARCHITECTURE OF ATOM

Protons:

Dictate Identity (Atomic Number). Changing this creates a completely new element.
Atomic Number

Neutrons:

Dictate Stability & Mass (Isotopes). Changing this creates a heavier or lighter version of the same element.
Mass Variance

Electrons:

Dictate Reactivity (Ions). Changing this changes how the atom bonds and reacts chemically.
Chemical Reactivity

FINAL TAKEAWAY: The periodic table tile gives us the identity (protons) and the AVERAGE mass (protons + natural blend of neutrons), but the specific isotope dictates the physical reality of the single atom.

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Module 2: Lesson 4

The Blueprint of Matter

By the early 1800s, the discovery of new elements was exploding, but they appeared entirely disconnected. Chemistry was a chaotic list of ingredients with no underlying recipe.

A

STANDARDIZING THE PUZZLE PIECES



- Before 1860, attempts to organize elements by atomic weight were doomed. The modern scientific consensus achieved at the Karlsruhe Congress finally provided an accurate, universal measuring stick for atomic mass, clearing the ground for true periodic laws.

The Rhythm of Matter: Helixes and Octaves

De Chancourtois (1862)

- Created the telluric helix, graphing elements on a cylinder where similar elements lined up vertically.

Newlands (1865)

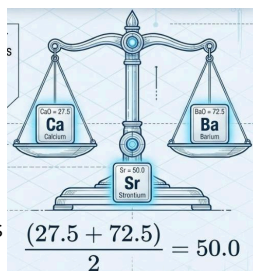
- Proposed the Law of Octaves, noticing properties repeated every eighth element, much like musical notes.

THE FLAW

- Newlands was mocked by the Chemical Society because his strict octave forced 10 transition metals into spaces meant for 8, ruining the pattern. The structure lacked flexibility.

First Attempts at Structure: Döbereiner's Triads (1829)

- Johann Wolfgang Döbereiner discovered that the properties of a middle element could be accurately predicted by taking the arithmetic mean of the elements above and below it.
- LIMITATION:** The architecture was incomplete. The math failed for elements with very high or low masses (like the F, Cl, Br triad).



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The Master Architects: Mendeleev vs. Meyer (1869-1870)

	Julius Lothar Meyer	Dmitri Mendeleev
Methodology	Plotted atomic volume against atomic weight, finding a series of peaks and valleys.	Played "chemical solitaire," arranging cards by atomic weight and valency.
The Breakthrough	Grouped elements into six families by valence.	Formulated the "Law of Periodicity," noting seven types of highest oxides.
Temperament and Impact	Cautious. Published a draft post-mortem.	Bold. Distributed broadsheets globally and aggressively mocked indecisiveness. (Both shared the 1882 Davy Medal).

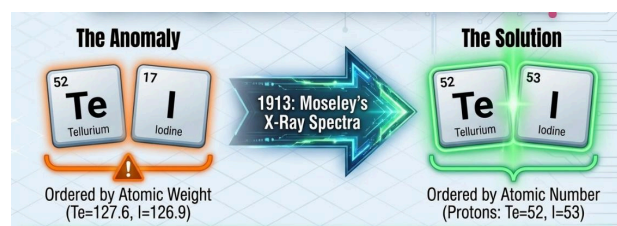
The Power of the Void: Predictive Architecture

- Eka-aluminum (Predicted 1869) Gallium (Discovered 1875)
- Eka-silicon (Predicted 1869) Germanium (Discovered 1886)
- Mendeleev's ultimate triumph was not just organizing what was known, but mapping the unknown. When the math didn't fit, he assumed the element simply hadn't been discovered yet, predicting exact atomic masses and properties for elements that would not be found for decades.

The Unexpected Wing: Noble Gases

- In the 1890s, William Ramsay and Lord Rayleigh discovered Argon and Helium. They were completely inert, defying known valency laws.
- Rather than shattering Mendeleev's periodic law, these elements fit perfectly as a brand new column (Group 0/18), proving the table's fundamental topological strength.

The Paradigm Shift: From Mass to Protons



- Henry Moseley redefined the table's foundation. By organizing elements by atomic number (nuclear charge) rather than atomic mass, he perfectly resolved the 'anomalies' Mendeleev had to force-fit, proving that periodicity is driven by subatomic structure.

