

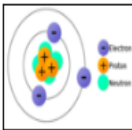


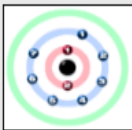
## Chem101.3 - Bond. Chemical Bond.

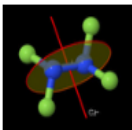
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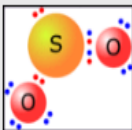
### Chemistry 101 Semester Pak

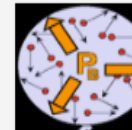
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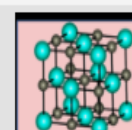
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1. Chemistry 101.1 -- Atoms: Basics  
Review and Improve your First Year Chemistry! This is the first maze in our 10-maze Semester Pak and tests atomic basics, from a historical / experimental perspective. Later you can try our new Biochem200 maze games.
- 


2. Chemistry 101.2 -- Atoms: Waves and Orbitals  
For the Quantum Warrior (EXPERT LEVEL): The Quantum Mechanics of de Broglie, Schrodinger and Heisenberg define the nature of the electron cloud --which is foundational to all chemical reactions. Plus a bit about electronegativity
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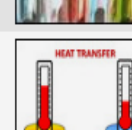
3. Chemistry 101.3 -- Bond. Chemical Bond.  
Review chemical bonds, valence, and other interactions that make molecules molecules. Ping us if you get stuck!
- 


4. Chemistry 101.4 -- Formulas and Reactions  
Chemistry 101.4 concerns chemical formulas and reactions including stoichiometry, molecular weights and redox.
- 

5. Chemistry 101.5 -- It's a GAS  
Chem 101.5 is a GAS, but also covers liquids, pressure, temperature. Plus it drills down into  $PV=nRT$ . This gets you halfway through our Chemistry 101 Semester Pak.
- 

6. Chemistry 101.6 -- Liquids and Solids  
Liquids and Solids are surveyed in regards to properties, structure and underlying physical attributes. Mazes are more fun if you use the TIPS...and...SKIM the RULES.
- 

7. Chemistry 101.7 -- Solutions + Acid-Base  
Solution basics are covered along with Acid-Base Models, electrolytes, solubility, colloids and some aqueous reactions. Our Biochem200.1 maze builds upon this topic.
- 

8. Chemistry 101.8 --Kinetics & Equilibria  
Questions in our Chemistry 101.8 maze will test your knowledge of udes collision theory, mass action, reaction rates, equilibria and catalysts.
- 

9. Chemistry 101.9 -- Thermodynamics  
Chemistry 101.9 concerns heat, entropy, temperature, Gibbs and more. The Greek symbol for delta (triangle) is not available so we use e.g. "delta-E" to represent "change in Energy".
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10. Chemistry 101.10 -- Kd, pH & Electrochemistry  
FINAL Maze in the Chem101 Semester Pak includes Kdiss, pH, buffers, redox, conductivity & Galvanic cells. NOW try our Biochem Mazes! (if you like Biochem!).



# Chemistry 101.3 – Bond. Chemical Bond.

Check the ALL MAZES button for more fun mazes. Let [contact@mazefire.com](mailto:contact@mazefire.com) know of any corrections or technical issues.

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## Q1. Valence

- A. is the same as atomic number**
- B. refers to the position of the element in the periodic table
- C. is proportional to the number of electrons in an atom
- D. relates to the number of electrons an atom can share**
- E. is the propensity to bond with water molecules

*Hydrogen has only one electron to share and has a valence of 1. Carbon has 4 outer shell (valence) electrons and so can bind 4 hydrogens (or 4 other molecules, e.g.  $CCl_4$ , aka carbon tetrachloride). Magnesium has two outer shell electrons (valence = 2) and can therefore bond with two chloride molecules making magnesium chloride. While valence relates to an atom's position in the periodic table, that is not what valence refers to. Molecules that like to bond to water are called hydrophilic.*

