

Pre-AP Chemistry Final Exam

Study Guide

1. Name the three subatomic particles that make up an atom.

Solution.

Protons, neutrons, and electrons

2. Which subatomic particle carries a charge of +1?

Solution.

Proton

3. Which subatomic particle carries a charge of -1?

Solution.

Electron

4. Which two subatomic particles reside in the nucleus?

Solution.

Proton and neutron

5. Briefly describe the nucleus. How much of the volume of an atom does the nucleus take up? How much of the mass of an atom does the nucleus hold?

Solution.

The nucleus takes up a tiny fraction of the volume of an atom but makes up practically all of its mass. (Less than 0.01% of the volume but more than 99.9% of the mass. You don't have to remember the exact values, just the general idea.)

6. How does the mass of a proton compare to the mass of a neutron? How does the mass of a proton compare to the mass of an electron?

Solution.

The mass of a single proton and a single neutron are practically equivalent. Electrons are much lighter than protons and neutrons. (One electron is $\sim 0.05\%$ the mass of a proton. Because of their tiny mass, electrons move at much faster speeds than protons.)

Detail: Classical physics predicts that if an electron and a proton both carry the same momentum (mass \times velocity), then the electron would be traveling about 1800 times faster than the proton. This is not a very accurate approximation because classical physics has issues approximating particles moving at size-able fractions of the speed of light.

7. The periodic table is made up of boxes with symbols that describe atoms. If you read the periodic table like a book (from left-to-right and top-to-bottom) you will notice that one of these numbers goes up by 1 each time. What is the significance of this number?

Solution.

The number which goes up by one each time is called the *atomic number*. The atomic number tells you how many protons are in the nucleus of an atom.

Details: The first element on the top left is Hydrogen. Hydrogen (H) has a nucleus with only 1 proton. The atom directly to the right of Hydrogen is Helium. Helium (He) has 2 protons in its nucleus. The next atom is Lithium (Li) which has 3 protons in its nucleus. The number of protons in the nucleus of an atom is what gives an atom its name. The reason we tend to care more about the protons in the nucleus than the neutrons is because the charge on the protons is what gives atoms their chemical properties. *Isotopes* are atoms with the same number of protons in the nucleus but different numbers of neutrons. Because neutrons are electrically neutral, they only effect the speed of reactivity (more neutrons means heavier atoms/molecules which means slightly slower reactivity). Different isotopes of the same atom tend to behave exactly the same in chemical reactions. It is for this reason that atoms get their names from the number of protons in their nucleus rather than the number of neutrons.

8. It is assumed that the atoms described on the periodic table are neutrally charged by default. If an atom is neutrally charged what does that mean about the number of protons and electrons in the atom?

Solution.

If an atom or molecule is neutral it means that there is an equal number of protons and electrons. For example, if a lithium atom has 3 protons and 3 electrons then its charge is 0.

9. If an atom or molecule has a charge of +2 (which looks like X^{2+}) then how many more protons are there than electrons?

Solution.

A charge of +2 means there are 2 more protons than electrons. For example, Be^{2+} has 4 protons and 2 electrons.

10. If an atom or molecule has a charge of -3 (which looks like X^{3-}) then how many more electrons are there than protons?

Solution.

A charge of -3 means there are 3 more electrons than protons. For example, N^{3-} has 7 protons and 10 electrons.

11. Heisenberg's uncertainty principle tells us that the act of measurement disrupts a system so that it is impossible to know the position and momentum of an electron at the same time. In other words, you can't know where an electron is and where it is going at the same time. What consequence does this have on modern scientific models which describe how electrons behave inside an atom? (Hint: when you can't know something for sure, the best way to model the information is using probability and statistics.)

Solution.

Modern models of the atom represent the position of electrons as *electron clouds*. Electron clouds are regions of space where electrons *might* exist. The more shaded regions have a higher calculated probability of containing an electron.

