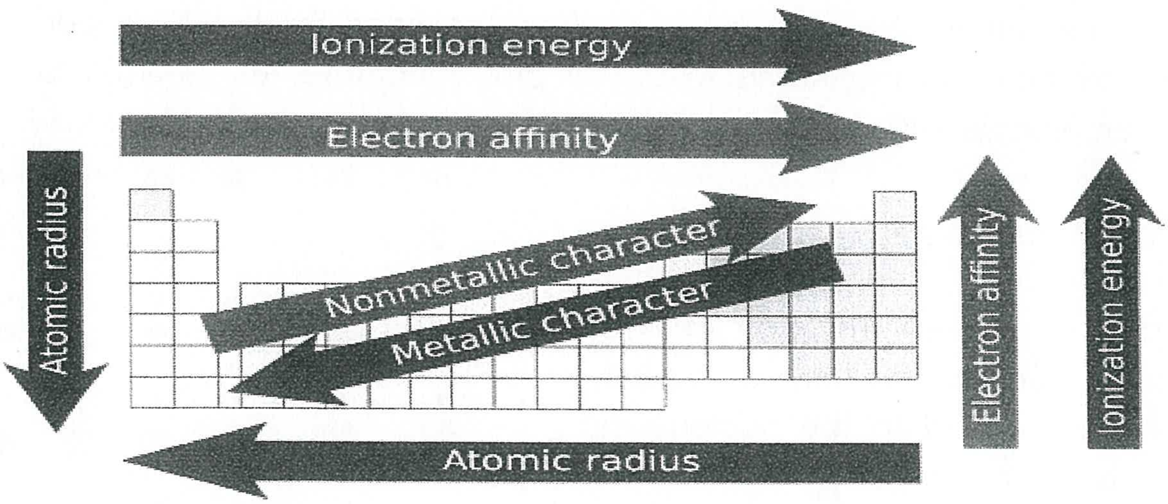
Year 11 chemistry: Periodic table trends



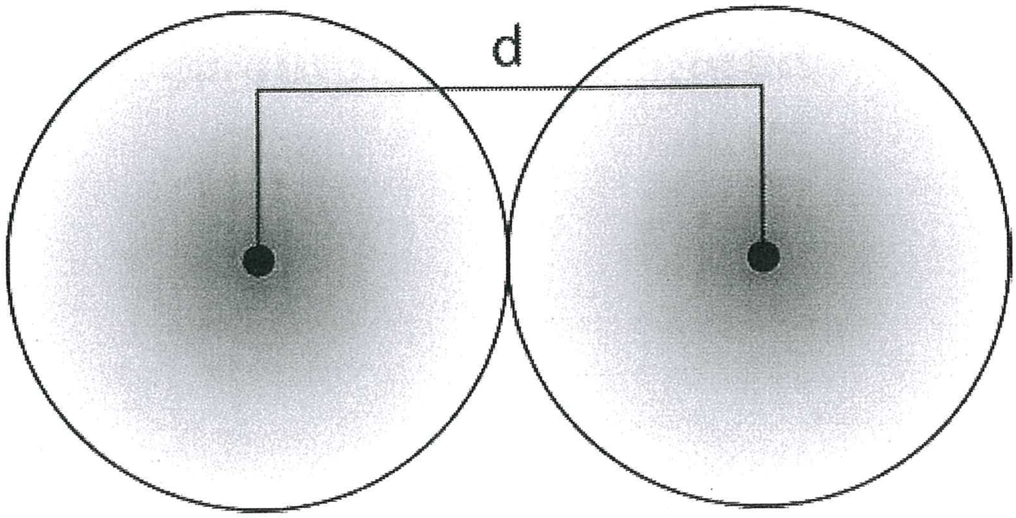
Periodic Table trends

Atomic Radius

The size of an atom is defined by the edge of its orbital. However, orbital boundaries are fuzzy and in fact are variable under different conditions. In order to standardize the measurement of atomic radii, the distance between the nuclei of two identical atoms bonded together is measured.

