Answers to Review #2: Atomic Theory, Periodic Table and Chemical Bonding

1. **Definitions:**

a) **Atom:** The smallest unit of matter that we study in "everyday" chemistry. The smallest unit of matter that has the properties of an element.

b) **Nucleus:** the dense centre region of an atom. It contains the protons and neutrons (if there are any).

c) **Proton:** a sub-atomic particle that is found it nucleus of an atom. Protons have a charge of 1+ and a mass of 1 amu.

d) **Neutron:** a sub-atomic particle that is found in the nucleus of an atom. Neutrons have no charge and have a mass of 1 amu.

e) **Electron:** a sub-atomic particle that is found in the space around the nucleus of an atom. Electrons have a charge of 1- and almost no mass (about 1/2000 of an amu).

f) **Atomic number:** the number of protons in the nucleus of an atom. It is the atomic number that defines the identity of the atom.

g) **Mass number:** the number of protons plus the number of neutrons in the nucleus of an atom. This gives us a rough idea of the mass of the atom.

h) **Isotope:** an atom that has the same atomic number but different mass number than another atom of the same element. Isotopes have the same chemical and physical properties as all other atoms of that element.

i) **Radio-isotope**: an isotope with an unstable nucleus that tends to break down by nuclear decay. The nucleus divides to release energy and/or particles.

j) **Alpha-decay**: when a radio-isotope breaks down to release an alpha particle (a helium nucleus), another particle and energy

eg. $${}^{209}_{84}\text{Po} \longrightarrow {}^{205}_{82}\text{Pb} + {}^{4}_{2}\text{He}^{2+}$$

k) **Beta-decay**: when a radio-isotope breaks down to release a beta particle (a high-speed electron), another particle and energy

eg. $${}^{14}_{6}\text{C} \longrightarrow {}^{14}_{7}\text{N} + {}_{1-}\text{e}$$

l) **Metal:** any element that is found on the left-hand side of the staircase line on the Periodic Table; tends to lose electrons to form positively charged ions.

m) **Non-metal:** any element that is found on the right-hand side of the staircase line on the Periodic Table; tends to gain or share electrons to complete a stable octet electron arrangement.

n) **Metalloid:** an element that is found close to the staircase line on the Periodic Table and has properties of both metals and non-metals.

o) **Electron Configuration:** a way of showing where the electrons are found in an atom. Includes the number of electrons found in each quantum level of the atom, arranged in order from lowest to highest energy.

p) **Orbital:** a region in three-dimensional space around the nucleus of an atom where there is a 90% probability that an electron will be found. Each orbital can hold a maximum of two electrons, with opposite spin. (**an orbital is not the same as an orbit!! An orbit is a defined and predictable path that an object follows. Electrons do not follow any kind of orbit- they just have regions where they are likely to be found- 90% of the time)

q) **Chemical groups:** the vertical columns on the Periodic Table. All of the elements in a chemical group have the same number of valence electrons (electrons in their outer shell) and for this reason, all of the members of a chemical group have similar chemical and physical properties.

r) **Chemical period:** the horizontal rows on the Periodic Table. All of the elements in a chemical period have their valence electrons in the same principal energy level (quantum level).

s) **Isoelectronic:** atoms and ions that are isoelectronic have the same electron configuration. Usually atoms gain or lose electrons to form a stable octet electron arrangement, this makes the ions that form isoelectronic with Noble gases.

t) **Halogen:** the Halogen Family is the common name for the Group VII B elements. The Halogen Family includes fluorine, chlorine, bromine, iodine and astatine.

u) **Alkali Metal:** the Alkali Metals is the common name for the Group I elements. The Alkali Metals include lithium, sodium, potassium, rubidium, cesium and francium.

v) **Alkaline Earth Metal:** the Alkaline Earth Metals is the common name for the Group II elements. The Alkaline Earth Metals include beryllium, magnesium, calcium, barium and radium.

w) **Noble Gas:** the Noble Gases is the common name for the Group VIII elements. The Noble gas elements have a full outer electron shell (stable octet electron arrangement) and include the elements: helium, neon, argon, krypton, and radon.

