

The octet rule and periodic trends

For those of you who like to ask questions like “What’s going to be on the test?”, I assure you that this will be on the test. In fact, this will be on every test from now on, because it’s so unbelievably important to understand chemistry. Seriously, this is the good stuff. Read on to learn the mysteries of the universe...

The octet rule:

ALL ELEMENTS WANT TO BE LIKE THE NEAREST NOBLE GAS!

Just to make sure this sinks in, let me hit you with it again:

ALL ELEMENTS WANT TO BE LIKE THE NEAREST NOBLE GAS!

If you really understand what this rule means, I don’t think it’s very far from the truth to say that you know most of what there is to know in chemistry.¹ This rule isn’t just something in one of the chapters of your book that you can forget; it’s something that you can use to derive almost everything else you’ll need to know. Interested in learning more? Read on...

What does this mean, anyway?

A somewhat longer version of the octet rule is this: All elements will perform whatever chemical processes are necessary so that they have the same number of valence electrons² as their nearest noble gas. If they need go gain electrons so they have this number of electrons, their chemistry will be dominated by this need to gain electrons. If they need to lose electrons to be like the nearest noble gas, their chemistry will be dominated by the need to lose electrons.

For example, a fluorine atom sits comfortably on the periodic table in the halogens section. Here he is just chilling:

1	2		13	14	15	16	17	18
H								He
Li	Be		B	C	N	O	F	Ne

Figure 1: Fluorine, in a rare introspective moment.

You may believe that fluorine is happy this way because he has the same number of protons (9) as electrons (9), making him electrically-neutral. However, if you think back to the periodic table section, you’ll remember that the noble gases are really really stable. This stability comes from the fact that they’ve got a filled valence shell, and all of the other elements want to have a filled valence shell like the noble gases, too.

In the case of fluorine, it can do two things: Lose seven electrons so that it has a filled first valence shell (like helium), or gain one electron so it has a filled second valence shell (like neon). Not surprisingly, fluorine is better at grabbing one electron than losing eight, so its reactivity is dominated by a need to gain one electron, which usually gives it a -1 charge.³

Upon gaining one electron, the fluorine atom becomes a fluoride ion.⁴ Because fluorine is way more stable when it gains that one extra electron to be like neon, fluoride ions tend to be fairly unreactive.



Figure 2: Sodium fluoride is a common ingredient in toothpaste

Pure fluorine was once considered for use as an oxidizer in rocket fuel, but the high reactivity scared people so badly that they never actually used it.

Random fact: I contacted the U.S. government and chatted with an online operator identified as Maria A. When I asked if she would give me a quote stating that it was a good idea to brush your teeth twice a day, she actually replied "I can't do that." Because I want to be controversial, I'll interpret this to mean that the Government encourages poor dental care.

Similarly, lithium atoms can either gain seven electrons to be like neon or lose one to get the electron configuration of helium. As you'd expect, it loses one electron to become a lithium cation. Just as in the case of fluorine, the lithium ion is much less reactive than elemental lithium.

Periodic trends

One of the cool things about the periodic table is that you can use it to figure out the properties of elements. The properties that change in a systematic way as you move either across a row in the periodic table or down a group are called periodic trends.

An important note: Periodic trends are just that: Trends. They're not laws that are written in stone, and there are exceptions. However, you'll find that these are extremely good guidelines for figuring out how things behave.

Atomic Radius

Because atoms are more-or-less spherical, their sizes are denoted by a term called their atomic radius. The atomic radius of an element is defined as half the distance between two bonded atoms of the same element. So, for example, if the distance between two atoms of the same element is 120 pm, the atomic radius of that element is said to be 60 pm.⁶

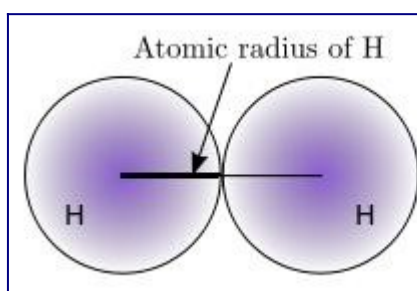


Figure 3: The atomic radius of hydrogen is one-half the distance between two bonded atoms of hydrogen.

And yes, as many students have told me in the past, I know these kind of look like boobs. Seriously, quit giggling and grow up a little.

