Entrance Examination

For October 2025 and April 2026 students

Master's Course

(Specialized subjects)

Notes

- Select and answer 3 QUESTIONS from the total 12 QUESTIONS. The 3 QUESTIONS can be selected from any subjects.
- One sheet should be used for each selected QUESTION. The reverse side could be used, if necessary.
- Name, examinee's number and subject name should be written on each answer sheet.
- QUESTION number should also be written on each answer sheet.

Division of Biosphere Science

Graduate School of Environmental Science

Hokkaido University

QUESTION No. 1. (Subject on Field Science)

Read the following sentences and answer the questions.

ⓐLand plants evolved from green algae and include bryophytes, ferns, lycophytes, angiosperms, and gymnosperms. According to recent molecular phylogenetic analyses, bryophytes form a (①) group and include mosses, liverworts and hornworts. The number of extant species is approximately 24,000 for bryophytes, 12,000 for ferns, 1,200 for lycophytes, 250,000 for angiosperms, and 800 for gymnosperms, making angiosperms overwhelmingly dominant. The prosperity of angiosperms is associated with ⓑinteractions with animals.

Land plants possess traits that enable survival and reproduction in dry terrestrial environments. The epidermis of most land plants is covered with (②), which prevents water loss from the plant body. However, to perform photosynthesis inside their leaves, plants need to uptake (③) from the atmosphere. For this reason, their leaf surfaces have adjustable openings called (④). In some plants that live in hot and dry climates, photosynthesis mechanisms different from the usual type have evolved. ⓒPlants with such photosynthetic mechanisms include C_4 plants and CAM plants. ⓓAngiosperms do not require water for fertilization.

All land plants except bryophytes have (⑤), which transport water and nutrients within the plant body, allowing them to grow tall. Among extant land plants, the tallest on Earth are gymnosperms, reaching heights of over 110 meters. This means that ⓔwater absorbed by the roots is transported up to a height of over 110 meters.

Question 1-1. Choose the appropriate word for blank (①) from the following list.

monophyletic, paraphyletic, polyphyletic

Question 1-2. Write the appropriate term for each blank (②) to (⑤).

Question 1-3. Regarding the underlined section ⓐ, draw a phylogenetic tree showing the evolutionary relationships among the following groups.

Green algae, Angiosperms, Gymnosperms, Hornworts, Lycophytes

Question 1-4. Regarding the underlined section ⓑ, explain the following mutualism observed between angiosperms and animals in no more than 25 words, respectively.

(1) Angiosperms and birds
(2) Angiosperms and insects

Question 1-5. Regarding the underlined section ⓒ, choose one C_4 plant and one CAM plant from the following list.

rice, wheat, watermelon, maize (corn), pineapple, banana

Question 1-6. Regarding the underlined section ⓓ, explain why angiosperms do not require water for fertilization, using all of the following terms.

sperm cell, ovule, pollen tube

Question 1-7. Regarding the underlined section ⓔ, explain the mechanism by which water is transported from the roots to the leaves in plants, using all of the following terms.

transpiration, cohesion, xylem sap

QUESTION No. 2. (Subject on Field Science)

Read the following text about biological conservation and answer the questions.

In recent years, the ongoing loss of ⓐbiodiversity and degradation of ⓑecosystem functions have become increasingly evident. These changes are largely driven by human activities such as the expansion of agricultural land and urban areas, environmental pollution, and the spread of ⓒinvasive species. Such disturbances are considered to compromise ⓓthe direct and indirect benefits of ecosystems to human society. Consequently, the effective and efficient conservation of biodiversity and ecosystem functions is now regarded as a significant societal issue, and ⓔefforts to identify and protect areas with minimal human impact are being promoted on a global scale.

Question 2-1. Regarding the underlined section ⓐ, biodiversity is divided into three components. Describe those three components and explain each within 15 words.

Question 2-2. Regarding the underlined section ⓑ, explain the definition of ecosystem functions within 25 words.