The atomic radius is defined as one-half the distance between the nuclei of identical atoms that are bonded together.

$$r = d/2$$

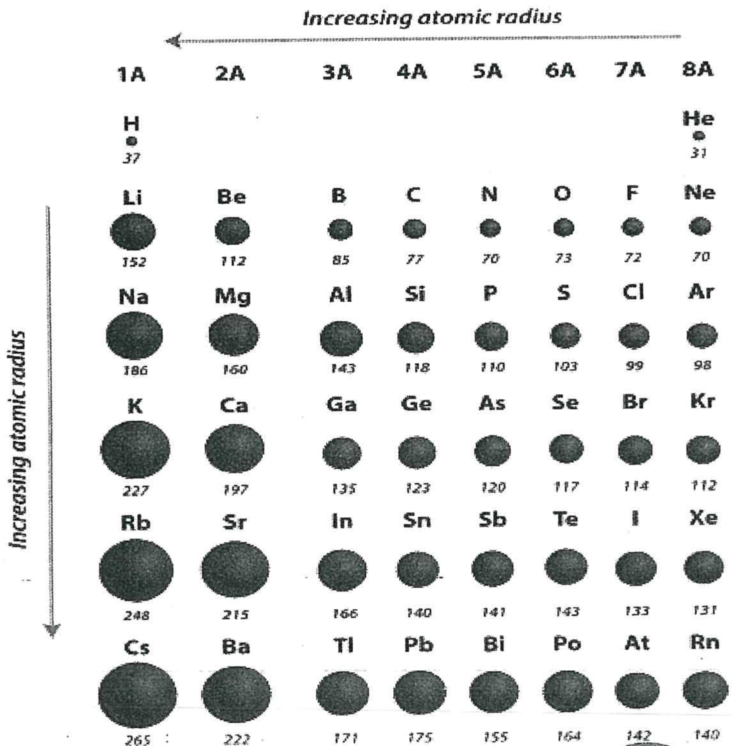


The units for atomic radii are picometers, equal to 10^{-12} meters.

As an example, the internuclear distance between the two hydrogen atoms in an H_2 molecule is measured to be 74 pm. Therefore, the atomic radius of a hydrogen atom is 742=37 pm.

Trends within periods

The atomic radius of atoms generally decreases from left to right across a period. Within a period, protons are added to the nucleus as electrons are being added to the same principal energy level. These electrons are gradually pulled closer to the nucleus because of its increased positive charge. *Since the force of attraction between nuclei and electrons increases, the size of the atoms decreases.*



Trends within groups

The atomic radius of atoms generally increases from top to bottom within a group. As the atomic number increases down a group, there is again an increase in the positive nuclear charge. However, there is also an *increase in the number of occupied principle energy levels*.

Summary

- Atomic radius is determined as the distance between the nuclei of two identical atoms bonded together.
- The atomic radius of atoms generally decreases from left to right across a period.
- The atomic radius of atoms generally increases from top to bottom within a group.

Review

1. Define "atomic radius."

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2. What are the units for measurement of atomic radius? ______________

3. How does the atomic radius change across a period?

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4. How does atomic radius change from top to bottom within a group?

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5. Explain why the atomic radius of hydrogen is so much smaller that the atomic radius for potassium.

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6. Rank the following elements by increasing atomic radius: carbon, aluminum, oxygen, potassium.

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ions

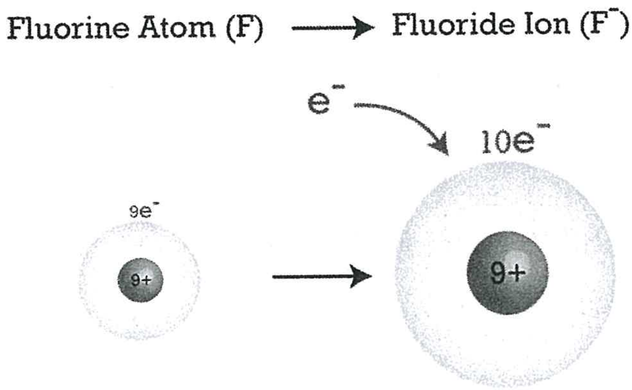
Atoms Are Neutral

An atom always has the *same number of electrons as protons*. Electrons have an electric charge of -1 and protons have an electric charge of +1. Therefore, the charges of an atom's electrons and protons "cancel out." This explains why *atoms are neutral in electric charge.*

Q: What would happen to an atom's charge if it were to gain extra electrons?

