IBO Challenge 2020

A Substitute for The 31st IBO 2020 Nagasaki, JAPAN

Clypeaster japonicus

Saccharina japonica

Undaria japonica

Lascothea japonica

Branchiostoma japonicum

Mauremys japonica

Hyla japonica

Anguilla japonica

Rana japonica

Elaeocarpus japonicum

Cryptomeria japonica

Castanea japonica

Ohmia japonica

Theoretical Exam 2

signature

2020.8.12.

Hydrophilus japonicus

Luehdorfia japonica

Hachiroshia japonica

Nihonmesa japonica

Penaeomens japonica

Aspergillus japonicus

Fibrocapsa japonica

Meyerisa japonica

Axinopora japonica

Omphalotus japonicus

Mimaletella japonica

Ephebe japonica

Coturnix japonica

Oxycomanthus japonicus

Panulirus japonicus

Mallotus japonicus

Scolopendra subspinipes japonica

Pterophora japonica

Lychaete japonica

Delisea japonica

Prosola japonica

Lotus japonicus

Clamunda japonica

Corrocapnatum japonicum

Nipponia nippon

General instructions for theoretical examinations
理論題的一般說明

Exam 2

- Date: August 12th 2020
- Total time of Exam 2 is 3 hours. Follow the instruction by Jury members of your country.
  理論題第 2 部分的考試時間為 3 小時，依監考老師的指示進行。
- Exam 2 consists of 45 questions.
  理論題第 2 部分共有 45 題。
- The score for correct answer is indicated in each question.
  每題的得分有個別註明。

Instruction and regulations
規則說明

- Make sure that you are using the correct answer sheets (Theoretical exam 2-1 and 2-2).
  先確定答案紙是對的(Theoretical exam 2-1 和 2-2)。
- Write your **Country code** and **student ID number** (provided by a jury member or supervisor) in the given box of the answer sheets provided, and write down **your name**.
  在答案紙的適當空格中，填寫**國家編號**以及**學生 ID** (將由監考老師提供)，並填寫你的**姓名**。
- Make sure to **sign all the answer sheets and the cover page of question sheets**.
  答案紙的每一頁，以及**試題卷的封面**，都要**簽名**。
- You must mark your answer to the answer sheets properly, using a pen or a pencil.
  用原子筆或鉛筆，在答案紙上清楚劃記。
- You must have the following equipment for this exam.
  本考試中，你應有下列工具
  ① Pen or pencil to mark answer sheets.
  原子筆或鉛筆，作答用。
  ② Scratch paper sheets provided by Jury member. (You must not bring any paper into the examination room by yourself.)
  由監考老師所提供的計算紙 (你不能自行攜帶任何紙張至考場中)。
  ③ Ruler and eraser.
  尺和橡皮擦。
- The use of a calculator is prohibited, including a calculator application on your PC or a web browser.
  禁止使用計算機，包括電腦或網路上的計算機。
- You must not communicate with any other people in the room during the examination.
  考試時，不能和考場中的任何人交談。
- You must not access any information that could unfairly help you answer the questions during the examination.
  考試時，不能使用任何可以不正當幫助你作答的資訊。

- Stop answering immediately at the end of examination time.
  考試時間結束時，立即停止作答。
- After the examination:
  考完之後：
  ① If you are under **on-site supervision, a jury member / supervisor** will collect your question and answer sheets immediately after each exam. Your country coordinator will later scan and submit the sheets to the IBO2020 Organizing Committee.
  屬於**現場被監考試**者，在每部分考試之後，將由監考老師立即收回試題卷和答案紙。然後再經由掃描所有相關紙張，並繳交檔案給 IBO2020 主辦大會。
  ② If you are under **online supervision**, **you (competitor)** must scan (or take photos of) the answer sheets. Then, digitally send the scanned files/photos and the PDF question sheets (with your signature on the cover page) to your country coordinator as soon as possible. Your country coordinator will submit the file to the IBO2020 Organizing Committee. Make sure the answer sheets are scanned correctly. The IBO2020 office may ask you to resubmit the sheet, so don't discard them.
  屬於**線上被監考試**者，參賽者必須掃描(或拍照)答案紙，然後儘快傳送檔案/照片及試題卷(封面有簽名)的 PDF 給你的主試者，他將繳交檔案給 IBO2020 主辦大會。須確切掃描答案紙。主辦單位得要求你再繳交答案紙，所以請勿丟棄。

Biochemistry
生物化學

Q1

Glycogen (and amylopectin) is a glucose polymer with some branching. Linear chains of these polymers consist of α(1→4) linkages and occasional branching is formed by α(1→6) linkage (Figure 1). For degradation in cells, glucose residues are released one-by-one from the end of the chains by phosphorylase up to the residue at the branching site. Then, the α(1→6) branching site is removed by a debranching enzyme.

肝醣 (與支鏈澱粉) 是具有一些支鏈的葡萄糖聚合物。這些聚合物的直鏈部分由 α(1→4) 鍵結構成，以及偶爾有一些由 α(1→6) 鍵結產生的支鏈 (Figure 1)。當其在細胞中降解時，葡萄糖分子會因磷解酶的作用而從鏈的末端逐一釋放出來，直到分支處。然後，α(1→6) 鍵結的分支會被一個去分支酵素移除。

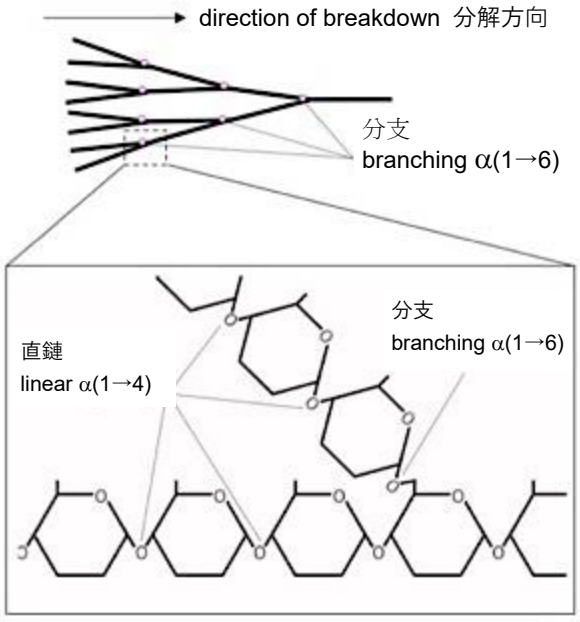


Figure 1 Breakdown of glycogen in cells.
圖 1. 細胞之肝醣分解

Q1-1 Given that a certain glycogen consisting of 10000 glucose residues is branched at every 10 residues, **how many terminal chains are available for phosphorylase?** [1] (1 point)

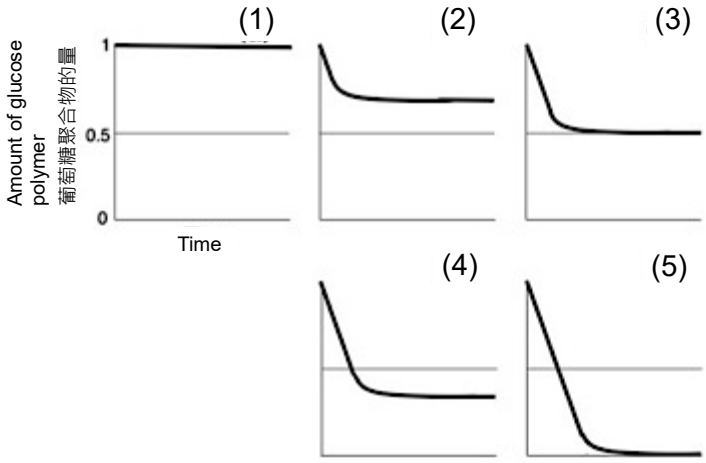
現有某一由 10000 葡萄醣分子構成的肝醣，且每 10 個葡萄醣分子處產生一個分支。**有多少個終端鏈可供磷解酶作用？**

(1) about 10 (2) about 50 (3) about 100 (4) about 500 (5) about 1000 (6) about 5000

Q1-2 For degradation of this glycogen by excess phosphorylase or by excess debranching enzyme, **choose an appropriate graph for its breakdown from below.** Assume that the phosphorylase releases all glucose residues from a linear chain without branching. (1 point each)

如果用過多的磷解酶或過多的分支酵素來降解此肝醣，**請從下列圖中各選出一個恰當的分解圖形**。 假設磷解酶從一無分支的直鏈將其上的所有葡萄醣分子都釋放出來。

phosphorylase 磷解酶: [2] debranching enzyme 去分支酵素: [3]



Q1-3 Plant amylopectin is similar to glycogen but branching occurs much less frequently. Given that the branching of an amylopectin of similar size of glycogen is formed at every 25 residues, **indicate the combination of correct descriptions about degradation of amylopectin by phosphorylase.** 4 (1 point)

植物的支鏈澱粉 (amylopectin) 與肝醣很相似，但是其分支則遠低於肝醣。某一個與肝醣大小相似的分支澱粉，其每 25 個葡萄醣分子處具有一個分支，**當以磷解酶降解分支澱粉時，請指出下列敘述正確的組合**。

(a) Breakdown speed is slower than that of glycogen.
降解速率比肝醣慢

(b) Breakdown speed is similar to that of glycogen.
降解速率與肝醣相似

(c) Breakdown speed is faster than that of glycogen.
降解速率比肝醣快

(d) Final breakdown extent is smaller than that of glycogen.
最終降解的程度小於肝醣

(e) Final breakdown extent is similar to that of glycogen.
最終降解的程度與肝醣相似

(f) Final breakdown extent is larger than that of glycogen.
最終降解的程度大於肝醣

(1) (a), (d) (2) (a), (e) (3) (a), (f)
(4) (b), (d) (5) (b), (e) (6) (b), (f)
(7) (c), (d) (8) (c), (e) (9) (c), (f)

Biochemistry
生物化學

Q2

Hydrolases that degrade biopolymers can be categorized into two types: (1) endo-type that hydrolyzes the interior bonds of the polymer, and (2) exo-type that releases the end unit from the polymer. These exo-type and endo-type hydrolases are often linked to their biological roles.

能降解生物聚合物的水解酶可區分為二類： (1) 能從聚合物內部鍵結進行水解的內切型，以及 (2) 從聚合物末端進行水解的外切型。這些外切型與內切型的水解酶經常聯合起來進行其生物角色。

Choose (1), if the enzyme mentioned below (A-D) is endo-type, and choose (2) if it is an exo-type. (1 point each)

如果下列各酵素 (A-D) 為內切型，請選 (1)。如果為外切型，請選 (2)。

A. Digestive proteases in stomach such as pepsin [5]
胃中的消化性蛋白酶，例如胃蛋白酶

B. Proteases that cleave off the translocation signal peptide [6]
切除易位訊息胜肽的 (translocation signal peptide) 蛋白酶

C. Proofreading nuclease in the DNA polymerase that removes misincorporated nucleotides during DNA replication. [7]
於 DNA 複製時，能夠移除錯誤併入之核苷酸的校對核酸酶 (proofreading nuclease)

D. Cas9 nuclease of the CRISPR-Cas9 system for genome editing. [8]
可進行基因體編輯之 CRISPR-Cas9 系統中的 Cas9 核酸酶

Biochemistry
生物化學

Q3
Alcohol dehydrogenase is known to convert ethanol to acetaldehyde, which is eventually metabolized to CO_2 and H_2O in humans and many other organisms. The enzyme also catalyzes the conversion of methanol to poisonous formaldehyde, but with less efficiency. This normally means that ethanol is the physiological substrate for the enzyme. However, we may regard that ethanol is an efficient competitive inhibitor for the enzyme against the reaction with methanol under certain conditions. For example, intake of ethanol may prevent the conversion of methanol, when a small amount of methanol is taken up erroneously. Here, you can **calculate the concentration of ethanol** which suppresses 90% of the initial formaldehyde production in a test tube containing 5 mM methanol and alcohol dehydrogenase, based on the equations and assumption of kinetic constants of methanol and ethanol that are 10 mM and 1 mM, respectively.

酒精去氫酶可將乙醇轉化為乙醛，於人體與許多其他生物中，最終會代謝成為 CO_2 與 H_2O。此酵素也可進行催化作用，將甲醇轉化成具有毒性的甲醛，但轉化效率較低。在正常情況下，乙醇被視為此酵素的生理性受質。然而在某些情況下，我們也可將以乙醇當作有效的競爭性抑制劑用來對抗甲醇。例如當誤食少量甲醇時，可食入乙醇來防止甲醇的轉化。此處，於一含有 5mM 甲醇與酒精去氫酶的試管中，**你可計算乙醇的濃度**，使其能抑制 90%的甲醇轉化。請利用下列方程式，並假設甲醇與乙醇的動力學常數 (kinetic constants) 分別為 10 mM 及 1 mM。

Ethanol concentration [9] [10] . [11] mM (3 points if 3 digits are correct)
乙醇濃度 [9] [10] . [11] mM (如果 3 個數字都正確可得 3 分)

The initial velocity (v_0) of methanol conversion can be obtained using equation 1.
可利用方程式 1 得到甲醇轉化的初速度 (v_0)

α is defined by equation 2. α 係使用方程式 2 來定義

[S]: the methanol concentration 甲醇濃度　　K_M: kinetic constant for methanol 甲醇的動力學常數

[I]: the ethanol concentration 乙醇濃度　　K_I: the kinetic constant for ethanol 乙醇的動力學常數

$$v_o = \frac{V_{max}[S]}{\alpha K_M + [S]}$$ equation 1

$$\alpha = \left(1 + \frac{[I]}{K_I}\right)$$ equation 2

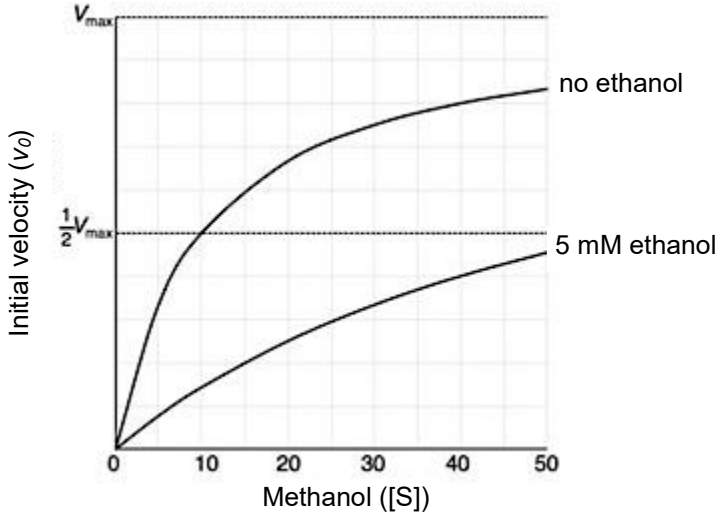


Figure 1 Methanol conversion with or without ethanol 圖 1. 在有無乙醇下的甲醇轉化情形

Cell Biology (細胞生物學)

Q4

Here is a mixture containing viruses, globular proteins, and cell nuclei, which are all assumed to have similar densities of approximately 1.3 g/mL. We would like to separate them by using three different centrifugation methods as shown in Figure 1. The first method entails centrifugation of the mixture (Mix) after placing it on the top of a medium (Med) that has a uniform density (*Exp. A*). The second method (*Exp. B*) entails centrifugation of the mixture using a medium that has a density gradient ranging from 1.0 to 1.6 g/mL (from the top to the bottom). The final method entails the use of a centrifuge tube with the same density gradient as that in *Exp. B*, but the mixture is placed at the bottom of the tube (*Exp. C*). ***g*** indicates the direction of centrifugal forces given to the specimens.