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The Subatomic Architect: Seaborg & The Actinides

- During his WWII work on Plutonium (1941), Glenn Seaborg realized the heaviest elements didn't belong in the main transition metal groups.
- In 1944, he proposed the "Actinide Concept" —a wildly controversial hypothesis that reshaped the table into the modern two-row bottom block we use today. He later co-discovered 10 transuranium elements.

Pushing the Limits: The Extended Table

- The orbital approximation breaks down at extreme atomic numbers.
- KEY CONCEPT: Due to spin-orbit coupling and relativistic effects, computer models by Pyykko and Fricke suggest elements beyond $Z=120$ will defy the Madelung rule, scattering their placement and breaking the perfect periodicity of the past.

Rethinking the Topology: The Cylindrical Table

- The modern IUPAC table is a 2D compromise that isolates the f-block. Al-ossmi's 3D cylindrical model wraps the elements vertically, seamlessly the Lanthanides and Actinides back into their natural sequence between the s- and d-blocks without interrupting the atomic order.

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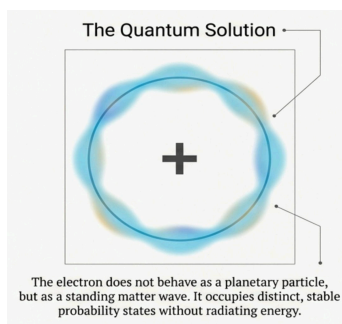
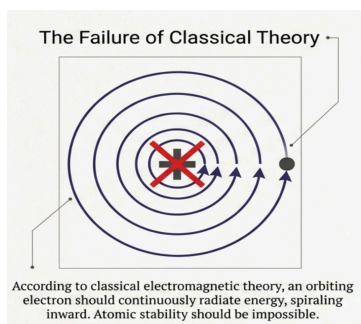
Module 2: Lesson 5

The Quantum Mechanical Model of the Atom

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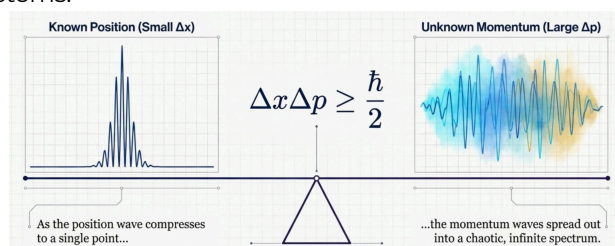
THE CLASSICAL PARADOX

If opposite charges attract, why doesn't the negative electron crash into the positive nucleus?



Heisenberg's Uncertainty Principle

It is fundamentally impossible to know both the exact position and momentum of a quantum particle simultaneously. This is not a measurement error, but an intrinsic property of wave-like systems.



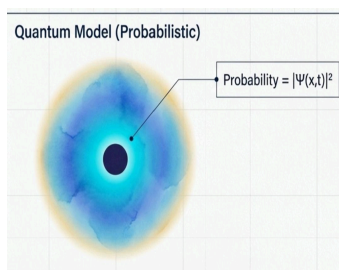
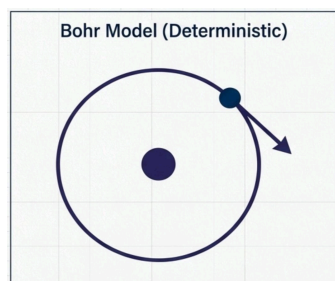
The Address Book of the Atom

Quantum Number	Symbol	Meaning	Allowed Values	Visual Icon
Principal	n	Shell (Size & Energy Level)	1, 2, 3, 4...	
Angular	l	Subshell (Geometric Shape)	0 to $n - 1$ (s, p, d, f)	
Magnetic	m_l	Orbital (Orientation in Space)	-1 to +1	
Spin	m_s	Electron Spin Direction	1/2 or -1/2	

From Deterministic Orbits to Probabilistic Waves

Louis de Broglie

Proposed that particles possess a matter wave. Max Born interpreted this wave's amplitude squared as the probability density of finding a particle at a specific location.



The paradigm shifts from exact trajectories to regions of high probability.