Nerdy Details: Scientists discovered how to calculate these probabilities by envisioning that particles propagates as waves. From this assumption, Schrodinger was able to define an equation which agrees with experimental data to a remarkable degree. Ever since, one of the major challenges of quantum physics and chemistry has been to

understand *why* the propagation of matter is better represented mathematically as waves. Some scientists believe that matter *actually* behaves as waves and the only reason why humans perceive particles is because we exist at the “object” level of reality where lots of small interactions and different timelines/pathways collapse into the perception of single moments/states. Human beings live at a resolution where cause and effect is clear, but countless pathways exist which can take the universe between one state and the next. From the perspective of a human, the pathways always collapse into a state with identifiable characteristics and locations. However, we aren’t able to tell which of the innumerable pathways were taken in order to arrive at the present state. Some really cool experiments have proven that, in fact, particles in the universe do not take “definite trajectories” in space and time **unless** they are being measured! The only way our brains can build a coherent model of reality is to compress the branching pathways into some representation which performs statistics to determine probable outcomes. Our perception is constructed so that we can see the universal features which stay consistent across branching states. It find it fun to imagine the consequences of branching brains inside of a branching universe.

12. What does an electron’s energy level tell you about its distance from the nucleus? How are electron energy levels organized on the periodic table?

Solution.

The higher an electron’s energy level, the further that electron tends to exist from the nucleus. The rows of the periodic table (called *periods*) are arranged so that each new row introduces a new energy level.

For example, in the first column (*group 1*) neutral H has the $1s^1$ electron, neutral Li has the $2s^1$ electron, neutral Na has the $3s^1$ electron (and so on). The leading numbers 1, 2, and 3 are the increasing energy levels that go up with each new row.

Details: Energy levels describe regions of space around the nucleus where electrons might be found. According to quantum chemistry, electrons can only take on certain definite values of energy which come in packets called *quanta* (quanta is plural for *quantum* which is the minimum possible amount of a given substance/property). The more energy an electron has, the less bound it is by the nucleus. This means that higher energy levels describe regions of space which are farther away from the nucleus. High energy electron occupy these high energy regions. As energy level increases, distance from the nucleus increases. As you go down the periodic table the energy level increases which means the outer electrons get further and further from the nucleus.

13. What are *valence electrons* and how are they different from *core electrons*?

Solution.

Valence electrons are the electrons in the outermost energy level. These are the electrons which are farthest from the nucleus and are free to interact between atoms. Core electrons are the electrons in the lower energy levels which are closer and more tightly bound to the nucleus. These electrons do not participate in bonding.

Extra Detail: Core electrons reduce the pull that the nucleus has on valence electrons by screening/shielding those outside electrons from the nucleus's positive charge. This effect becomes more pronounced as atoms/molecules gain more and more core electrons. This, alongside the fact that electrostatic attraction decreases with distance, is why atoms towards the bottom of the periodic table require far less energy to eject electrons (called *ionization energy*) than atoms at the top of the periodic table.

14. What are bonds and what do they have to do with valence electrons?

Solution.

Bonds are electrostatic forces which hold atoms together through interactions involving valence electrons. Complete exchange of valence electron(s) from one atom to another is called *ionic bonding*. Sharing of valence electrons between atoms is called *covalent bonding*. (Covalent bonding can either be polar or nonpolar.)

Extra Details: The reason that bonding occurs is because the overall potential energy *after* bonding is lower. Nature always tries to minimize potential energy. The more protons a nucleus has, the more strongly it pulls on outside electrons. *Electronegativity* is a description of how strongly a nucleus pulls on outside electrons. Electronegativity is determined by how many protons a nucleus has and how close an outside electron can get to that nucleus.

15. The periodic table is separated into 18 columns called *groups*. The *main group* elements are the atoms in groups 1-2 and 13-18. The periodic table is organized so that the groups correspond with a trend in valence electrons. What is the trend in valence electrons for the neutral main group elements?

Solution.

