SCIENCE PRACTICE CHALLENGE QUESTIONS

2.1 Atoms, Isotopes, Ions, and Molecules: The Building Blocks

31 At a time when the theory of evolution was controversial (the year following the Scopes Monkey Trial), Macallum (*Physiological Reviews*, 2, 1926) made an observation that is still contested by some who do not see the pattern in the data in the table showing percentages (g solute/100 g solution) of major biologically important inorganic elements in a variety of sources.

Source	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**
Ocean water	0.306	0.011	0.012	0.0037	0.55
Lobster	0.903	0.0337	0.0438	0.0156	1.547
Dog fish	0.5918	0.02739	0.01609	0.0146	0.9819
Sand shark	0.6173	0.0355	0.0184	0.0172	1.042
Cod	0.416	0.0395	0.0163	0.00589	0.6221
Pollock	0.4145	0.017497	0.01286	0.00608	0.5613
Frog	0.195	0.0233	0.00627	0.00155	0.2679
Dog lymph	0.3033	0.0201	0.0085	0.0023	0.4231
Human					
Blood	0.302	0.0204	0.0094	0.0021	0.389
Lung	0.2956	0.02095	0.00839	0.0021	0.3425
Testes	0.3023	0.01497	0.00842	0.001914	0.3737
Abdominal cavity	0.2935	0.0164	0.0091	0.00184	0.3888

A. Using a spreadsheet, or by sharing calculations with your classmates, **construct a quantitative model** of these data from these percentages as ratios of mass fractions relative to that of sodium, %X/%Na. Of course, you will not be asked to use a spreadsheet on the AP Biology Exam. However, you may be assessed on the ability to develop a quantitative model through the transformation of numerical data. The question that led Macallum to investigate the elemental composition of different species and compare these with the composition of seawater follows from the central organizing principle of biology: the theory of evolution.

B. The elements in the table all occur in aqueous solution as ions. Cells expend energy to produce a charge gradient and an ion gradient that is necessary for basic cellular functions. Large differences in the concentrations of ions inside versus outside of the cell results in stresses that the cell must expend energy to relieve. Based on this constraint on the total number of ions, **connect** this refined model based on ratios of ion concentration rather than absolute ionic concentrations to the modern concept of shared ancestry.

Frequently, a follow-up question regarding scientific data on the AP Biology Exam will ask you to pose questions that are raised by the data. You will be awarded credit for scientific questions. These questions usually look for a cause-and-effect relationship, and are testable.

C. Examine relative concentrations of potassium and magnesium ions in terrestrial and marine organisms. **Pose a question** that could be investigated to connect concentrations of these ions to adaptations to a change in the environment.

Macallum noted the high potassium to sodium ratio relative to seawater, and made this claim about what the ratio implied about the oceans of early Earth:

"At once it is suggested that as the cell is older than its media is [presently] the relative proportions of the inorganic elements in it are of more ancient origin than the relative proportions of the same amount of elements which prevail in the media, blood plasma and lymph or in the ocean and river water of today."

D. In your own words, summarize the argument that Macallum is using **to justify this claim**.

Solution Sample answer:

A.

Source	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**
Ocean water	0.036	0.039	0.012	1.8
Lobster	0.037	0.048	0.017	1.7
Dog fish	0.046	0.027	0.025	1.7
Sand shark	0.057	0.030	0.028	1.7
Cod	0.095	0.039	0.014	1.5
Pollock	0.042	0.031	0.015	1.35
Frog	0.12	0.032	0.0080	1.4
Dog lymph	0.07	0.028	0.0076	1.4
Human				
Blood	0.067	0.031	0.0070	1.3
Lung	0.0715	0.028	0.0071	1.2
Testes	0.049	0.028	0.0063	1.2
Abdominal cavity	0.056	0.031	0.0062	1.3

Table of Ratios %ion/%Na

B. The hypothesis that all animal life originated in the oceans seems to be supported by the observation that the ratios of ions in the tissues of terrestrial animals are similar to those found in ocean water. The absolute amounts of ions may vary from

animal to animal, however, relatively similar ratios point to inherited cellular mechanisms that require similar ratios of ions.

C. The lower concentrations of K^+ and Mg^{2+} in terrestrial animals compared to those found in ocean water can be attributed to adaptation to life in air rather than a reflection of concentrations present in ancient oceans. One question to pose would be why the concentrations of K^+ and Mg^{2+} changed over time in the oceans. Examination of ancient sediments, and studies of how the weathering of rock adds salts into the ocean may provide insights into the composition of ancient oceans.

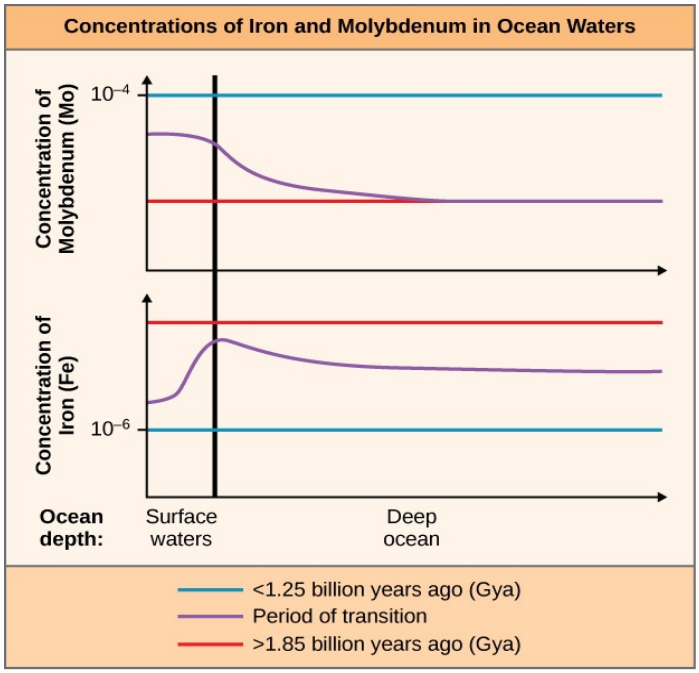
D. The proportion of ions in the blood and tissues of terrestrial animals are a reflection of the composition of salts in the marine environment existing at the time when animals moved to land. It is not tied to present day ocean composition.

