**Chemistry NAME: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Acid Rain Period \_\_\_\_\_\_\_\_\_**

The term “acid rain” is something of a misnomer, in that it actually refers to all types of precipitation (rain, snow, sleet, hail, etc.) that is more acidic than precipitation that would naturally occur. Precipitation is naturally acidic due to the carbon dioxide in air reacting with water in air to form carbonic acid (recall the carbon cycle). Indeed, the pH of natural rainfall averages around 5.6. Acid rain is most often formed as a result of impurities in fuel sources for the combustion reactions that are used to power our society. For example, the combustion of

gasoline using air (instead of pure oxygen) also produces some nitrogen oxides. Reduction of the amount of nitrogen oxides produced is a major focus of modern engine design. Still, as long as we are burning fuels in air, we will also be polluting our atmosphere.

Acid rain is toxic to many forms of animal and plant life. Acid rain falling to earth will also react with inorganic material (such as metals and minerals in the soil), thus it can be very damaging man-made structures (buildings, statues, bridges, etc.) and to man-made objects (such as statues, cars, etc.) that are themselves made from materials refined from earthen sources. And don’t forget about our drinking water – city water supplies for most cities are drawn from water reservoirs that are collections sites for water that precipitates from the atmosphere.

**1.** When coal is burned, ultimately to produce electrical energy, the impurities in the coal are also incinerated. One such impurity is sulfur. Sulfur burns in oxygen to form sulfur dioxide, a precursor to “acid rain”.

Write a balanced chemical equation for the burning of *sulfur* to form *sulfur dioxide*:

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**2.** Further reaction of the sulfur dioxide from the reaction in (1) with moisture in the atmosphere mostly yields *sulfurous acid*.

a. Write a balanced chemical equation for the formation of sulfurous acid in the atmosphere:

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

b. Sulfurous acid is a *diprotic* acid, meaning that each mole of sulfurous acid can react with water to produce up to two moles of hydronium ion in solution. Write two balanced chemical equations for the successive formation of hydronium ions by the reaction between sulfurous acid and water:

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

c. What would be the pH of the solution in (2a) if the hydronium ion concentration is 2.3 x 10-3 ?

Ans:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**3.** A different reaction of the sulfur dioxide (see reaction 1a) with oxygen in the atmosphere can yield a very hazardous substance sulfur trioxide – often called *sulfuric anhydride* – this is another precursor to “acid rain.” Sulfuric anhydride has the empirical formula, SO3.

a. Write a balanced chemical equation for the formation of sulfuric anhydride in the atmosphere:

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**4.** Sulfuric anhydride reacts with moisture in the air to form *sulfuric acid*. One form of acid rain results when the sulfuric acid is carried down to earth in by forms of precipitation (*i.e.*rain).

a. Write a balanced chemical equation for the formation of sulfuric acid in the atmosphere:

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

b. If the pH of the above acid measures 1.06 calculate the actual concentration of hydronium ion in solution.

Ans:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**5.** Many statues and monuments are made from carved marble. Marble is naturally occurring“rock” that is formed through the metamorphosis of limestone deposits. Limestone is a sedimentary rock that is comprised mostly of small *calcite crystals* (CaCO3). Under great pressure and high temperatures, the small calcite crystals of limestone recrystallize into the somewhat larger, denser-packed crystals of marble. The different colors of marble come from impurities that are mixed with the calcite crystals before the metamorphosis.

a. Write a balanced chemical equation for the reaction of sulfuric acid in acid rain with the calcite found in marble. (Note – this is a neutralization reaction, thus both acidic protons will react.):

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

b. The pH of acid rain has been measured as low as 4.5; in some cities in Asia, Eastern Europe, and formerly in the United States as well. The effects of acid rain are visible in the erosion of statues and buildings in many large cities. What is the hydronium ion concentration in acid rain that has a measured pH of 4.5?

Ans: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

c.(extra credit) A marble statue with a mass of 1500 kg sits 50 years in an environment where very acidic (pH 4.5) acid rain frequently falls. Suppose it rains 20 times each year, and each rainfall washes an average of 320 L of acid rain across the surface area of the heavy statue. If only half of the hydronium ion in the rain reacts with the calcite in the marble, what mass of calcite will be destroyed?

Ans:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

In the previous scenario, you calculated only the mass of marble that was *chemically* destroyed. Although this direct chemical action slowly defaces marble statues, the unfortunate truth is that the acid rain seeps into all the cracks found in natural marble. The weakening of the structure of the marble through internal chemical erosion causes larger pieces of marble to chip and fall thereby greatly accelerating the damage. And this is just and example one of the many destructive actions caused by acid rain!