## Q2. Covalent bonds differ from ionic bonds

- A. in that each element can form only one type of bond
- B. based strictly upon the size of the atoms involved
- C. based upon the degree to which electrons are shared**
- D. based upon the degree to which protons are shared
- E. for ALL of the above reasons

*In the case of ionic bonds, as e.g. in  $NaCl$ , a loosely held electron (e.g. sodium's) is essentially completely transferred to a strongly electronegative (electron seeking) atom such as chlorine, which needs just one electron to fill its outer electron shell. Atoms can form different types of bonds, e.g. hydrogen forms an ionic bond with chlorine (in  $HCl$ ) but forms a covalent bond when bonding with itself, making molecular hydrogen (aka  $H_2$  - sorry no subscript fonts available on mazefire yet).*

## Q3. A polar bond

- A. is one with a north and a south spin**
- B. forms between two positively charged ions
- C. forms between two negatively charged ions
- D. is a covalent bond with unequal sharing of electrons**
- E. is a very, very cold bond

*When two atoms in a molecule like  $NaCl$  completely dissociate in water they are considered ions (and partake in ionic bonding when in solid form). Bonds within molecules that do not come apart in water are covalent and can be either polar or non-polar. When oxygen ( $O_2$ ) is dissolved in water, electrons are shared equally between the atoms and so the bonds are nonpolar. When glucose is dissolved in water, there is unequal sharing of electrons and so its bonds are polar -- which helps it to dissolve in water.*

## Q4. A chemical dipole

- A. is a molecule with two elongated rods
- B. is a dumb-bell shaped molecule
- C. is a molecule with a positive charge at each end**
- D. is a molecule with a negative charge at each end
- E. comes in units of debyes, named after Peter Debye**

*Any molecule with a positive and a negative region (with e.g. a polar bond) is said to be a dipole. As such, it can orient in an electric field and has a dielectric constant (which is a measure of the degree to which it can act as a capacitor). The unit for measuring dipole moments, the debye, is named after Peter J. W. Debye who first described polar molecules. Water is a polar molecule and likes to be around other polar molecules. In contrast, non-polar molecules like methane and fats hate being dissolved in water and are thus rightly dubbed hydrophobic.*

Q5. The water molecule is NOT linear because

- A. a 3-atom molecule can never be linear
- B. oxygen's valence electrons are all on one side of its nucleus
- C. the hydrogens in the water molecule like to be close to one another
- D. oxygen's 2p orbitals are at an angle to one another**
- E. there is no reasonable explanation for the shape of water molecules

Although water molecules could, in principle, assume a linear configuration: H-O-H, these molecules are instead boomerang or V-shaped. This is because the hydrogen electrons bind to oxygen electrons situated in 2p orbitals, which are nominally at right angles to one another in the oxygen atom. But in the H<sub>2</sub>O molecule, interactions between the atomic orbitals that also involve the hydrogen nucleus (a proton!), lead to the formation of molecular orbitals. The net result, which also depends upon oxygen's two lone pairs of electrons, is a slightly larger angle between the two H-O bonds, of about 104 degrees. Certain molecules with 3 atoms can form a linear chain, as is the case with carbon dioxide: O=C=O

Q6. A tetrahedral orbital

- A. involves hybrid orbitals
- B. is a mixture of modified 2s and 2p orbitals**
- C. is an orbital with bonds at ~ 108 degree angles
- D. defines the shape of both methane and water molecules
- E. fits with ALL of the above**

A common molecular situation is one with 4 orbitals occupied: one 2s orbital and three 2p orbitals. When these orbitals are occupied by 4 bonds between atoms, e.g. CH<sub>4</sub> (methane), the molecule can often assume a tetrahedral (pyramid-like) shape. This ensues because the formerly distinct atomic orbitals (2s vs. 2p) are now replaced by four equivalent hybrid orbitals directed towards the four corners of the tetrahedron. The hybridization of these orbitals also affects other molecules like water, where the two covalent bonds result from two of the four tetrahedral dimensions, while the other two orbitals are occupied by electron pairs comprised of oxygen's four unused outer electrons.