x) **Shielding Effect**: the number of electrons in the full electron shells between the valence electrons and the nucleus. These electrons essentially "shield" the valence electrons so they can not get closer to the nucleus. Shielding effect is constant across each period, but increases down each group. As shielding effect increases, the attraction between the nucleus and valence electrons decreases.

y) **Net Nuclear Attraction** (Zeff or Effective nuclear charge): this is the "real" or true attraction between the nucleus and the valence electrons. It is defined as the nuclear charge (atomic number) minus the shielding effect. Net nuclear attraction increases from left to right across each period because the nuclear charge increases but the shielding effect remains constant. As net nuclear attraction increases, the attraction between the nucleus and the valence electrons increases.

z) **Ionization Energy:** the amount of energy that is required to remove an electron from an atom in its gaseous state. Ionization energy increases as net nuclear attraction increases, and decreases as shielding effect increases.

aa) **Electronegativity:** a measure of the attraction that an atom has for the electrons ***in a bond***. Electronegativity increases as net nuclear attraction increases, and decreases as shielding effect increases.

bb) **Atomic Radius:** a measure of the distance from the nucleus to the outermost electron of an atom. Atomic radius decreases as net nuclear attraction increases, and increases as shielding effect increases.

cc) **Chemical bond:** the force of attraction between two atoms that occurs when atoms exchange or share electrons to complete a stable octet electron arrangement. A chemical bond results in the atoms being held close together to form a molecule. Chemical bonds are forces of intra-molecular attraction.

dd) **Octet rule:** atoms tend to gain, lose or share their valence electrons to achieve a full outer electron shell (often the full outer electron shell contains eight electrons).

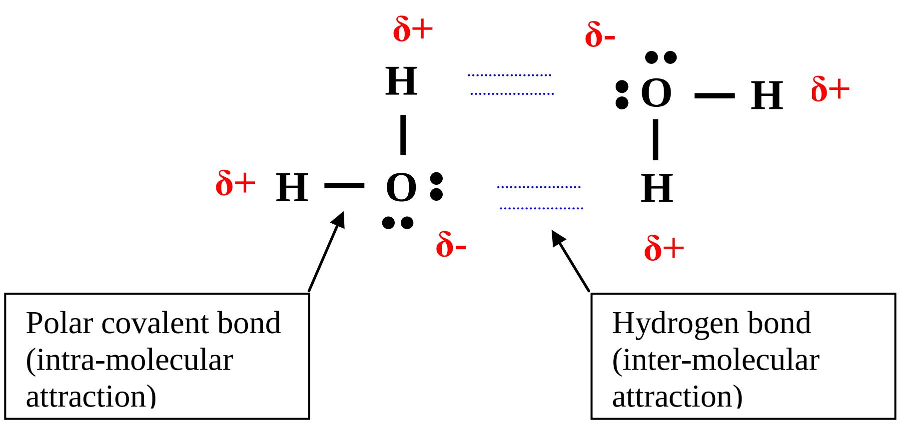
ee) **Ionic bond:** the electro-static attraction between positively and negatively charged atoms. The difference in electronegativity between the two bonding atoms is greater than 1.70.

ff) **Covalent bond:** the force of attraction between two atoms when they share electrons to complete a stable octet arrangement. The difference in electronegativity between the two bonding atoms is less than or equal to 1.70.

gg) Non-polar (pure) covalent bond: the force of attraction between two atoms when they share electrons to complete a stable octet electron arrangement. The difference in electronegativity between the two bonding atoms is less than 0.60, so the electrons are shared essentially equally between the two atoms.

hh) Polar covalent bond: the force of attraction between two atoms when they share electrons to complete a stable octet electron arrangement. The difference in electronegativity between the two bonding atoms is greater than, or equal to 0.60 and less than 1.70. The electrons are unequally shared between the bonding atoms- they are pulled closer to the more electronegative atom which results in this atom having a slight negative charge (δ -) while the less electronegative atom has a slight positive charge (δ +).