一個含有病毒、球蛋白、與細胞核的混合液，並假設三者的密度大約相同，都為 1.3 g/mL。現在我們欲使用三種離心方法來分離它們，如 **Figure 1** 所示。第一種方法 (*Exp. A*) 是將此混合液放在一個均勻的培養液 (Med) 上，然後加以離心。第二種方法 (*Exp. B*) 是使用一個梯度介於 1.0 至 1.6 g/mL (由上而下) 的培養液來進行離心。 最後一種方法 (*Exp. C*) 使用與 *Exp. B* 相同的梯度離心培養液，但將混合液放置在離心管的底部，然後加以離心。***g*** 代表施加於標本的離心力方向。

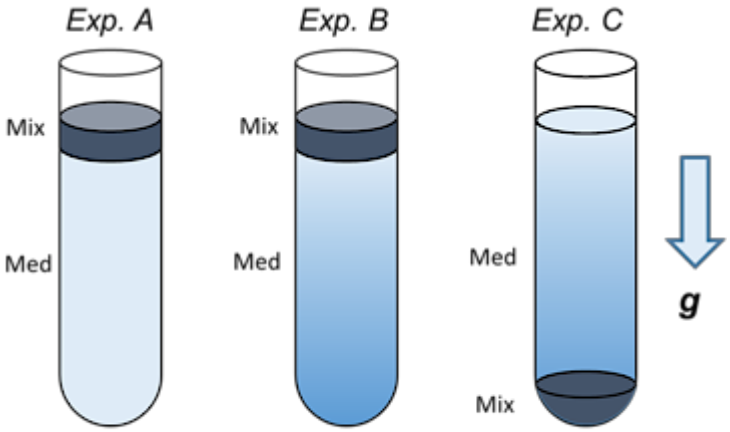


Figure 1

In *Exp. A*, how are viruses, globular proteins, and nuclei supposed to sediment? Choose the most appropriate diagram from (1) **I**, (2) **II**, (3) **III**, (4) **IV** in Figure 2 that shows the sedimentation time courses of specimens. [12] (1 point)

於 *Exp. A*, 病毒、球蛋白、以及細胞核會如何沉澱？請從 Figure 2 的 (1) **I**, (2) **II**, (3) **III**, (4) **IV** 中選出最合適的樣本沉澱時程圖。 [12] (1 分)

Additionally, choose appropriate lines from (1) **a**, (2) **b,** or (3) **c** in the selected diagram that indicate the time courses of sedimentation of viruses [13], globular proteins, [14] and nuclei [15], respectively. (1 point if 3 correct answers)

另外請從所選取的時程圖中選出線條 (1) **a**, (2) **b,** 或 (3) **c** 分別對應病毒 [13], 球蛋白, [14] 以及細胞核 [15] 的沉澱。(如果 3 個答案都正確得 1 分)

In *Exp. B,* how are viruses, globular proteins, and nuclei supposed to sediment? Choose the most appropriate diagram from (1) **I**, (2) **II**, (3) **III**, (4) **IV** in Figure 2 that shows the sedimentation time courses of the specimens. [16] (1 point)

於 *Exp. B*，病毒、球蛋白、以及細胞核會如何沉澱？ 請從 Figure 2 的 (1) **I**, (2) **II**, (3) **III**, (4) **IV** 中選出最合適的樣本沉澱時程圖。 16 (1 分)

Additionally, choose appropriate lines from (1) **a**, (2) **b**, or (3) **c** in the selected diagram that show the time courses of sedimentation of viruses 17, globular proteins, 18 and nuclei 19, respectively. (1 point if 3 correct answers)

另外，請從所選取的時程圖中選出線條 (1) **a**, (2) **b**, 或 (3) **c** 分別對應病毒 **17**, 球蛋白, 18 以及細胞核 19 的沉澱。(如果 3 個答案都正確得 1 分)

In *Exp. C*, how are viruses, globular proteins, and nuclei supposed to float? Choose the most appropriate diagram from (1) **V**, (2) **VI**, (3) **VII**, (4) **VIII** in Figure 3 that shows the floating time courses of specimens. 20 (1 point)

於 *Exp. C*, 病毒、球蛋白、以及細胞核會如何漂浮？ 請從 Figure 3 的 (1) **V**, (2) **VI**, (3) **VII**, (4) **VIII** 中選出最合適的漂浮時程圖。 20 (1 分)

Additionally, choose appropriate lines from (1) **a**, (2) **b**, or (3) **c** in the selected diagram that show the time courses of floating of viruses 21, globular proteins 22 and nuclei 23, respectively. (1 point if 3 correct answers)

另外，請從所選取的時程圖中選出線條 (1) **a**, (2) **b**, 或 (3) **c** 分別對應病毒 **21**, 球蛋白, 22 以及細胞核 23 的漂浮。(如果 3 個答案都正確得 1 分)

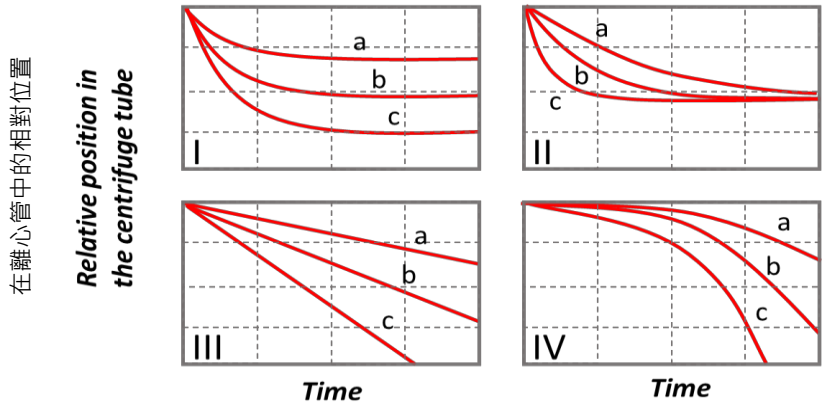


Fig. 2

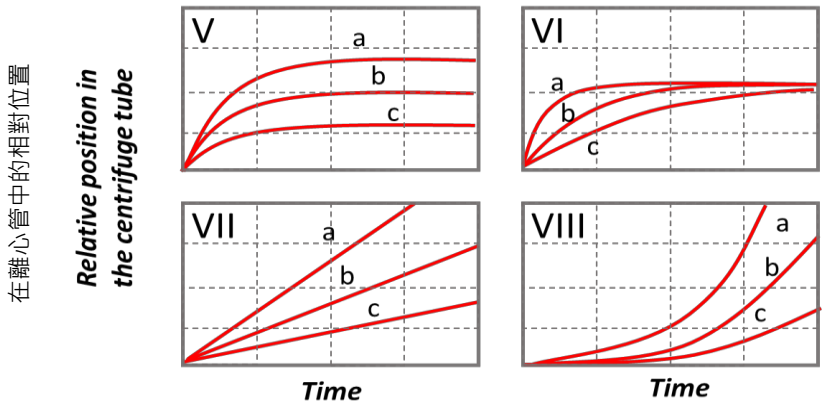


Fig. 3

Cell Biology

細胞生物學

Q5

Cytoplasm is generally occupied by very high concentrations of biomolecules and condensed organelles. This property is called "molecular crowding", which affects the rate of intra-cytoplasmic diffusion and enzymatic reactions. Mammalian red blood cells (RBCs, Figure 1) are a typical case that demonstrate molecular crowding.

細胞質通常充滿了高濃度的生物分子與濃密的胞器。這種現象稱為"分子擁擠"，可影響細胞質內彼此間的擴散與酵素反應。哺乳類紅血球細胞 (RBCs, Figure 1) 是一個典型的例子，可用來展示分子擁擠現象。

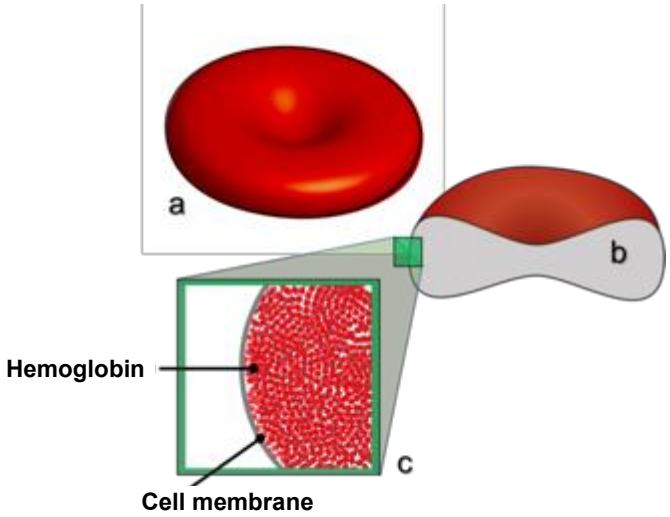


Figure 1 Schematic drawing of red blood cells (RBCs). c, Hemoglobin molecules assumed in a RBC cross section (b).

圖 1 紅血球細胞 (RBCs) 示意圖。假設位於 RBC 橫切面 (b)的血紅素分子(c)

The concentration of hemoglobin molecules (molecular mass, 64,000 g/mol) inside RBCs is called "mean corpuscular hemoglobin concentration (MCHC)". It is as high as about 320 mg/mL in humans. From this concentration, we can estimate the mean cytoplasmic volume in a RBC occupied by a single molecule of hemoglobin. If hemoglobin molecule has a density as usual protein molecules of about 1.35 g/mL, we can also estimate how large is the molecular volume of hemoglobin. Using these values, the hemoglobin molecules are estimated to occupy about [24] % of the total cytoplasmic volume in RBCs.

RBCs 內血紅素分子(分子量, 64,000 g/mol) 的濃度，稱為"平均紅血球血紅素濃度 (MCHC)" 於人類，此值可高達大約 320 mg/mL。從這個濃度，我們可估計被單一血紅素分子所占滿之紅血球的平均細胞質體積。 如果血紅素分子的密度與一般蛋白質的密度相似，都為 1.35 g/mL，我們還可估計出血紅素分子體積的大小。利用這些數值，估計血紅素分子可佔有 RBCs 大約 [24] % 的細胞質體積。

Q5-1 Choose the closest number to enter in [24]. Use the Avogadro constant, 6.02×10^{23} for the calculation if needed. (3 point)

選出最接近的數字填入 [24]。如果有必要，可使用亞佛加厥常數 6.02×10^{23} 用來計算。(3 分)

(1) 3 (2) 6 (3) 12 (4) 24 (5) 48

Q5-2 How does this hemoglobin concentration affect the rate of diffusion in the actual RBCs? Scientists succeeded in measuring the diffusion rate of hydrogen ions. They first put RBCs in saline with different osmolarity and examined how the cell volume changed (Figure. 2a), and then measured the diffusion rate of hydrogen ions (Figure. 2b). Diffusion rates were also examined for red blood cells from different species (human, chicken, alpaca; 320, 305, and 450 mg/mL of MCHC, respectively) as shown in Figure. 3.

於實際的 RBCs 中，這個血紅素濃度如何影響擴散速率？科學家們已經能夠測量出氫離子的擴散速率。他們首先將 RBCs 放置到不同滲透壓的食鹽水中，觀察細胞體積的變化 (Figure. 2a)，然後測量氫離子的擴散速率 (Figure. 2b)。不同物種 (人類、雞、羊駝，其 MCHC 分別為 320, 305, and 450 mg/mL) 的紅血球，也用來測量其擴散速率，如 Figure. 3 所示。

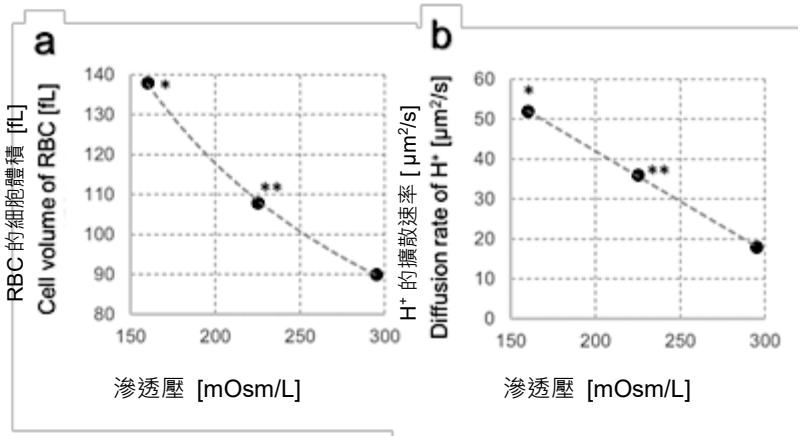


Figure 2 Examination of the relationship between (**a**) the cell volume of RBC (fL = 1×10 $^{-15}$ L) and (**b**) the measured diffusion rate of hydrogen ions [μm^2/s] versus osmolarity [mOsm/L] of saline solutions. 300 mOsm/L corresponds to the osmosis of the body fluid in a healthy human.

檢測二者的相互關係 (**a**) RBC 的細胞體積 (fL = 1×10 $^{-15}$ L) 與 (**b**) 觀測到食鹽水中的氫離子擴散速率 [μm^2/s] 和相對應的滲透壓 [mOsm/L]。 300 mOsm/L 相當於一個健康人類體液的滲透壓。

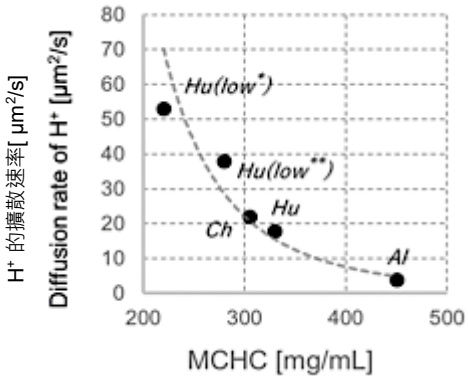


Figure 3 Diffusion rate of intracellular hydrogen ions measured using RBCs from different animal species. *Hu*, *Ch*, and *Al* represent humans, chickens, and alpacas from which RBCs were derived. *Hu (low*)* and *Hu (low**)* indicate the results obtained at 155 and 225 mOsm/L (* and ** in Figure. 2), respectively.

從不同物種紅血球測量出的細胞內氫離子擴散速率，*Hu*, *Ch*, a 以及 *Al* 分別代表人類、雞、以及羊駝所取得的 RBCs。*Hu (low*)* 與 *Hu (low**)* 分別代表從 155 和 225 mOsm/L (Figure. 2 中的 * 和 **), 得到的結果.

Indicate whether each of the following statements is true (1) or false (2). (1 point each)
指出下列各敘述為正確 (1) 或錯誤 (2)。 (每個 1 分)

A. Alpaca RBCs, which have a hemoglobin concentration about 1.5 times higher than that of humans, have an internal ion diffusion rate of less than 50% of that of human RBCs. 25

羊駝 RBCs 的血紅素濃度大約比人類高 1.5 倍，其細胞內離子擴散速率比人類 RBCs 低 50%。 25

B. Ion diffusion rate is low inside human RBCs at low osmolarity, due to the reduced volume of RBCs. 26

於低滲透壓時，人類 RBCs 內的離子擴散速率較低，這是由於 RBCs 的體積降低的緣故。

C. There is a proportional relationship between the concentration of hemoglobin and the rate of ion diffusion in RBCs. 27

RBCs 內血紅素濃度與離子擴散速率呈現比例關係。 27

D. Alpaca RBCs have been evolutionally optimized to increase hemoglobin concentration and transport large amounts of oxygen, while promoting O_2 and CO_2 diffusion. 28

羊駝 RBCs 經由演化上的優化而增加血紅素濃度而可運送大量的氧氣，因而促進 O_2 與 CO_2 的擴散。 28

Cell Biology
細胞生物學

Q6
Animal cells generally have three types of cytoskeletons: (1) microtubules, (2) actin filaments, and (3) intermediate filaments. Figure 1 shows the morphology of a cytoskeleton during the mitotic metaphase or in interphase. For each statement below A-E, **indicate the corresponding type of cytoskeleton from (1) to (3) in the first box (e.g. 29), and the schematic diagram from ① to ⑥ in Figure 1 in the second box (e.g. 30)** (1 point if 2 correct answers)
動物細胞通常有三種細胞骨架: (1) 微管， (2) 肌動蛋白纖維， 以及 (3) 中間絲。Figure 1 顯示一個細胞骨架在有絲分裂中期或間期時的形態。針對下列 A-E 的每個敘述，請於第一個框架 (例如 29) 中指出 (1) 到 (3) 相對應的細胞骨架類型，以及於框架 2 (例如 30) 中指出 Figure 1 中從① 到 ⑥的示意圖。(如果 2 個答案都正確，得 1 分)

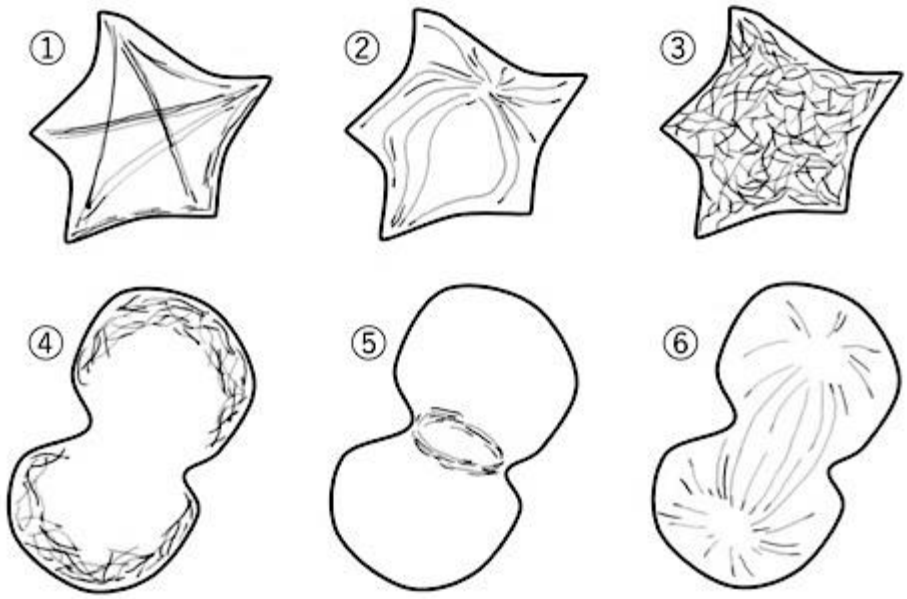


Figure 1

Statements **敘述**	**Type of cytoskeleton** **細胞骨架類型**	**Schematic diagram** **示意圖**
A	29	30
B	31	32
C	33	34
D	35	36
E	37	38

A. They are entangled inside interphase cells and exist in a meshwork. They enhance the elasticity of cells and provide a mechanically supportive structure. 29 30

它們在間期細胞內糾纏在一起，形成一個網格狀結構。它們可強化細胞的彈性並提供一個機械性的支撐結構。 29 30

B. It is called a stress fiber. It builds a support beam inside cells and works to maintain the shape of the cell in interphase. 31 32

它稱為應力纖維(stress fiber)。它在細胞內建立起一個支臂用來維持間期細胞的形狀。 31 32

C. This spindle-shaped structure is formed during cell division. It plays a role in separating replicated chromosomes accurately into daughter cells. 33 34