Q7. Which statement on molecular vibrations in a diatomic molecule is INCORRECT?

- A. as two atoms in a molecule vibrate, total energy varies in continuous fashion**
- B. stretching of the two atoms from a median distance can increase potential energy
- C. compression of the two atoms from a median distance can increase potential energy
- D. potential energy can be described by a parabolic function
- E. the total amount of kinetic and potential energy remains constant**

As two molecules vibrate (which apparently happens even at absolute zero iaw Sienko), the level of potential energy violates in counter-phase to the nuclear kinetic energies. Potential energy increases with compression (as the protons repel one another) and when the bond is stretched (since relaxing will lead to a lower potential energy state). These changes are exactly (and magically?) balanced by changes in kinetic energy. Even more mysterious is that only quantal changes in total energy are allowed, but for each discrete state, the parabolic function applies, methinks.

Q8. An alternative to quantum-mechanics based molecular orbital theory is the less correct, but much simpler, molecular theory called

- A. diatomics
- B. hybrid atomic theory
- C. resonance symmetry theory
- D. valence bond theory**
- E. electron shell game theory

Valence bond theory is based upon quantum-inspired atomic orbitals but focuses on discrete atoms that share electrons with one another or, in the case of ionization reactions, donate electrons to one another. Diatomics sounds too much like Dianetics to have even a quantum of validity and would fit better within the shell games genre! Resonance and symmetry are quite important concepts explored in molecular orbital theory.

Q9. Which statement about double-bonds is INCORRECT? 🌐

- A. they involve four electrons
- B. they tend to be stronger than single bonds**
- C. they tend to be longer than single bonds**
- D. they affect the shape of the molecule
- E. they satisfy the octet rule

Double-bonds are found in many different molecules, including  $\text{CO}_2$  and in unsaturated fatty acids.  $\text{H}_2\text{O}$  has two SINGLE bonds, since each H is sharing one electron with the central oxygen atom.  $\text{CO}_2$  has two double bonds, i.e. the central carbon shares two electrons with the oxygens on either side of it ala  $\text{O}=\text{C}=\text{O}$ . For each double bond, carbon donates 2 electrons and the oxygen donates two electrons, making 4 electrons in each double bond. Double bonds tend to be shorter than single bonds (and triple bonds shorter than doubles). In the case of  $\text{CO}_2$ , the molecule is linear and relatively non-polar, making it easier to cross membranes (a very GOOD thing). Carbon-carbon double bonds in fatty acids cause kinks in the fatty acid tails which alter membrane properties.

Q10. Nitrogen has 5 valence electrons. To form nitrogen gas aka  $\text{N}_2$  (i.e. two nitrogen atoms bound together) entails a nitrogen-nitrogen

- A. single bond
- B. double bond
- C. triple bond**
- D. quadruple bond
- E. quintuple bond

The only way to get from 5 to 8 is to add 3: triple bond it is. Thus, 3 of the 5 outer electrons of the first nitrogen orient towards the second nitrogen, which also delivers 3 electrons to the bond (making 6 electrons in total). The tripling of the bonds make this a strong and short bond, but both of these are attenuated a bit by the repulsive forces of putting so many electrons into one space (or molecular orbital to be more precise). Valence theory offers a useful and practical description of such bonds, but quantum mechanics provides the more rigorous answers-- if they are computable.

