1 Cognitive reasoning in the chemical sciences 6.6

1. The reaction of solid sulfur and aqueous nitrate ions under acidic conditions produces sulfite and nitrogen gas according to the unbalanced equation

$$S_8 + NO_3^- \longrightarrow SO_3^{2-}(aq) + NO(g)$$

   18.03 g of NO is produced when 45.12 g of NO_3^- is reacted with 30.3 g of sulfur. In the lab, this reaction produces What is the percent yield of this reaction?

2. Earth has a circumference of 40,000 km. The ocean occupies $\frac{3}{4}$ of the Earth's surface and is on the average $2\frac{1}{2}$ miles deep. Assume the density of water is the same whether the water is at the bottom of the sea or at sea level and that seawater has the same density as fresh water. To one significant figure, and within a factor of 20% of the true answer, calculate the new atmospheric pressure of the Earth if all the water in the sea were to boil. (Please note the *unit* 1 atm pressure is defined to be 760 mm Hg, and Hg has the density of 13 g/mL.) Assume no water leaves the Earth's atmosphere. Please base your answer solely on numbers given above.

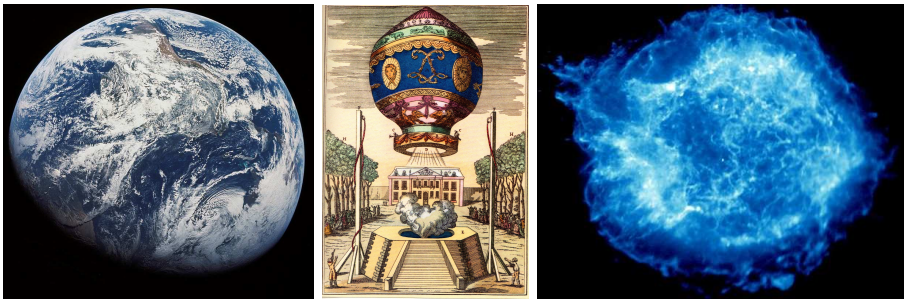


Figure 1: the Earth, the original Montgolfier ballon, and Caseopeia A, which surrounds a neutron star

3. The original Montgolfier balloon, built in 1783, was a hot air balloon with fixed volume but with a hole in the bottom by which air could enter or leave the balloon. It was a simple hole without any mechanical device. On a beautiful early fall day when it was 25 ^{o}C outside, the air in the balloon was heated to 55^{o}C. Louis XVI and Marie-Antoinette observed the balloon's ascent.

   To one significant figure, by what percent had the *density* of the air inside the rising heated balloon been reduced compared to the air in the garden outside the balloon? To one significant figure, what was the *pressure* inside the balloon compared to the air outside? Please show your work.

4. So far, astronomers have identified 2000 neutron stars. A neutron star can be thought of as a nucleus of macroscopic dimensions. It can be thought of as a huge single nucleus composed entirely of neutrons. The density of the neutron star, to one significant figure, is the same as ordinary atomic nuclei.

   Based on the above knowledge and on the knowledge (1) that the nucleus of an atom has a radius 10^{-4} to 10^{-5} times smaller than an atom and (2) that closest-packed metals have denisities between 5-20 g/mL, estimate to within two orders of magnitude of the correct answer, the true density of neutron stars in g/mL. For credit, please show your work and briefly explain your thinking.

5. Please deduce the π-MO diagram of ozone. Ozone is O_3, a molecule with no rings of bonded atoms.

6. Please now consider the ion, AtH_2^-.

   (a) Starting from the atomic orbitals, and using the left-to-right construction method for MO diagrams, please deduce the MO diagram of AtH_2^-.

(b) Please make a self-consistent Rosetta Stone diagram for this ion. The bond orders should be the same in *all* three panels of your Rosetta Stone diagram. (Note that it is OK if in an individual Lewis resonance structure the molecule looks to have come apart as long as in all the resonance structures taken together, net bonding between the atoms in question actually still is present.)

7. For each of the following molecules, please draw the lowest energy way that you can envision for two of the same molecule to approach one another. Use dotted lines to indicate intermolecular attractions. To receive credit, you must show the correct shape of the actual molecules. *It may help to draw Lewis structures for each of the three molecules.*

   Please state the name of the intermolecular interactions which you are portraying in each of your answers. State also which of the three molecules has the **strongest** and which has the **weakest** intermolecular interactions. For credit please briefly explain your reasoning.

   (a) CH_2O

   (b) CO_2

   (c) CSe_2, a molecule with a similar covalent bonding pattern as carbon dioxide.

8. Please draw plausible molecular shapes for the extended solids given below. Please provide sufficient details to your picture so that the reader of the answer can deduce (1) the number of bonds that each atom type makes, (2) the type of atom that each atom is bonded to, and (3) the molecular shape of any covalently bonded molecular ion contained within the overall extended solid structure.

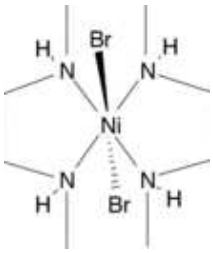
   (a) KNO_3, one of the three ingredients of gun powder.

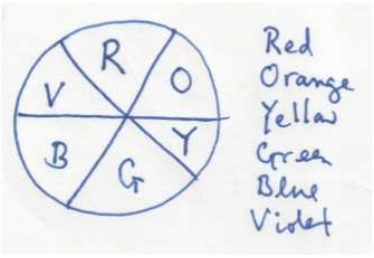
   (b) GaS. There are no Ga-Ga or S-S bonds within this structure and all gallium atoms have a formal charge of Ga^{-1}.

9. The following problems require use of the spectrochemical series, the series which determines the interaction strrength between ligand and metal atom,

$$CO \approx CN^- > NO_2^- > en > NH_3 > H_2O > OH^- > F^- > Cl^- > Br^- > I^-.$$

   (a) Please derive the *d*-orbital energy diagram for the low spin $NiBr_2(NH_3)_4$ molecule shown below. In making your diagram, please assume the z-axis points along a Br-Ni bond.





   (b) Four vials each containing one of the three compounds $Cr(H_2O)_6^{3+}$, $Cr(H_2O)_5Cl^{2+}$, and $Cr(H_2O)_4Cl_2^+$ are blue-green, green and violet. Which compound is in which vial?

   (c) Which compound is more likely to be high spin of the two $Co(H_2O)_6^{2+}$ or $Co(NH_3)_6^{2+}$?

   (d) Which compound is more likely to be high spin of the two $Co(H_2O)_6^{2+}$ or $Co(H_2O)_6^{3+}$?

   (e) One of the two componds, $Co(NH_3)_6^{3+}$ and CoF_6^{3-} is paramagnetic, the other diamagnetic. Which one is which?