這個紡錘形的結構於細胞分裂時產生。它在將複製的染色體加以分開並精確地送入子細胞中扮演重要的角色。 33 34

D. After chromosomal segregation, it forms a ring structure and mechanically separates two daughter cells. 35 36

於染色體分離之後，它形成一個環狀結構並以機械性方式將細胞分開成二個子細胞。 35 36

E. Having radial distributions starting near the nucleus, the fibrous structure is assumed to have structural polarity or directionality. 37 38

從靠近細胞核處呈輻射狀分布，其纖維構造被認為具有結構性的極性或方向性。 37 38

Cell Biology
細胞生物學

Q7
GLUT1, a protein present in the membrane of red blood cells, is a transporter that transports glucose into cells. The relationship between the extracellular glucose concentration (S) and the rate of glucose uptake (V) into red blood cells is shown in Figure 1. This relationship between V and S can be described by the following equation (1)

GLUT1是一個存在於紅血球細胞膜上的蛋白質，是一個可將葡萄糖運送到細胞內的運輸蛋白。細胞外葡萄糖濃度 (S) 與紅血球細胞攝取葡萄糖的速率 (V) ，二者的相關情形如 Figure 1。V 與 S 的相關性可用方程式 (1) 來表示。

$$V = \frac{V_{max}}{1+\frac{K_M}{S}} \quad \ldots. (1)$$

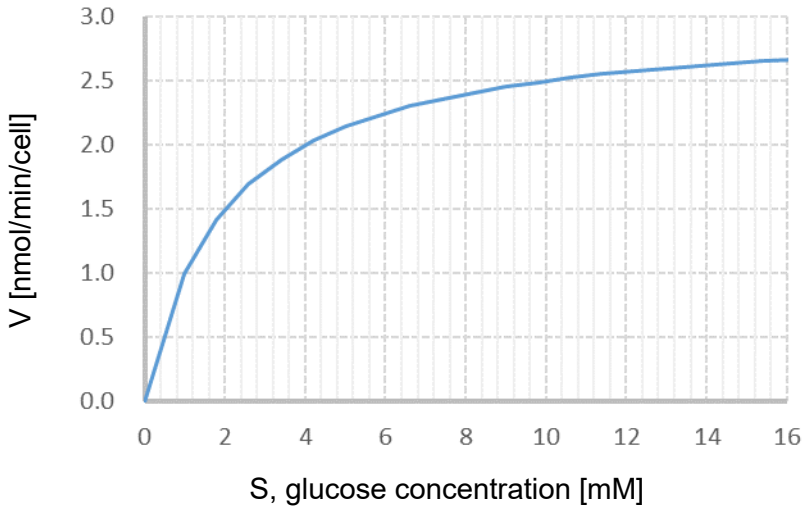


Figure 1 Relationship between S (extracellular glucose concentration, mM) and V (the rate of glucose uptake into red blood cells).
圖1. S (細胞外葡萄糖濃度, mM) 與 V (紅血球細胞攝入葡萄糖的速率the) 的相關性

Q7-1 Estimate the approximate integer values for V_{max} and K_M in this equation from the curve shown in Figure 1. (1 point each)
估計 Figure 1 所示方程式中之 V_{max} 和 K_M 的大約整數值。 (每個1分)

V_{max}:	39	(1) 1	(2) 2	(3) 3	(4) 4	(5) 5	(6) 6	(7) 7	(8) 8	(9) 9
K_M:	40	(1) 1	(2) 2	(3) 3	(4) 4	(5) 5	(6) 6	(7) 7	(8) 8	(9) 9

GLUT2 is a glucose transport protein expressed in hepatocytes in an insulin-independent manner, and V_{max} and K_M are 2 nmol/min/cell and 9 mM, respectively. GLUT4 is another transporter expressed in muscles or hepatocytes functioning in an insulin-dependent manner, and V_{max} and K_M are 0.85 nmol/min/cell and 0.8 mM, respectively.
GLUT2 是一個肝細胞非胰島素依賴型 (insulin-independent) 的葡萄糖運送蛋白， 其 V_{max} 和 K_M 分別為 2 nmol/min/cell 及 9 mM。 而 GLUT4 則是另一個表現於肌肉與肝細胞上的胰島素依賴型

(insulin-dependent) 運送蛋白，其 V_{max} 和 K_M 分別為 0.85 nmol/min/cell 與 0.8 mM。

Q7-2 Indicate whether each of the following statements is true (1) or false (2). (1 point each)
指出下列各敘述為正確 (1) 或錯誤 (2) (每個 1 分)

A. Healthy humans that typically has 4 to 6 mM of blood glucose. The rate of glucose transport per molecule by GLUT2 is considered to be approximately equal to that by GLUT4. 41
健康人類血液中的葡萄糖含量通常介於 4 至 6 mM。 GLUT2 傳送一分子葡萄糖的速率被認為是與 GLUT4 大約相同的。 41

B. Although the transport rate of glucose by GLUT1 and GLUT4 is almost saturated in healthy humans, GLUT2 has an additional capacity to increase the transportation rate. 42
雖然於健康的人體中，GLUT1 和 GLUT4 運送葡萄糖的速率已經幾乎飽和，但 GLUT2 還具有額外的潛能來增加運送率。 42

Cell Biology
細胞生物學

Q8
Carbon assimilation in photosynthesis begins when Ribulose-bisphosphate carboxylase/oxygenase (Rubisco) binds one molecule of CO_2 to Ribulose 1,5-bisphosphate to form two molecules of 3-phosphoglycerate. Rubisco is considered to be one of the most important enzymes on the planet due to its ability to produce organic carbon compounds that support almost all organisms.
當核酮糖雙磷酸羧化酶 (Rubisco) 將一分子的 CO_2 結合到核酮糖-1,5-雙磷酸上，而產生二分子的 3-磷酸甘油酸時，光合作用之碳同化作用便展開了。Rubisco 被認為是植物最重要的酵素之一，因為它能產生有機碳提供給所有的生物使用。

O_2 can bind to the active site of Rubisco instead of CO_2, in which case one molecule of 3-phosphoglycerate and one molecule of 3-phosphoglycorate are formed. Thus, CO_2 and O_2 function as antagonists. The following values show the enzymatic properties of Rubisco of a seed plant and the environmental condition in vivo.
當 O_2 結合到 Rubisco 的活性位 (active site) 而非 CO_2 時， 這時可產生一分子的 3-磷酸甘油酸 (3-phosphoglycerate) 和一分子的 3-phosphoglycorate。因此 CO_2 和 O_2 的作用是互為拮抗劑。下列數值是於活體 (in vivo) 觀測時，一個種子植物 Rubisco 之酵素特性以及環境狀況。

(a) Kinetic characteristics of Rubisco (substrate concentration at 50% of saturation at 25 ° C)
(a) Rubisco 的動力學特性 (25 ° C ，受質濃度 50% 飽和)

K_M [X]: the affinity of the enzyme for substrate X.
K_M [X]: 酵素對受質 X 的親和性
K_M [CO_2] = 9 μM, K_M [O_2] = 535 μM, K_M [RuBP] = 28 μM

(b) Maximum activity (number of repetitions of enzyme reaction per second)
(b) 最大活性 (Maximum activity) (酵素反應每秒的重複次數)

kcat [X]: the maximum reaction rate when the enzyme catalyzes the reaction of substrate X.
kcat [X]: 當酵素催化受質 X 時之最大反應速率
kcat [CO_2] = 3.3 / s, kcat [O_2] = 2.4 / s

(c) Concentration in water in equilibrium with air (assuming 0.035% CO_2 and 21% O_2) at 25 ° C
CO_2 = 11 μM, O_2 = 253 μM
RuBP concentration in chloroplast stroma is 4 to 10 mM.
(c) 於 25 ° C 時，與空氣平衡時在水中的濃度 (假設 0.035% CO_2 ，以及 21% O_2)
CO_2 = 11 μM, O_2 = 253 μM
葉綠體基質中 RuBP 的濃度為 4-10 mM.

Which properties from (a) to (c) above are necessary to explain the following facts from A to D? Choose the most suitable set from the following ones:
上述 (a) 至 (c) 何者之特性是用來解釋下列 A 至 D 現象時所必需的？請從下列組合中選取最合適的一組:

(1) (a) (b) (c), (2) (a) (b), (3) (a) (c), (4) (b) (c), (5) (a), (6) (b), (7) (c) (1 point each)

A. The carboxylase activity of Rubisco increases as the oxygen concentration in the air decreases. 43

當空氣中氧氣濃度下降時，Rubisco 之羧酶 (carboxylase) 活性會增加。 43

B. In the current global environment, the carboxylase activity of Rubisco is higher than the oxygenase activity. 44

在目前地球環境下， Rubisco 之羧酶活性比加氧酶 (oxygenase) 的活性高 44

C. Plants must have large amounts of Rubisco to maintain the full capacity of photosynthesis. 45

植物必須具備大量的 Rubisco 來維持光合作用的滿載產能 45

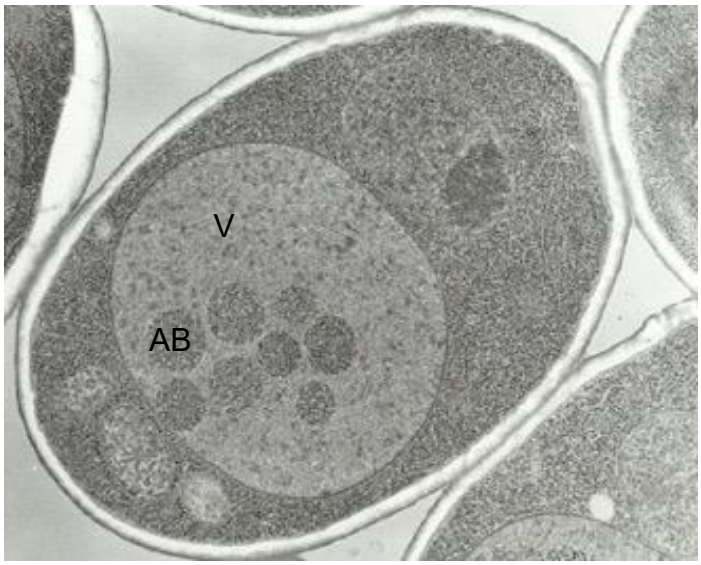
D. Increasing the concentration of CO_2 in the air increases the carboxylase activity of Rubisco. 46

增加空氣中 CO_2 的濃度，可增加 Rubisco 之羧酶活性 46

Cell Biology
細胞生物學

Q9
All cells must constantly synthesize and degrade intracellular substances and structures, one of processes is autophagy. In autophagy, the intracellular structure is non-specifically decomposed by lysosomes and vacuoles. The first molecular analysis of autophagy, was carried out by Nobel Prize winner, Dr. Ohsumi, by using yeast mutant, as follows.
所有細胞必須不斷地合成與降解細胞內的物質及構造，其中一個程序稱為自噬 (autophagy)。於自噬，細胞內的構造以非專一性的方式被溶體與液泡所分解。第一個用分子分析法研究自噬的人，是一位諾貝爾獎得主 Dr. Ohsumi，他利用酵母突變株進行以下程序

1. His group cultured a yeast mutant under nitrogen starvation.
他的研究團隊於氮飢餓 (nitrogen starvation) 狀態下培養一個酵母突變株。
2. After a certain period, many round structures (autophagic bodies) (right figure AB) appeared in the vacuoles (right figure V).
經過一段時間，液泡 (右圖 V) 中出現許多圓形的構造 (自噬體) (右圖中的 AB)。
3. When observed with an electron microscope, ribosomes were found in the autophagic body.
當以電子顯微鏡觀察時，自噬體中可發現具有核醣體



4. Mutants of this process were isolated and many genes that work in the autophagy system were found out.
從此程序中分離出許多突變株，並發現許多與與自噬有關的基因。

Q9-1 What kind of gene had a mutation in this experiment? [47] (1 point)
在此實驗中何種基因發生突變？ [47] (1 分)

(1) 磷酸酶 (Phosphatase)
(2) 蛋白酶 (Protease)
(3) 纖維素酶 (Cellulase)
(4) DNA 聚合酶 (DNA polymerase)

Q9-2 What was the organelle found in the autophagic body ? [48] (1 point)
在自噬體中所發現的胞器為何? [48] (1 分)

(1) 葉綠體 (Chloroplast)
(2) 粒線體 (Mitochondrion)
(3) 黑色素體 (Melanosome)
(4) 細胞壁 (Cell wall)

Cell Biology
細胞生物學

Q10
The growth patterns of plant cells assume the following types.
A. Diffuse growth: the whole cell more or less grows on entire facets of the cell.
B. Tip growth: only the tip of the cell grows.
C. Inclusive growth: combination of A and B.
When diffuse growth occurs in plant cells, the cell wall must be loosened, and the growth direction is affected by the orientation of the cellulose microfibrils constituting the cell wall. In cells undergoing diffuse growth, a cellulose synthase complex synthesizes cellulose microfibrils while moving on the cell membrane along the orientation of cortical microtubules inside the cell membrane.
假設植物細胞的生長方式有下列幾種

A. 瀰漫式生長 (Diffuse growth): 整個細胞或多或少可以向任何面向生長。

B. 頂端式生長 (Tip growth): 只有細胞的頂端可以生長。

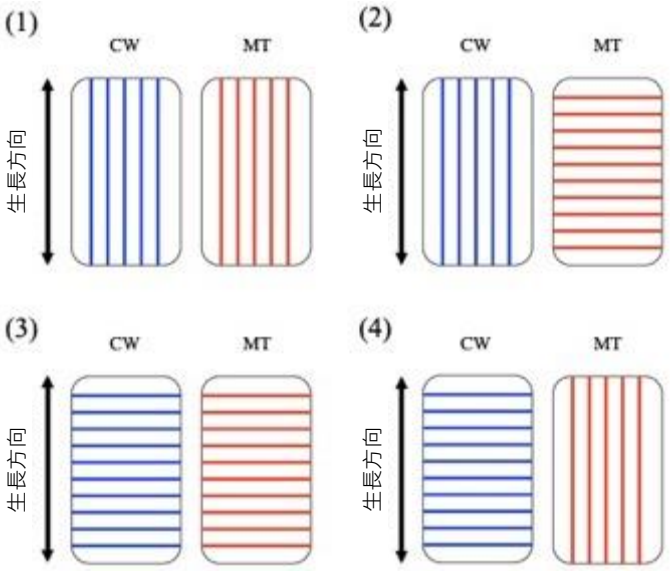
C. 融合式生長 (Inclusive growth): 結合 A 與 B 二種方式

當植物細胞發生瀰漫式生長時，細胞壁必須先鬆散，其生長方向會受到細胞壁中纖維素微絲 (cellulose microfibrils) 之排列方向的影響。 正在進行瀰漫式生長的細胞，一個纖維素合成酶複合體會沿著細胞膜裡面皮層微管之方向而移動來合成纖維素微絲。

Q10-1 Select a combination of the following (1) to (6) that correctly matches the types of growth (A to C) and the types of plant cells. 49 (1 point)
從 (1) 至 (6) 的組合中，選出一項能夠正確吻合其生長方式 (A 至 C) 以及植物細胞的類型。 **49** (1 分)

(1) A—Pollen tube, Root hair, B—Leaf epidermal cells, C—Root cortical cells
(1) A—花粉管, 根毛, B—葉片表皮細胞, C—根皮層細胞
(2) A—Pollen tube, Root hair, B—Root cortical cell, C—Leaf epidermal cell
(2) A—花粉管, 根毛, B—根皮層細胞, C—葉片表皮細胞
(3) A—Root cortical cells, B—Leaf epidermal cells, C—Pollen tube, Root hair
(3) A—根皮層細胞, B—葉片表皮細胞, C—花粉管, 根毛
(4) A—Root cortical cells, B—Pollen tube, root hair, C—Leaf epidermal cells
(4) A—根皮層細胞, B—花粉管, 根毛, C—葉片表皮細胞
(5) A—Leaf epidermal cells, B—Pollen tube, root hair, C—Root cortical cells
(5) A—葉片表皮細胞, B—花粉管, 根毛, C—根皮層細胞
(6) A—Leaf epidermal cells, B—Root cortical cells, C—Pollen tube, Root hair
(6) A—葉片表皮細胞, B—根皮層細胞, C—花粉管, 根毛

Q10-2 The following schematic diagrams (1) to (4) show the orientation of cellulose microfibrils of the cell wall (CW) and the orientation of cortical microtubules (MT) in plant cells extending in the longitudinal direction. **Choose the most appropriate combination.** 50 (1 point)
下列示意圖 (1) 至 (4) 顯示出植物細胞縱向延伸時，細胞壁纖維素微管 (CW) 的方向以及皮層微管 (MT) 的方向。**請選出最恰當的組合** 50 (1 分)


(1)
CW
MT
生長方向
(2)
CW
MT
生長方向
(3)
CW
MT
生長方向
(4)
CW
MT
生長方向

Cell Biology
細胞生物學

Q11
A cultured cell of somatic cell A and a cultured cell of somatic cell B of an animal were prepared. A culture dish containing an appropriate amount of cells was prepared, and the number of cells after a certain period of time (at the start of the experiment) and the number of cells after 48 hours were counted. The results are shown in Table 1.
某種動物的體細胞 A 和 B 被分別進行培養。將含有適當數量細胞的培養皿培養一段時間後(作為實驗之初始階段)，分別計數其與培養 48 小時後的細胞數目。結果如表 1。