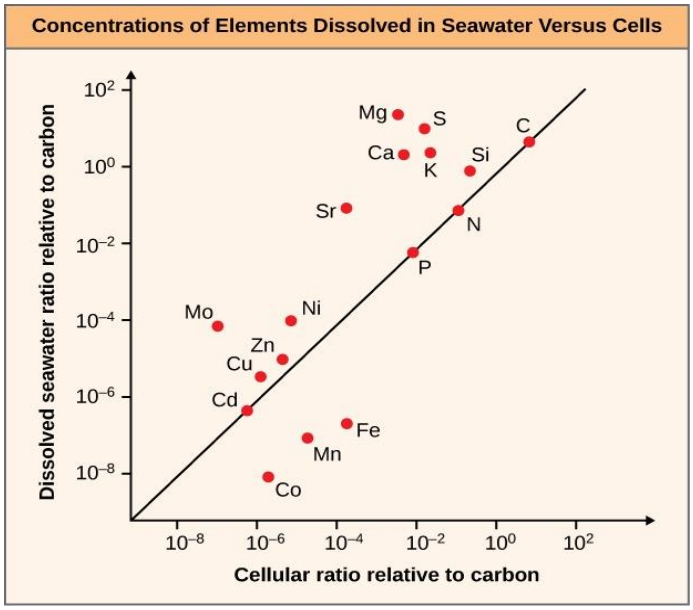
2.2 Water

32 Approximately half the energy that flows through Earth's biosphere is captured by phytoplankton, photosynthetic microscopic organisms in the surface waters of the oceans. Scientists think the growth of phytoplankton in the Atlantic Ocean is limited by the availability of nitrogen, whereas growth in the Pacific Ocean is limited by the availability of iron.

The concentration of oxygen (O_2) in the atmosphere of early Earth was low and, therefore, so was the concentration of dissolved oxygen in the early ocean. Because insoluble iron oxides (rust) do not form in the absence of oxygen, soluble iron ions $\left(Fe^{2+}\right)$ were more available in the early ocean than at present. Nitrogen (N_2), while always abundant in the atmosphere, was not biologically available until the evolution of molybdenum-based enzymes that allow nitrogen fixation.

The graphs (Anbar and Knoll, *Science*, 297, 2002) show models of concentrations of two trace elements, iron (Fe) and molybdenum (Mo), in ocean waters (first), as well as the concentration of various elements dissolved in seawater versus within cells (second). The model describes the change over time of these elements from early Earth (>1.85 billion years ago, Gya) to a modern era (<1.25 Gya) and a period of transition between these. Surface waters of the oceans lie to the left of the vertical double line while deep ocean water lies to the right. Modern concentrations of dissolved iron and molybdenum (relative to dissolved carbon) are shown.





A. The principal chemical processes of life today have been conserved through evolution from early Earth conditions. Using this fact, **justify the selection of these data** shown in the graphs in the construction of a model of ocean photosynthetic productivity.

Iron and molybdenum are two of 30 elements that are required by the chemical processes supporting life on Earth. Concentrations of these two and 15 other elements are shown in the second graph. Of these elements, the three most abundant in cells are also found in seawater in approximately the same concentrations. By increasing the mass of phytoplankton in the ocean, we may be able to compensate for the increasing concentration of carbon produced by the combustion of gas, oil, and coal.

B. Select, with justification, the element or elements that, if added in large amounts to the ocean, could boost the growth of phytoplankton.

C. Before implementing a large-scale geo-engineering effort to avert the effects of climate change due to carbon pollution, we must test the legitimacy of this solution. **Describe a plan** for collecting data that could be used to evaluate the effect of enrichment on phytoplankton productivity.

Solution Sample answer:

A. The first graph shows the concentration of rate-limiting elements, including iron and molybdenum, available for photosynthesis. At the surface molybdenum is abundant. Iron is less available, perhaps because it reacts with oxygen in the atmosphere to form insoluble iron oxide that sinks.

B. The second graph shows that iron, manganese, and cobalt are also abundant in the ocean than in the cells. This means cells will have a hard time obtaining enough of these elements, and adding more would increase productivity. Manganese is an essential component of the reaction center of photosystem II where it is involved in the splitting of water molecules.

C. In controlled laboratory conditions, supplemental metal could be added to phytoplankton grown and the productivity could be measured. It is important to stress that the oceans are vast areas with different local conditions. The unintended effects of overgrowth of phytoplankton must also be addressed. Eutrophication, or overgrowth of algae leading to dead zones in lakes and coastal areas, occurs when excess nitrogen is present in the water.