As you move left to right across the periodic table, the atomic radii of the elements decreases. This is because the nuclei of these elements pick up more protons as you move across the table, while the energies of the electrons stay the same.⁷ Since the nucleus can pull harder but the electrons have the same energy, the electrons get pulled closer to the nucleus, making the atom smaller.

As you move down a group in the periodic table, the atomic radius of the elements increases. That's because the electrons are in higher energy levels, which puts them into bigger orbitals. Not surprisingly, bigger orbitals = bigger atoms.

If you knock electrons off of an atom or add electrons, the resulting atom is referred to as an ion. Cations are ions with positive charge⁸ and anions are ions with negative charge.⁹ Generally, adding electrons to an atom it makes it bigger, while removing electrons makes it smaller.

Ionization energy

Imagine that you're at a party with all of your friends. You're all having a good time when suddenly, one of your friends gets out an atom of sulfur and tries to knock electrons off of it by putting it over the stove. What do you think you would do?¹⁰



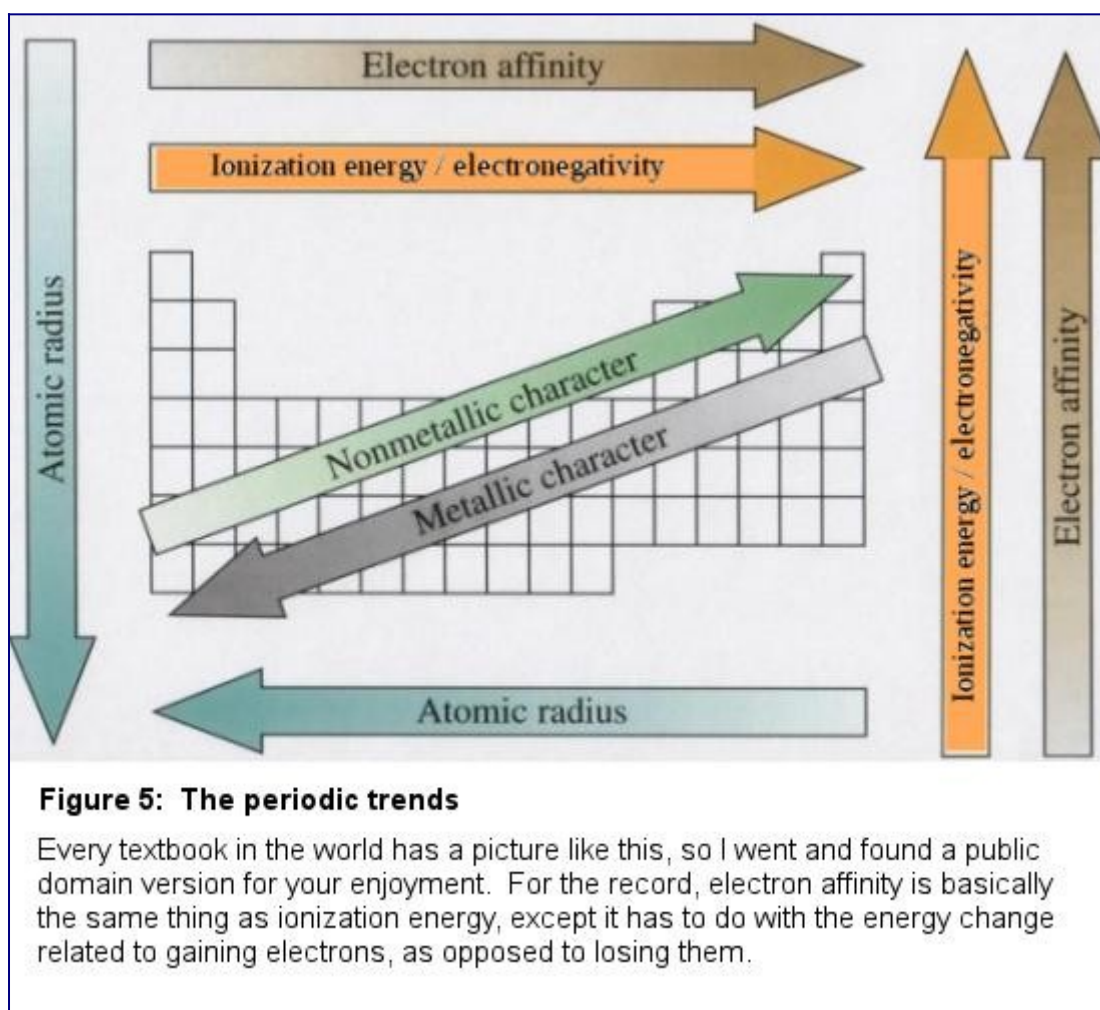
Figure 4: Something having to do with sulfur

It's hard to find free images of sulfur, so you're stuck looking at this one. At least, I think it's sulfur.

