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Note to 2003: Some of these questions emphasize points that I did not stress, or cover material we did not cover this year. So use this test only as an indicator of the kinds of questions. Remember also that Quiz I from 2001 has some secondary productivity questions you should look at. Any numbers that you need (e.g. fluxes or reservoir sizes) will be provided (as they are at the end of this test).

Pace yourself by using the point values on the questions as a measure of the time it should take to answer them. ***Any numbers you need in the calculations (and more…..) can be found on the last page of the exam or in one of the questions.*** *Some of these questions are very easy. Don't look for complications where they don't exist.* ***Be sure to show your work in all calculations and explain your assumptions. Use the back side of the page if necessary.***

I. (6 points). In 1772, Joseph Priestly used an enclosed ecosystem experiment to prove that "biogeochemical" cycles are linked. Describe his experiments (draw pictures if necessary) and explain their significance.

II. (12 points) The Hydrologic Cycle

a) The global hydrologic cycle is driven by solar radiation, which provides energy to fuel evaporation off the oceans and land surface. What portion of the total radiative energy received from the sun is used to evaporate water and drive the global hydrologic cycle? (4pts)

b) What is the residence time of water in the oceans? (2pts)

c) What fraction of the water in the oceans is replaced with new water annually? (2pts)

d) What assumptions did you make in these calculations? Are they reasonable? (4pts)

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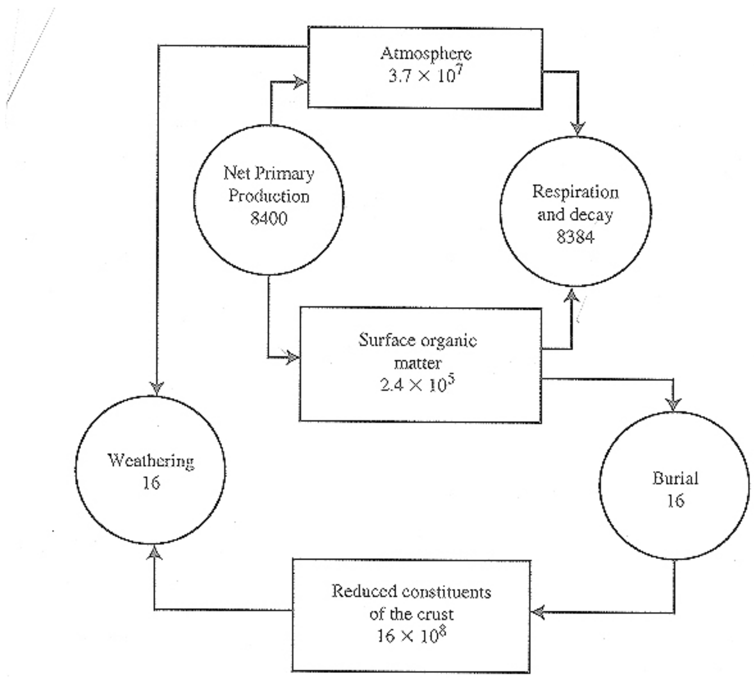
III. (14 points) The Carbon Cycle

a) Assuming for the moment that the global biogeochemical cycle of carbon is in steady state, what is the minimum amount of time required to pass the entire atmospheric CO_2 reservoir through the sedimentary organic matter in the earth's crust? (5pts)

b) Burning fossil fuel and deforestation is introducing about 7 Gt C per year into the atmosphere. Yet the CO_2 concentration is only increasing at a rate of about 3.2 Gt C per year. Why? (5pts)

c) Methane is increasing steadily in the atmosphere, yet the rise cannot be accounted for by tallying all of the increased fluxes of CH_4 from the land to the atmosphere. Increased production of CO from the burning of fossil fuels is blamed for a significant fraction of the increase in CH_4. Explain the connection. (4pts)

IV. **(6 points)** Below is a simple model of the annual biogeochemical cycle of O_2 as we view it today. The numbers are expressed in units of 10^{12} moles of O_2 or the equivalent amount of reduced compounds.
How would you change this diagram to reflect the conditions on earth 3 billion years ago? [Note: you don't need to worry about the exact numbers, just make sure you tell us, either by changing the drawing or in words, how things were different]



V. **(24 points)** Michael Markels holds patents in 15 countries on a floating pellet that releases iron and phosphorus to the ocean over a period of days. Markels hopes to use this technology to fertilize near the Marshall Islands, where he now has exclusive property rights to over 2.7 million square kilometer of the countries Exclusive Economic Zone.