ii) Hydrogen bonding: is a force of inter-molecular attraction; that is, it is an attraction between partially charged regions on adjacent molecules. It is not a true chemical bond. When molecules contain hydrogen bonded to nitrogen, oxygen or fluorine (NOF), the bonded electrons are strongly shifted away from the hydrogen atom and strongly attracted toward the small, strongly electronegative N, O or F atoms. This shifting of electrons creates strong δ+ and δ– regions on the molecule, and these partial charges are strongly attracted to the δ+ and δ– regions on adjacent molecules. The inter-molecular attraction BETWEEN adjacent molecules is called hydrogen bonding.



jj) Inter-molecular attraction: the attraction between adjacent molecules because of fully or partially charged regions on the molecules.

kk) Intra-molecular attraction: the attraction between atoms within a molecule because the bonding electrons are simultaneously attracted to the nuclei of two different atoms. Intra-molecular attraction is another name for chemical bonds, either ionic or covalent bonds.

2. Complete the following chart:

Element symbol	Atomic Number	Mass Number	Number of Neutrons	Number of Electrons in Neutral Atom	Ionization Reaction	Ion and its charge	Number of Electrons in Ion
Ag	47	108	61	47	$Ag \rightarrow Ag^{1+} + e^-$	Ag^{1+}	46
Ca	20	40	20	20	$Ca \rightarrow Ca^{2+} + 2e^-$	Ca^{2+}	18
Cl	17	35	18	17	$Cl + e^- \rightarrow Cl^{1-}$	Cl^{1-}	18
Ar	18	40	22	18	does not ionize	N/A	N/A
K	19	39	20	19	$K \rightarrow K^{1+} + e^-$	K^{1+}	18
Ag	47	107	60	47	$Ag \rightarrow Ag^{1+} + e^-$	Ag^{1+}	46
Zn	30	65	35	30	$Zn \rightarrow Zn^{2+} + 2e^-$	Zn^{2+}	28
Cu	29	63	34	29	$Cu \rightarrow Cu^{1+} + e^-$	Cu^{1+}	28
Se	34	79	45	34	$Se + 2e^- \rightarrow Se^{2-}$	Se^{2-}	36
Br	35	80	45	35	$Br + e^- \rightarrow Br^{1-}$	Br^{1-}	36

3a) Referring to the chart above (in Q2) , the ions and atoms that are isoelectronic (have the same electron arrangements) with each other are:

- Ca-40, Cl-35, Ar-40 and K-39. They all have 18 electrons.
- Ag-108 and Ag-107. They both have 46 electrons.
- Zn-65, and Cu-63. They both have 28 electrons.
- Se-79 and Br-80. They both have 36 electrons.

3b) Referring to the chart above (in Q2), the ions and atoms that are isotopes (have the same atomic number but different mass numbers) are:

- Ag-107 and Ag-108

4. The chemical properties of an element are determined by the arrangement (configuration) of the electrons, and in particular, by the number and arrangement of an atom's valence electrons.
5. The electrons are attracted to the nucleus of an atom by electrostatic attraction. The negatively charged electrons are attracted to the positively charged protons in the nucleus of the atom.
6. As an electron moves further away from the nucleus of an atom, the potential energy of the electron increases.
7. For the atom U-238, the number 238 represents the mass number of the atom. Uranium atoms have 92 protons, so a U-238 atom must have (238 – 92) equals 146 neutrons.
8. The electron configurations for the following elements are:

$_{30}Zn$ $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10}$

$_{18}Ar$ $1s^2 2s^2 2p^6 3s^2 3p^6$

$_{47}Ag$ $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^9$

$_{53}I$ $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5$

9. Ions or atoms that are isoelectronic with a Ca^{2+} ion are: P^{3-} , S^{2-} , Cl^{1-} , Ar, K^{1+} , Sc^{3+}
   - these same ions and atoms are also isoelectronic with P^{3-} (they all have 18 electrons)

10. Use the concepts of net nuclear attraction and shielding effect to explain why:

a) atomic radius decreases from left to right across each period on the periodic table