Question 2-3. The underlined section ⓒ indicates species that have been anthropogenically introduced from their original range to other non-native areas and have become established and expanded their range there. Those species are also referred to as alien species. Using the following three terms, explain under what circumstances invasive or alien species are thought to cause declines in native species within 75 words. Plural forms are permitted for these words.

Ecological niche, competition, predator-prey relationship

Question 2-4. Choose the most appropriate term that corresponds to the underlined section ⓓ from the options below, and answer with its letter.

(1) Ecosystem services

(2) Ecosystem engineer
(3) Biome
(4) Ecological modeling
(5) Public benefits of ecosystem functions

Question 2-5. Regarding the underlined section ⓔ, there is a concept of protecting habitat areas of a specific species for the conservation of other species. Choose the most appropriate term for a species whose conservation can be linked to conserving many other species from the options below, and answer with its letter.

(1) Flagship species
(2) Endangered species
(3) Charismatic species
(4) Umbrella species
(5) Top predator

QUESTION No. 3. (Subject on Field Science)

Read the following sentences and answer the questions.

A wide variety of microorganisms inhabit the surfaces and digestive tracts of animals, ⓐestablishing symbiotic relationships with their hosts. Cattle, which are economically important livestock, are particularly notable for their digestive capabilities that make effective use of ⓑmicrobial activity. The bovine stomach harbors large populations of microorganisms that, ⓒin coordination with the host's gastrointestinal motility, work together to efficiently break down plant fibers derived from forage. The microbial degradation of these fibers produces ⓓshort-chain fatty acids, which are absorbed and utilized as an energy source by the host. However, ⓔthis microbial fermentation process also generates methane, which has recently raised environmental concerns due to its impact.

Question 3-1. Regarding the underlined section ⓐ, describe, in 100 words or fewer, a symbiotic relationship between animals and the microorganisms inhabiting their bodies, using an example not mentioned in the passage.

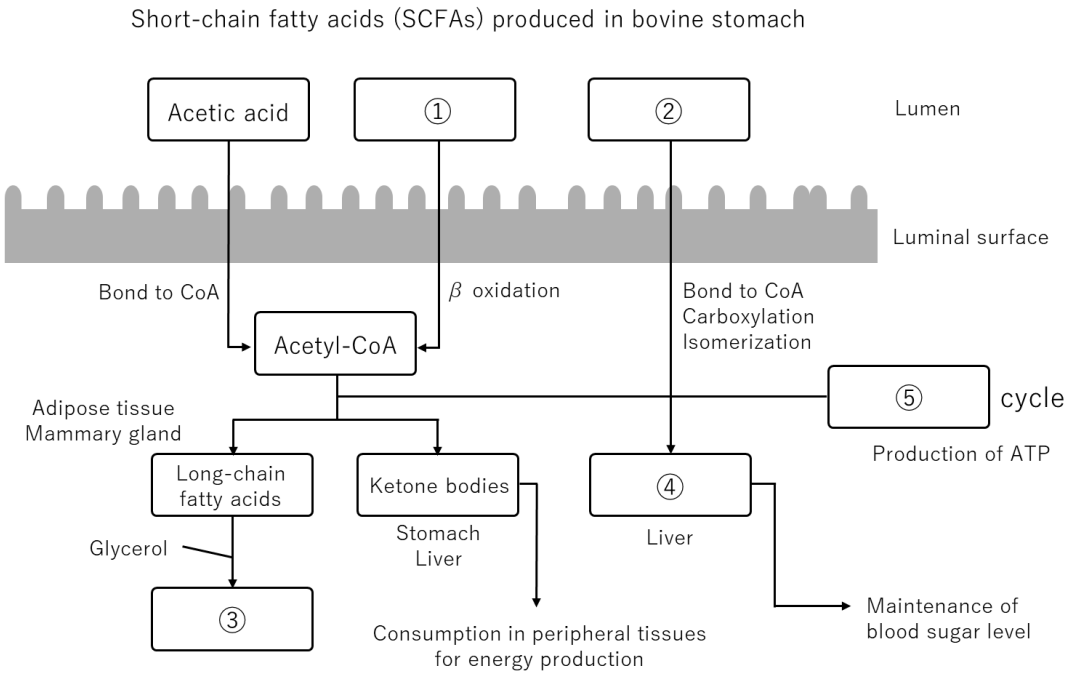
Question 3-2. Regarding the underlined section ⓑ, list all the kingdoms to which the microorganisms found in the stomachs of cattle belong, based on the five-kingdom classification system (Monera, Protista, Plantae, Fungi, Animalia).