A: If an atom were to gain extra electrons, it would have more electrons than protons. This would give it a negative charge, so it would no longer be neutral.

Atoms to Ions



Atoms cannot only gain extra electrons. They can also lose electrons. In either case, they become **ions**. *Ions are atoms that have a positive or negative charge because they have unequal numbers of protons and electrons*. If atoms lose electrons, they become **positive ions**, or cations. If atoms gain electrons, they become **negative ions**, or anions. Consider the example of fluorine. A fluorine atom has nine protons and nine electrons, so it is electrically neutral. If a fluorine atom gains an electron, it becomes a fluoride **ion** with an electric charge of -1.

Removing more than one electron

Successive Ionization Energies for the Period 2 Elements

Element	Valence Electrons	Ionization Energy (kJ/mol)*								
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Li	1	520	7300							
Be	2	900	1760	14,850						
B	3	800	2430	3660	25,020					
C	4	1090	2350	4620	6220	37,830				
N	5	1400	2860	4580	7480	9440	53,270			
O	6	1310	3390	5300	7470	10,980	13,330	71,330		
F	7	1680	3370	6050	8410	11,020	15,160	17,870	92,040	
Ne	8	2080	3950	6120	9370	12,180	15,240	20,000	23,070	115,380

* mol is an abbreviation for mole, a quantity of matter.

After removing the first electron from an atom, it is possible to remove additional electrons. The amount of energy required to remove a second electron from a 1+ ion is called the **second ionization energy**, the amount of energy required to remove a third electron from a 2+ ion is called the **third ionization energy**, and so on.

Reading across **Table** from left to right, you will see that the energy required for each successive ionization always increases. However, the increase in energy does not occur smoothly. Note that for each element there is an ionization for which the required energy increases dramatically.

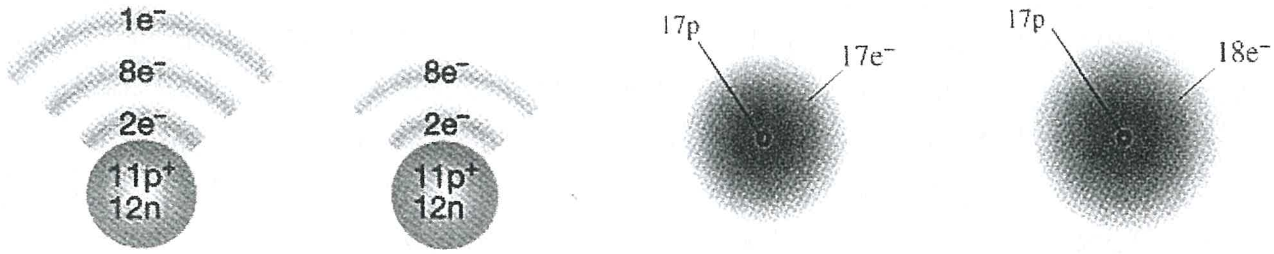
OCTET RULE

Most elements, except noble gases, combine to form compounds. Compounds are the result of the formation of chemical bonds between two or more different elements.

- In the formation of a chemical bond, atoms lose, gain or share valence electrons to complete their outer shell and attain a noble gas configuration.
- This tendency of atoms to have eight electrons in their outer shell is known as the ***octet rule***.

Formation of Ions:

- An ***ion*** (charged particle) can be produced when an ***atom gains*** or ***loses*** one or more ***electrons***.