Assuming your friend wasn't overcome with chemical fumes, he¹¹ would find that after adding some energy, an electron would come off of the atom forming a cation. The ionization energy of an element is the amount of energy it takes to pull one electron off of an atom.

As you move left to right across the periodic table, the ionization energies of elements increase. Consider this: Elements on the left side of the periodic table want to lose electrons because their nearest noble gases have fewer electrons than they do. As a result, it doesn't take much energy to make this happen. Elements on the right side of the periodic table want to gain electrons to be like their nearest noble gas, so it takes a lot of energy to pull off electrons.

As you move down a group, the ionization energies of elements decrease. This is due to the shielding effect, which states that electrons in orbitals near the nucleus shove electrons further from the nucleus away from them. Because elements at the bottom of their periods have more energy levels, there are more electrons pushing on the outer electrons. This enhanced push makes it easier to pull off electrons (i.e. it takes less energy to pull an electron off).¹²



Electronegativity

The electronegativity of an element measures how hard it tries to pull electrons away from other atoms it is bonded to. Elements on the right side of the periodic table really want to grab electrons¹³ and have high electronegativities (they want to grab electrons). Elements on the left side of the periodic table really want to lose electrons and have low electronegativities¹⁴ (i.e. they don't want to gain electrons very much). The noble gases, on the other hand, don't really care about picking up electrons so have no noticeable electronegativities at all.¹⁵

Footnotes:

1. I honestly believe this to be true. If you learn how the octet rule works, you're well on your way to being a better chemist than many I've worked with professionally.
2. A reminder: Valence electrons are the electrons in the outermost energy shell of an atom. They're the ones that are responsible for the making and breaking of bonds we see when reactions occur.
3. This -1 charge is found by comparing the number of protons (9) to the number of electrons that fluorine has when it gains one (10) – this extra electron gives it a -1 charge. As a rule, atoms get negative charges when they gain electrons and positive ones when they lose electrons.

4. More specifically, an anion. Anions are atoms or groups of atoms that have negative charge, while cations are atoms or groups of atoms with positive charge.
5. One compound that contains lithium ions is lithium stearate, which is used as a grease because it's so stable under a variety of conditions. On the other hand, pure lithium has to be stored under oil because it will react with the tiny amount of moisture in air.
6. "pm" stands for "picometers", or one-trillionth (10^{-12} m).
7. Remember, elements in the same period have nearly identical orbital energies.
8. i.e. they lost electrons, so have more positive charge than negative.
9. i.e. they gained electrons, so have more negative charge than positive.
10. I'm guessing the smell would make you puke.
11. I'm assuming your friend is male in this case, because women are usually too smart to pull dumb stunts like this one.
12. If you add enough energy, it's possible to knock more than one electron off of an atom. As a result, you can have multiple ionization energies for the same atom ("first ionization energy", "second ionization energy", etc.) Each electron takes more energy to remove than the one before, so the first ionization energy of an element will always be lower than the second (and so forth). This is particularly true if you're trying to pull electrons away from an element that has the same number of electrons as its nearest noble gas. For example, it takes only 522 kJ/mol of energy to remove one electron from lithium (which gives it the same number of electrons as helium), but 7,301 kJ/mol to remove a second (which takes it away from its happy helium configuration). Yet again, the octet rule is the cause of something amazing.
13. Because of the octet rule.
14. Octet rule!
15. Though most numbers in science have units associated with them (cm, kg, etc.), electronegativity values are just plain ol' numbers that indicate how much pull each element has. The most common of these scales is the Pauling electronegativity scale. Named after two-time Nobel laureate Linus Pauling, the concept of electronegativity is only one of the incredible things this dude discovered. Seriously, Pauling was badass.