- across each period, the shielding effect is constant so it has no effect on atomic radius (there are the same number of electrons in the full shells between the nucleus and the valence electrons)
- as you move from left to right across each period, the net nuclear attraction increases so there is a stronger attraction between the nucleus and the valence electrons
- the stronger net nuclear attraction pulls the valence electrons in closer to the nucleus, so atomic radius decreases as you go further to the right

b) electronegativity increases from left to right across each period on the periodic table (except Noble gases)

- across each period, the shielding effect is constant so it has no effect on electronegativity (there are the same number of electrons in the full shells between the nucleus and the valence electrons)

- as you move from left to right across each period, the net nuclear attraction increases so there is a stronger attraction between the nucleus and the valence electrons and a stronger attraction for new electrons (except for the Noble gases which have a full valence shell)
- the stronger net nuclear attraction means that there is a stronger attraction for the electrons in a bond, so these bonded electrons are pulled more tightly toward the atom with higher net nuclear attraction, which gives the atom higher electronegativity

c) metals become more reactive down each Group

- metals react by losing valence electrons to achieve a more stable electron arrangement, so the more easily an atom can lose electrons, the more reactive it will be
- down each group, the net nuclear attraction is constant, so there is the same "real pull" between the nucleus and the valence electrons
- down each group, the shielding effect increases which means that the valence electrons move further and further from the nucleus
- as the distance between the nucleus and the valence electrons increases, the valence electrons are less attracted to the nucleus so they are more easily lost, which makes metals more reactive

d) non-metals become less reactive down each Group

- non-metals (except the Noble gases) react by gaining valence electrons to achieve a more stable electron arrangement, so the more easily an atom can gain electrons, the more reactive it will be
- down each group, the net nuclear attraction is constant, so there is the same "real pull" between the nucleus and the valence electrons
- down each group, the shielding effect increases which means that the valence electrons move further and further from the nucleus
- as the distance between the nucleus and the valence electrons increases, the valence electrons are less attracted to the nucleus so it is harder for the atom to attract new electrons, which makes non-metals less reactive

11. The trends on the Periodic Table for the following characteristics are:

a) Ionization energy:

- increases from left to right ($\longrightarrow$)
- decreases as you move down the groups (electrons are easier to remove as you move down a group)

b) Atomic Radius:

- decreases from left to right ($\longrightarrow$)
- increases as you move down the groups

c) Electronegativity:

- increases from left to right ($\longrightarrow$)
- decreases as you move down the groups (larger atoms have a weaker attraction for the electrons in a bond)

d) Reactivity of Metals:

- reactivity of metals increases as you move down a group (easier to lose an electron)
- reactivity of metals decreases as you move from left to right ($\longrightarrow$) because electrons are more difficult to remove

e) Reactivity of Non-Metals:

- reactivity of non-metals decreases as you move down a group (harder to gain an electron)
- reactivity of non-metals increases as you move from left to right (⟶), except for the Noble Gases, because electrons are being attracted more strongly

f) Metallic Characteristics:

- metallic character increases as you move down a group
- metallic character decreases as you move from left to right (⟶)

12. Complete the following chart comparing the different chemical groups:

Common Name of Group	**Alkali Metals**	**Alkaline Earth Metals**	**Halogens**
Group #	Group I	Group II	Group VII
Elements in the Group	Li, Na, K, Rb, Cs	Be, Mg, Ca, Ba, Ra	F, Cl, Br, I, At
Number of valence electrons?	1	2	7
Metals or non-metals?	metals	metals	non-metals
What is the last term in the electron configuration?	s^1	s^2	p^5
Will these elements tend to gain or lose electrons?	lose	lose	gain
In water, will these elements produce acid or basic solutions?	basic phenolphthalein will turn pink; bromothymol blue will turn blue; red litmus will turn blue	basic phenolphthalein will turn pink; bromothymol blue will turn blue; red litmus will turn blue	acidic phenolphthalein will stay colourless; bromothymol blue will turn yellow; blue litmus will turn red

13. Answer the following questions about quantum levels and electron orbitals:

a) How is an orbital different from an orbit?