Group/Column Number	# of Valence Electrons
1	1
2	2
13	3
14	4
15	5
16	6
17	7
18	8

16. *Ions* are formed when an atom/molecule gains or loses electrons so that the number of protons and electrons in the atom/molecule are not equal. The noble gases in group 18 have 8 valence electrons and are the most stable and nonreactive elements on the periodic table. The *octet rule* tells us that atoms prefer to gain or lose electrons so that they form ions with 8 valence electrons. Draw a table that shows the common ions formed by atoms in Groups 1, 2, 13, 15, 16, and 17.

Solution.

Group/Column Number	Common Ion	# of Valence Electrons	Change from Neutral Atom
1	1+	8	Gives up 1 electron
2	2+	8	Gives up 2 electrons
13	3+	8	Gives up 3 electrons
15	3-	8	Obtains 3 extra electrons
16	2-	8	Obtains 2 extra electrons
17	1-	8	Obtains 1 extra electrons

Note: When metals give up electrons, they go from having 1, 2, or 3 valence electrons to having 8. This is because they give up all of their valence electrons in order to revert their valence shells to the previous energy level. Since the previous energy level is completely full of electrons the metal ends up with an octet! For example, when sodium (Na) gives up one electron it goes from having 1 valence electron ($3s^1$) to having the same electron configuration as Neon (which has 8 valence electrons). Particularly small

ions can end up with less than 8 valence electrons. For example H^+ has zero electrons, but is still extremely stable! It still follows the group 1 rule of losing 1 electron.

17. What ionic compound is formed between Magnesium (Mg – group 2) and Bromine (Br – group 17)?

Solution.

Magnesium is from group two and forms the ion Mg^{2+} . Bromine is from group 17 and forms the ion Br^- . Ionic compounds form so that the charge between the ions cancels out to zero. Since one Mg ion has a $2+$ charge and one Br ion has a $1-$ charge, *one* Mg ion bonds to *two* Br ions. The resulting compound is $MgBr_2$ which is neutral because the charge between 1 Mg^{2+} ion and 2 Br^- ions is $2 - 2 = 0$.

18. What neutral element has the electron configuration $1s^22s^22p^6$? Which $+1$ ion has the same configuration? Which -1 ion has the same configuration?

Solution.

Neon (Ne) is the atom on the periodic table whose terminal electron is $2p^6$. You can also count the total number of electrons from the superscripts. $2 + 2 + 6 = 10$. The atom must have 10 protons in order to be neutral, making the atom Neon.

Na^+ is the $+1$ ion with the same electron configuration. A charge of $+1$ means there must be 1 more proton than there are electrons. Na has 11 protons which is 1 more than 10.

F^- is the -1 ion with the same electron configuration. A charge of -1 means there must be 1 more electron than there are protons. F^- has 9 protons and 10 electrons (which is one more electron than there are protons).

19. A friend asks you to make her a cup of coffee using 3 teaspoons of sugar. You accidentally use 3 tablespoons instead. How many **extra** Calories does your friend consume when she accepts to drink it?

1 tablespoon : 3 teaspoons

1 tablespoon of sugar : 49 Calories

Solution.

In order to determine how many more calories our friend drinks than what she requested we want to solve the expression:

$(Calories \text{ in } 3 \text{ tbsp}) - (Calories \text{ in } 3 \text{ tsp}).$

$$Calories \text{ in } 3 \text{ tbsp} = 3 \cancel{\text{tbsp}} \times \frac{49 \text{ Cal}}{1 \cancel{\text{tbsp}}} = 147 \text{ Cal}$$

We also need to know how many Calories are in 3 teaspoons. We could do the dimensional analysis for this part, but it is easy to see the answer. Since 3 teaspoons equals 1 tablespoon and 1 tablespoon of sugar is 49 Calories then it follows that 3 teaspoons of sugar is 49 Calories.

$$147 \text{ Cal} - 49 \text{ Cal} = 98 \text{ Cal}$$

Therefore, your mistake causes your friend to drink 98 unintended Calories.

