

Course in Biogeochemistry

Division of Earth System Science

Graduate School of Environmental Science, Hokkaido University

Entrance Examination

- Give answers to questions in English or Japanese.
- Answer two Questions of specialized subjects and describe the question number on the answer sheet.
- Use an answer sheet per each Question. You may use both faces of the answer sheet. In case the space of the sheet is not enough for your answers, please contact an examiner.

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Question 1:

- I. Select the appropriate words or phrases from the word list below to fill in the blanks (**A**) through (**F**) in the following text.

Because the Japanese Archipelago is located on a convergent plate boundary, it consists of an assemblage of rocks originating from both oceanic and continental sources. Exotic rocks relative to the present-day Japanese Archipelago are those derived from oceanic plates. Representative examples include (**A**), (**B**), and (**C**). (**A**) originates from the second layer of the oceanic plate or from seamounts formed at hotspots. (**B**) corresponds to coral reefs formed at the summits of seamounts, whereas (**C**) corresponds to pelagic sediments.

On the other hand, rocks of continental and island-arc origin consist of sand, mud, and fragments of volcanic rocks of felsic to intermediate composition—such as rhyolite and (**D**)—as well as felsic plutonic rocks like (**E**) and various metamorphic rocks, all transported via rivers and submarine canyons to be deposited in trenches or forearc basins. Many of these form (**F**), which are characterized by alternating beds of sandstone and shale exhibiting graded bedding.

Word list

banded iron formation, stromatolite, convolute lamination, turbidite, peridotite,
radiolarian chert, reef limestone, pillow lava, gabbro, granite, tsunamiite, andesite

- II. Explain each of the following terms related to topography and geology in six lines or fewer.

(1) Back-arc basin

(2) Flood basalt

(3) Volcanic front

III. Read the following text and answer each question.

Seawater contains approximately 3.5% dissolved salts (salt ions). The primary cations in seawater are (**G**), and the primary anions are (**H**). Because these components have long average residence time, they are well-mixed throughout the ocean and maintain nearly constant concentrations. On the other hand, (a)nutrient concentrations vary significantly by regions and depths due to biological activity. In the pelagic ocean, (b) dissolved oxygen is abundant down to a depth of around 200 m, and decreases sharply below that depth. In the Pacific and Atlantic Oceans, the depth of the oxygen minimum zone lies approximately between 400 and 1,000 m. (c) Dissolved carbon dioxide shows low concentrations in the surface ocean, and increases with depth.

- (1) List four cations that are appropriate for the blank (**G**) in the text.
- (2) List three anions that are appropriate for the blank (**H**) in the text.
- (3) List the three elements that are the major nutrients for the underlined (a).
- (4) Explain the reason for the vertical pattern indicated by the underlined (b) in ten lines or fewer.
- (5) Explain the reason for the vertical pattern indicated by the underlined (c) in ten lines or fewer.

Question 2:

Read the following text and answer the questions (1) – (4).

Earth's climate changes over long timescales not only because of variations in solar activity but also because of changes in Earth's orbital parameters. This concept was developed by the Serbian scientist Milutin Milankovitch and is now known as the Milankovitch cycles. The Milankovitch cycles consist of three orbital parameters: [A], [B], and [C]. The changes in [A] are variations in Earth's orbital shape from nearly circular to more elliptical, with a principal periodicity of approximately [D] thousand years. The changes in [B] are variations in the tilt of Earth's rotational axis. The present axial tilt is about 23.4° , but it varies between approximately 22.1° and 24.5° . The periodicity of this cycle is about [E] thousand years. [C] refers to the wobble of Earth's rotational axis with a periodicity of about 26 thousand years.

(1) Fill in [A]–[E] with the appropriate terms or numerical values.

(2) According to the Milankovitch theory, which region and which season's insolation are considered most important for driving glacial–interglacial cycles? Also explain the reason in ten lines or fewer.

(3) Explain each of the following terms in three lines or fewer.

- Mid-Pleistocene Transition (MPT)
- Dansgaard–Oeschger oscillation
- Heinrich Event
- Messinian salinity crisis

(4) Alkenone unsaturation and foraminiferal Mg/Ca ratios have been proposed as proxies for reconstructing ocean temperature. Explain the principles in ten lines or fewer for each.

Question 3:

I. Answer the definition of the following terms within two lines for each.

(1) Activation energy

(2) Aromatic compound

II. State the difference between the following pairs of terms. You may answer using chemical structure.

(1) Stereoisomer – Structural isomer

(2) Amine – Imine

(3) Carboxyl group – Carbonyl group

(4) Alkane – Alkyne

III. The internal standard method is a method to quantify target compounds in unknown samples using the amount of an artificially added chemical. Calculate the monosaccharide concentrations of an unknown sample from peak areas using the internal standard method based on Table 1 and Table 2, assuming no sample loss and contamination during sample preparation and measurement.

Table 1. Information on peak areas of the mixture of monosaccharide standards (Glucose, Mannose, Galactose) and an internal standard (myo-inositol) measured by chromatography, with three proportions of concentrations.

	Concentration of standards (mg/g)			Peak area		
	1st run	2nd run	3rd run	1st run	2nd run	3rd run
Glucose	0.1	0.1	0.1	100	100	100
Mannose	0.08	0.08	0.08	100	100	100
Galactose	0.1	0.1	0.1	100	100	100
myo-inositol	0.02	0.1	0.2	10	50	100

Table 2. Peak area of monosaccharides in an unknown sample measured under the same chromatographic conditions. Ten μg of internal standard (myo-inositol) was added in 100 mg of the sample.