An **orbit** is a predictable, defined, often circular path that an object follows as it moves around another object. An **orbital** is a region in three-dimensional space around the nucleus of an atom where there is a 90% probability that an electron will be found. Orbitals are not predictable or very well defined. Each orbital can hold a maximum of two electrons, with opposite spin. Electrons do not follow any kind of orbit- they just have regions where they are likely to be found- 90% of the time.

b) For n=1, What is the maximum number of electrons in this principle quantum level? $\mathbf{2n^2 = 2}$

How many orbitals are there? $\mathbf{n^2 = 1}$

How many types of orbitals are there? **n = 1** type of orbital named **1s**

c) For n=2, What is the maximum number of electrons in this principle quantum level? $\mathbf{2n^2 = 8}$

How many orbitals are there? $\mathbf{n^2 = 4}$

How many types of orbitals are there? **n = 2** types of orbital named **2s and 2p**

d) For n=3, What is the maximum number of electrons in this principle quantum level? $\mathbf{2n^2 = 18}$

How many orbitals are there? $\mathbf{n^2 = 9}$

How many types of orbitals are there? **n = 3** types of orbital named **3s, 3p and 3d**

e) For n=4, What is the maximum number of electrons in this principle quantum level? $\mathbf{2n^2 = 32}$

How many orbitals are there? $\mathbf{n^2 = 16}$

How many types of orbitals are there? **n = 4** types of orbital named **4s, 4p, 4d and 4f**

14. What is the maximum number of electrons that can be designated (held in): 3s holds 2, 2p holds 6, 4d holds 10, 1s holds 2, 4f holds 14, 6s holds 2, 3d holds 10, 5p holds 6

15. Write the balanced nuclear reactions to show the:

a) alpha decay of U – 238

$$^{238}_{92}\mathbf{U} \longrightarrow {}^{234}_{90}\mathbf{Th} + {}^{4}_{2}\mathbf{He}^{2+}$$

b) alpha decay of Am-243

$$^{243}_{95}\mathbf{Am} \longrightarrow {}^{239}_{93}\mathbf{Np} + {}^{4}_{2}\mathbf{He}^{2+}$$

c) beta decay of I-131

$$^{131}_{53}\mathbf{I} \longrightarrow {}^{131}_{54}\mathbf{Xe} + \mathbf{e}_{1-}$$

d) beta decay of C-14

$$^{14}_{6}\mathbf{C} \longrightarrow {}^{14}_{7}\mathbf{N} + \mathbf{e}_{1-}$$

16. Canada is proposing to build more nuclear reactors to generate electricity to replace old thermal generating stations that burn coal, oil or natural gas. Give three advantages and three disadvantages of using nuclear reactors. See text pages 34-35.

Some Advantages of Nuclear Power	Some Disadvantages of Nuclear Power
• relatively small amounts of uranium can produce very large amounts of energy, so transportation of fuel is less expensive and less polluting than moving tonnes and tonnes of coal • does not generate carbon dioxide, so does not contribute to global warming • does to contribute to acid rain • can be built close to where the power is needed, so electricity does not need to transported over long distances, which is expensive and inefficient	• mining and handling uranium ore to fuel the reactors is dangerous for workers • creates nuclear wastes that are extremely radio-active and will last for thousands of years • long term storage of nuclear wastes is problematic • radio-active wastes may be used to make nuclear warheads and bombs • requires huge volumes of cold water to cool the reactor, so they must be built close to large bodies of water. When waste water is pumped back into the lake or ocean, it causes thermal pollution which may upset the ecosystem

17. What is the difference in electronegativity (ΔEN) between bonding atoms in:
ionic bonds: >1.70
non-polar covalent bonds: <0.60
polar covalent bonds 0.60 – 1.70

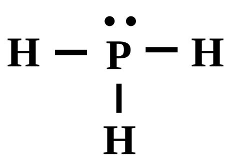
18. Complete the following chart for the shapes of covalent molecules:

Shape Code	Name of Shape	Is this SHAPE Symmetrical or Asymmetrical?
AX_2E_0	linear	the shape is symmetrical
AX_3E_0	trigonal planar	the shape is symmetrical
AX_2E_1	V-shaped or bent	the shape is asymmetrical
AX_4E_0	tetrahedral	the shape is symmetrical
AX_3E_1	trigonal pyramidal	the shape is asymmetrical
AX_2E_2	V-shaped or bent	the shape is asymmetrical