Question 3-3. Regarding the underlined section ⓒ, the following passage describes the process by which plant-derived fiber consumed by cattle is broken down. Fill in the blanks ① to⑥ with appropriate terms. For blanks ② and ③, name the kingdoms to which the corresponding microorganisms belong, based on the five-kingdom classification system.

After being consumed by cattle, forage such as grasses is retained in the (①), then regurgitated into the oral cavity and chewed again, resulting in physical breakdown. The fragmented forage pieces are roughly decomposed in the (①) as (②) extend their hyphae into the fiber structure. Next, (③) produce enzymes such as cellulase and xylanase to break down the fiber components, namely (④), into oligosaccharides and monosaccharides. The resulting oligosaccharides and monosaccharides are taken up by the (③) and fermented via (⑤) fermentation, producing organic acids along with ATP. In addition, (⑥) produced during (⑤) fermentation reacts with carbon dioxide and is

converted into methane, which is expelled from the stomach as eructated gas (commonly known as a burp).

Question 3-4. Regarding the underlined section ⓓ, the figure below provides an illustration of how the major short-chain fatty acids produced in the stomach of cattle are metabolized in their body. Select the appropriate terms to fill in blanks ① through ⑤ from the options (A) to (L) listed below.



(A) Propionic acid	(B) Butyric acid	(C) Citric acid
(D) Palmitic acid	(E) Oleic acid	(F) Glucose
(G) Sucrose	(H) Triglycerides	(I) Cholesterol
(J) Oxygen	(K) Carbon	(L) Glycolytic

Question 3-5. Regarding the underlined section ⓔ, name the domain to which methane-producing microorganisms belong. Additionally, describe, in 100 words or fewer, any methods you know for reducing greenhouse gases such as methane derived from livestock.

QUESTION No. 4. (Subject on Field Science)

Read the following sentences and answer the questions.

In mature forests, when a disturbance causes the death or fall of large canopy trees, a localized bright area known as a (①) forms. Once a (①) is formed, it provides a site for regeneration of trees. However, among the tree species that compose the forest, there is a trade-off between growth rate in bright environments and survival rate in shaded environments. Therefore, the optimal size of a (①) for regeneration differs by species. For example, light-demanding (②) species require large (①) for regeneration, while (③) species can grow even in small (①) or under the closed canopy, where (②) species cannot survive. Such differences in ⓐniche preferences, such as interspecific variation in light requirements, and environmental heterogeneity, such as the size of (①)s, are among the factors that contribute to tree species diversity in forests.

The frequency of disturbance also affects tree diversity. In forests where large-scale disturbances rarely occur, (②) species have limited opportunities for regeneration and gradually decline over time after a disturbance. On the other hand, in forests where large disturbances occur frequently, (②) species become dominant, while (③) species become less abundant. Therefore, species diversity tends to be highest when the frequency and magnitude of disturbances are moderate. This idea is referred to as the (④) hypothesis in the context of biodiversity.

In tropical rainforests, it is known that ⓑthe survival rate of seedlings and saplings decreases near adult trees of the same species. As a result, the more dominant a species becomes, the lower its seedling survival rate tends to be, leading to (⑤) density dependence, which is thought to contribute to the maintenance of tree species diversity in forests.

It is known that forest tree species diversity is higher in tropical forests than in boreal or temperate forests. Contributing factors include ⓒhistorical processes, ⓓthe complexity of physical structure, and the high available energy.

As illustrated, various factors and mechanisms interact in complex ways to shape forest tree species diversity.

Question 4-1. Fill in the blanks (①) to (⑤) with the most appropriate terms. For (⑤), write either “positive” or “negative.”