Na　　Na^+　　Cl atom　　Cl^- ion

IONIC CHARGES

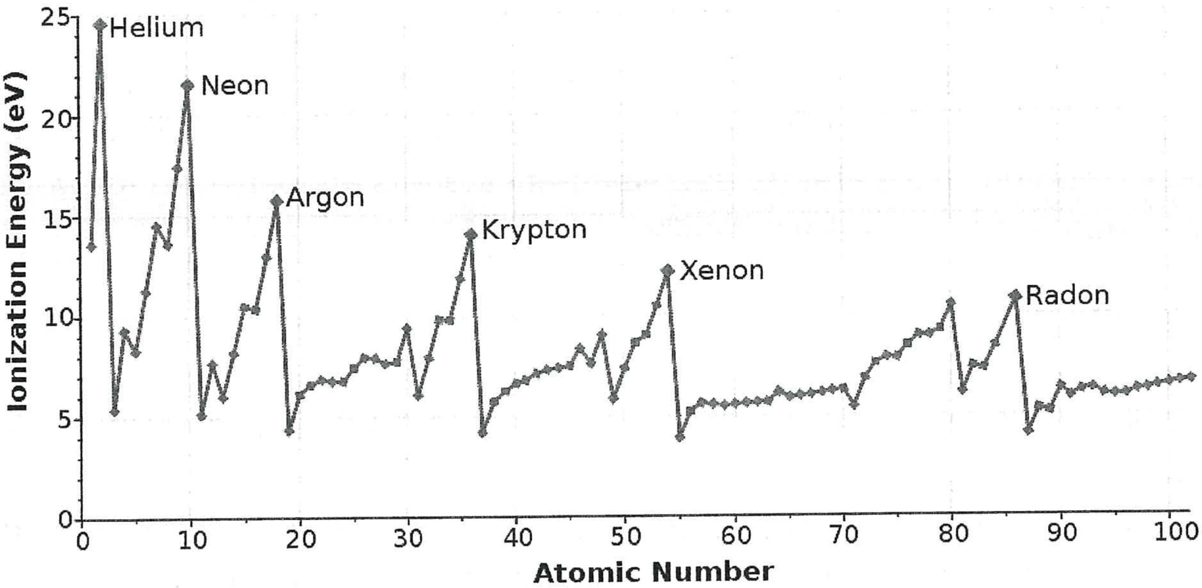
The ionic charge of an ion is dependent on the number of electrons lost or gained to attain a noble gas configuration.

For most main group elements, the ionic charges can be determined from their group number,

		Metals Lose Valence Electrons			Nonmetals Gain Valence Electrons				
Noble Gases		1A (1)	2A (2)	3A (13)	5A (15)	6A (16)	7A (17)		Noble Gases
He	⇦	Li^+							
Ne	⇦	Na^+	Mg^{2+}	Al^{3+}	N^{3-}	O^{2-}	F^-	⇨	Ne
Ar	⇦	K^+	Ca^{2+}		P^{3-}	S^{2-}	Cl^-	⇨	Ar
Kr	⇦	Rb^+	Sr^{2+}				Br^-	⇨	Kr
Xe	⇦	Cs^+	Ba^{2+}				I^-	⇨	Xe

Ionization Energy

Ionization energy is the energy required to remove an electron from a specific atom. It is measured in kJ/mol, which is an energy unit, much like calories.



Trends within periods

Moving from left to right across the periodic table, the ionization energy for an atom increases. We can explain this by considering the nuclear charge of the atom. The more protons in the nucleus, the stronger the attraction of the nucleus to electrons. This stronger attraction makes it more difficult to remove electrons.

Trends within groups

Within a group, the ionization energy decreases as the size of the atom gets larger. On the graph, we see that the ionization energy increases as we go up the group to smaller atoms. In this situation, the first electron removed is farther from the nucleus as the atomic number (number of protons) increases. Being farther away from the positive attraction makes it easier for that electron to be pulled off.