Table 1: Cell numbers of somatic cell A and somatic cell B. 體細胞 A 和 B 的細胞數目

	Cell number ($x10^5$)	
Time from start of experiment (hours)	0	48
somatic cell A	7.2	115.2
somatic cell B	9.7	77.6

Q11-1 How long are the cell cycles of somatic cell A and somatic cell B, respectively? **Write the letter of your answer in the space provided.** (1 point each)
體細胞 A 和 B 的細胞週期分別為多久？**將答案編號分別填入所提供得空格中**。
(1) 3, (2) 4, (3) 6, (4) 8, (5) 10, (6) 12, (7) 16, (8) 24, (9) 32

somatic cell A: [51] hours
somatic cell B: [52] hours

Q11-2 When somatic cells A and B were mixed at a certain ratio and a culture was started in a culture dish, the ratio of the cell numbers of A and B after 4 days was 2 : 1. What was the ratio of somatic cell A and B cell numbers when the culture was started? **Write the letter of your answer in the space provided.** (It is assumed that the cell cycle of the somatic cells A and B progresses independently. The nutrients required by the cells during the cultivation are well-supplied.) [53] (1 point)
當體細胞 A 和 B 以特定比例混合，並在同一培養基中進行培養。四天之後，其中 A 和 B 的細胞數目比為 2 : 1。試問初始培養時的體細胞 A 和 B 的細胞數目比為何？**將答案編號分別填入所提供得空格中。**
(假設體細胞 A 和 B 的細胞週期是獨立進行的。培養期間，細胞所需的營養素足夠)
(1) A : B = 1 : 1 (2) A : B = 2 : 3 (3) A : B = 1 : 2

Cell Biology
細胞生物學

Q12
Yeast can metabolize glucose using aerobic respiration and alcohol fermentation depending on environmental conditions. Each reaction formula is as follows.
酵母菌可隨環境條件而利用有氧呼吸和酒精發酵來代謝葡萄糖。其反應式如下所示。

Aerobic respiration 有氧呼吸

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (32 ATP production)

Alcohol fermentation 酒精發酵

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (2 ATP production)

Yeast was cultured in a glucose solution under conditions A and B, and gas inflow and outflow from the incubator were measured to obtain the results shown in the Table 1. Answer the following questions (it is assumed that the same amount of glucose was completely metabolized under conditions A and B).
在 A 和 B 條件下，以葡萄糖溶液培養酵母菌，並分別測量流入和流出生長箱的氣體量，結果如表 1。回答下列問題(假設在 A 和 B 條件下，等量的葡萄糖被完全代謝掉)。

Table1

Conditions	O_2 absorption 吸收 (mL)	CO_2 emissions 釋出 (mL)
A	0	20
B	30	40

Q12-1 How was glucose metabolized under condition A and condition B, respectively? (1 point each)
分別在 A 和 B 條件下，葡萄糖會如何代謝？

(1) aerobic respiration only 只行有氧呼吸

(2) alcohol fermentation only 只行酒精發酵

(3) aerobic respiration and alcohol fermentation 有氧呼吸和酒精發酵

Condition A: 54
Condition B: 55

Q12-2 Assuming that 100 equivalents of ATP were generated under condition A, **how many equivalents of ATP were generated under condition B?** 56 (1 point)
假設在 A 條件下，產生 100 當量的 ATP，則在 B 條件下，會產生多少當量的 ATP？
(1) 50 (2) 100 (3) 300 (4) 500 (5) 750 (6) 850 (7) 1000 (8) 1200 (9) 1400

Genetics
遺傳學

Q13
Lisa is the daughter of Carl with ABO blood-type B and Jane with AB type. Lisa's blood type is O. Normally, there is no parent-child relationship between AB type and O type. Detailed examinations revealed that Lisa is a rare Bombay O type (Figure 1).
血型為 O 型的 Lisa 是 ABO-B 血型 Carl 及 AB 型 Jane 的女兒。通常 AB 血型及 O 血型的人不會有親子關係，仔細探究顯示 Lisa 是稀有 Bombay O 血型(Figure 1)。

The ABO blood-type is determined by the outermost antigen of sugar chains on the cell membrane of red blood cells. The gene for this antigen is located on chromosome 9. Type A has A antigen, type B has B antigen, type AB has both, and type O has neither.
Since the A and B antigens bind to the sugar of H antigen, the phenotype will be O regardless of the genotype in the absence of the H antigen. A person who has a homozygous h allele with a defect in the H antigen gene (H) on chromosome 19 cannot synthesize H antigen and expresses Bombay O-type (Figure 2).
ABO 血型由紅血球細胞膜上最外面的抗原糖鏈所決定。決定此抗原的基因位在第 9 號染色體上，A 血型者具有 A 抗原、B 血型者具 B 抗原、AB 型者具有 A 及 B 兩種抗原，而 O 型者則不具 A 或 B 抗原。由於 A 及 B 抗原會與 H 抗原的糖結合，所以在無 H 抗原的人，其外表型為 O 型，不論其原先 ABO 血型基因型為何。一個具有同型合子 h 等位基因的個體，其 19 號染色體上的 H 抗原的等位基因有缺陷而無法表現 H 抗原，故表現 Bombay-O 血型(Figure 2)。

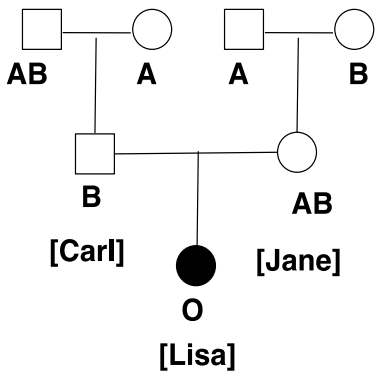


Figure 1

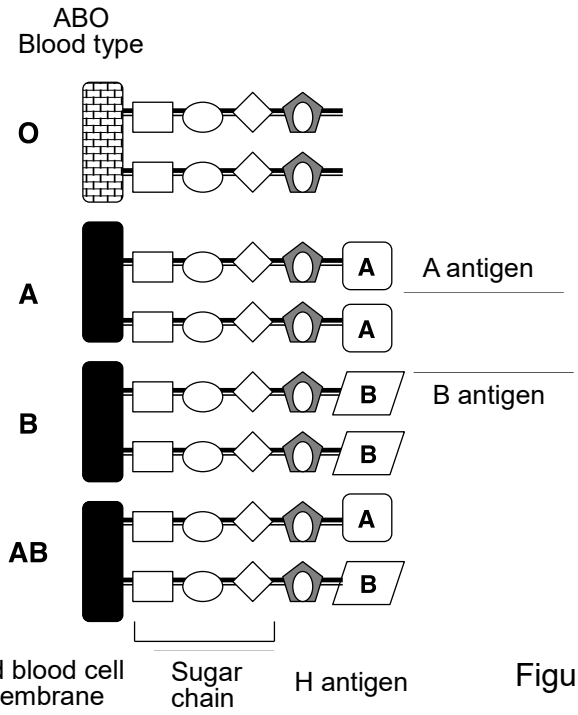


Figure 2

When Carl and Jane have another child, the chance of their child's blood type being B is [57] [58] . [59] %. (3 points)
當 Carl 及 Jane 有另一小孩時，其血型為 B 型的機會為 [57] [58] . [59] %. (3 points)

Genetics

遺傳學

Q14

One cycle of the PCR reaction doubles the number of DNA fragments. Further, each time one cycle of the PCR reaction progresses, the primer pair, the substrate dNTP, and the DNA polymerase molecule are required double amount, so the amount of these components limits the overall amount of DNA that can be synthesized in PCR.

一次 PCR 反應會使 DNA 片段產物增加 2 倍，每次 PCR 反應週期，其引子對反應物 dNTP 及 DNA 聚合酶的需求量皆雙倍增加，故這些成分的量會限制 PCR 合成 DNA 的總量。

The length of the DNA fragment to be amplified was 100 base pairs including the primers, and the PCR reaction was started with the primer length of 20 bases. The four types of bases A, C, G, and T are evenly distributed in the sequence to be amplified, and the amplification efficiency of PCR is 100%. As the PCR reaction progresses, the reaction will not be completed due to running out of one of the components in a certain cycle.

假設以增幅 100 鹼基對長的 DNA 片段，使用引子長 20 鹼基，四種鹼基出現在序列中的頻率均等，且 PCR 增幅效率為 100%。

當 PCR 反應進行時，如有任一種反應成分用完，則反應無法完成。

Choose the correct No. of the reaction stop cycle and the limiting component. 60 (3 points)

選擇出正確的 PCR 反應停止週期數目及限制成分

Template DNA fragment：4 copies

Primer：1,000 sets

dNTPs (dATP, dTTP, dGTP, dCTP)：48,000 molecules (12,000 molecules each)

DNA polymerase：1,200 molecules

No.	Cycles	Limiting component
(1)	7	Primer pairs
(2)	7	dNTPs
(3)	7	DNA polymerase
(4)	8	Primer pairs
(5)	8	dNTPs
(6)	8	DNA polymerase
(7)	9	Primer pairs
(8)	9	dNTPs
(9)	9	DNA polymerase
(0)	Others	

Genetics

遺傳學

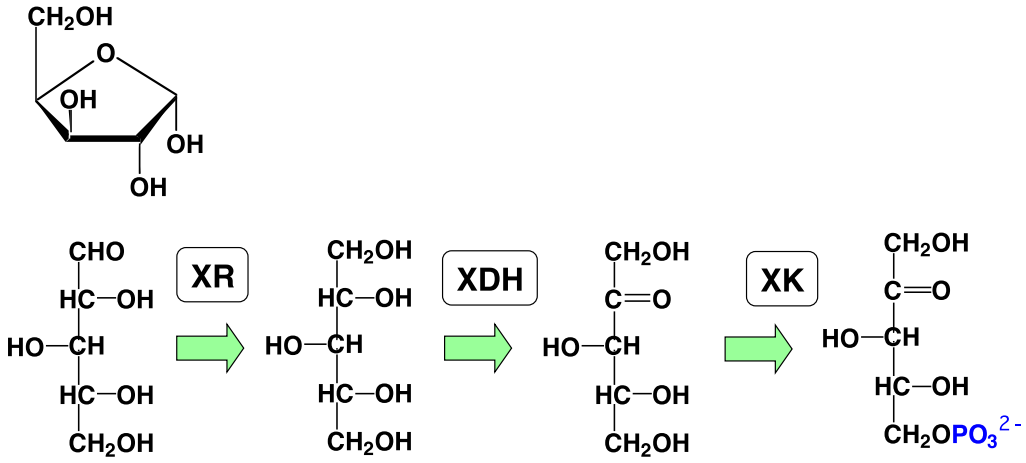
Q15

Streptococcus mutans, which causes tooth decay, cannot utilize xylitol ($C_5H_{12}O_5$). Therefore, xylitol is used as a sweetener to prevent tooth decay. Xylitol is produced by microbial conversion from xylose contained in hemicellulose.

會造成蛀牙鏈球菌的(*Streptococcus mutans*)無法利用木糖醇。因此木糖醇被用作防蛀牙的甜味劑，其來源是由半纖維素所含的木糖醇經微生物轉化而得。

The diploid yeast strain *Candida tropicalis* AT36 can grow with xylose as the sole carbon source 1(Figure 1). In this strain, the enzyme activities of XR, XDH, and XK are almost proportional to the copy number of each gene.

雙倍體酵母菌(*Candida tropicalis* AT36)可用木糖醇作為主要碳源 1(Figure 1)。這株酵母菌的 XR, XDH, 及 XK 酵素活性與其各自基因的拷貝數成比率。



Xylose **C5H10O5** Xylitol **C5H12O5** Xylulose **C5H10O5** Xylulose-5-phosphate

XR: Xylose reductase(XYL1 gene)

XDH: Xylitol dehydrogenase(XYL2 gene)

XK: Xylulokinase

Figure 1

The AT36 strain was cultured by adding 40 g of xylose and 5 g of glucose as a carbon source in the culture solution (1 L). As the result, about 25 g of xylitol was produced, as shown in the graph (A) in Figure 2. Therefore, the following gene-disrupted strains were constructed and cultured in the same manner in order to increase xylitol production.

AT36 菌株以 1 公升含 40 g 木糖醇及 5 g 葡萄糖為主要碳源的培養基培養，結果可產生 25 g 木糖醇，如 Figure 2 的圖(A)所示。因而，將下列基因破壞突變株建立後，也以相同方式培養，希望能增加木糖醇的產量。

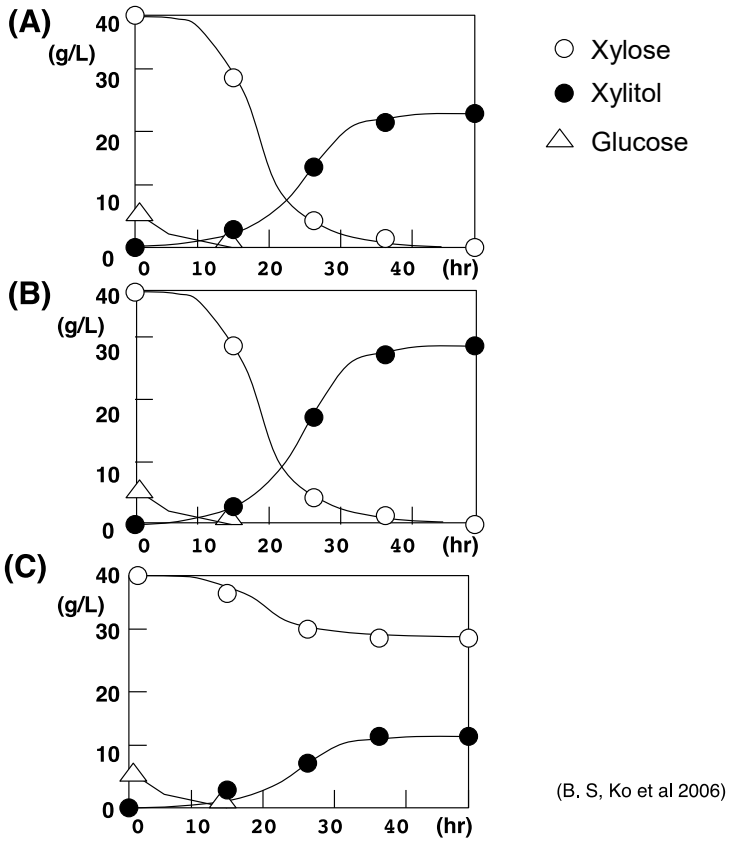


Figure 2

(Disruptant A) One of the *XYL1* genes of the AT36 strain was disrupted.
(基因破壞菌株 **A**)將 AT36 菌株的 *XYL1* 基因之一破壞掉
(Disruptant B) Both of the *XYL1* genes of the AT36 strain were disrupted.
(基因破壞菌株 B)將 AT36 菌株的兩個 *XYL1* 基因都破壞掉
(Disruptant C) One of the *XYL2* genes of the AT36 strain was disrupted.
(基因破壞菌株 C)將 AT36 菌株的 *XYL2* 基因之一破壞掉
(Disruptant D) Both of the *XYL2* genes of the AT36 strain were disrupted.
(基因破壞菌株 D)將 AT36 菌株的兩個 *XYL2* 基因都破壞掉

Based on the above information, select the number of the most appropriate combination of the culture progress graph (Figure 2) and the disrupted strain. [61] (2 points)
根據以上資訊，請選出 Figure 2 中培養程序圖與基因破壞菌株間之最恰當組合的號碼

	Graph A	Graph B	Graph C
(1)	AT36	Disruptant A	Disruptant D
(2)	AT36	Disruptant A	Disruptant C
(3)	AT36	Disruptant B	Disruptant D
(4)	AT36	Disruptant C	Disruptant D
(5)	AT36	Disruptant D	Disruptant C
(6)	AT36	Disruptant C	Disruptant B

Genetics

遺傳學

Q16

In order to teach the principles and techniques of DNA replication, professor A instructed graduate students B and C to reproduce the classic experiment of replicating DNA *in vitro* by properly mixing nucleic acids and proteins individually purified from *E. coli* cells.
Professor A was disappointed with the following results of the experiments of student B and C.

教授 A 為了教學生 DNA 複製原理及技術，他請研究生 B 及 C 重現試管中 DNA 複製的經典實驗，將大腸桿菌細胞中純化得的蛋白與核酸恰當混合。但學生 B 及 C 的下列實驗結果卻令 A 教授相當失望。

Result of student B: Long single-stranded DNA fragments and short single-stranded DNA fragments with attached RNA fragments were replicated, but complete double-stranded DNA was not replicated.

學生 B 實驗結果：附著有 RNA 片段的長單股 DNA 及短單股 DNA 片段有複製，但完整的雙股 DNA 則未複製。

R1: Student B failed to add polymerase I.

反應 1：學生 **B** 忘了加聚合酶 I

R2: Student B failed to add polymerase III.

反應 2：學生 **B** 忘了加聚合酶 III

R3: Student B failed to add DNA ligase.

反應 3：學生 **B** 忘了加 DNA 連接酶

Result of student C: Long single-stranded DNA fragments and many short single-stranded fragments were replicated, but complete double-stranded DNA was not.

學生 C 實驗結果：長單股 DNA 片段及許多短單股 DNA 片段有複製，但完整的雙股 DNA 則未複製。

R4: Student C failed to add polymerase I.

