Chemistry 31A Autumn 2007
Professor Chidsey
Due at 1:15 pm on Monday 10/1/2007
Problem Set 1

1. How many protons, neutrons and electrons are there in the carbonate dianion, $^{13}C^{18}O_3^{2-}$**?**

2. Professor Chidsey and his wife were looking to refinance their house. One lender was offering a 15-year mortgage at an interest rate of 5.75% per year. This is equal to:

(choose one) (i) $5.75(year)^{-1}$ (ii) 21.0days (iii) 0.0575 (iv) $1.82x10^{-9}s^{-1}$

3. A hydrogen-powered fuel-cell car would require about 25kg of H_2 to be stored in an on-board tank to offer an acceptable distance of travel between fuelings. All the electrons are stripped from the hydrogen in the fuel cell and are forced to flow through the electric motor that drives the wheels before being deposited into oxygen molecules from air. The protons are separately delivered to the oxygen molecules such that the only exhaust from the fuel cell is H_2O. How many electrons are in 25kg of H_2?

(choose one) (i) 0.025Mmol (ii) $1.5x10^{27}$ (iii) 25,000 (iv) $25kmol^{-1}$

4. Spencer problem 2-35

Calculate the number of water molecules that can be prepared from 500 H_2 molecules and 500 O_2 molecules.

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$$

What would happen to the potential yield of water molecules if the amount of O_2 were doubled? What if the amount of H_2 were doubled?

5. Spencer problem 2-38

Calculate the mass of hydrogen chloride that can be produced from 10.0g of hydrogen and 10.0g of chlorine.

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

What would have to be done to increase the amount of hydrogen chloride produced in the reaction?

6. The lustrous mineral anglesite is a naturally occurring form of the compound lead sulfate, $PbSO_4(s)$ (formula mass = 303.3amu). Lead sulfate is also formed every time a car is started by the reaction in the car's battery:

$$PbO_2(s) + Pb(s) + 2\ H_2SO_4(l) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$$

What is the maximum mass of $PbSO_4$ that can be formed in a typical car battery that contains 21kg of Pb (atomic mass = 207.2amu), 0.24kg of PbO_2 (formula mass = 239.2amu) and 0.49kg of H_2SO_4 (formula mass = 98.08amu)?

7. Spencer problem 2-44

Two strips of metal each weighing 100g are placed into a cylinder containing water. The volume of water displaced is 8.8mL in one case and 37.0mL in the other case. Identify the two metal strips.

Metal	Au	Fe	Al	Pb	Ag
Density/(g/mL)	19.3	7.9	2.7	11.3	10.5

8. A megawatt is to a milliwatt as a kilowatt is to a _____ watt, the abbreviation for which is: ____.

9. Chromium is separated from the iron in the ore chromite, $FeCr_2O_4(s)$, by heating the ore with molten

sodium carbonate, $Na_2CO_3(l)$, and oxygen gas, $O_2(g)$, to form solid ferric oxide, $Fe_2O_3(s)$, liquid sodium chromate, $Na_2CrO_4(l)$, and gaseous carbon dioxide, $CO_2(g)$. Provide a balanced chemical equation for this reaction.

10. What mass of F_2 gas is needed to form 20. short tons of HF gas? (1 short ton = 2000lbs = 907.18474kg.) Any unit of mass is acceptable in your answer. Explain why you do not need a calculator for this problem.

11. Neutrons are stable when bound inside a nucleus, but a free neutron outside the nucleus eventually falls apart to a proton and an electron. The decay rate is such that half the neutrons initially present disappear in about 10.3 minutes. The mass of a neutron is 1.0086649amu, that of a proton is 1.0072765amu, and that of the electron is 0.0005486amu.

(a) To how many significant figures is the mass of the electron known?

(b) Does the mass of the system increase or decrease for this nuclear process?

(c) Find the change in mass in units of kg when a neutron decays into a proton and an electron.

(d) Where does the change in mass go, assuming that only a proton and an electron are formed?

(e) Using Einstein's famous formula, $E = mc^2$, calculate the energy released in SI units using scientific notation. E is the energy released, m is the loss of mass and $c = 2.99792458 \times 10^8 m \cdot s^{-1}$ is the speed of light in a vacuum.

12. Carbon-14 (^{14}C) is made artificially by irradiation of a calcium compound with neutrons from a nuclear reactor to make radioactive calcium bicarbonate ($CaH_2C_2O_6$), which is then purified away from the residue of the original calcium compound. Assuming all elements have their normal abundances in the purified calcium bicarbonate except carbon which is entirely carbon-14 with an atomic mass of 14.0032amu, what is the formula mass of this compound?