Summary

- Ionization energy refers to the amount of energy needed to remove an electron from an atom.
- Ionization energy decreases as we go down a group.
- Ionization energy increases from left to right across the periodic table.

Review

1. Define "ionization energy."

2. Do valence electrons have larger or smaller ionization energies that the inner-shell kernel electrons?

3. Describe the trends in ionization energy from left to right across the periodic table.

4. Describe the trends in ionization energy from top to bottom of a group in the periodic table.

5. Circle the atom in each pair that has the greater ionization energy.
   a. Li or Be
   b. Ca or Ba
   c. Na or K
   d. P or Ar
   e. Cl or Si
   f. Li or K

6. Explain the relationship between the relative size of an ion to its neutral atom and the charge on the ions.

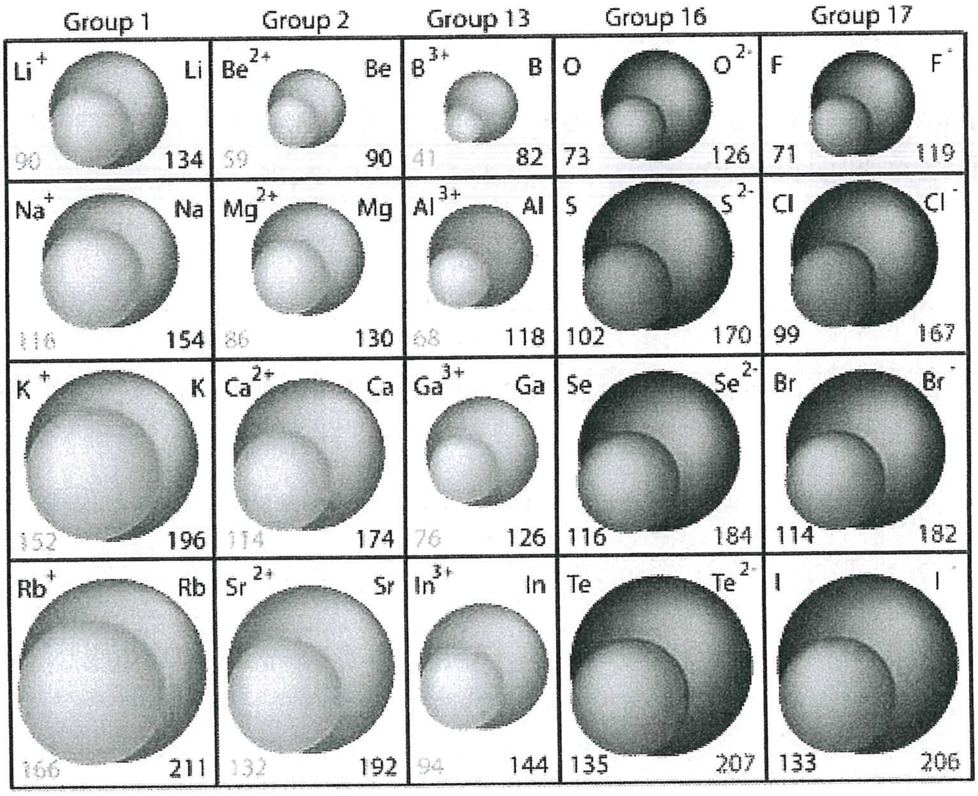
7. Rank each of the following in order of INCREASING ionization energy
   a. O, S, Ge ____________________
   b. Be, Ba, B ____________________

8. Rank each of the following in order of DECREASING ionization energy
   a. Cl, Cu, Au ____________________
   b. Te, Sb, Xe ____________________

ionic Radius

The **ionic radius** for an atom is measured in a **crystal lattice**, requiring a solid form for the compound.

Size of Atoms and Their Ions in PM



The removal of electrons always results in a cation that is considerably smaller than the parent atom.

Why?

1) When the valence electron(s) are removed, the resulting ion has one fewer occupied principal energy level, so the electron cloud that remains is smaller
2) Another reason is that the remaining electrons are drawn closer to the nucleus because the protons now outnumber the electrons.