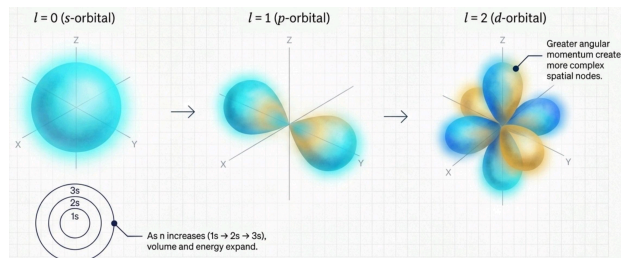
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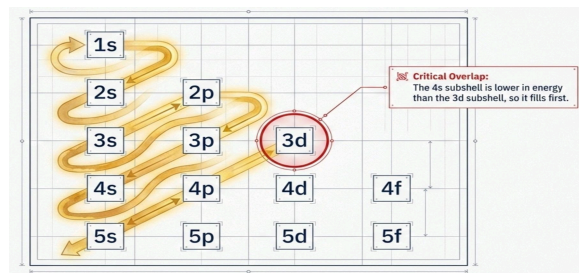
Sculpting Probability: Size (n) and Shape (l)

The principal number dictates distance and energy. The angular number dictates geometric complexity.



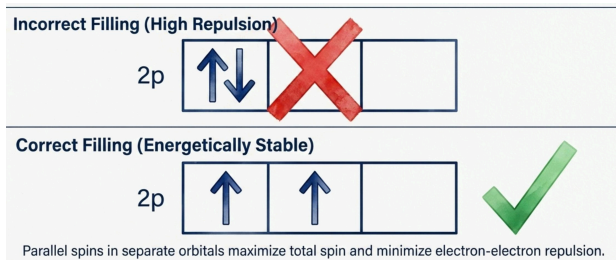
Rules of Residence: The Aufbau Principle

Electrons "build up" by filling the lowest energy orbitals first. Energy is controlled by both orbital size (n) and shape (l).



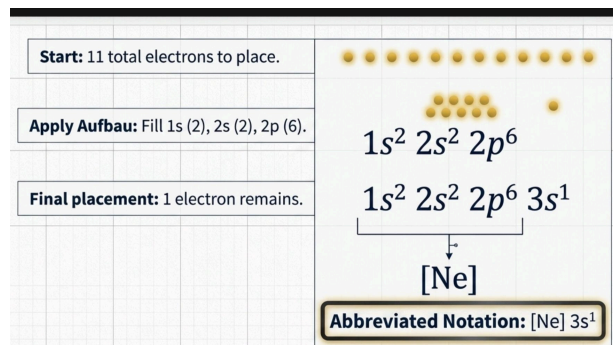
Rules of Residence: Hund's Rule

When filling degenerate orbitals, add one electron to each orbital with parallel spin before pairing them. This minimizes electrical repulsion.



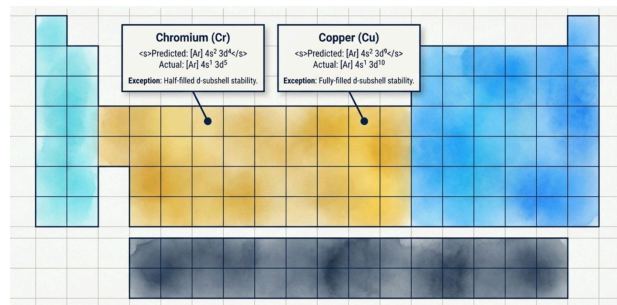
Constructing an Electron Configuration

Translating quantum rules into standard notation for a Sodium atom (Na, Z=11).



The Periodic Table is a Quantum Map

The macro-structure of the periodic table perfectly mirrors the filling of s, p, d, and f subshells.



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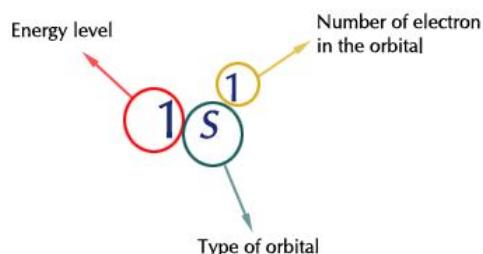
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Module 2: Lesson 6

Electric Configurations

What are Valence Electrons?

- Electron configuration tells how electrons are arranged in an atom's **atomic orbitals**.
- Uses a **standard notation** listing atomic subshells in order, e.g.:
 - The electron configuration of **sodium** is $1s^2 2s^2 2p^6 3s^1$.