20. The gram is the most common unit for measuring mass in the chemistry lab. How does 1 gram relate to the mass of protons and neutrons?

Solution.

Because protons and neutrons have equivalent mass, scientists have named this value the *atomic mass unit* (amu). There are 6.022×10^{23} atomic mass units in 1 gram. This is exactly the reason why Avogadro's Number is 6.022×10^{23} .

For a minimal answer you could write, "there is 6.022×10^{23} protons or neutrons in 1 gram."

Details: This conversion factor is what allows us to relate the masses that we measure in the lab to the masses of individual atoms/molecules. The atomic masses on the periodic table are the same values whether you read them in amu or g/mol. It's important to be able to relate the mass of a sample to its fundamental particles. If we know what a sample is made of, then we know roughly how many protons and neutrons there are in one molecule of that sample. Molar mass allows us to perform many convenient calculations (such as finding limiting reactants).

21. Calculate the molar mass of NH₃ and use it to determine the number of moles in 25 g of the substance.

Solution.

Atom	Atomic Mass	# of Atoms in Molecule
N	14.01 g/mol	1
H	1.008 g/mol	3

$$MM_{NH_3} = (1 \times 14.01) + (3 \times 1.008) = 17.025 \text{ g/mol}$$

There are 17.025 grams in every 1 mol of NH₃. To find the number of moles in 25 grams, use the molar mass as a conversion factor (make sure that you set up your conversion so that units cancel correctly!).

$$25 \text{ g} \times \frac{1 \text{ mol}}{17.025 \text{ g}} = 1.5 \text{ mol } \text{NH}_3$$

22. Balance the following chemical reaction.



Solution.

First, we count the number of atoms on both sides of the skeleton equation.

Reactant Side	Count	Product Side	Count
Ag	1	Ag	2
NO ₃	1	NO ₃	2
H	2	H	1
SO ₄	1	SO ₄	1



We need to balance the constituents on both sides of the reaction. We place a two in front of AgNO₃ on the reactant side to balance the Ag atom. This causes NO₃ to increase to two on the left hand side as well. This works out in our favor because when we compensate by putting a 2 in front of HNO₃ on the product side of the equation we end up balancing both the NO₃ ion and the H atom. Now we can see that the reaction is balanced.

23. Molarity is a measure of the concentration of a solution where

$$\text{Molarity} = \frac{\text{mol of solute}}{\text{L of solution}}.$$

The *solute* is the substance which is being dissolved. Molarity is denoted by the unit *M* where $M = \frac{\text{mol}}{\text{L}}$. What is the **molarity** of 50 g of NaCl dissolved in 2 L of water? (Hint: Use the molar mass of NaCl to convert 50 g of NaCl to moles. Then, solve for Molarity.)

Solution.

First, we find out the molar mass of NaCl using the atomic masses provided on the periodic table.

$$MM_{NaCl} = (1 \times 22.99) + (1 \times 35.45) = 58.44 \text{ g/mol}$$

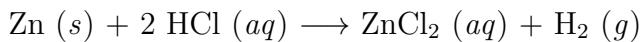
Next we figure out how many moles of NaCl are in 50 g by using the molar mass as a conversion factor.

$$50 \text{ g} \times \frac{1 \text{ mol}}{58.44 \text{ g}} = 0.86 \text{ mol NaCl}$$

The concentration of the solution is equal to 0.86 moles of NaCl divided by the number of liters of our solution (which the problem tells us is 2 L).

$$\text{Molarity} = \frac{0.86 \text{ mol}}{2 \text{ L}} = \frac{0.86}{2} \frac{\text{mol}}{\text{L}} = \boxed{0.43 \text{ M}}$$

24. Take a look at the following balanced equation:



100 g of solid Zn reacts with 2 L of 2M HCl solution. Use the coefficients of the balanced reaction as conversion factors to answer the following:

- Convert 100 g of Zn to moles, and then determine how much ZnCl₂ is produced if all of the Zn reacts.
- Convert 2 L of 2M HCl solution into moles, and then determine how much ZnCl₂ is produced if all of the HCl reacts.
- Which reactant is the *limiting reactant*?
- What is the *maximum yield* for ZnCl₂ in grams?