One other factor is the number of electrons removed. The potassium atom has one electron removed to for the corresponding ion, while calcium loses two electrons.

The addition of electrons always results in an anion that is larger than the parent atom.

Why?

1) When the electrons outnumber the protons, the overall attractive force that the protons have for the electrons is decreased.
2) The electron cloud also spreads out because more electrons results in greater electron-electron repulsions

Trends within periods

As you move across the table from left to right the size of positive ion decrease gradually. Then, beginning in group 15 or 16 the size of the much larger negative ions also decreases.

Trends within groups

As you move down a group, the size of positive and negative ions increase because of adding more and more energy levels.

Summary

- Ionic radius is determined by measuring the atom in a crystal lattice.
- Removal of electrons results in an ion that is smaller than the parent element.
- Addition of electrons results in an ion that is larger than the parent atom.

Review

1. Explain why the radius of the rubidium ion is smaller than the radius of the rubidium atom.

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2. Explain why the radius of the tellurium ion is larger than the radius of the tellurium atom.

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3. Why is the oxygen anion larger than the fluoride anion?

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4. Why is the sodium cation larger than the magnesium cation?

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Electronegativity

Valence electrons of both atoms are always involved when those two atoms come together to form a chemical bond. Chemical bonds are the basis for how elements combine with one another to form compounds. When these chemical bonds form, **atoms of some elements have a greater ability to attract the valence electrons involved in the bond than other elements**.

Electronegativity is a measure of the ability of an atom to attract the electrons when the atom is part of a compound.

Electronegativity is not measured in energy units, but is rather a relative scale. All elements are compared to one another, with the most electronegative element, **fluorine, being assigned an electronegativity value of 3.98**. Fluorine attracts electrons better than any other element. The table below shows the electronegativity values for the elements.

PAULING ELECTRONEGATIVITY VALUES

1 H 2.20																
3 Li 0.98	4 Be 1.57											5 B 2.04	6 C 2.55	7 N 3.04	8 O 3.44	9 F 3.98
11 Na 0.93	12 Mg 1.31											13 Al 1.61	14 Si 1.90	15 P 2.19	16 S 2.58	17 Cl 3.16
19 K 0.82	20 Ca 1.00	21 Sc 1.36	22 Ti 1.54	23 V 1.63	24 Cr 1.66	25 Mn 1.55	26 Fe 1.83	27 Co 1.88	28 Ni 1.91	29 Cu 1.90	30 Zn 1.65	31 Ga 1.81	32 Ge 2.01	33 As 2.18	34 Se 2.55	35 Br 2.96
37 Rb 0.82	38 Sr 0.95	39 Y 1.22	40 Zr 1.33	41 Nb 1.6	42 Mo 2.16	43 Tc 1.9	44 Ru 2.2	45 Rh 2.28	46 Pd 2.20	47 Ag 1.93	48 Cd 1.69	49 In 1.78	50 Sn 1.96	51 Sb 2.05	52 Te 2.1	53 I 2.66
55 Cs 0.79	56 Ba 0.89	57 La 1.1	72 Hf 1.3	73 Ta 1.5	74 W 2.36	75 Re 1.9	76 Os 2.2	77 Ir 2.20	78 Pt 2.28	79 Au 2.54	80 Hg 2.00	81 Tl 1.62	82 Pb 2.33	83 Bi 2.02	84 Po 2.0	85 At 2.2
87 Fr 0.7	88 Ra 0.9															

The electronegativity scale was developed by Nobel Prize winning American chemist Linus Pauling. The largest electronegativity (3.98) is assigned to fluorine and all other electronegativities measurements are on a relative scale.