Why Electron Configurations matter:

- Determine **valency / valence electrons**
- Predict properties of elements in the **same group**
- Help interpret atomic spectra
- Support the **periodic law** (repeating patterns)

Quantum Numbers: Shells and Subshells

Shells (principal quantum number n)

- The **maximum number of electrons** that can be **accommodated** in a **shell** is based on the **principal quantum number (n)**.
- Shell number n determines which shell you're filling.

$$\text{Max electrons in shell} = 2n^2$$

Subshells (azimuthal quantum number l)

- For a given n , possible l values are:
$$l = 0, 1, 2, \dots, (n-1)$$
- Names
 - $l = 0 \rightarrow s$
 - $l = 1 \rightarrow p$
 - $l = 2 \rightarrow d$
 - $l = 3 \rightarrow f$
- Max electrons in a subshell
$$\text{Max in subshell} = 2(2l + 1)$$
 - $s \rightarrow 2$
 - $p \rightarrow 6$
 - $d \rightarrow 10$
 - $f \rightarrow 14$

A

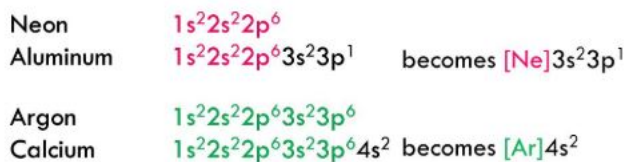
TYPES OF NOTATION

Long/Standard Notation

- Write **every occupied subshell** with electron count in superscript.

Abbreviated/Condensed Notation (Noble Gas Notation)

- Replace the sequence of filled subshells of a noble gas by its symbol in square brackets.
- Ex:



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Principal Quantum Number, n	Angular Momentum Quantum Number, ℓ $\ell = 0, 1, 2 \dots n-1$	Subshells
1	$\ell = 0$	s (1 subshell)
2	$\ell = 0$ $\ell = 1$	s p (2 subshells)
3	$\ell = 0$ $\ell = 1$ $\ell = 2$	s p d (3 subshells)
4	$\ell = 0$ $\ell = 1$ $\ell = 2$ $\ell = 3$	s p d f (4 subshells)

Architectural Anomalies (The Rulebreakers)

Sometimes, a half-filled or fully-filled d-subshell is more stable than following the Aufbau rule strictly.

	Expected Configuration	Actual Configuration
Chromium (Cr):	$[\text{Ar}] 4s^2 3d^4$	$[\text{Ar}] 4s^1 3d^5$
Copper (Cu):	$[\text{Ar}] 4s^2 3d^9$	$[\text{Ar}] 4s^1 3d^{10}$

Writing Electron Configuration (Labels Format)

- Write subshells as:
 - shell number + subshell letter + number of electrons in superscript
- Ex:
 - 2 electrons in 1s $\rightarrow 1s^2$

Pauli's Exclusion Principle

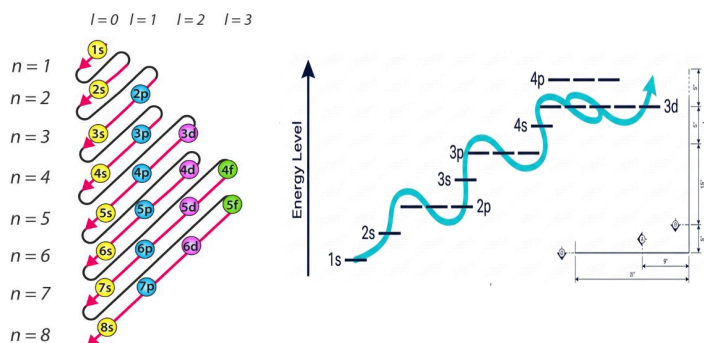
- Maximum **2 electrons per orbital**
- They must have **opposite spins**
- No** two electrons in an atom **can have the same values of all four quantum numbers**.

B

FILLING OF ATOMIC ORBITALS

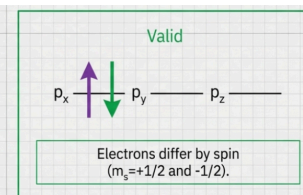
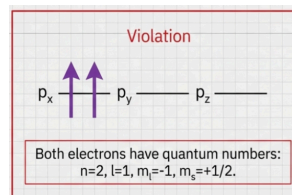
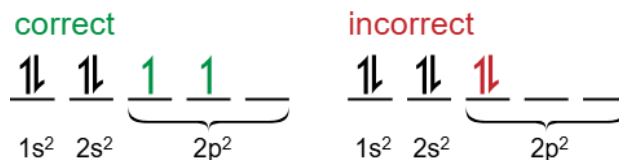
Aufbau Principle (Build-up)

- Electrons fill **lower energy orbitals first**, then higher ones.
- Filling order commonly remembered:
 - 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p...