Question 4-2. Regarding the underlined section ⓐ, what are some other commonly observed types of niche differentiation among species besides differences in light

requirements? Answer in about 10 words.

Question 4-3. Regarding the underlined section ⓑ, explain why this phenomenon occurs in approximately 20 words.

Question 4-4. Regarding the underlined section ⓒ, explain what kind of historical factors are involved. Use the word “glacier” in your explanation in approximately 20 words.

Question 4-5. In relation to the underlined section ⓓ, the presence of emergent trees in tropical forests that exceed 50 meters in height is thought to be related to the structural complexity of the forest and to contribute to tree species diversity. Explain why the presence of emergent trees contributes to tree species diversity in approximately 30 words.

QUESTION No. 5. (Subject on Life Science)

Question 5-1. Read the following passage and answer the questions (Question 5-1-1 and Question 5-1-2).

When genome sequences are compared among many human individuals, two individuals have one base pair difference per 1000 bases on average. Most of these variations are harmless. When two sequence variants are observed in a population and are both common, we call them (①). Most of (①) are single-base substitutions, which we call (②). The rest are mostly insertion or deletion mutations, and if their changes are relatively small, we call them (③), and if they are large and repeated, we call them (④). Common variants are found throughout a genome, but they are not distributed randomly or independently of each other. (①) tend to combine and jointly move as (⑤) and are inherited in a population.

[snip…]

In population studies of heritable diseases, DNA samples are collected from many patients with a given target disease and compared with samples from normal (control) populations. This enables us to screen variants that are more prevalent in the group of patients. The presence of such disease-linked variants suggests the nearby existence of alleles responsible for the susceptibility to the target disease, because ⓐDNA sequences that are close together on a chromosome are often inherited together. Specifically, (⑥) refers to a statistical method that narrows down phenotype-linked variants and (⑤) using many (①) in a genome, which is widely used in the genetic analysis of complex human diseases. In conventional genetics such as (⑥), we start from mutants' phenotypes, identify causative mutations, and finally reveal a gene function. The workflow of conventional genetics is called forward genetics. (adapted from *Molecular Biology of the Cell 6th ed.*)

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Question 5-1-1. Select the most adequate term from (A)-(I) for (①)-(⑥), respectively.

（A） single nucleotide polymorphism(s)
（B） QTL mapping
（C） polymorphism(s)
（D） haplotype block(s)
（E） copy-number variation
（F） translocation(s)
（G） genome-wide association study(ies)
（H） indel(s)
（I） inversion(s)

Question 5-1-2. Regarding the underlined text ⓐ, why do DNA sequences closely located on a chromosome tend to be inherited together? Explain in one or two sentences.

Question 5-2. What is "reverse genetics"? Explain its research workflow in two or three sentences by exemplifying one of the representative methods.

Question 5-3. Suppose that we are going to study gene expressions. Which methods suit the following aims (i) and (ii)? Select one of the suitable methods for each aim from the keywords below, and explain how it works in one or two sentences.

Aim (i): To analyze expressions of many genes by once

Aim (ii): To analyze where and when a single target gene is expressed

Keywords: DNA microarray, *in situ* hybridization, Quantitative reverse transcription-PCR, RNA-seq, Reporter gene assay

Question 5-4. Compared to the conventional Sanger sequencing method, what are the key differences in next-generation sequencing? Answer more than two differences using bullet points.

QUESTION No. 6. (Subject on Life Science)

Read the following sentences and answer the questions.

Table 1 lists the elements of the human body. In descending order, they are oxygen, carbon, hydrogen, nitrogen, calcium, (①), potassium, and (②). The top three elements—oxygen, carbon, and hydrogen—are predominant because more than half of the human body is composed of (③), followed by organic compounds with carbon as their skeletal structure.

The major organic compounds are carbohydrates, proteins, lipids, and nucleic acids. Carbohydrates are an important group of compounds that serve as energy sources and structural components of organisms. (④) is a monosaccharide that mainly serves as the substrate for cellular respiration and is converted into pyruvate through the process of glycolysis in the cytoplasm. Additionally, ⓐ(④) forms polymers in organisms, which are stored as starch and cellulose in plants and glycogen in animals.