Solution.

- Zinc is simply an atom so molar mass is simple to find. You do not have to add up multiple atoms. The molar mass is equal to the atomic mass for Zn given by the periodic table.

$$MM_{Zn} = (1 \times 65.38) = 65.38 \text{ g/mol} \quad \underline{\text{The periodic table gives us the molar mass.}}$$

$$100 \text{ g} \times \frac{1 \text{ mol}}{65.38 \text{ g}} = 1.5 \text{ mol Zn} \quad \underline{\text{Use MM as a conversion factor.}}$$

The balanced reaction gives conversion factors between reactants and products. If there is no number before an atom/molecule in a chemical equation then that means the

coefficient is assumed to be 1. The given equation tells us that 1 mol of Zn reacts for every 1 mol of $ZnCl_2$ produced.

$$1.5 \text{ mol Zn} \times \frac{1 \text{ mol } ZnCl_2}{1 \text{ mol Zn}} = 1.5 \text{ mol } ZnCl_2$$

If all 100 g of Zn reacts then that means 1.5 mol of Zn reacts to produce 1.5 mol of $ZnCl_2$.

(b) The concentration for HCl provided by the problem tells us that there are 2 moles of HCl for every 1 liter of solution (this is what $2M$ means). The number of moles of HCl that react can be calculated by using the molarity as a conversion factor. If all 2 liters react then:

$$2 \text{ L} \times \frac{2 \text{ mol}}{1 \text{ L}} = 4 \text{ mol HCl}$$

Now we use the reaction coefficients to see how many moles of $ZnCl_2$ are produced if all 4 moles of HCl react. The balanced equation tells us that 1 mol of $ZnCl$ is produced for every 2 moles of HCl that reacts.

$$4 \text{ mol HCl} \times \frac{1 \text{ mol } ZnCl_2}{2 \text{ mol HCl}} = 2 \text{ mol } ZnCl_2$$

If all 2 liters of HCl solution reacts then that means 4 mol of HCl reacts to produce 2 mol of $ZnCl_2$.

(c) Zn is the limiting reactant. Zn will be depleted once 1.5 mol of $ZnCl_2$ is produced. There will not be enough Zn to react all of the initial HCl.

Details: The *limiting reactant* is the reactant which runs out first. This is determined by two factors – (1) how fast each reactant is used up in the reaction, and (2) how much of each reactant there is at the start of the reaction. Steps (a) and (b) are an example of the most reliable method for determining a reaction's limiting reactant. You first convert the given quantities of your reactants into moles. Then you use the reaction coefficients as conversion factors to convert between moles of products and reactants. The reactant which reacts to produce the *least* amount of the specified product is the limiting reactant.

In summary, a reaction begins with a certain quantity of reactants. The reaction proceeds by converting reactants into products until the limiting reactant runs out. The limiting reactant is the reactant depleted *quickest* by the reaction. To find the limiting reactant, find the reactant which – from its starting amount – converts to the *least* amount of a specified product (according to the reaction coefficient conversion factors).

(d) *Details:* The *maximum yield* is the amount of product that can be produced if a reaction is 100 percent efficient at converting all of its limiting reactant. We know that the limiting reactant in our problem can react to produce 1.5 mol of ZnCl₂. This value is the maximum yield in moles, but the problem asks for it in grams. We simply need to find the molar mass of ZnCl₂ using the periodic table and convert from moles to grams.

$$MM_{ZnCl_2} = (1 \times 65.38) + (2 \times 35.45) = 136.28 \text{ g/mol}$$

$$1.5 \text{ mol } ZnCl_2 \times \frac{136.28 \text{ g}}{1 \text{ mol}} = 204.4 \text{ g } ZnCl_2$$

Therefore, based on the reaction and its starting conditions, the maximum yield for ZnCl₂ is 204.4 g.