Hund's Rule (Maximum Multiplicity)

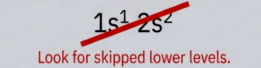
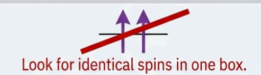
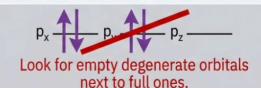
- For orbitals within the same subshell:
 - Orbitals fill singly first**
 - Then pairing starts only after all have one electron.
 - To maximize total spin, singly occupied orbitals have the **same spin direction**.



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The Principle	The Metaphor	Visual Diagnostic
Aufbau	Build from the ground up.	
Pauli	Opposite spins only.	
Hund	Fill empty rooms first.	

EXAMPLES:

Hydrogen ($Z = 1$)

- Configuration: **$1s^1$**
- a. Oxygen ($Z = 8$)
 - Filling
 - K Shell (2 electrons)
 - L Shell (6 electrons)

Therefore, the electron configuration of **oxygen** is **$1s^2 2s^2 2p^4$**

- b. Chlorine ($Z = 17$)
 - K Shell (2 electrons)
 - L Shell (8 electrons)
 - M Shell (7 electrons)

The electron configuration of chlorine is illustrated below. It can be written as **$1s^2 2s^2 2p^6 3s^2 3p^5$** or as **$[\text{Ne}] 3s^2 3p^5$**

REMEMBER:

- **Electron configuration = electrons distributed in orbitals.**
- **Standard writing:**
 - **energy level → orbital type → electrons**
 - **e.g. carbon: $1s^2 2s^2 2p^2$**
- **Rules:**
 1. **Aufbau: fill lower energy first**
 2. **Pauli: max 2 per orbital, opposite spins**
 3. **Hund: singly fill orbitals first with same spin**

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Module 2: Lesson 7

Valence Electrons

What are Valence Electrons?

- Valence electrons are the electrons in the **outer shells** of an atom that **are not completely filled**.
- They are the electrons an atom **must lose, gain, or share** to achieve a **noble-gas (inert gas) electron configuration**.
- They are part of **chemical reactions** because they have **more energy** than inner electrons.
- They help determine an element's chemical properties, including:
 - valence / valency
 - ability to form bonds
 - number of unpaired electrons
 - how many atoms can participate in bonding

2.0

Characteristics of Valence Electrons

Characteristics of Valence Electrons

- Valence electrons are involved in **chemical bonding and reactions**.
- They occupy **orbitals** in the atom.
- For **main group elements**, valence electrons are found **only in the outermost shell**.
- For **transition metals**, valence electrons may be in **inner shells too** (the **d sub-shell** can be involved).

Key Points

Atoms	are most stable when they have a filled valence shell .
Atoms	transfer or share electrons to reach a filled shell .
A closed-shell atom	is usually chemically inert (less reactive).
Valence electrons	can absorb or release energy as photons .
Valence electrons	affect electrical conductivity : - Metals conduct better (their valence electrons are more mobile) - Non-metals/insulators do not conduct well

3.0

Method 1: Periodic Table Shortcut (Main Group Rule)

- The easiest method: look at the element's **vertical column (group number)**.
- For **main-group elements**, the **group number = number of valence electrons**.
 - Group 1 → 1 valence e⁻
 - Group 14 → 4 valence e⁻
 - Group 17 → 7 valence e⁻

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Method 1: The Periodic Table Shortcut

Exceptions to the Rule

A. Helium Exception

- Helium is in **Group 18**, but it has only **2 valence electrons**.
- Helium is inert because its **1s orbital is completely full** (duet), making it stable.