ⓑProteins are a group of compounds formed by the polymerization of 20 amino acids and have ⓒdiverse functions and structures. Compounds with advanced functions, such as enzymes that promote chemical reactions and receptors that respond to chemical stimuli in cells, are all proteins. In addition, proteins are characterized by containing (②) as an element, and (②) forms covalent bonds within proteins to maintain a robust structure. ⓓKeratin, which constitutes hair, is a representative example.

Lipids are a general term for hydrophobic molecules and include fatty acids and triacylglycerols, which are important energy sources, (⑤), which form the double layer of cell membranes, and steroids. ⓔ(⑤) that has unsaturated fatty acids, which form double bonds and create a bent structure, play a role in increasing the fluidity of cell membranes.

Finally, nucleic acids are compounds that code genetic information. They are polymers in which sugars linked by bases are bridged by (⑥), containing (①) as an element, and can generate complex genetic information through the nucleotide sequences.

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Table 1 Elements of the human body

Element	Mass percentage
Oxygen	65.0%
Carbon	18.5%
Hydrogen	9.5%
Nitrogen	3.3%
Calcium	1.5%
(①)	1.0%
Potassium	0.4%
(②)	0.3%

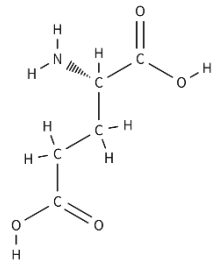
Source: Campbell Biology, 11th edition

Question 6-1. Answer the appropriate elements or substances in the blanks from (①) to (⑥).

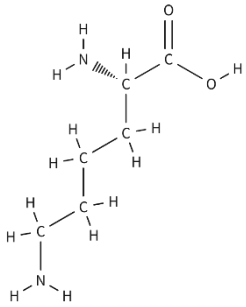
Question 6-2. Regarding the underlined part ⓐ, cellulose and glycogen are both polymers of (④). Explain how their structures differ in less than 30 words.

Question 6-3. Regarding the underlined part ⓑ, even a slight difference in the amino acids that construct a protein can significantly change its function. For example, sickle cell disease is caused by a change in the amino acid at a certain position in hemoglobin, which transports oxygen, from glutamate to valine. Choose the chemical structures of glutamate and valine from the following images.

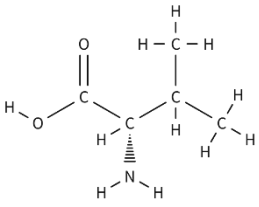
（A）



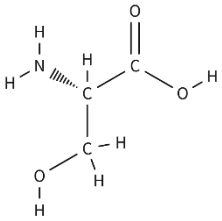
（B）



（C）



（D）



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Question 6-4. Regarding the underlined part ⓒ, there are two motifs that form the structure of proteins: α-helices and β-sheets. These two motifs have very different properties. For example, prion proteins with a high percentage of α-helices, are found on the membrane of neurons and other cells. However, in abnormal prions, a high percentage of β-sheets are found instead, and this is believed to be the cause of the neurological pathogenesis known as prion disease. Why might a high percentage of β-sheets be associated with the pathogenesis? Explain in less than 50 words.

Question 6-5. Regarding the underlined part ⓓ, the strong covalent bonds formed by (②) can be broken by reducing agents, which is used in a perm. On the other hand, even without using a perm, hair can be temporarily reshaped by wetting with water. This is because the keratin in hair maintains its structure with weak bonds. What is the name of this bond? Additionally explain the difference between it and a covalent bond in less than 50 words.

Question 6-6. Regarding the underlined part ⓔ, keratinocytes in the skin have a high proportion of saturated fatty acids, while nerve cells and immune cells have a high proportion of unsaturated fatty acids. Why is this? Focus on the differences in cell function and explain the reason in less than 50 words.

QUESTION No. 7. (Subject on Life Science)

Read the following sentences and answer the questions.