反應 4：學生 **C** 忘了加聚合酶 I

R5: Student C failed to add polymerase III.

反應 5：學生 **C** 忘了加聚合酶 III

R6: Student C failed to add DNA ligase.

反應 6：學生 **C** 忘了加 DNA 連接酶

Choose the combination of the number that most likely caused the failures of students B and C. [62] (2 points)

請選出最可能造成學生 B 及 C 實驗失敗原因的組合號碼

No.	Student B	Student C
(1)	R1	R5
(2)	R1	R6
(3)	R2	R4
(4)	R2	R6
(5)	R3	R4
(6)	R3	R5

Genetics

遺傳學

Q17

With the progress of genome research, the genomes of many organisms have been analyzed, and it has been revealed that the genomes of organisms vary widely in size.
Faster-growing organisms with a simpler structure tend to have smaller genomes. Most mammalian genomes range from 2.5 to 3.3 billion bases, and human genomes are about 3 billion bases.

隨著基因體研究之進展，許多生物的基因體已被分析，且結果顯示生物間的基因體大小差異很大。

快速生長且結構較簡單的生物常具有較小基因體 ,多數哺乳類的基因體大小落在 25 億到 33 億鹼基間，

而人類基因體約有 30 億鹼基。

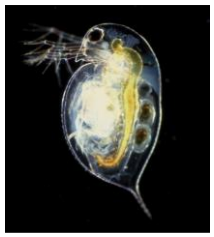
Arrange the genomes of the organisms in the photo in descending order.
Choose the correct one by number. 63 (2 points)

將下列相片中的生物，依其基因體由大至小順序排列。

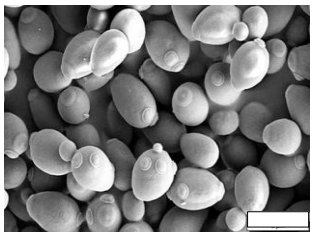
選出正確組合之數字

A

B



C

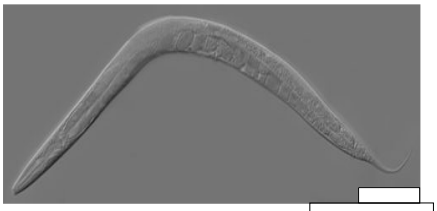


Bar: 5 m

D

Bar: 5 m

E



Bar: 200 m

	Genome size (large - small)
(1)	A – B – C – D – E
(2)	A – B – C – E – D
(3)	A – C – B – D – E
(4)	A – C – B – E – D
(5)	A – B – E – D – C
(6)	A – B – D – E – C
(7)	A – B – E – C – D
(8)	A – C – B – E – D

Genetics
遺傳學

Q18
In its life cycle, baker's yeast *Saccharomyces cerevisiae* has haploid and diploid generations. The haploid has α-type and a-type mating types and grows independently. When α-type cells and a-type cells meet, they undergo sexual conjugation and become diploid (a/α-type) cells. When the nitrogen source is depleted, the diploid cells undergo meiosis and form four spores (two a-type cells and two α-type cells) inside the cell.
烘培用酵母菌(*Saccharomyces cerevisiae*)的生活史中具有單倍體及雙倍體世代，單倍體具獨立生長的α及 a 兩種交配型。當此兩種交配型碰到彼此，會進行有性接合生殖而形成雙倍體(a/α-type)細胞。當氮源匱乏時，雙倍體細胞進行減數分裂並在細胞內形成 4 個孢子(2 個 a 型及 2 個α型)。

Wild type genes of yeast are written in capital letters and mutant genes are written in lower case. For example, the genes encoding leucine biosynthetic enzymes are written as *LEU1, LEU2*..., and the corresponding mutant genes are written as *leu1, leu2*.... Strains that do not have the *LEU2* gene cannot grow in a medium without leucine.
野生型以大寫字母表示，突變型以小寫字母表示，如白胺酸(leucine)生合成酶的編碼基因為 *LEU1*, *LEU2*…，其相對應突變基因為 *leu1*, *leu2*…。無 *LEU2* 基因的菌株無法在不含白胺酸的培養基中生長。

The haploid XY-1A strain (genotype: *a, ura3, leu2*) requires uracil and leucine for growth, and the XY-2B strain (genotype: *α, his3, leu1*) requires histidine and leucine for growth.
單倍體 XY-1A 菌株(基因型：*a, ura3, leu2*)需有脲嘧啶(uracil)及白胺酸才能生長，而 XY-2B 菌株(基因型：*α, his3, leu1*)需有組胺酸(histidine)及白胺酸才能生長。

A diploid XY-3C strain (*a/α, ura3/URA3, leu2/LEU2, LEU1/leu1, HIS3/his3*) was obtained by sexual mating of the XY-1A strain and the XY-2B strain. Out of 160 spores obtained from the XY-3C strain, approximately [64] spores can grow on a medium containing uracil but not leucine/histidine.
一雙倍體 XY-3C 菌株(*a/α, ura3/URA3, leu2/LEU2, LEU1/leu1, HIS3/his3*)可由 XY-1A 菌株及 XY-2B 菌株進行有性交配形成。在由 XY-3C 菌株得到 160 顆孢子中，約有[64] 顆孢子可在含脲嘧啶但不含白胺酸/組胺酸的培養基中生長。

The genes of the mating type, the *URA3*, the *LEU2*, the *LEU1*, and the *HIS3* are all present on different chromosomes.
交配型的基因(*URA3*, *LEU2*, *LEU1*, 及 *HIS3*)都位在不同染色體上。

Choose the appropriate number that is most likely. [64] (2 points)
選出最可能的適當數字

No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
spores	10	20	25	40	50	80	120	150

Genetics
遺傳學

Q19
As part of the functional analysis of the april gene found in a diploid plant, a mutant strain was discovered in which a DNA fragment (T-DNA) of 3 kb or more was inserted into one april gene. Since this strain is considered heterozygous for the april gene, seeds were obtained by self-pollination.
雙倍體植物的 april 基因之功能分析發現一株突變株中有一段約 3 Kb 或更大的 T-DNA 片段插入到 april 基因中。由於此突變株為 april 基因異型合子個體，故以自花授粉方式取得種子。

Figure 1 shows the gene map of the april gene and the T-DNA insertion site. The arrow in the figure indicates the region in which the primers used for genotyping PCR were designed.
Figure 1 顯示 april 基因的基因圖譜及 T-DNA 插入位點，圖中箭頭所指區為用以進行基因型分析 PCR 的引子所在。

The obtained seeds were grown, genomic DNA was extracted from three different plants (A, B, C), and PCR was performed using the designed primers.
所取得的種子經種植生長，並由(A, B, C)三株不同植株中，抽取其基因體 DNA，以所設計的引子進行 PCR 分析。

The results of agarose gel electrophoresis shown in Figure 2 indicate that the genotype of the april gene of each of A, B, and C was determined.

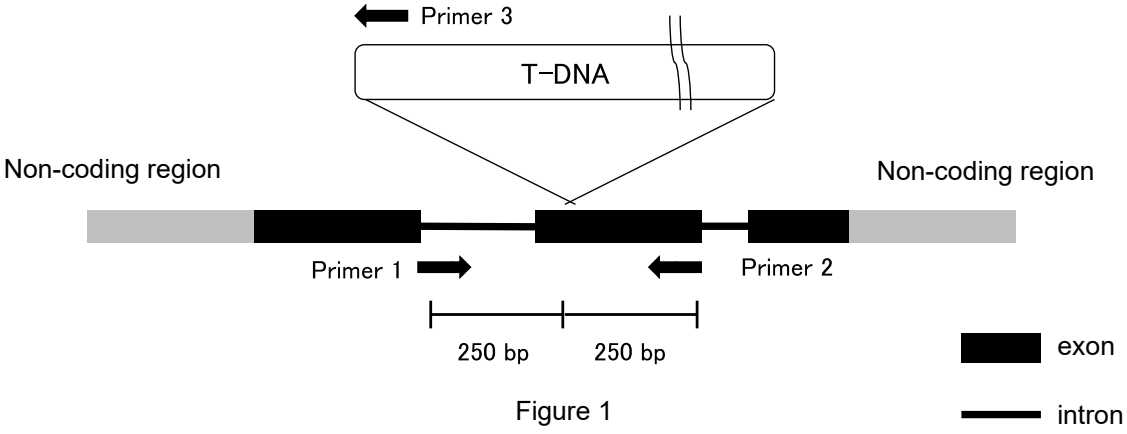
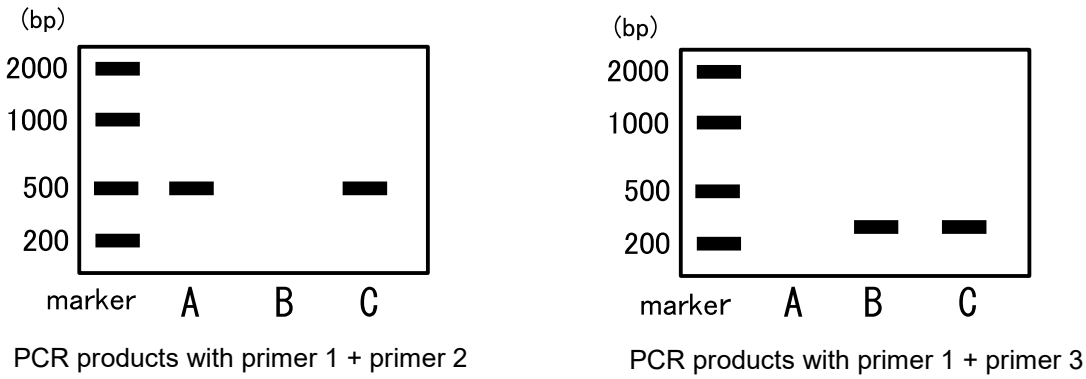


Figure 1



PCR products with primer 1 + primer 2

PCR products with primer 1 + primer 3

Figure 2

結果經洋菜膠體電泳分析如 Figure 2，圖中顯示已測定出 A, B, C 各植株之 april 基因型。

Choose the correct homozygous, heterozygous, and wild-type combination for T-DNA insertions in Strain A, B, and C. 65 (2 points)

依據 T-DNA 在 A, B, 及 C 三株植株插入情況，選出其為同型合子、異型合子、以及野生型之正確組合。

	Strain A	Strain B	Strain C
(1)	homo	hetero	wild type
(2)	homo	wild type	hetero
(3)	hetero	homo	wild type
(4)	hetero	wild type	homo
(5)	wild type	homo	hetero
(6)	wild type	hetero	homo

Genetics
遺傳學

Q20
The plants discovered on a remote island have purple, reddish purple, red, blue, light blue, and white flowers. Observations of this plant for several years revealed the following results.
在偏遠島嶼中發現某種植物，其會開紫色、紅紫色、紅色、藍色、淡藍色及白色花。經多年觀察得到下列結果：

a. This plant is capable of self-pollination and cross-pollination.
這植物可行自花授粉及異花授粉

b. There was no relationship between the flower color and the seed formation efficiency of this plant.
此植物的花色與種子形成效率間沒有關係

c. Self-pollination of white-flower individuals revealed that all F1 generation individuals had white flowers. This strain was regarded as a white flower pure strain and was designated as a WW strain.
白花植株自花授粉顯示，其所有 F1 子代個體都開白花。此品系植株被認為是白花純品系(WW)。

d. Self-pollination of blue-flower individuals revealed that all F1 generation individuals had blue flowers. This strain was regarded as a blue flower pure strain and was designated as a BB strain.
藍花植株自花授粉顯示，其所有 F1 子代個體都開藍花。此品系植株被認為是藍花純品系(BB)。

e. After the self-pollination of light blue flowers, blue, light blue, and white flowers appeared in the F1 generation.
淡藍花植株經自花授粉之後，其 F1 子代有開藍色、淡藍色及白色花的個體。

f. After the self-pollination of red-flower individuals, red flower and white-flower individuals appeared in the F1 generation.
紅花植株經自花授粉之後，其 F1 子代有開紅花及白花的個體。

g. After the self-pollination of purple flowers, purple and blue flowers appeared in the F1 generation.
紫花植株經自花授粉之後，其 F1 子代有開紫花及藍花的個體。

h. After the self-pollination of reddish purple flower individuals, flower individuals of all colors appeared in the F1 generation.
紅紫花植株經自花授粉之後，其 F1 子代所開出的花各種花色都有。

i. When blue flowers and white flowers were crossed, light blue flowers appeared in the F1 generation.
將藍花植株與白花植株雜交後，其 F1 子代為開淡藍花的個體。

j. When a red-flower individual and a white-flower individual were crossed, red and white flower individuals appeared in the F1 generation. Therefore, by repeating the self-pollination of red-flower individuals, a red flower pure strain in which all red-flower individuals appeared was obtained. It was named the RR strain.
將紅花植株與白花植株雜交後，其 F1 子代為開紅花及白花的個體。再將紅花個體經由重複自花授粉之後，得到一個其所有後代個體皆開紅花的純品系(RR)。

k. When a BB strain and an RR strain were crossed, reddish purple-flower individuals all appeared in the F1 generation. This strain was named the BR strain.
將 BB 品系與 RR 品系雜交後，其 F1 子代個體皆開紅紫色花，故稱為 BR 品系。

The probability that reddish-purple individuals appear in the F2 generation obtained by self-pollination of the BRWW strain is [66] [67] . [68] %.
Mark the appropriate numbers in the Answer boxes. (3 points)
BRWW 品系自花授粉後，其 F2 子代中，開紅紫色花的機率為[66] [67] . [68] %
Note: In this question, descendants resulting from self-pollination are also indicated as “F1”.

The genes related to flower color are not linked in this plant.

注意：本題中自花授粉之後代都稱 F1。此植物之花色基因無連鎖。

Genetics
遺傳學

Q21

Animal viruses are classified by the nucleic acid contained in the capsid. In addition to nucleic acid, some viruses contain enzyme proteins, such as RNA polymerases, inside the virus particles.
動物病毒依據其外殼(capsid)所包覆的核酸種類來分類。有些病毒顆粒內除核酸外，還含有酶蛋白，如 RNA 聚合酶。

From the following animal viruses, select the most appropriate combination of those that must contain an enzyme in the capsid for replication from the answer group, from (1) to (8). 69 (2 points)
下表所列為各種動物病毒類別。在答案選項(1)-(8)中，選出其外殼內必定含有複製酶的病毒選項之最適當組合 69 。

Type	Virus	Nucleic acids
A	Smallpox virus	Double-stranded DNA
B	B19 parvovirus	Single-stranded DNA
C	Rotavirus	Double-stranded RNA
D	Rhinovirus	Single-stranded RNA (mRNA)
E	Influenza virus	Single-stranded RNA (temperate of mRNA)
F	HIV (retrovirus)	Single-stranded RNA

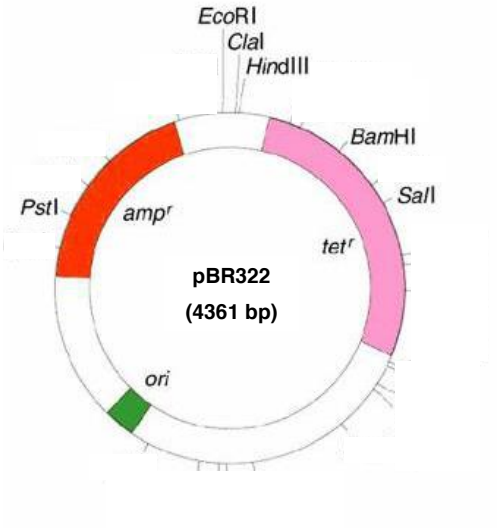
Answer group

(1)	A, C	(5)	B, F
(2)	B, C	(6)	C, E
(3)	B, D	(7)	D, E
(4)	B, E	(8)	E, F

Genetics
遺傳學

Q22
In the 1980s, a plasmid vector called pBR322 was frequently used for DNA recombination experiments. pBR322 is a 4361-base pair plasmid containing ampicillin resistance and tetracycline resistant genes, and has the restriction enzyme sites shown in Figure 1.

在 1980 年代，pBR322 質體載體常用於重組 DNA 實驗，其具有 4361 鹼基對，帶有青黴素及四環黴素抗性基因，並帶有如 Figure 1 圖中所示的限制酶切位。



EcoRI	5′-G↓AATTC-3′
ClaI	5′-AT↓CGAT-3′
HindIII	5′-A↓AGCTT-3′
BamHI	5′-G↓GATCC-3′
BglII	5′-A↓GATCT-3′
PstI	5′-CTGC↓AG-3′
SalI	5′-G↓TCGAC-3′
XhoI	5′-C↓TCGAG-3′

Restriction enzyme cleavage sites are indicated by arrows

***tet*^{r} : tetracycline resistant gene**

***amp*^{r} : ampicillin resistant gene**

***ori* : replication origin**

Figure 1

In order to learn the technique for the gene recombination experiment, we planned the experiment such that both the gene P (plasmid 1) and the gene Q (plasmid 2) are ligated with pBR322 using only the restriction enzyme and the DNA ligase (Figure 2). The experimental procedure is as follows.

為了學習基因重組技術，我們計畫進行一個實驗將 P 基因(來自質體 1)與 Q 基因(來自質體 2)，去和 pBR322 (Figure 2)連接，過程中只使用限制酶及連接酶，實驗程序如下所述。

Step 1: Cleavage of plasmid 1 or plasmid 2 with appropriate restriction enzymes and electrophoresis to obtain DNA fragments containing gene P or Q.