19. For each of the covalent compounds below:

- draw their 'stick diagrams' (Lewis structures), including all lone pairs (LP) of electrons
- write the shape code
- write the name of the shape
- determine the symmetry of the molecule, considering BOTH its shape and bonded atoms
- calculate the ΔEN of all bonds
- considering BOTH the symmetry of the molecule and the polarity of the bonds, determine the overall polarity of the molecule as non-polar, slightly polar or very polar

a) PH_3

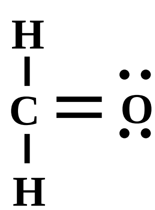


shape code: AX_3E_1
name of shape: trigonal pyramidal
symmetry: asymmetrical
ΔEN: $|2.20 - 2.19| = 0.01$
overall polarity: asymmetrical with non-polar bonds
∴ slightly polar

b) CO_2

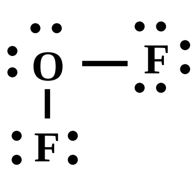
shape code: AX_2E_0
name of shape: linear
symmetry: symmetrical (shape and atoms)
ΔEN: $|3.44 - 2.55| = 0.89$
overall polarity: symmetrical ∴ non-polar

c) CH_2O



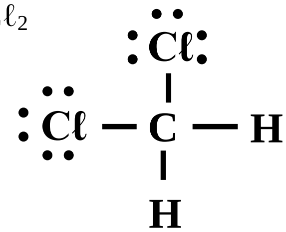
shape code: AX_3E_0
name of shape: trigonal planar
symmetry: symmetrical shape BUT asymmetrical atoms ∴ **asymmetrical** overall
ΔEN: C – H: $|2.55 - 2.20| = 0.35$
C – O: $|2.55 - 3.44| = 0.89$
overall polarity: asymmetrical with polar bonds
∴ very polar

d) OF_2



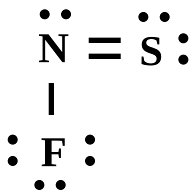
shape code: AX_2E_2
name of shape: V-shaped or bent
symmetry: asymmetrical
ΔEN: $|3.98 - 3.44| = 0.54$
overall polarity: asymmetrical with polar bonds
∴ very polar

e) $CH_2C\ell_2$



shape code: AX_4E_0
name of shape: tetrahedral
symmetry: symmetrical shape BUT asymmetrical atoms ∴ **asymmetrical** overall
ΔEN: C – H: $|2.55 - 2.20| = 0.35$
C – Cℓ: $|2.55 - 3.16| = 0.61$
overall polarity: asymmetrical with polar bonds ∴ very polar

f) NSF



shape code: AX_2E_1
name of shape: V-shaped or bent
symmetry: asymmetrical
ΔEN: N – S: $|3.04 - 2.58| = 0.46$
N – F: $|3.04 - 3.98| = 0.94$
overall polarity: asymmetrical with polar bonds ∴ very polar

20. Referring to the molecules in question 19:

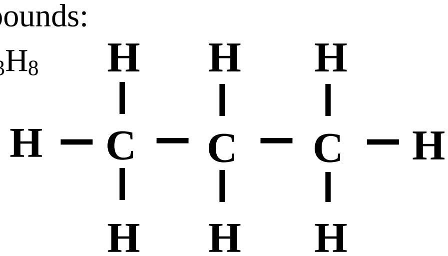
a) which compound will have the lowest melting point? Explain why.
- CO_2 will have the lowest melting point because it is non-polar
- non-polar molecules have essentially no charges, so there are no significant forces of inter-molecular attraction
- inter-molecular attraction is very, very weak so the molecules are not attracted to one another so it will take very little energy to separate the molecules from one another, so melting point will be extremely low (CO_2 is a gas at SATP)

b) which compound will have the highest melting point? Explain why.
- NSF will probably have the highest melting point because it is very polar and has the highest ΔEN
- the molecule will have significant partial charges on the N – F bond
- the δ– charge on the F atom of one molecule will be attracted to the δ+ on the N atom of adjacent molecules
- it will take a great deal of energy to overcome the strong inter-molecular attraction between molecules so the melting point of NSF will be quite high