The cell is the basic unit of organisms. By cell division, one cell produces a daughter cell from the original cell. ⓐCell division produces the cells in the next generation in unicellular organisms and the individuals in the development of multicellular organisms.

The cell cycle is a series of processes of cell division, divided into four phases: G1, (①) for DNA replication, G2, and M. ⓑAt the end of the M phase, cytokinesis occurs, resulting in two cells. (②) is the protein which regulates cell cycle progression through the activation of (②)-dependent kinases by drastic change of the concentration of (②) during cell cycles. For example, M-(②) required for progression of M phase, undergoes proteolysis mediated by (③) , a protein modification in the mid- to late M phase, resulting in a rapid decrease in the concentration.

To keep the accuracy of genetic information for newly formed daughter cells during cell division, cells have various mechanisms. DNA polymerase, responsible for DNA replication, has 3′→5′ (④) activity for a ⓒproofreading function. DNA repair mechanisms are also important. Mutations in DNA sequence caused by UV or environmental agents are repaired. As an example, ⓓnaturally occurring deamination converts cytosine to uracil.

In general, cells with linear DNA can undergo only a limited number of cell divisions. This is because the DNA ends are shortened in every cycle of DNA replication, and cell division stops when the shortening exceeds a certain level. In contrast, ⓔthere are some cells with linear DNA in which the DNA ends are not shortened even after DNA replication process.

Question 7-1. Answer the most appropriate words in the blanks from (①) to (④).

Question 7-2. Answer the three domains of life.

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Question 7-3. Regarding the underlined part ⓐ, calculate the total time required for an unicellular organism to divide from one cell to one million cells. You can assume that each cell division takes 3 hours, and all cells are alive and able to divide. Use $Log_2 3 = 1.585$, $Log_2 5 = 2.322$. Describe the calculation process and provide the answer.

Question 7-4. Regarding the underlined part ⓑ, explain the differences in the cytokinesis between animal and plant cells in about 70 words.

Question 7-5. Regarding the underlined part ⓒ, the proofreading function of RNA polymerase, which functions in synthesis of RNA with DNA as template, is generally lower than that of DNA polymerase. Therefore, quality control of mRNA is performed after it is synthesized. Explain the mechanism of "nonsense-mediated mRNA decay" by which abnormal mRNA is degraded in about 70 words.

Question 7-6. Regarding the underlined part ⓓ, explain and discuss why thymine is used in DNA but uracil is used in RNA from the perspective of DNA repair in about 70 words.

Question 7-7. Regarding the underlined part ⓔ, raise one example of a type of cells with linear DNA in which the DNA end does not shorten. Then, explain why the DNA end is not shortened, including the name of the enzyme involved, in about 15 words.

QUESTION No. 8. (Subject on Life Science)

Read the following sentences and answer the questions.

Inside the cells of eukaryotic organisms, there are compartments surrounded by membranes collectively referred to as (①), which each perform distinct functions. Genomic DNA, the source of genetic information, is typically wrapped around histone proteins to form units called (②), which then undergo higher-order folding to be stored within the nucleus. In the cytoplasm, there exist mitochondria, which are the primary site for ATP synthesis through a reaction known as (③), involving the formation of a proton gradient via the electron transport chain. Also present are (④), a type of (①), which carry out photosynthesis. ⓐMembrane and secretory proteins first localize to the endoplasmic reticulum, then are transported via vesicles to the (⑤), where they undergo glycosylation and are then directed to their proper destinations. ⓑSubstances that bind to receptors located on the cell membrane are transported into the cell by a pathway called endocytosis, in which the plasma membrane invaginates and pinches off into vesicles, leading to endosomes with acidic interiors. Other compartments include the (⑥), which are acidic and contain various hydrolytic enzymes, and the (⑦), which contain oxidative enzymes and are involved in fatty acid breakdown. When (①) are no longer necessary or when the cell are starved, (①) are degraded via a pathway known as (⑧).

Question 8-1. Answer the most appropriate words in the blanks from (①) to (⑧).