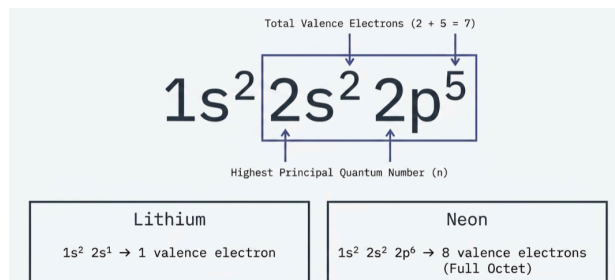
B. Transition Metal Complexity

- Transition metals have **overlapping orbitals**:
 - (n-1)d orbitals** and **ns orbitals**
- Because of this, they don't follow simple main-group valence rules and can show **variable oxidation states**

(e.g., Fe^{2+} vs Fe^{3+})

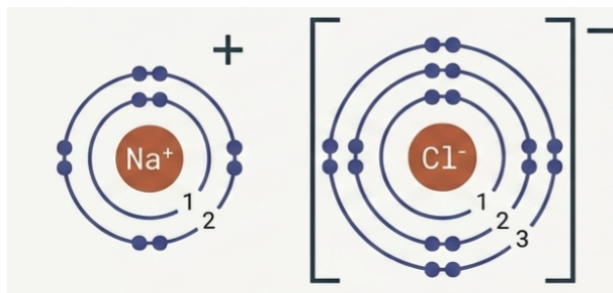
Method 2: Decoding Configurations (Valence from Orbitals)

- Valence electrons are located in orbitals at **the highest energy level**



5.0 The Driving Force: Octets & Ions

- Atoms try to achieve stability by reaching a **full outer energy level** (usually **8 electrons**).
- Ion formation:
 - lose electrons** → **cation (+)**
 - gain electrons** → **anion (-)**
- Example shown:
 - NaNaNa forms $\text{Na}^+\text{Na}^+\text{Na}^+$
 - ClClCl forms $\text{Cl}^-\text{Cl}^-\text{Cl}^-$
 - The result is an ionic stability based on octet completion.



6.0 Chemical Bonding Matrix

IONIC BOND

(Metal + Non-metal)

Valence electrons are **transferred**

Extreme ΔE_N .
Forms strong attraction between **cations and anions**.

Example: **NaCl**

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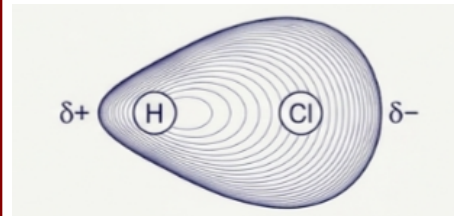
POLAR COVALENT (Non-metal + Non-metal)

Valence electrons are **unequally shared**.

Moderate ΔEN .

Creates partial charges ($\delta+$ and $\delta-$).

Example: **HCl**

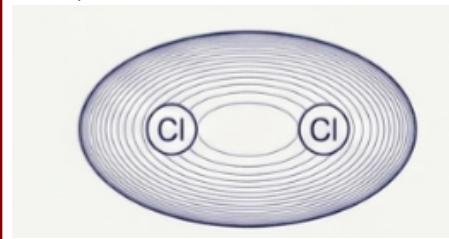


NON-POLAR COVALENT (Identical Non-metals)

Valence electrons are **equally shared**.

No charge separation ($\approx$ zero Δ electronegativity difference).

Example: **O₂, Cl₂**



6.0 Lewis Theory & Electron Pairs

Bonding Pairs

- shared valence electrons that form the covalent bond.

Lone Pairs (Non-bonding Pairs)

- valence electrons not shared in bonding.

Valence Bond Idea

- shared electrons come from **overlapping half-filled orbitals**, forming an electron "cloud" between nuclei.

7.0 Valence Electrons in Molecules

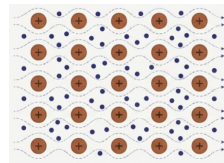
Water (H ₂ O)	
H: 2 × 1 =	2
O: 1 × 6 =	6
Total Molecular Valence = 8 e ⁻	

Sulfuric Acid (H ₂ SO ₄)	
H: 2 × 1 =	2
S: 1 × 6 =	6
O: 4 × 6 =	24
Total Molecular Valence = 32 e ⁻	

8.0 From Micro to Macro: Conductivity

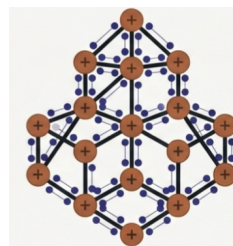
Conductors (Metals)

valence electrons are **loosely held**
they can move freely across the lattice → **high conductivity**



Insulator (Non-metals)

valence electrons are **tightly held**
in rigid bonds
electrons can't move freely → act as **insulators**