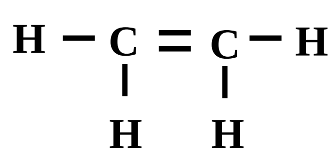
c) which compound will be the least soluble in water? Explain why.
- CO_2 will be the least soluble in water because it is non-polar
- non-polar molecules have essentially no charges, so there are no charges to be attracted to the δ– and δ+ charges on polar water molecules
- because the uncharged CO_2 molecules are not significantly attracted to the charged water molecules, very little CO_2 will dissolve in water

21. Draw the stick diagrams (Lewis structures), including all lone pairs (LP), for the following covalent compounds:

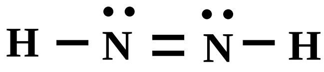
a) C_3H_8



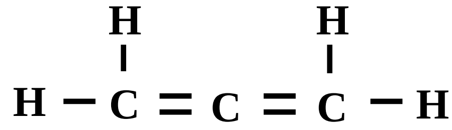
e) C_2H_4



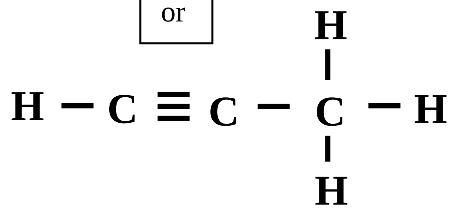
b) N_2H_2



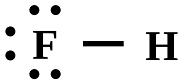
f) C_3H_4



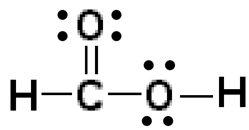
or



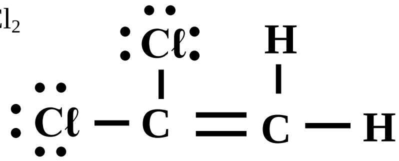
c) HF



d) CHOOH



g) $C_2H_2Cl_2$

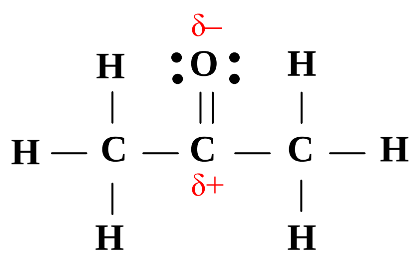


Cℓ and H atoms can go on either carbon atom

22. Referring to the covalent compounds in questions 19 and 21, write the chemical formulas for all of the compounds that are able to hydrogen bond.
    - N_2H_2, HF and CHOOH can hydrogen bond because these molecules have a hydrogen atom bonded to either N, F or O

23. A molecule of acetone is drawn to the right.
    a) this molecule is asymmetrical (there is a C = O bonded to only one side of the molecule)
    b) ΔEN:

C – H:	|2.55 – 2.20|	= 0.35
C – O:	|2.55 – 3.44|	= 0.89
C – C:	|2.55 – 2.55|	= 0.00



b) The molecule is asymmetrical and has a polar bond, so the overall polarity is **very polar**
c) Label any full or partial charges on the molecule.
d) Can this molecule hydrogen bond? **NO!!**
(hydrogen is not bonded to the oxygen atom)
e) Predict three physical properties of acetone.
Acetone is covalent and very polar so it will:
- be very soluble in water
- have a medium melting point
- be liquid at SATP
- have an odour
- not conduct in pure form
- not conduct in solution with water

24. Compare the physical properties of acetone (drawn in question 23) and propane (C_3H_8, drawn in question 21).
Acetone is very polar while propane is symmetrical and non-polar therefore:
- acetone is soluble in water while propane is not
- acetone has a medium melting point while propane has a very low melting point
- acetone is liquid at SATP while propane is a gas at SATP
- both compounds have odours
- neither compound will conduct in its pure form or in solution with water