步驟 1：質體 1 或 2 各自用適當限制酶切割，並以電泳分別取得含基因 P 或基因 Q 的 DNA 片段

Step 2: Cleavage of pBR322 vector with appropriate restriction enzymes.

步驟 2：將 pBR322 載體以適當限制酶切割。

Step 3: Ligation of the DNA fragment (containing gene P or Q) with the vector to obtain the first recombinant plasmid.

步驟 3：將含基因 P 或 Q 的 DNA 片段跟載體 DNA 連接，產生第一個重組質體。

Step 4: Cleavage of the other plasmid with appropriate restriction enzymes to obtain a DNA fragment containing the second gene (gene Q or P).

步驟 4：將另一個質體以適當限制酶切割，以產生含第二個基因(Q 或 P)的 DNA 片段。

Step 5: Cleavage of the first recombinant plasmid with appropriate restriction enzymes.

步驟 5：將第一個重組質體以適當限制酶切割。

Step 6: Ligation of the DNA fragment (containing gene Q or P) with the first recombinant plasmid.

步驟 6：將含基因 Q 或 P 的 DNA 片段與第一個重組質體連接。

Recombinant *E. coli* cells are selected by ampicillin resistant phenotype. The presence of two replication origins in one plasmid results in very low stability and should be avoided. The restriction enzyme reaction should proceed completely.

以青黴素抗性表型篩選出重組大腸桿菌細胞。要避免具有兩個複製起始點的質體，因其穩定性非常低。限制酶切割反應要進行完成。

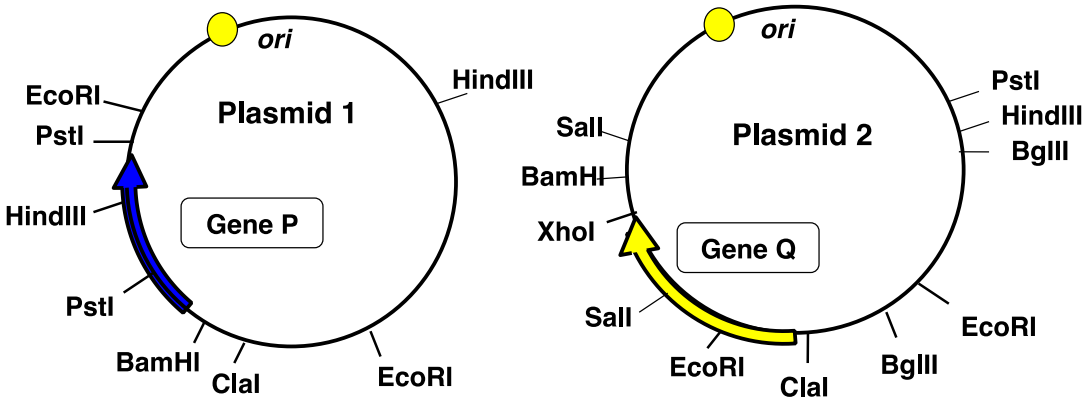


Figure 2 ***ori* : replication origin**

The operations of Step 1 to Step 6 are indicated by A - I, X, and Y. **From the procedures shown in the table, select the number that indicates the appropriate procedure for producing the desired recombinant plasmid.** 70 (3 points)

實驗步驟 1-6 之操作以 A-I，X，及 Y 表示，**從表格中所呈現的程序，選出能建構出想要重組質體的實驗先後程序之號碼。**

A: Cleavage of plasmid 1 with EcoRI and BamHI to obtain a DNA fragment containing gene P.
用 EcoRI 及 BamH1 切割質體 1 以獲得帶有 P 基因的 DNA 片段

B: Cleavage of plasmid 1 with EcoRI and ClaI to obtain a DNA fragment containing gene P.
用 EcoRI 及 ClaI 切割質體 1 以獲得帶有 P 基因的 DNA 片段

C: Cleavage of plasmid 2 with ClaI and BamHI to obtain a DNA fragment containing gene Q.
用 ClaI 及 BamHI 切割質體 2 以獲得帶有 Q 基因的 DNA 片段

D: Cleavage of plasmid 2 with ClaI and SalI to obtain a DNA fragment containing gene Q.
用 ClaI 及 SalI 切割質體 2 以獲得帶有 Q 基因的 DNA 片段

E: Cleavage of plasmid 2 with ClaI and XhoI to obtain a DNA fragment containing gene Q.
用 ClaI 及 XhoI 切割質體 2 以獲得帶有 Q 基因的 DNA 片段

F: Cleavage of pBR322 plasmid with EcoRI and ClaI
用 EcoRI 及 ClaI 切割 pBR322 質體

G: Cleavage of pBR322 plasmid with EcoRI and BamHI
用 EcoRI 及 BamHI 切割 pBR322 質體

H: Cleavage of pBR322 plasmid with ClaI and BamHI
用 ClaI 及 BamHI 切割 pBR322 質體

I: Cleavage of pBR322 plasmid with ClaI and SalI
用 ClaI 及 SalI 切割 pBR322 質體

X: Ligation of the DNA fragment containing the gene P with the cleaved pBR322 plasmid.

將帶有 P 基因的 DNA 片段與切割過的 pBR322 質體相連接

Y: Ligation of the DNA fragment containing the gene Q with the cleaved pBR322 plasmid.

將帶有 Q 基因的 DNA 片段與切割過的 pBR322 質體相連接

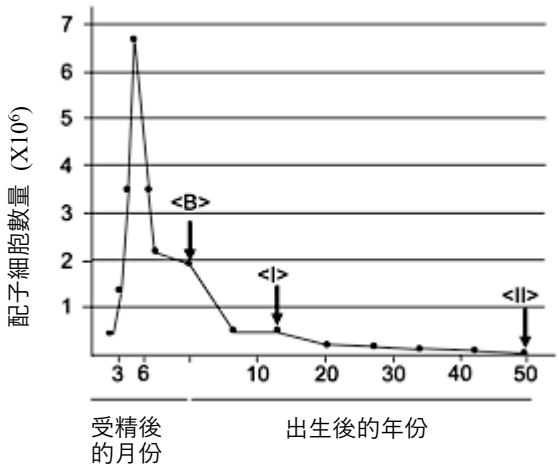
Note: Both native pBR322 and the first recombinant plasmid obtained by Step 1 – 3 are described as pBR322 plasmid.

注意: pBR322 原來質體及由步驟 1-3 所產生的第一個重組質體都稱為 pBR322 質體

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
(1)	A	G	X	C	H	Y
(2)	C	H	Y	A	G	X
(3)	A	G	X	D	I	Y
(4)	D	I	Y	A	G	X
(5)	B	F	X	D	I	Y
(6)	D	I	Y	B	F	X
(7)	B	F	X	E	I	Y
(8)	E	I	Y	B	F	X

Animal biology
動物學

Q23
The oocytes in the human ovary is the most numerous in the 5-months-old fetus, in which the number of the oocytes is approximately 7 million. The number of the oocytes then decreases rapidly, reaching about 2 million at birth.
人類胎兒在五個月大時，卵巢內卵母細胞數量最多，其數量約為 700 萬顆。 爾後卵母細胞的數量會迅速減少，出生時約剩 200 萬顆。



<B> : birth. 出生 <I>: menarche 初經 <II>: menopause 停經

Q23-1 Indicate whether each of the following statements is True (1) or False (2). (1 point each)
The number of germ cells decreased by 70% at the birth because the oocytes die during the period of meiosis II. [71]
Q23-1、指出下列的敘述是正確(1)或是錯誤(2)。(每題 1 分)
由於卵母細胞在減數分裂 II 時死亡，出生時生殖細胞的數量減少了 70%。

Q23-2 Indicate the most suitable number to fill in the blank from the choices below. (1 point)
The number of oocytes that are ovulated during menstrual periods is less than [72] of the germ cells surviving at menarche.
(1) 0.001% (2) 0.01% (3) 0.1% (4) 1%

Q23-2 自下方選項中，選出最合適的數字來填入空白處(1 分)
在全部月經週期中，排卵排出的卵母細胞總數量，少於初潮時存活之生殖細胞的_____。
（1）0.001%（2）0.01%（3）0.1%（4）1%

Q23-3 The risk of Down syndrome increases with the age of the mother. The ratio of babies with Down syndrome born to a mother in her forties is 10 to 100 times higher than for a mother in her twenties. **Choose the most appropriate sentences below for the reason for this.** 73 (1 point)

(1) accumulation of mutation on oocyte DNA
(2) prolongation of chromosome synapsis in primary oocytes
(3) increase in improperly formed spindle in oocytes
(4) transformation of oocytes

Q23-3 唐氏症的風險隨著母親的年齡而增加。 四十多歲母親產出唐氏症嬰兒的比例是二十多歲母親的 10 至 100 倍。請自下方選出最適當的解釋(1 分)。

(1) 卵母細胞 DNA 突變的積累
(2) 延長了初級卵母細胞的染色體聯會
(3) 增加了卵母細胞中不正確的紡錘體形成
(4) 卵母細胞的轉形

Animal biology
動物學

Q24
Figure 1 represents the changes in aortal (Ao), left atrial (At), and left ventricular (Ve) pressures and the left ventricular volume during a human cardiac cycle. During the cycles, the atrioventricular valve opens when the atrial pressure is higher than ventricular pressure, and the aortic valve opens when the ventricular pressure is higher than aortic pressure. Figure 2 shows the changes in ventricular pressure and volume before (dotted line) and after (solid line) a ten-minute period of exercise.
圖 1 呈現了人類心臟週期中主動脈（Ao）、左心房（At）和左心室（Ve）的壓力以及左心室容積的變化。週期中，當心房壓力大於心室壓力時，房室瓣會打開；當心室壓力大於主動脈壓力時，主動脈瓣會打開。圖 2 顯示了於運動十分鐘之前(虛線)和運動後(實線)心室壓力和容積的變化。

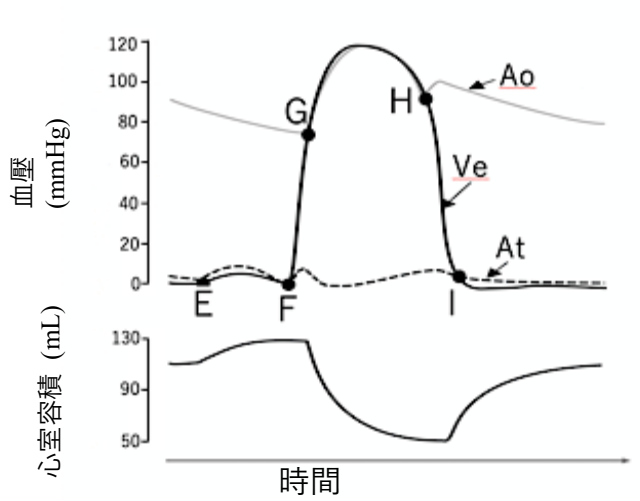


圖 1

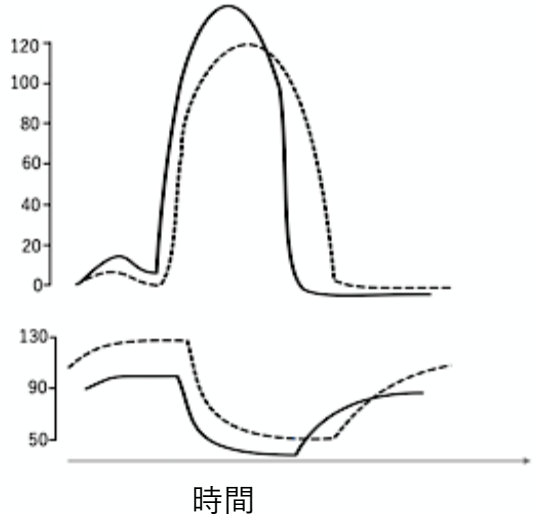


圖 2

Q24-1 Indicate whether each of the following statement is true (1) or false (2). (1 point)
Elevation of heart rate did not change in duration between the point E and F in Figure 1. 74

Q24-1 標示下方是正確(1)或錯誤(2)的陳述。 (1 分)
心跳增加不會改變圖 1 中的 E 點和 F 點間的持續時間。

Q24-2 Choose the corresponding period between point H - I in Figure 1 from (1) – (4) of the pressure-volume relationship of the left ventricle (Figure 3). 75 (1 point)
Q24-2 選出圖 1 中點 H - I 間相應於圖 3 內(1) –(4)期間之左心室壓力-容積關係。(1 分)

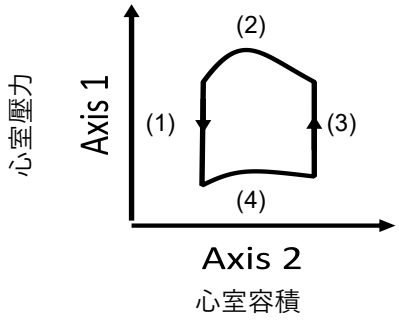


圖 3

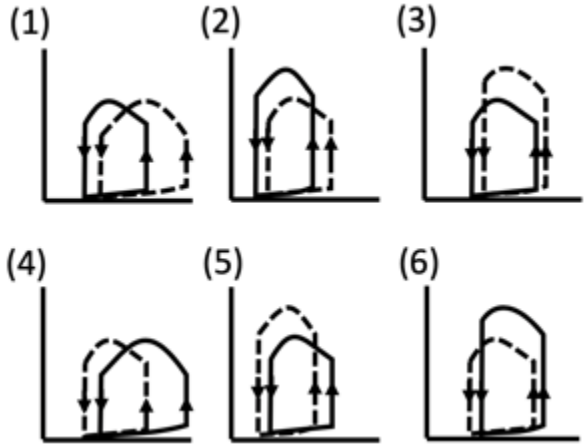
Q24-3 Indicate whether this statements is true (1) or false (2). (1 point)
After point I in Figure 1, blood flows into both atria and ventricles. 76

Q24-3 下列敘述請標示正確(1)或錯誤(2)。 (1 分)

圖 1 中的 I 點之後，血液流入心房和心室。

Q24-4 Choose the most appropriate pressure and volume relationship of left ventricle before (dotted line) and after (solid line) the activation of sympathetic nervous system from (1)-(6). 77 (1 point)

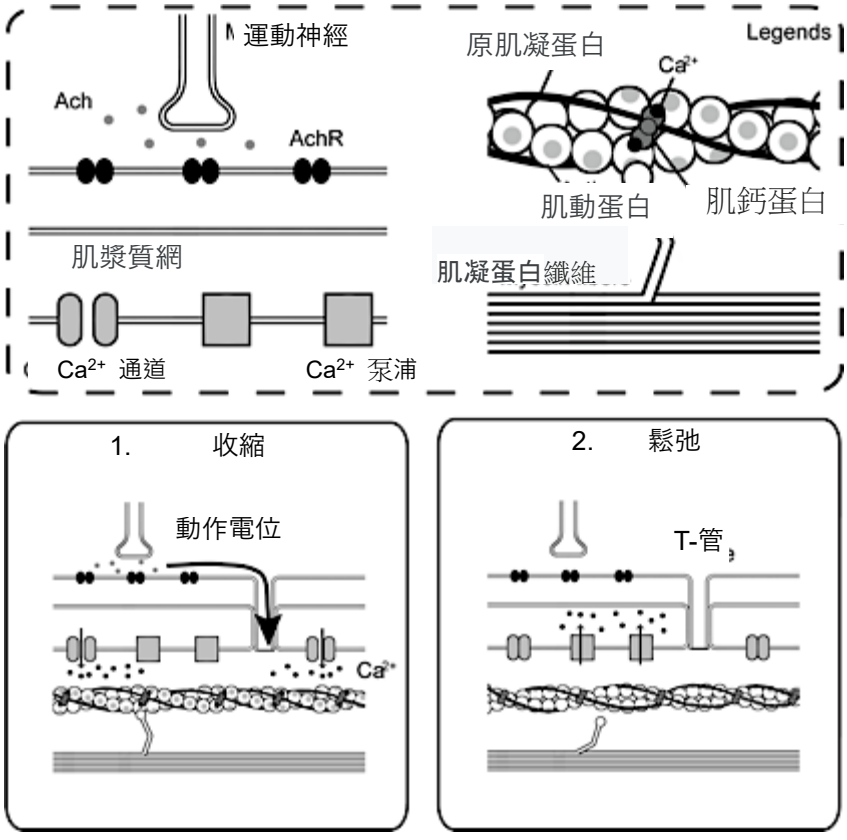
Q24-4 從(1) – (6)中選出最適合用以描述交感神經系統激活前(虛線)和激活後(實線)，左心室壓力和容積的關係圖。(1 分)



Animal biology
動物學

Q25
The following figures illustrate the molecules in muscle fibers in two states: 1. Contraction, 2. Relaxation. The mutation or insufficient function of those molecules are associated with abnormal muscle functions. For example, a mutation in the Ca^{2+} channel or Acetylcholine receptor (AChR) may cause congenital myopathy.
下圖描述了肌肉纖維在 1.收縮 2.鬆弛這兩種狀態下的分子。這些分子的突變或功能不足與肌肉功能異常有關。例如，$Ca2^{+}$通道或乙醯膽鹼受體(AChR)的突變可能會導致先天性肌肉病變。