Q11. Ethylene ( $2\text{H}-\text{C}=\text{C}-\text{H}_2$ ) is unlike many other hydrocarbons (e.g. methane and ethane) because it

- A. is spherical
- B. has a tetrahedral structure
- C. has a planar structure**
- D. has 73 axes of symmetry
- E. undergoes explosive ionization when mixed with water

Methane is tetrahedral, as are the monomeric subunits of the ethane "polymer" (so to speak). In contrast, the 8 atoms of ethylene lie in a single plane, joined by  $\text{C}=\text{C}$  double bond which is strongly resistant to rotation. It has only a few axes of symmetry and mixes poorly with water (and does not explode). It is used to make plastics (e.g. polyethylene) and its worldwide production exceeds that of any other organic compound.

Q12. Which is NOT an established type of hybrid orbital? 🌐


- A. point**
- B. linear
- C. tetrahedral
- D. square-planar
- E. trigonal

When orbitals of atoms overlap during the formation of molecules, the orbitals generally vary from the appear in single atoms. For example, linear orbitals emerge from combining s and p orbitals, while a trigonal pattern emerges from s plus 2p. Adding the orbitals s plus 3p yields the tetrahedral pattern. Further patterns, including square planar, arise when d orbitals are merged, but "point" is not any kind of orbital: not atomic, hybrid or molecular. An electron cannot exist in a stationary point.

Q13. Which is NOT one of the major classes of molecular symmetry? 


- A. probability axis
- B. axis of rotation
- C. mirror plane
- D. center of inversion
- E. ALL of the above ARE major classes of symmetry

Molecules generally have inherent symmetries and their behaviors and reactions have to be consistent with those symmetries. Axes of symmetry come in different forms and molecules can have one-fold, two-fold and more distinct axes of symmetry. The water molecule e.g. can be rotated about a line bisecting the angle made by the two H-bonds. Mirror planes and inversion centers are other kinds of symmetry and the mathematics of group theory is used to describe sets of molecular symmetry operations. TIP: Symmetries are quite definite things.

Q14. In understanding the behavior of electrons in orbitals, the term shielding (or screening) refers to 


- A. the shielding of outer electrons from nuclear protons
- B. the shielding of inner electrons from other atoms
- C. a protective effect whereby electrons prevent damage to the nucleus
- D. barriers which electrons impose between orbitals
- E. the masking of neutrons and protons during efforts to visualize them

Protons in the nucleus exert an attractive force on electrons, and this attraction is greatest for the innermost electrons. Successive layers of electrons are shielded from the nuclear charge making them easier to remove from the atom. "Shielding" also refers to repulsive effects, e.g. it is easier to remove an electron from helium than from hydrogen because in helium the remaining electron repels the electron being removed. Shielding also affects the residency of electrons in orbitals. Lithium's 3rd electron might prefer to reside in the 2p orbital, which has a large regime of lower energy than 2s, but part of the 2s orbital penetrates the 1s orbital, and this relatively unshielded access to the nucleus results in the electrons first populating the the 2s orbital.

Q15. An antibonding orbital 

- A. accompanies every bonding orbital
- B. is usually of lower energy than bonding orbitals
- C. occurs only with antimatter
- D. has an electron density profile the opposite of that in bonding orbitals
- E. is found only in molecules where no bonding orbitals are possible

In general most molecules are held together by conventional bonding orbitals that are shared between two atoms. But there are additional orbitals of HIGHER energy (which makes them less favorable) that can exist. Hydrogen molecules, e.g. are held together by the two 1s orbitals of each H atom. A second, anti-bonding orbital is also possible with electron densities distributed to either side of the molecule. This results in proton-proton repulsion and is therefore energetically unfavorable. Two helium atoms could bind via (1) the favorable bonding orbital used in hydrogen molecules, plus a second anti-bonding orbital using the other two He2 electrons. But the anti-bonding is so unfavorable that He2 cannot stably exist. In some larger molecules, anti-bonding orbitals do occur, but only if the aggregate advantage of all the bonding orbitals outweighs the antibonding cost.