Question 8-2. Regarding underlined part ⓐ, explain the mechanism by which secretory proteins are transferred into the lumen of the endoplasmic reticulum simultaneously with translation using following words in about 50 – 100 words.

Signal sequence, SRP, translocon

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Question 8-3. Regarding underlined part ⓑ, mammalian cells uptake iron ions through endocytosis of a water-soluble protein called transferrin, which exists in the bloodstream and binds iron ions. This protein binds to receptors called TfR located on the cell membrane. After endocytosis, the TfR is recycled back to the cell membrane. Select two statements from the choices below that correctly describe characteristics of transferrin and TfR. Transferrin and TfR have two following characteristics;

1. Transferrin binds iron ions in neutral solutions, but not in acidic solutions.
2. Transferrin not bound to iron binds to TfR in acidic solutions, but not in neutral solutions.

Then, explain what advantages these characteristics provide in about three sentences.

Question 8-4. Indicate with a ○ when each of the following statements is correct, and with an × if it is incorrect. For incorrect statements, write a corrected version.

a) The endoplasmic reticulum is the main storage site for calcium ions.
b) Nuclear pores are relatively large, allowing proteins to freely diffuse between the nucleus and the cytoplasm.
c) During endocytosis, coat proteins called clathrin binds to the cell membrane, causing membrane invagination and vesicle formation.
d) Rab proteins present on vesicles bind specifically to proteins on target membranes, ensuring proper vesicle targeting.
e) Seven-transmembrane proteins on the plasma membrane have both N-terminus and C-terminus exposed to the extracellular side.

QUESTION No. 9. (Subject on Aquatic and Marine Science)

Question 9-1. Read the following statements about seaweeds and answer the question that follows.

Organisms commonly referred to as "seaweeds" include several types of multicellular algae: (1), (2), and (3). Among them, (3) have the most complex body plans, with morphologies resembling those of land plants. However, both morphological and genetic data indicate that these similarities are examples of (4), not (5), meaning they were acquired independently in brown algae and land plants.
The cell walls of (2) mainly contain (6), which is also found in land plants. In contrast, the cell walls of (3) and (1) contain distinct polysaccharides characteristic of each group. In (3), (7) and (8) are present in the cell walls and are used as thickeners, pharmaceuticals, and functional food ingredients. The cell wall component (9) of (1) is also used as a gelling agent, thickener, and stabilizer in various products.

Question 9-1-1. Choose the most appropriate words from the following words of candidates to fill in the blanks.
Words: alginate, brown algae, carrageenan, diatoms, red algae, convergence, cellulose, analogy, homology, fucoidan, green algae

Question 9-1-2. Regarding the underlined sentence, some large brown algae, such as those belonging to the orders Laminariales and Fucales, have balloon-like structures called *bladders* (small, air-filled sacs) on their blades. Describe, in approximately 50 words, the function and adaptive significance of these bladders.

Question 9-2. Read the following statements and answer the following questions.
Red algae and green algae possess chloroplasts that originated through primary endosymbiosis, whereas brown algae have chloroplasts derived from secondary endosymbiosis.

Question 9-2-1. Using the following wards, describe in approximately 40 words the origin of chloroplasts in red and green algae, with focus on the process of chloroplast formation and the origin of the double membrane.

Wards: organelle, outer membrane, cyanobacterium, heterotrophic eukaryote, phagocytosis, phagosomal membrane, inner membrane

Question 9-2-2. Other than chloroplasts, what is the name of another organelle that is thought to have originated through endosymbiosis.
This organelle is believed to have been acquired earlier than chloroplasts. Explain the reason for this in approximately 30 words.

Question 9-2-3. What are the names of two groups of algae that, like brown algae, have acquired chloroplasts through secondary endosymbiosis? For each group, specify whether the chloroplast originated from a green alga or a red alga.
Example answer: Brown algae (red alga)

QUESTION No. 10. (Subject on Aquatic and Marine Science)

Read the following paragraph about biological productivity and conservation in coastal area, and answer the questions.