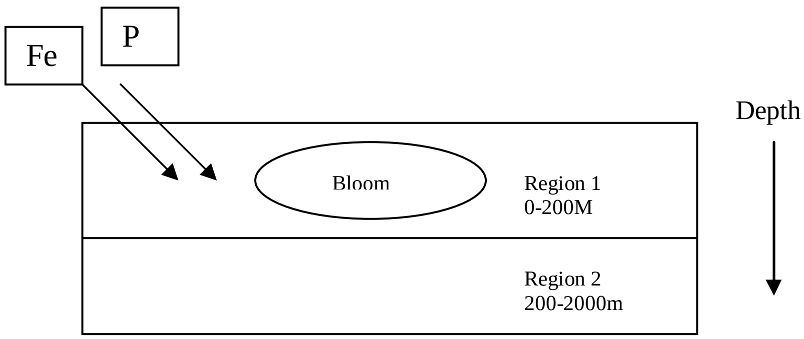
a) To what end does Markels want to fertilize the seas surrounding the Marshall Islands? (4pts)

b) During the IronEx experiments in the Equatorial Pacific Ocean, the addition of iron alone caused phytoplankton blooms. Why does Markels proposal for the Marshall Islands call for the addition of both Fe and P? (4pts)

c) Phytoplankton require C:N:P:Fe in the following molar proportions: 106:16:1: 0.005. Yet Markel's fertilizer does not contain nitrogen. Where does he propose the N will come from? (4pts)

d) What is the most significant natural source of iron to the world's oceans? (2pts)

e) Markels carries out his experiment as follows: (10pts)



- What are the relative magnitudes of NPP and ($R_H + R_A$) in region 1 and region 2. [Answer by putting a " < " or "> " between the terms below]:

  Region 1 NPP ($R_H + R_A$)

  Region 2 NPP ($R_H + R_A$)

- With sustained fertilization, what will happen to the oxygen concentration in these two regions? Why?

- Describe the potential consequences of this anoxic zone and its effect on global climate.

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VI. (10 points) Atmospheric CO_2 Levels

a) Plots of atmospheric CO_2 concentration as a function of time over the past 25 years show a strong annual oscillation in the northern hemisphere (Point Barrow Alaska) but very little annual variability in the southern hemisphere (South Pole). Why?

b) The ***amplitude*** of the oscillation at Point Barrow has been increasing steadily. What is the leading hypothesis to explain this?

VII . (8 points). Ozone depletion in the stratosphere is linked to what other biogeochemical cycle? Explain the link.

VIII (20 points) The Nitrogen Cycle:

a) Name three types of organisms that have the capability of fixing atmospheric nitrogen. (5pts)

b) Does nitrogen fixation require energy or release energy? (2pts)

c) You find a plant outside your dormitory that you suspect might be capable of nitrogen fixation. Describe three different methods you could use to determine whether or not it fixes nitrogen. (7pts)

d) If there were no nitrogen cycle, how long would it take for the atmospheric pool of N_2 to disappear? (3pts)

e) Why is this atmospheric pool of N_2 not depleted by nitrogen fixation? (3pts)

BONUS (5pts)

An ambitious MIT start-up proposes to solve world food shortages through the introduction of bioengineered crops that fix nitrogen. Trained in ecology, your first thought is that you should be cautious about this approach, and should first consider all of the indirect ecological effects that could occur. If all of the crop plants were able to fix nitrogen, how might global biogeochemical cycles change? (use back of page for your answer).

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Numbers that may be useful in answering the questions above [note: this is not to say that you will use all of them, but what you need is here]

Reservoir sizes:

Volume of the ocean = 1.37×10^9 km^3.
Atmospheric CO_2 = 720×10^{15} g C
Fossil Fuel, sedimentary organic carbon = 18×10^{18} g C
Atmospheric N pool = 3.8×10^{21} g of N.
Carbon in terrestrial biomass = 550 Gt C
Atmospheric N_2O = 1.4×10^4 Gt N
Mineable P – 10 Gt P

Fluxes:

Global N-fixation rates = 2.25×10^{13} g N/yr
Evaporation off the ocean: 3.19×10^{20} g yr^{-1}.
Evaporation off the land: 5.9×10^{19} g yr^{-1}
CO from Burning Fossil Fuels = 0.4 Gt yr^{-1}
River runoff of P from land to ocean = 104 Tg yr^{-1}

Energy

2.24 kJ required to evaporate 1 g H_2O
Solar energy flux = 1.3×10^{21} kJ/yr

Equivalents:

Density of H_2O = 1g cm^{-3}
1Gt = 10^{15} g
1 Tg = 10^{12} g
1 ton = 10^6 g = 10^3 kg