Note that the choices of muscle abnormality are:
請注意，肌肉異常的選項為：
(1) Myopathy (muscle weakness)
(1) 肌肉病變 (肌肉無力)
(2) Difficulties in arm extension
(2) 伸臂困難
(3) Tetany (involuntary contraction of muscle)
(3) 破傷風(肌肉非自主性收縮)
(4) Hypercontractility (contraction occurs quickly, but relaxation occurs slowly)
(4) 過度收縮 (能迅速收縮，但鬆弛則很緩慢)



Indicate the above symptoms (1)-(4) that will occur in each type of muscle abnormality (A-D). (1 point each)
標示出前述的(1)-(4)症狀，為(A-D) 何種類型的肌肉異常所造成(各 1 分)。

A. Missense mutation in the Tropomyosin binding site of Actin that causes the muscle to be more sensitive for intracellular Ca^{2+} concentration. 78

肌動蛋白的原肌球蛋白結合位點發生錯義突變，導致肌肉對細胞內 Ca^{2+}濃度更敏感。

B. Blocking the Ach release by Botulinum toxin treatment. 79

肉毒桿菌毒素處理會阻斷 ACh 的釋放。

C. Nonsense mutation in Ca^{2+} pump gene, which causes a deficiency in the removal of Ca^{2+} from cytosol. 80

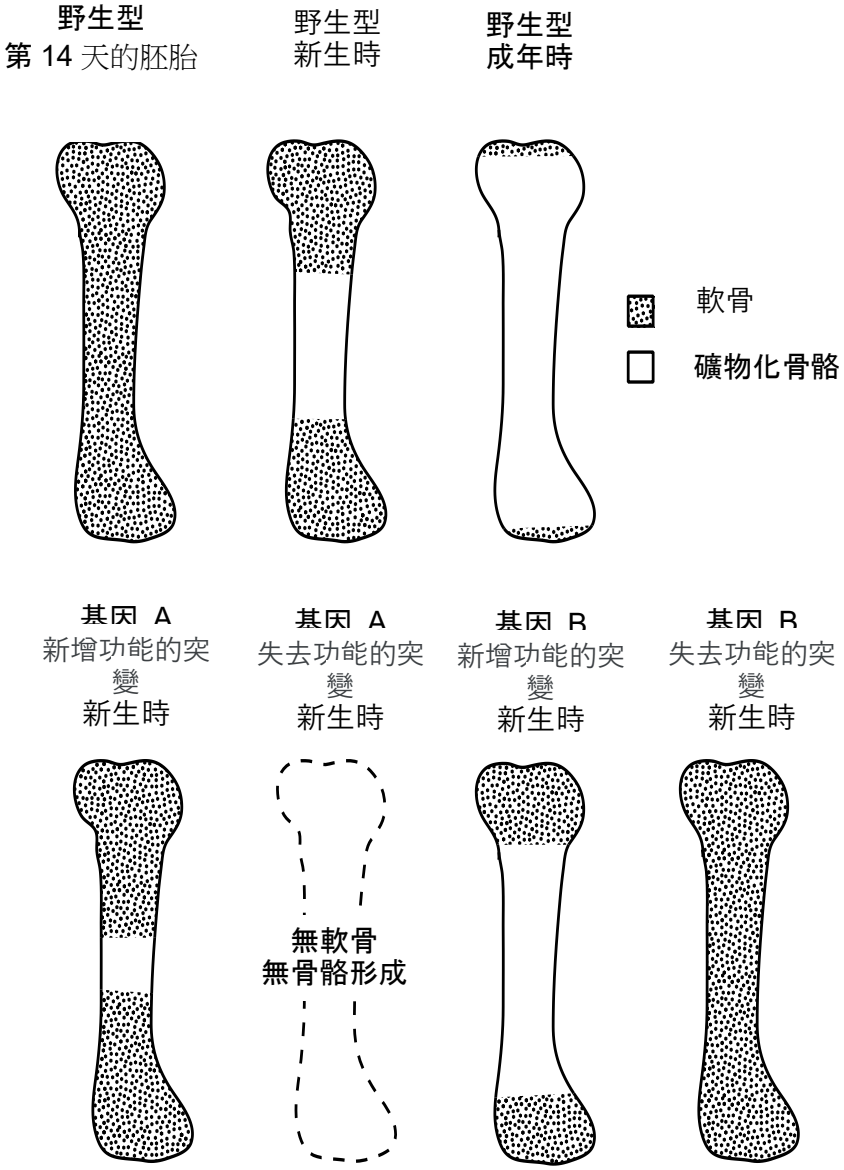
Ca^{2+}泵浦的基因發生無義突變，導致從細胞質中移除 Ca^{2+}的功能不足。

D. Low blood magnesium level, which results in frequent and uncontrolled depolarization. 81

血鎂濃度偏低，導致頻繁且不受控制的去極化。

Animal biology
動物學

Q26
Most mammalian bones are formed through a process called “endochondral ossification,” in which the cartilages first form the template of skeletal elements and then are mostly replaced by mineralized bones. Below is a schematic drawing of the endochondral ossification of the long bone of mice (upper), and the long bone of the mouse with gain or loss of function in gene A or B (lower). Both gene A and gene B are involved in skeletal development. Choose the correct interpretation of endochondral ossification and the function of genes A and B from (1) – (9) in the table. 82 (2 points)
大多數哺乳動物的骨骼是透過稱為“軟骨內骨化”的過程而形成的，其中軟骨先形成骨骼元素的模板，然後大部分被礦物化的骨骼所取代。下圖為小鼠長骨的軟骨內骨化之示意圖(上層)，以及在獲得或喪失功能基因 A 或 B 中的小鼠長骨的軟骨內骨化(下層)。基因 A 和基因 B 均參與了骨骼的發育。從表中的(1)–(9)中選出對軟骨內骨化，以及基因 A 和 B 的功能之正確解釋 (2 分)。



Choices	Gene A		Gene B	
	Cartilage formation 軟骨形成	Cartilage-bone replacement 軟骨置換	Cartilage formation 軟骨形成	Cartilage-bone replacement 軟骨置換
(1)	Not required 不需要	Promote 促進	Required 需要	Promote 促進
(2)	Required 需要	Promote 促進	Required 需要	Promote 促進
(3)	Required 需要	Promote 促進	Required 需要	Repress 抑制
(4)	Required 需要	Promote 促進	Not required 不需要	Promote 促進
(5)	Required 需要	Promote 促進	Not required 不需要	Repress 抑制
(6)	Required 需要	Repress 抑制	Required 需要	Promote 促進
(7)	Required 需要	Repress 抑制	Required 需要	Repress 抑制
(8)	Required 需要	Repress 抑制	Not required 不需要	Promote 促進
(9)	Required 需要	Repress 抑制	Not required 不需要	Repress 抑制

Animal biology
動物學

Q27
The honeybee (*Apis mellifera*) communicates the distance of a food source to others by dancing. The bee performs “round dances” when the feeder is within 50 m. If the feeder is over 50 m, they perform “waggle dances.” The mean durations (milliseconds, ms) of waggle dances are plotted in Figure 1. To determine how bees measure this distance, two types of wooden tunnels with a food source were positioned outdoors (Figure 2; the cylinder in the tunnel shows the position of the feeder). The tunnel is 6 m long, 11 cm wide, and 20 cm high. The top of the tunnel was covered with screen cloth, which provided the direction of the sun, and the far end was closed. The walls and floor of the tunnel were randomly patterned (black-and-white pattern of pixel size 1 cm by 1 cm) in experiments 1, 2, and 4, and axially striped in experiment 3. The type of dance that the bees performed in each experiment is shown in Figure 2. In experiments 2 and 4, the mean waggle durations were 529 ms and 441 ms, respectively.

蜜蜂(*Apis mellifera*)透過舞蹈傳達食物源的距離訊息給同類。當餵食器在 50 m 以內時，蜜蜂會跳“圓舞”。如果餵食器超過 50 m，牠們會跳“搖擺舞”。搖擺舞的平均持續時間(毫秒，ms)如圖 1 所示。

為判斷蜜蜂如何測量該距離，於室外置放了兩種帶有食物源的木製隧道 (圖 2；隧道中的圓柱體顯示了餵食器的位置)。隧道長 6 m，寬 11 cm，高 20 cm。隧道的頂部覆蓋有遮蔽布，遮蔽布提供了太陽的方向，而隧道的遠端是封閉的。在實驗 1、2 和 4，隧道的牆壁和地板塗有隨機的圖案 (像素大小為 1 cm x 1 cm 的黑白圖案)，實驗 3 則為具軸向的條紋。圖 2 中顯示了各實驗中蜜蜂的舞蹈。在實驗 2 和 4，搖擺舞的平均持續時間依序分別為 529 ms 和 441 ms。

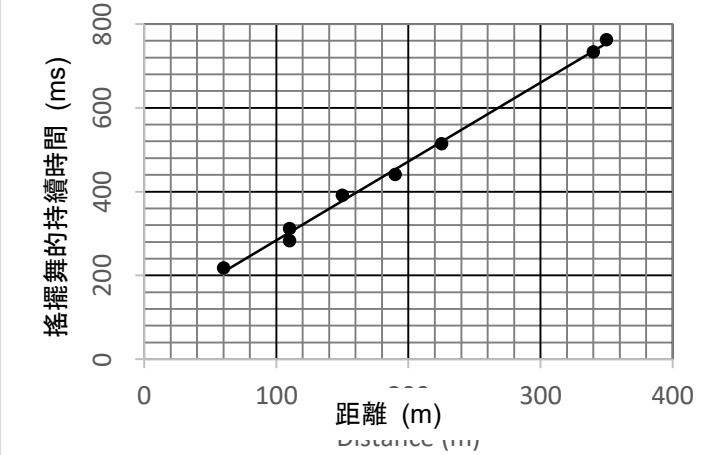


Figure 1

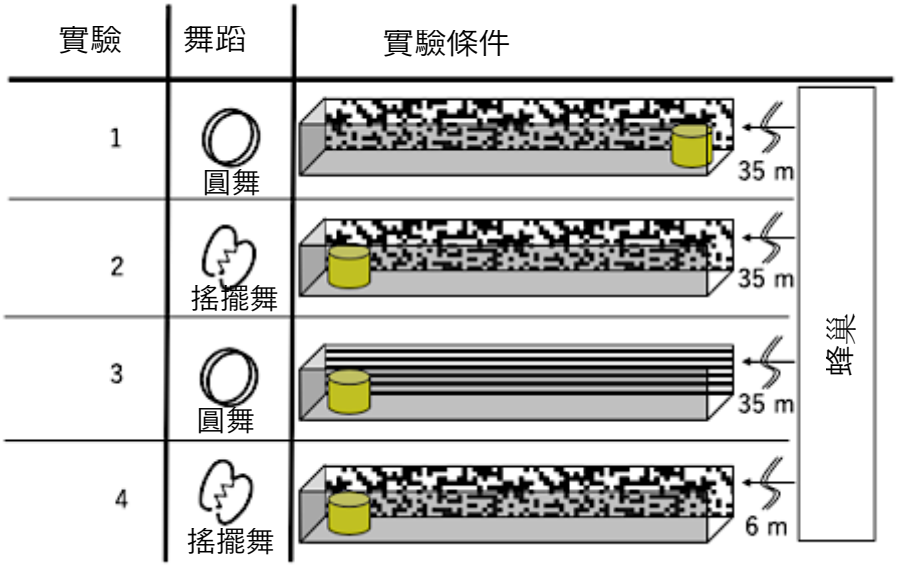


Figure 2

* black-and-white random pattern of pixel size 1 cm by 1 cm

* 像素大小為 1 cm 乘 1 cm 的黑白隨機圖案

Q27-1 How long is the duration of the waggle dance when the tunnel was extended to be two-times longer in the opposite direction of the hive in experiment 2? **Choose the most appropriate answer from the following.** (3 point) 83

Q27-1 將實驗 2 的隧道沿蜂巢的相反方向延長兩倍時，搖擺舞的持續時間會是多久？ **自下方選出最合適的答案。** (3 分)

(1) 634 ms (2) 740 ms (3) 846 ms (4) 952 ms

Q27-2 Choose the most appropriate answer from the following statements. 84 (1 point)

Q27-2 自下方敘述中選出最適當的答案(1 分)

1. When the walls and floor are lined with vertically oriented strips in experiment 3, most bees will perform the waggle dance.
   在實驗 3，將牆壁和地板畫上垂直方向的條帶，大多數蜜蜂將會跳搖擺舞。
2. Bees perform a waggle dance with the same duration for two different feeders. If bees fly to the two feeders with a same speed, the durations from the hive to the feeders are same.
   蜜蜂對兩個不同的餵食器，跳搖擺舞的持續時間相同。如果蜜蜂以相同的速度飛向兩個餵食器，則從蜂巢到餵食器的持續時間相同。
3. The duration of the waggle dance does not change if the bees fly at the different height.
   如果蜜蜂以不同的高度飛行，則搖擺舞的持續時間不會改變。

Animal biology
動物學

Q28
CYP2C19 belongs to the cytochrome P450 families of enzymes expressed in the liver for detoxification. It is one of the major enzymes that metabolizes and inactivates various drugs. However, there are single nucleotide polymorphisms (SNPs) in the *CYP2C19* gene (Table 1 for combinations of SNPs denoted 1*, 2* and 3*), and the allele frequencies of these SNPs are different among Asian and European populations (Table 2).
CYP2C19 屬於表現在肝臟用於解毒的細胞色素 P450 家族。它是代謝及讓多種藥物去活化的主要酵素之一。而 *CYP2C19* 基因具有單核苷酸多態性(SNP)(表 1 中表示為 1 *，2 *和 3 *的 SNP 組合)，這些 SNP 的等位基因頻率在歐亞人種間並不相同(表 2)。

Omeprazole is a drug used for the treatment of gastric ulcer and reflux esophagitis. It is metabolized mainly by CYP2C19 for inactivation. Conversely, Clopidogrel is a drug used for the prevention of myocardial and cerebral infarction. Clopidogrel is also metabolized by CYP2C19, and this metabolite inhibits the target molecule on the surface of the platelets, thus showing the drugs' effect.
奧美拉唑(Omeprazole)為治療胃潰瘍和胃食道逆流的藥物，主要經 CYP2C19 代謝而失去活性。 而氯吡格雷(Clopidogrel)是用於預防心肌和腦梗塞的藥物。氯吡格雷也會被 CYP2C19 代謝，其代謝產物會抑制血小板表面的靶分子，因而產生其藥物作用。

Table 1

Genotype of *CYP2C19* CYP2C19 的基因型	Phenotype 表現型
**1/*1*	Extensive metabolizer 強的代謝者
**1/*2, *1/*3*	Intermediate metabolizer 一般的代謝者
**2/*2, *2/*3, *3/*3*	Poor metabolizer 弱的代謝者

Table 2

Country	Allele frequency (%) 等位基因頻率		
	**1*	**2*	**3*
Sweden 瑞典	69.4	27.8	2.7
France 法國	56.7	37.2	6.1
China 中國	38.2	47.2	14.6
Japan 日本	27.7	49.9	22.5

A. Orally administered drugs absorbed in the intestinal epithelium are first transported to [85].
(1) Inferior vena cava (2) liver (3) heart (right atrium)
(4) pancreas (5) Large intestine

B. What is the order of genotypes for the effect of omeprazole from the most long-lasting to the shortest lasting effect after oral administration? [86]
(1) **1/*1 > *1/*3 > *2/*2* (2) **1/*1 > *3/*3 > *1/*2*
(3) **3/*3 > *1/*2, > *1/*1* (4) **3/*3 > *1/*1, > *1/*3*

C. Which countries have the highest proportion of patients for whom omeprazole works well? [87]
(1) Sweden (2) France (3) China (4) Japan

D. If clopidogrel does not show sufficient effect due to the *CYP2C19* SNPs in the patient, what is expected by combining omeprazole on the effectiveness of the clopidogrel? [88]
(1) improves the effectiveness (2) no change in the effectiveness (3) worsens the effectiveness

A-D (1 point each)

A. 口服的藥物經腸道上皮細胞吸收後，首先運送到。

(1) 下腔靜脈　(2) 肝臟　(3) 心臟(右心房)

(4) 胰臟　(5) 大腸

B. 口服奧美拉唑後，按作用最持久到作用最短的基因型之排列順序為何？

(1) * 1 / * 1> * 1 / * 3> * 2 / * 2　(2) * 1 / * 1> * 3 / * 3> * 1 / * 2

(3) * 3 / * 3> * 1 / * 2，> * 1 / * 1　(4) * 3 / * 3> * 1 / * 1，> * 1 / * 3

C. 奧美拉唑對患者有效的比例最高之國家為？

(1) 瑞典 (2) 法國 (3) 中國 (4) 日本

D. 假設病患因 CYP2C19 的 SNPs 使氯吡格雷未能產生充分的作用，如合併奧美拉唑投藥，則對氯吡格藥效的預期影響為？

(1) 提升藥效（2）藥效無變化（3）藥效變更差

A-D（各 1 分）

Animal biology
動物學

Q29
Three stages of transmission are considered before a zoonotic disease leads to a pandemic in the human society (Figure 1). Coronaviruses are a group of viruses that can cause such pandemics. The natural host of coronaviruses are generally believed to be bats.
人畜共通傳染病在人類社會造成大流行前，會有三個階段的傳播(圖 1)。 冠狀病毒為一群可引發這種大流行的病毒。一般認為，冠狀病毒的天然宿主是蝙蝠。

Q29-1 Which factor increases variation of the coronavirus genome in A? **Choose a combination of**

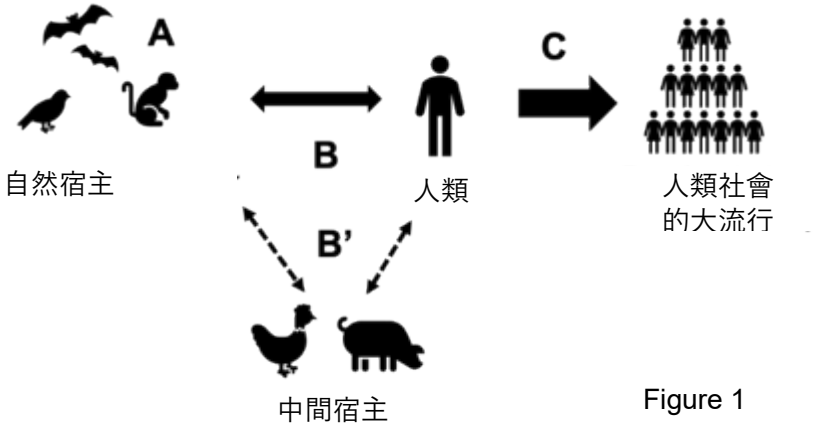


Figure 1

correct answers. [89] (1 point)
a) The viral genome is surrounded by capsids.
b) The virus has an envelope.
c) The host DNA replication mechanism has a proofreading function.
d) The genome size is large for a RNA virus.
e) The genome is segmented by some polycistronic genes.
(1) a), b) (2) b), c) (3) c), d) (4) d), e) (5) a), c) (6) b), c) (7) c), d) (8) d), e)

Q29-1 哪個因素會增加冠狀病毒基因組的變異？選出正確答案的組合(1 分)。

a) 病毒基因組被外殼包覆。

b) 病毒具有外套膜。

c) 宿主 DNA 複製機制具有校對功能。

d) RNA 病毒的基因組很大。

e) 基因組被一些多順反子的基因(polycistronic genes)所分段。

(1) a)、b) (2) a)、c) (3) a)、e) (4) b)、c)
(5) b)、d) (6) c)、d) (7) c)、e) (8) d)、e)

Q29-2 Which of the following facts contribute to the transmission of coronavirus in B and B'?
Choose a combination of correct answers. [90] (1 point)
a) Disease do not develop in natural host bats.
b) Multiple types of coronaviruses are detected in the fecal masses of bats in one cave by using RT-PCR.
c) Many bat species are nocturnal.
d) Habitat changes that occur due to climate change.
e) Many bat species feed on various insects.

