Geochemical Cycles Assignment

Work Chapter 6 problems in Danial Jaboc's book.

6.1 Short Questions on the Oxygen Cycle

1. Comment on the following statement: “Destruction of the tropical rain forests, the lungs of the Earth, menaces the supply of atmospheric oxygen”

2. A developer in Amazonia has a plan to raise the levels of atmospheric oxygen by cutting down the rain forest and replacing it with a managed forest. The managed forest would be cut every 20 years, the cut trees would be sealed in plastic bags loaded with weights, and the bags would be dumped to the bottom of the ocean. What is the developer’s reasoning? Would the plan work? Why or why not?

3. In oxygen-depleted (anoxic) muds on the ocean floor, bacteria derive energy by using Fe_2O_3 and H_2SO_4 to oxidize organic material. The stoichiometry of the reaction is as follows (“CH_2O” represents the organic material):

$$2Fe_2O_3 + 8H_2SO_4 + 15CH_2O \xrightarrow{\text{Bacteria}} 4FeS_2 + 15CO_2 + 23H_2O$$

This reaction represents an important source of atmospheric oxygen. Why? Where do Fe_2O_3 and H_2SO_4 originate from? Comment on the role of the reaction in the oxygen cycle.

4. Hydrogen atoms are produced in the upper atmosphere by photolysis of water vapor and can then escape to outer space because of their light mass. This escape of H atoms is effectively a source of O_2 to the atmosphere; explain why. The present-day rate of H atom escape to outer space is 5.4×10^7 kg H yr^{-1}. Assuming that this rate has remained constant throughout the history of the Earth (4.5×10^9 years), calculate the resulting accumulation of oxygen. Is this an important source of oxygen?

5. Atmospheric O_2 shows a small seasonal variation. At what time of year would you expect O_2 to be maximum? Explain briefly. Estimate the amplitude of the seasonal cycle at Mauna Loa, Hawaii.

6.2 Short Questions on the Carbon Cycle

1. Does growth of corals ($Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(s)$) cause atmospheric CO_2 to increase or decrease? Explain briefly.

2. There are no sinks of CO_2 in the stratosphere. Nevertheless, the CO_2 mixing ratio in the stratosphere is observed to be 1-2 ppmv lower than in the troposphere. Explain. [Source:Boering, K.A., et al., Stratospheric mean ages and transport rates from observations of CO_2 and N_2O,Science, 274,1340, 1996]

3. Humans ingest organic carbon as food and release CO_2 as product. As the world population grows, will increased CO_2 exhalation from humans contribute to increasing CO_2 in the atmosphere?

4. A consequence of global warming is melting of the polar ice caps. This melting decreases deep water formation. Why? Would this effect represent a negative or positive feedback to global warming? Briefly explain.

5. Comment on the statement: “Planting trees to reduce atmospheric CO_2 is not an appropriate long-term strategy because the organic carbon in the trees will return to atmospheric CO_2 in less than a century”.

6.3 Atmospheric Residence Time of Helium

Helium (He, atomic weight 4 g mol^{-1}) and argon (Ar, atomic weight 40 g mol^{-1}) are both produced in the Earth’s interior and exhaled to the atmosphere. Helium is produced by radioactive decay of uranium and thorium; argon is produced by radioactive decay of potassium^{-40} (40K). Both helium and argon, being noble gases, are chemically and biologically inert and are negligibly soluble in the ocean. Present-day atmospheric mixing ratios of helium and argon are 5.2 ppmv and 9340 ppmv, respectively.

1. Atmospheric argon has no sink and has therefore gradually accumulated since Earth’s formation 4.5×10^9 years ago. In contrast, atmospheric helium has a sink. What is it?

2. Show that the average source of argon to the atmosphere over Earth’s history is $P_{ar} = 1.5 \times 10^7$ kg yr^{-1}.

3. Potassium-40 has no sources in the Earth’s interior and decays radioactively with a rate constant $k = 5.5 \times 10^{-10}$ yr^{-1}. Hence the source of argon has decreased gradually since Earth’s formation. Let $P_{Ar}(\Delta t)$ represent the present-day source of argon, where $\Delta t = 4.5 \times 10^9$ years is the age of the Earth. Show that

$$P_{ar}(\Delta t)/P_{ar\,=}\, k\Delta t/(\exp(k\Delta t) - 1) = 0.23$$

4. Observations in geothermal and bedrock gases show that the present-day sources of atmospheric helium and argon (kg yr^{-1}) are of the same magnitude: $P_{ar}(\Delta t) \approx P_{He}(\Delta t)$. Deduce the residence time of helium in the atmosphere

6.5 Global Fertilization of the Biosphere

We apply here the box model of the nitrogen cycle presented in Figure 6-3 to examine the possibility of global fertilization of the biosphere by human activity over the past century.

1. What is the residence time of nitrogen in each of the reservoirs of Figure 6-3?

2. Consider a "land reservoir" defined as the sum of the land biota and soil reservoirs. What is the residence time of nitrogen in that reservoir? Why is it so much longer than the residence times calculated for the individual land biota and soil reservoirs?

3. Human activity over the past century has affected the nitrogen cycle by cultivation of nitrogen-fixing crops and application of industrial fertilizer to crops (increasing the land biofixation rate from 110 Tg N yr^{-1} to 240 Tg N yr^{-1}), and by fossil fuel combustion (increasing the nitrogen fixation rate in the atmosphere from 5 Tg N yr^{-1} to 30 Tg N yr^{-1}). Estimate the resulting percentage increases over the past century in the global nitrogen contents of the land biota reservoir and of the ocean biota reservoir. Conclude as to the extent of global fertilization of the Earth’s biosphere by human activity.

[To know more: Vitousek, P.M., et al., Human alteration of the global nitrogen cycle: sources and consequences,Ecol. Appl., 7,737-750, 1997]