Coastal area, including estuary, tidal flat and salt marsh, is a habitat for various aquatic organisms and has been utilized as a fishing ground. In addition to harvesting natural resources, coastal waters are actively used for ⓐaquaculture of bivalves such as oysters. Because coastal areas are close to land and subject to intense human activity, they are easily affected by ⓑanthropogenic influences.

Question 10-1. Regarding the underlined part ⓐ, explain the taxonomic status and morphological characters of oyster in approximately 50 words.

Question 10-2. Regarding the underlined part ⓐ, explain why the life cycle and ecological traits of bivalves, such as oysters, make them suitable for aquaculture in coastal area in approximately 100 words.

Question 10-3. Regarding the underlined part ⓑ, functions of estuary, tidal flat and salt marsh have been recently recognized. Describe characteristics and conservation measures of tidal flats and salt marshes, incorporating the following keywords in approximately 150 words.

Keywords:
benthos, detritus food chain, eutrophication, grazing food chain

QUESTION No. 11. (Subject on Aquatic and Marine Science)

Read the following text and answer the questions.

Krill are shrimplike (①) that abound in the ocean. About eighty-five species of krill are distributed worldwide, ranging from the tropics to the poles, each species adapted to specific water temperatures. Krill are one of the most (②) animal groups on the Earth. Antarctic krill (*Euphasia superba*) are distributed widely in the circumpolar waters of Antarctica. Adult Antarctic krill reaches 6 cm or more in length and over one gram in weight. It is as adults that krill aggregate into large swarms that can extend over 100 km^2 in very dense concentrations of up to more than 2 kg/m^3. Typically, the swarms of krill engage in (③) migration, remaining at depth during daylight and rising to the surface to feed during the night.

ⓐAntarctic krill are considered to be a keystone species by biologists, meaning that, being herbivores, they are the single most critical link between (④) and (⑤). They are preyed upon by an incredible variety of carnivores, such as fish, squid, seabirds, and baleen whales. Therefore, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) has established regulations such as an upper limit on the catch to protect Antarctic krill resources. However, according to some fisheries biologists, ⓑestimates of krill stock in Antarctic waters vary tremendously, ranging between a million and a billion metric tons (three orders of magnitude).

Question 11-1. Select the most appropriate word(s) in the blanks (①) - (⑤) from the options below to complete the abovementioned text.

phytoplankton / zooplankton / crustaceans / insects / mollusks / decomposers / large animals / number of species / abundant / seasonal / diurnal vertical / horizontal

Question 11-2. There are problems in commercial krill fisheries caused by their physiological characteristics. Explain the problem in about 25 words.

Question 11-3. Regarding the underlined part ⓐ, explain how the decline in the population of Antarctic krill affects the ecosystem, in about 100 words.

Question 11-4. Regarding the underlined part ⓑ, explain the potential concerns that may arise when stock estimates show large variability, in about 50 words.

QUESTION No. 12. (Subject on Aquatic and Marine Science)

Answer the following questions related to marine primary production.

Question 12-1. List the three nutrient elements that often limit the abundance of marine phytoplankton, and all of the dissolved ion forms of each element in seawater.

Question 12-2. Coastal waters are considered to have high primary productivity due to the large supply of these nutrients. List three representative nutrient supply processes and explain the characteristics and mechanisms of each process in approximately 50 words.

Question 12-3. Explain the definition of "critical depth," which is closely related to the spring bloom, in which phytoplankton proliferate in spring, in 30 words or less. Also, explain the mechanism of the spring bloom using the term "critical depth" in approximately 100 words.

Question 12-4. If a diatom species that formed a spring bloom was reproducing at a rate of two divisions per day, what was the specific growth rate (day^{-1}) of this species? Specific growth rate, μ, is defined as the increase in cell biomass per day. If you do not know the numerical value, you may express it in logarithmic or exponential form.

Question 12-5. In areas where diatoms are highly productive, surface sediments are formed from siliceous ooze. Explain why siliceous ooze is found in open oceans in approximately 50 words. Also, answer three representative areas where this occurs.