13. In order to determine how a drug is metabolized in the liver of mammals, the drug is synthesized with carbon derived entirely from the radioactive calcium bicarbonate from the preceding problem. The intention is to administer the drug to rats, remove the rats' livers at predetermined times after administering the drug, separate the many compounds in each rat's liver and measure their radioactivity to determine what compounds are derived from the drug as the degradation proceeds. To confirm that the desired drug has been synthesized, a sample of the drug is burned in a combustion train. 13.801mg of CO_2 and 4.504mg of H_2O are obtained. Assuming the drug contains only carbon-14 and hydrogen of normal abundance, what is the empirical formula of the drug?

Mass spectroscopy wins half the Nobel Prize in Chemistry for 2002
9 October 2002
The Royal Swedish Academy of Sciences awarded the Nobel Prize in Chemistry for 2002 "for the development of methods for identification and structure analyses of biological macromolecules" with one half jointly to John B. Fenn, Department of Chemistry, Virginia Commonwealth University, Richmond, VA, USA, and to Koichi Tanaka, Shimadzu Corp., Kyoto, Japan "for their development of soft desorption ionisation methods for mass spectrometric analyses of biological macromolecules" ...
For more details see:
http://www.nobel.se/chemistry/laureates/2002/press.html

14. A sample containing 2.0pg of an important protein with a suspected molecular mass of 19,841amu is loaded into a Shimadzu mass spectrometer. The sample is then, in the words of the Nobel Foundation's description, "blasted" off the sample holder. In the process, each protein molecule is hopefully turned into one ion (the key methods for which Fenn and Tanaka won the Nobel prize), and then the mass of the ions are determined. What number of protein ions are

available for this determination if the suspected molecular mass is correct and entire sample is successfully turned into charged ions?

15. The other half of the Nobel Prize in Chemistry for 2002 was awarded to Kurt Wüthrich for the development of methods to determine the shape of protein molecules based on the pattern of magnetism from some of the nuclei in the atoms in the protein molecules. In such studies, the protein is often created by growing bacteria that produce the protein from a broth containing ^{15}N-enriched ammonium chloride, NH_4Cl. The supplier of such ^{15}N-enriched ammonium chloride claims that 95% of the nitrogen atoms in their compound are ^{15}N (atomic mass = 15.000g·mol^{-1}) and that all other atoms have their normal abundance. You are assigned to make up a broth for growing the bacteria and need to weigh out enough of this ammonium choride to get a specific number of formula units. What should you use for the formula mass the ^{15}N-enriched ammonium chloride?

16. As you may know, it is dangerous to mix household beach (NaOCl(aq)) and household ammonia (NH_3(aq)). Under proper conditions, the slow addition of bleach to ammonia produces hydrazine (N_2H_4), water (H_2O) and common salt (NaCl). How many molecules of ammonia will remain after the addition of 5.0g of a solution of 5.25% by mass NaOCl in water to 4.1g of a solution of 3.00% by mass NH_3 in water if the reaction is complete and no side products are formed?

17. Plants from Water? In 1648, Joan-Baptista van Helmont described the following experiment.

> "That all plants immediately and substantially stem from the element water alone I have learnt from the following experiment. I took an earthern vessel in which I placed two hundred pounds of earth dried in an oven, and rain water. I planted in it the stem of a willow tree weighing five pounds. Five years later, it had developed a tree weighing one hundred and sixty-nine pounds and about three ounces. Nothing but rain (or distilled water) had been added. The large vessel was placed in earth and covered by an iron lid with a tin-surface that was pierced with many holes. I have not weighed the leaves that came off in the four autumn seasons. Finally I dried the earth in the vessel again and found the same two hundred pounds of it diminished by about two ounces. Hence one hundred and sixty-four pounds of wood, bark and roots had come up from water alone."

(a) This experiment has since been repeated many times. The elemental composition of wood, bark and roots have been found to be approximately 40.0% by mass carbon, 6.7% by mass hydrogen and 53.3% by mass oxygen. Suggest a balanced chemical equation for how the wood, bark and roots were likely formed in van Helmont's experiment. Make sure to label the state or phase of all species in your equation.

(b) In no more than 2 sentences, comment on one feature of van Helmont's work that is still believed to be true today and one feature that is no longer believed to be true.