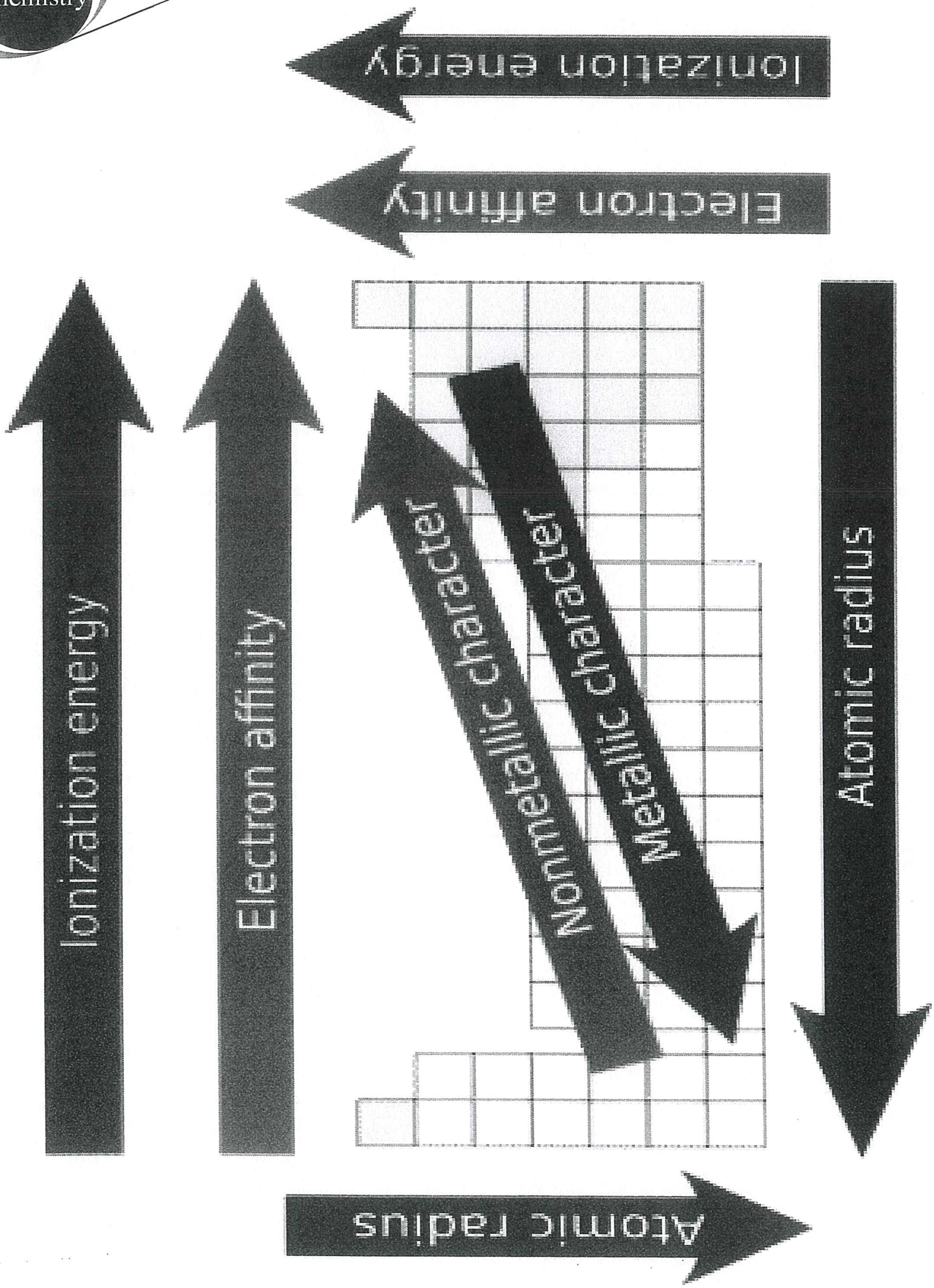
Because most noble gases do not form compounds, they do not have electronegativities.

Summary

- Electronegativity is a measure of the ability of an atom to attract the electrons when the atom is part of a compound.
- The highest electronegativity value is for fluorine.

Review

1. Define "electronegativity."


Ionization energy
Electron affinity
Ionization energy
Electron affinity
Nonmetallic character
Metallic character
Atomic radius
Atomic radius