9.0 From Micro to Macro: Conductivity

Atomic Number (5)

- determines **electron configuration**

Electron configuration

- Dictates **orbital filling**

Valence electrons

- The **outermost reactive layer**

Bonding behavior

- Ionic, covalent, metallic

Macroscopic Properties

- Conductivity, reactivity, phase

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Module 2: Lesson 8

PERIODIC TRENDS

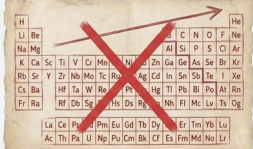
A

PERIODIC TRENDS

- Specific, predictable patterns in the properties of elements based on their position in the periodic table.
 - Driven by atomic structure, primarily the pull of the nucleus on electrons (**COULOMB'S LAW**) and the distance between them
- Periods (rows) and groups (columns)
- The trend is an observation, but never an explanation. Understanding the invisible forces that dictate the architecture of every element is more important than simply stating an element's location and properties.

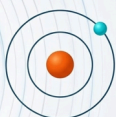
The Golden Rule of Periodicity

The Trap



"Because it is further to the right."
A location on a table is a human construct.
It exerts no physical force.

The Truth


$$F = k \frac{(Q^+)(Q^-)}{d^2}$$

"Because of Effective Nuclear Charge."
Chemistry is the study of matter and energy.
All explanations must be rooted in the energy of electrostatic attractions and repulsions.

The Mantra: A trend is an observation, not an explanation.

B

MAPPING THE ARCHITECTURE OF THE ELEMENTS:

Step 1: The Forces (The Engine)

- COULOMB'S LAW** – explains how electric charges interact; opposite charges attract and like charges repel
- EFFECTIVE NUCLEAR CHARGE (Z_{eff})** – net positive charge that a valence electron experiences in an atom
- SHIELDING** – when inner-shell electrons block or reduce the attractive pull of a positive nucleus on outer valence electrons

The physical engine of chemistry: Coulomb's Law

$$F = \frac{k(Q^+)(Q^-)}{d^2}$$

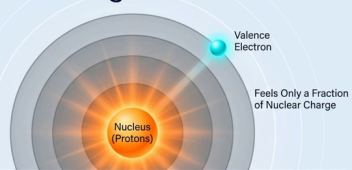
The Engine: Almost all periodic properties rely on the electrostatic attraction between the outer electrons and the nucleus.

Direct Proportionality: Force (F) increases as the magnitude of charges (Q^+ , Q^-) increases.

Inverse Proportionality: Force drops exponentially as the distance (d) between the charges increases.

Takeaway: To explain any trend, you must explain how atomic structure alters Q or d.

Shielding and Effective Nuclear Charge (Z_{eff})



Shielding: Core (non-valence) electrons repel valence electrons, shielding them from the full attractive force of the protons.

Effective Nuclear Charge (Z_{eff}): The net positive charge from the nucleus that a valence electron actually "feels".

The Horizontal Rule: Across a period, Z_{eff} increases while shielding remains constant, pulling the electron cloud tighter.

Element	Z_{eff}
Lithium (Li)	1.28
Boron (B)	2.58
Carbon (C)	3.22
Nitrogen (N)	3.85
Oxygen (O)	4.49
Fluorine (F)	5.13

Step 2: The Trends (The Output)

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– atomic radius, ionization energy, electron affinity, and electronegativity (based strictly on atomic structure)

Step 3: The Exceptions (The Nuance)

– deviations in trends using electron-electron repulsions and orbital shapes

Primary Trends

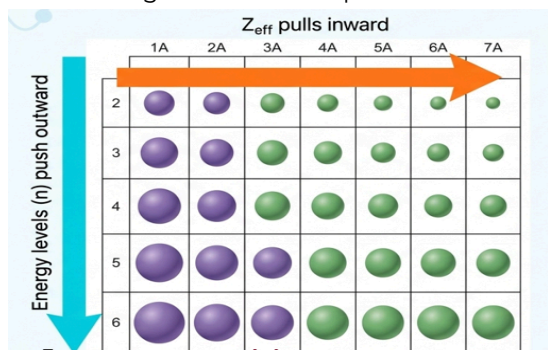
4. **Atomic Radius** – refers to the total distance from the center of an atom's nucleus to its outermost electron shell
- **Across a period (left to right):** Decreases. Protons are added to the nucleus while electrons fill the same principal energy level. The increased positive charge pulls electrons tighter, reducing the atom's size.
 - **Down a group (top to bottom):** Increases. Electrons are added to higher energy levels further from the nucleus, physically expanding the atom.