Q16. Electronic orbitals 

- A. have different shapes
- B. have different orientations
- C. can be symmetric or non-symmetric
- D. differ for different atomic shells
- E. exhibit ALL of the above properties

The concept of orbitals (as opposed to orbits) concerns the probability of finding electrons at different locations outside the nucleus. While Hydrogen's sole electron might be thought to reside in a single orbital, higher-level orbitals are available to it when it absorbs energy, and its spectral lines reflect emissions yielded when electrons fall back to the ground state, s1 orbital. The orbitals of larger atoms such as carbon and chlorine are more complex but are equally determinative of these atoms' behaviors. While it is convenient to discuss chemical bonds purely in terms of valence electrons, some nuances of the behaviors and reactions of atoms and molecules stem from the specifics of the orbitals that are most involved with such interactions, i.e. the orbitals of the outermost electrons. Hint: Pretty good starting list

Q17. Which statement about a chemical compound below is INCORRECT?


- A. CO<sub>2</sub> (carbon dioxide) has polar bonds but is a non-polar molecule
- B. NH<sub>3</sub> (ammonia) takes the shape of a pyramid and is a polar molecule
- C. H<sub>2</sub>O (water) is a linear molecule and thus is non-polar**
- D. CO<sub>2</sub> has a low dielectric constant
- E. electron sharing in SO<sub>2</sub> (sulfur dioxide) follows a resonance hybrid rule

Answer C is most incorrect, since it is the polarity of water molecules that defines the behavior of aqueous solutions, including living cells. CO<sub>2</sub> has polar bonds, but its linear arrangement causes them to cancel out, so it has no dipole moment. This also results in a low dielectric constant. NH<sub>3</sub> is polar and when bound to H<sup>+</sup> (making NH<sub>4</sub><sup>+</sup> aka ammonium ion) becomes an ion. The situation with SO<sub>2</sub> is more complex since there is no formula consistent with both the octet rule and the observed behavior of SO<sub>2</sub> (with both bonds showing the same length and a high dipole moment) and so SO<sub>2</sub> exhibits chemical "resonance" (which is different from oscillating resonance).

Q18. Which of the following has ONE valence electron?

- A. sodium**
- B. calcium
- C. carbon
- D. fluorine
- E. argon

Valence-bond theory is predicated on the octet: the fundamental desire of atoms to have 8 electrons in their outer orbital (except for H and He). Sodium has ONE electron in its outer shell, so the easiest thing is to donate that electron to chlorine, fluorine or another halogen (because they have 7 outer electrons and so exert a strong force, so to speak, on potential electron donors). Carbon has 4 valence electrons and so can make molecules like methane (CH<sub>4</sub>, sharing 4 hydrogen valence electrons) or CO<sub>2</sub> (carbon dioxide) by sharing 2 electrons with each oxygen (which has electrons and would love to share 2 from carbon).

Q19. In which instance below is the term "molecule" least apropos? 

- A. glucose molecules dissolved in water
- B. nitrogen molecules bouncing around in the air
- C. RNA molecules being read by a ribosome
- D. carbon dioxide molecules passing through a membrane
- E. NaCl molecules comprising a crystal**

The concept of molecule dates at least to John Dalton's "compound atoms" circa 1800, while the word molecule seems to have been coined by Stanislao Cannizzaro in 1860. The describing, analyzing and understanding of molecules, and their reactions, are the essence of chemistry, be those molecules glucose in water or polymers inside cells. An exception to true "molecular" behavior is found in crystalline, repeating structures, such as salt crystals, in which pairs of Na and Cl atoms are not operating as discrete molecules. The hint said that the molecule in question was "not much of a molecule in solution either, but for very different reasons". In solution, Na<sup>+</sup> and Cl<sup>-</sup> ions are not interacting (much) with one another, but rather are hydrogen-bonded to water molecules, so NaCl as a "molecule" does not really exist in solution. In the crystal shown, each sodium is surrounded by a shell of Cl, and each Cl is surrounded by a shell of Na. So here also, we do not have discrete NaCl molecules to work with or analyze.