	Peak area
Glucose	200
Mannose	40
Galactose	20
myo-inositol	50

Question 4:

I. One mole of any gas has a fixed volume at 20°C and the standard pressure.

- (1) Answer the standard pressure in atm and Pa.
- (2) Answer the volume (L at 20°C and the standard pressure) of CO₂ produced by the decomposition of 50 g of calcium carbonate, if the molecular weight of calcium carbonate is 100.
- (3) The ideal gas follows the ideal gas law using pressure (P , in Pa), volume (V , in m³), temperature (T , in K), the amount of gas (n , in mol), and the molar gas constant (R , in J/K•mol). Write the ideal gas law.
- (4) Using the ideal gas law, calculate the volume (in m³ at 20°C and the standard pressure) of 0.50000 mol of a gas, if the molar gas constant (R) is 8.3145 J/K•mol, and 0°C is 273.15 K. Show your calculation result (the volume with five significant digits) and process.

II. The pH of water changes largely by adding small amounts of strong acids or strong bases. On the other hand, an aqueous solution containing a weak acid and its salt has the [A] effect, such that its pH remains nearly constant even if small amounts of strong acids or strong bases are added.

- (1) Answer the word that is suitable for the blank [A].
- (2) Answer the pH of the following HCl solutions to four significant digits. Show your calculation process to achieve the answer. If necessary, use the following approximations: $\log(1.005) = 0.002$, $\log(1.05) = 0.021$, and $\log(1.5) = 0.176$.
 - (a) 1.0×10^{-1} mol/L
 - (b) 1.0×10^{-4} mol/L
 - (c) 1.0×10^{-9} mol/L
 - (d) 1.0×10^{-14} mol/L
- (3) Answer the molar ratio (in three significant digits) of acetic acid to its salt to prepare 100 mL of the acid [A] solution with pH = 5.00. Show your calculation process to achieve the answer. If necessary, use $pK_a = 4.74$ for acetic acid, and the following approximations: $10^{0.26} = 1.82$, $10^{4.74} = 5.50 \times 10^4$, $10^{9.26} = 1.82 \times 10^9$, and $10^{9.74} = 5.50 \times 10^9$.

Question 5:

Read the sentences below and answer the questions from (1) to (5).

Organelles are structures within cells that perform specific roles or functions. In eukaryotic cells, the nucleus, mitochondria, plastids (chloroplasts), endoplasmic reticulum, Golgi apparatus, and other functional components are classified as organelles. The nucleus is a relatively large structure within the cell and can therefore be easily isolated using (a) cell fractionation techniques. The nucleolus, a non-membrane-bound structure located within the nucleus, forms the large and small subunits of [A]. These subunits pass through nuclear pores into the cytoplasm, where they bind to messenger RNA (mRNA) and facilitate protein synthesis. Mitochondria, like the nucleus, are surrounded by two biomembranes. The inner membrane of mitochondria folds inward to form structures called [B], thereby increasing its surface area and enabling the efficient production of chemical energy molecules. Plastids (chloroplasts) are organelles characteristic of plant cells and are the sites of photosynthesis. (b) Like mitochondria, plastids (chloroplasts) contain their own DNA. In the chloroplasts of eukaryotic organisms, the regions where internal disc-shaped sacs called thylakoids are stacked are called [C], and the fluid-filled region surrounding [C] is termed [D].

- (1) Fill in the blanks A, B, C, and D with the appropriate words.
- (2) Explain the principle and experimental procedure of the cell fractionation techniques described in the underlined section (a) in ten lines or fewer.
- (3) Regarding the underlined section (b), explain why plastids (chloroplasts) and mitochondria have their own DNA in ten lines or fewer.
- (4) Write each name of the chemical energy compound and the reducing agent produced during the photochemical reactions of photosynthesis. Also, write the name of the pathway that uses these chemical compounds to convert carbon dioxide into organic matter.
- (5) Describe the characteristics and functions of the endoplasmic reticulum and the Golgi apparatus in six lines or fewer for each.

Question 6:

Answer the following questions I to III.

I.

In ecology, a population is a group of individuals of the same species living in a specific geographic area at the same time. Population growth is the change in the number of individuals in a population over time. Let the population size be N , time be t , the growth rate of the species be r , and the carrying capacity be K ; the population growth curve is modeled by formula A or B.

$$\frac{dN}{dt} = rN \quad \dots A$$

$$\frac{dN}{dt} = rN \left(1 - \frac{N}{K}\right) \quad \dots B$$

1. For both Models A and B, set $r > 0$ and $K > 0$. Set $N = N_0$ at $t = 0$ and $0 < N_0 < K$. Draw the growth curve of Models A and B, with t on the horizontal axis and N on the vertical axis, and indicate the position of K on the vertical axis.
2. Explain the definition of K (carrying capacity). Also, in Model B, state what $N = K$ means. Describe each within two lines.

II.

In the context of life-history evolution, r -selection occurs under environmental conditions that favor a high rate of population increase, whereas K -selection occurs under conditions in which strong competitive ability is favored as population density approaches the carrying capacity, K .

1. List three traits associated with an r -selected life-history strategy.
2. Organisms' adaptation can occur not only from changes in the abiotic environment but also from interactions with other organisms. In some pairs of interacting species, each species evolves in response to the other's adaptations. Answer the term describing this evolutionary process.

III.

There are four types of interactions between different species.

Competition, Predation, Mutualism, Parasitism

1. Answer the definition of each interaction in one line for each.
2. Interactions in a two-species predator-prey system generate periodic oscillations in the population sizes of both species. Explain how these oscillations occur in five lines or fewer.