→ Atomic Radius (Neutral)

- **Decreases across a period:** Higher Z_{eff} pulls electrons closer.
- **Increases down a group:** Increased number of energy levels (n) creates greater distance.

→ Ionic Radius (Charged)

- **Cations (+):** Smaller than neutral atoms. Loss of valence shell decreases distance and electron-electron repulsions.
- **Anions (-):** Larger than neutral atoms. Gaining electrons increases repulsions, causing the cloud to expand.



5. **Electronegativity** – how strongly an atom pulls shared electrons towards itself in a

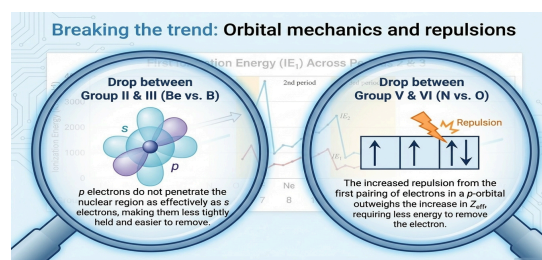
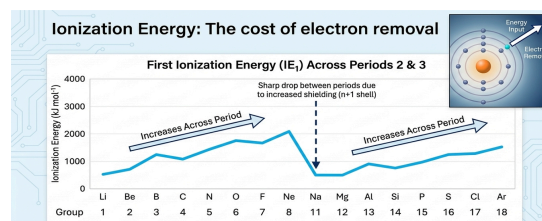
chemical bond; relative scale showing how strongly a bonded atom pulls on shared electrons (measured on the **PAULING SCALE**)

- **Across a period (left to right):** Increases. A smaller radius and higher effective nuclear charge mean the atom has a stronger pull on shared electrons (higher Z_{eff} = smaller size).
- **Down a group (top to bottom):** Decreases. Electrons are further out and easier to remove.

Fluorine is the most electronegative element. Francium is the weakest. Noble gases are excluded as they rarely bond

6. **Ionization Energy** – the energy required to remove the highest-energy electron from an isolated, gaseous atom; energy required to remove (or pull away) an electron from a free atom

- **Across a period (left to right):** Increases. As the atomic radius shrinks and nuclear charge increases, it becomes harder to pull an electron away. Higher Z_{eff} holds electrons more tightly and requires more energy to break the attraction.
- **Down a group (top to bottom):** Decreases. Electrons are further out and easier to remove. Increased distance (n) weakens the nuclear attraction, making the outer electrons easier to steal.

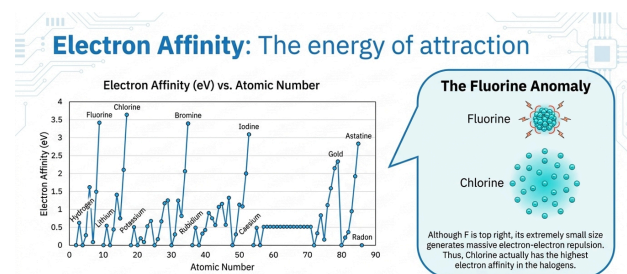


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7. **Electron Affinity** – the energy released when a neutral gaseous atom gains an extra electron (exothermic = stable)
- **Across a period (left to right):** Increases. Elements become more eager to gain an electron to fill their outer shell, releasing more energy in the process. This becomes more negative due to higher Z_{eff} .
 - **Down a group (top to bottom):** Decreases. The added distance makes it harder to attract new electrons.



8. **Reactivity**– losing and gaining of electrons; driven by an atom's tendency to achieve a stable electron configuration
- **Metals (losers of electrons):** Increases as you move down a group. Increased distance weakens nuclear attraction, making the valence electrons more loosely held and ready to react.
 - **Non-metals (gainers of electrons):** Increases as you move up a group. A smaller atom with high Z_{eff} and fewer energy levels exerts the strongest pull on external electrons.
9. **Vector Cancellation** – refers to how individual polar bonds within a molecule interact; stems from electronegativity
- **Phenomenon:** Diagonally adjacent pairs exhibit remarkably similar chemical properties
 - **Moving right:** Increases electronegativity and shrinks radius