25. What is electronegativity? How does electronegativity change as the number of protons in the nucleus increases? How does electronegativity change as the energy level of the valence electrons increases?

Solution.

Electronegativity is a measure of how strongly a nucleus pulls on valence electrons.

As the number of protons in the nucleus increases, the positive charge builds up which causes electronegativity to increase (more positive charge means stronger pull on negative electrons).

As energy level increases, the distance between the nucleus and valence electrons increases. This causes electronegativity to decrease because the pull from the positive nucleus trails off as distance increases (like a magnet).

26. What is the trend for electronegativity from left to right across a row (period) on the periodic table? What is the trend for electronegativity from the top to the bottom of a column (group) on the periodic table?

Solution.

Electronegativity increases as you go from left to right across a period.

Electronegativity decreases as you go from the top to the bottom of a group.

Details: Across a single row the valence electrons are all roughly the same distance from the nucleus (they have the same energy level) so distance doesn't have an effect. As you go down a column, energy level increases which increases the distance between the valence electrons and the nucleus. This turns out to be a larger effect than the increase in protons which also occurs (remember, in coulomb's law distance is squared).

27. When two atoms are bonded, the bond is *polar* (that is, there is a positive pole and a negative pole) if there is a significant difference in electronegativity between the atoms. Take the two molecules Cl_2 and NaCl . Identify which is polar and which is non-polar and explain your reasoning.

Solution.

Cl_2 is non-polar because the two atoms that are bonded are the same. The two atoms have the same electronegativity and therefore share atoms equally (no pole is formed).

NaCl is strongly polar. It is easy to tell that Na and Cl have a large difference in electronegativity because they are at separate ends of the same row on the periodic table.

Detail: NaCl is so electronegative it is, in fact, *ionic* (Na gives Cl complete control over its $3s^1$ electron).

28. The procedure for drawing a lewis diagram is as follows:

Step 1: Count the total number of valence electrons in the molecule including electrons lost or gained due to charge (if the atom/molecule is an ion).

Step 2: Connect the center atom (generally the least electronegative atom – often it is obvious) to the outside atoms using single bonds. Keep track and subtract 2 electrons from the total for each bond placed during this step.

Step 3: Use remaining electrons to add lone pairs to each of the outside atoms until they all have octets (remember, a bond counts for 2 electrons when counting for valence electrons). *Hydrogen atoms do not take on lone pairs and can only form one single bond.*

Step 4: Any remaining electrons go on the central atom.

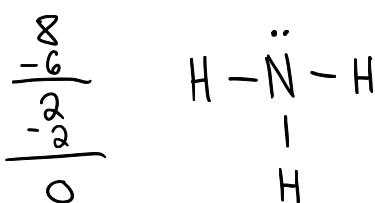
Step 5: If any atom still does not have an octet, a lone pair can be shifted from an outside atom to form a double bond with the central atom. If needed this could be done once more to form a second double bond or a triple bond.

Step 6: Count and label formal charge for any atom which is not neutral.

Draw NH_3

atom	group	valence electrons
N	15	5
H	1	1
H	1	1
H	1	1

Total: 8



First, I added single bonds between the atoms. Three single bonds used up 6 electrons. Hydrogens don't accept lone pairs. We place the remaining two electrons on Nitrogen which fulfills its octet. Hydrogen atoms do not form octets because they form only one single bond.

Bonus 1: Draw the lewis structure for CN^- .

Bonus 2: Draw the lewis structure for $(\text{SO}_3)^{2-}$.

Bonus 3: When provided with an image of a model, be able to identify the name of its molecular geometry. It might be linear, trigonal planar, bent, tetrahedral, or trigonal pyramidal. An extra bonus will be given if you can tell whether or not the given molecule is polar or non-polar.