(1) a), b), c)　(2) a), b), d)　(3) a), b), e)　(4) a), c), e)
(5) b), c), d)　(6) b), d), e)　(7) b), c), d)　(8) b), c), e)

Q29-2 下列哪些事實促成了冠狀病毒在 B 和 B’ 間傳播？ 選出正確的答案組合 (1 分)。

a) 在自然寄主蝙蝠身上不會造成疾病。

b) 使用 RT-PCR 在一個洞穴的蝙蝠糞便中，檢測到多種類型的冠狀病毒。

c) 多種蝙蝠是夜行性的。

d) 因氣候變化而造成的棲地改變。

e) 許多蝙蝠攝食各式各樣的昆蟲

。

(1) a), b), c)　(2) a), b), d)　(3) a), b), e)　(4) a), c), e)
(5) b), c), d)　(6) b), d), e)　(7) b), c), d)　(8) b), c), e)

Plant biology
植物學

Plant biology

Q30
Early splendor, a cultivar of ornamental amaranth (*Amaranthus tricolor*) begins to form red leaves in late summer to early autumn, after producing fully green leaves. The first few red leaves are only partially red, each consisting of distal green and proximal red regions. Finally, fully red leaves form after the formation of partially red leaves (Figure 1a). The color pattern of each leaf remains unchanged after leaf emergence. The timing of red leaf formation is considerably influenced by photoperiodic conditions (Figure 1b).
雁來紅(一個莧屬植物的觀賞用變種；*Amaranthus tricolor*)在夏末秋初時節，會由全綠的葉片之後，開始長出紅葉。最初，極少數紅葉只有局部是紅的(每片葉子的遠端綠、近端紅)；最後，在局部紅色的葉片形成之後，就會有全紅的葉片(圖 1a)。在葉片長出之後，每片葉子的顏色模式就維持不變。紅葉形成的時程完全受到光週期條件之影響(圖 1b)。

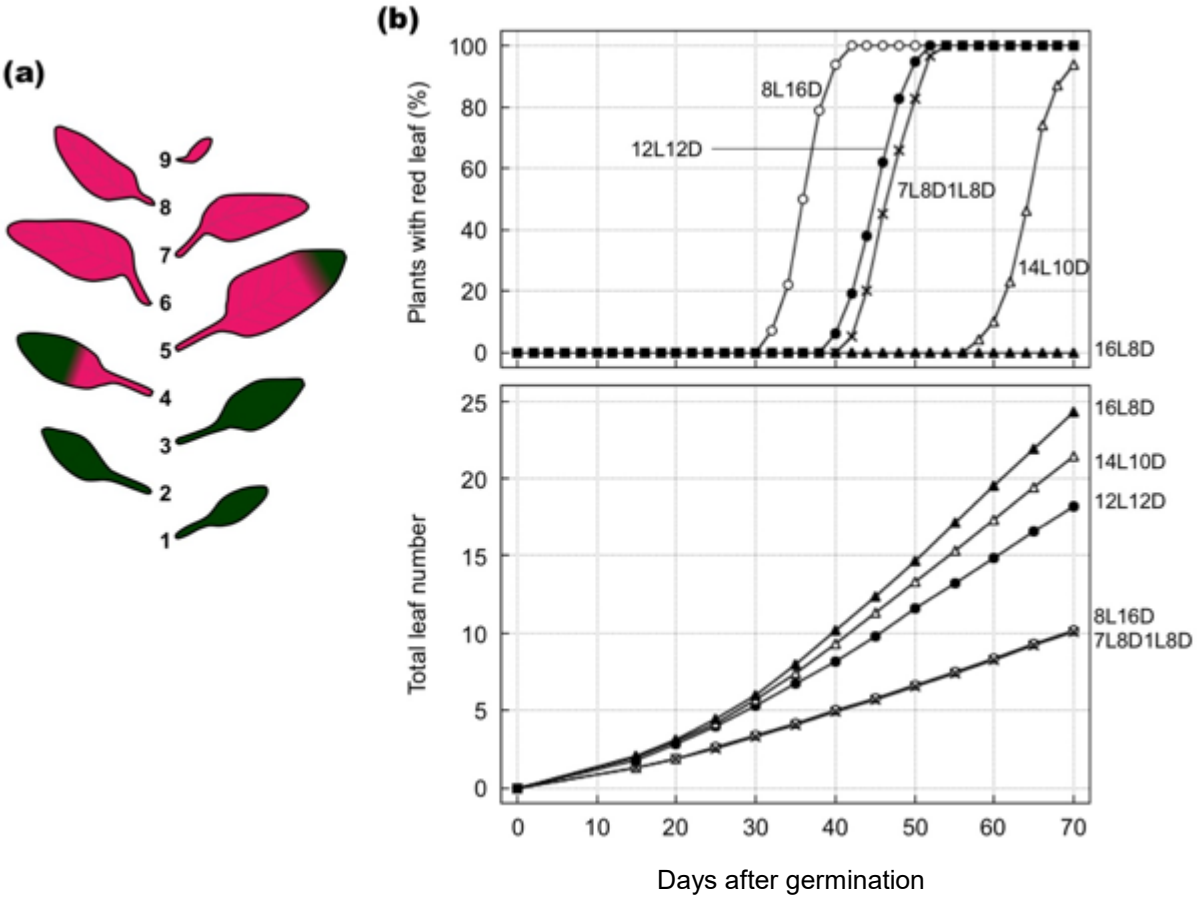


Figure 1

(a) Sketch of leaves excised from a 60-day-old plant cultured under 8-h light/16-h dark conditions. Numbers indicate leaf positions from the base to the apex on the stem.
手繪圖顯示，一株60天大的植株，種植在8小時光照/16小時黑暗的條件下。圖中的數字代表葉子從莖的基部到頂端的位置。

(b) Plants were cultured in the 16-h light/8-h dark (closed triangles, 16L8D), 14-h light/10-h dark (open triangles, 14L10D), 12-h light/12-h dark (closed circles, 12L12D), 8-h light/16-h dark (open circles, 8L16D), or 7-h light/8-h dark/1-h light/8-h dark (saltires, 7L8D1L8D) conditions. 'Plants with red leaf' indicates plants that form at least one partially red leaf. 'Total leaf number' indicates the average number of total leaves per plant.

植物分別種植在不同的條件下：16小時光照/8小時黑暗(實心三角形, 16L8D)、14小時光照/10小時黑暗(空心三角形, 14L10D)、12小時光照/12小時黑暗(實心圓形, 12L12D)、8小時光照/16小時黑暗(空心圓形, 8L16D)、或7小時光照/8小時黑暗/1小時光照/8小時黑暗(星形, 7L8D1L8D)。縱軸'Plants with red leaf'是指植物至少形成一片局部紅葉。'Total leaf number' 是指平均每株植物的葉片總數。

Q30-1 The timing of red leaf formation and the growth rate can be related to the number of red leaves. **Rank the 70-day-old plants cultured under different photoperiodic conditions in the order of their average number of red leaves.**

紅葉形成的時程以及生長速率會與紅葉數目有關。將在不同光週期條件下生長 70 天大的植株，依其平均紅葉數目由大而小排序。

[91] > [92] > [93] > [94] > [95] (3 points)

(1) 16L8D
(2) 14L10D
(3) 12L12D
(4) 8L16D
(5) 7L8D1L8D

Q30-2 Assuming that some red leaf-inducing signal X is produced in expanded leaves in response to photoperiodic conditions and transported to the shoot apical region by analogy to the photoperiodic regulation of flowering, the following two hypotheses are considered to explain the color pattern of partially red leaves.

假設開展的葉片會感應光週期條件而產生某種紅葉誘導訊息 X，該訊息會類似光週期調節開花的情況，被運送至莖頂。下列兩個假說被認為可解釋局部紅葉的顏色模式。

I. The distal part of each leaf primordium requires higher concentrations of the signal X for red coloration than that required by the proximal part.
相較於近端，每個葉原體的遠端需要較高濃度的訊號 X，以形成紅色模式。

II. During leaf primordium development, the distal part is determined for coloration earlier than the proximal part.
在葉原體的發育過程中，遠端的顏色被決定得較近端者早。

Which of the following experiments is most informative to distinguish between these hypotheses?

下列實驗中，哪一個是最能用以區別這兩個假說？

[96] (2 points)

(1) Examine color patterns of leaves newly formed on the scion after grafting the scion of the 60-day-old 8L16D plant on the stock of the 60-day-old 16L8D plant.
將 60 天大、8L16D 的接穗嫁接在 60 天大、16L8D 的砧木上，檢視其接穗新形成葉片的顏色模式。

(2) Examine color patterns of leaves newly formed on the scion after grafting the scion of the 60-day-old 16L8D plant on the stock of the 60-day-old 8L16D plant.
將 60 天大、16L8D 的接穗嫁接在 60 天大、8L16D 的砧木上，檢視其接穗新形成葉片的顏色模

式。

(3) Examine color patterns of leaves newly formed after transferring 60-day-old plants from the 8L16D condition to the 16L8D condition.

將 60 天大植株的生長條件從 8L16D 轉移至 16L8D，檢視其接穗新形成葉片的顏色模式。

(4) Examine color patterns of leaves newly formed after transferring 60-day-old plants from the 16L8D condition to the 8L16D condition.

將 60 天大植株的生長條件從 16L8D 轉移至 8L16D，檢視其接穗新形成葉片的顏色模式。

Plant biology
植物學

Q31
When protonemata of the moss *Physcomitrella patens* were cultured without exchanging the culture medium, some of the cells formed buds, which grew into gametophores (Figure 1). The culture medium did not originally contain any plant hormones, but auxin and cytokinin were detected in the medium after the culture of protonemata.
在培養苔類植物(*Physcomitrella patens*)的原絲體時，且不再更換其培養基，有些原絲體的細胞會形成芽體，進而長成幼小配子體(圖 1)。培養基起初並不含有任何植物激素，但在培養出原絲體之後，則可在培養基中測得植物生長素和細胞分裂素。

Next, protonemata were cultured while keeping the medium fresh by continuous medium exchange using an apparatus shown in Figure 2, and the effects of addition of auxin and/or cytokinin to the medium on bud formation were examined in this system (Table 1).
接下來，將原絲體培養在持續更新的培養基中，其裝置如圖 2 所示，並在此系統中添加植物生長素和細胞分裂素、或各別添加此兩種激素，以檢測其對芽體形成的影響，結果如表 1 所示。

Protonemata of mutant ***x***, which do not form buds in natural conditions, were inoculated into hormone-free medium, auxin-containing medium, or cytokinin-containing medium and cultured without medium exchange to examine the effects of the addition of auxin or cytokinin on bud formation (Table 1).
在天然狀況下不會產生芽體的突變株 *X* 原絲體被接種到缺乏植物激素的培養基、含有生長素的培養基、或含有細胞分裂素的培養基，並在不進行培養基交換的情況下進行培養，以檢查添加植物生長素或細胞分裂素對芽形成的影響 (表 1)。

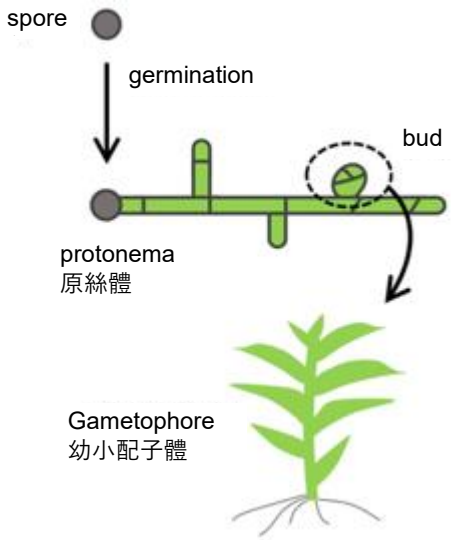


Figure 1
Part of the lifecycle of *Physcomitrella patens*
此種苔的部分生活史

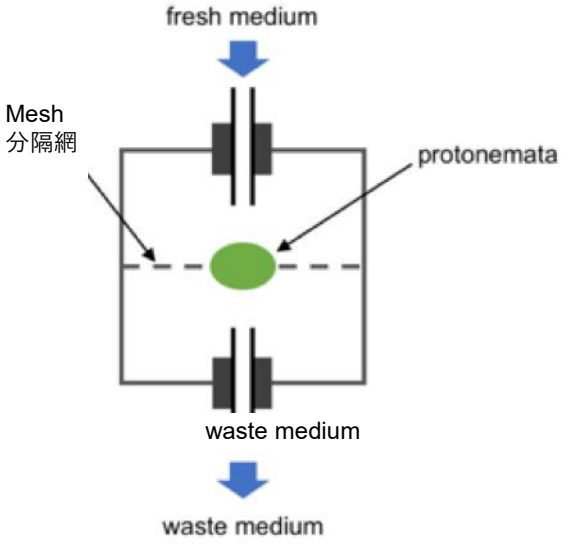


Figure 2
Apparatus for keeping the medium fresh by continuous medium exchange
持續更新培養基，以維持其新鮮的裝置

Table 1

Genotype 基因型	Medium exchange 更新培養基	Addition of auxin 添加植物生長素	Addition of cytokinin 添加細胞分裂素	Bud formation 芽體形成
wild type	No	No	No	Occurred
wild type	Yes	No	No	Did not occur
wild type	Yes	Yes	No	Did not occur
wild type	Yes	No	Yes	Did not occur
wild type	Yes	Yes	Yes	Occurred
mutant ***x***	No	No	No	Did not occur
mutant ***x***	No	Yes	No	Did not occur
mutant ***x***	No	No	Yes	Occurred

Choose the most appropriate answer set to fill in the following blanks (A, B and C). 97 (2 points)

從下表 A, B and C 的答案組合中，選出一個最適當者的編號。

- The wild-type protonemata secrete (A).
  野生型原絲體會分泌(A)。
- Auxin sensitivity is (B) in mutant ***x***.
  突變株 ***x*** 的植物生長素敏感性是(B)。
- Protonemata are more likely to form buds when their growing density is (C).
  當原絲體生長密度(C)時，較可能會形成芽體。

	A	B	C
(1)	both auxin and cytokinin	lost	higher
(2)	both auxin and cytokinin	lost	lower
(3)	both auxin and cytokinin	normal	higher
(4)	both auxin and cytokinin	normal	lower
(5)	auxin but not cytokinin	lost	higher
(6)	auxin but not cytokinin	lost	lower
(7)	auxin but not cytokinin	normal	higher
(8)	auxin but not cytokinin	normal	lower

Plant biology
植物學

Q32
In some plants, fruit valves bend and/or coil explosively to disperse seeds. While, in many cases, dehydration of fruit valves triggers this explosive movement, fruit valves of *Cardamine hirsuta* bend and coil explosively upon mechanical stimulation (e.g., by animals) when the fruits are fresh and turgid (Figure 1).
在某些植物中，果瓣會爆發性地彎曲且/或捲起，以傳播種子。在許多例子中，果瓣乾燥脫水會誘發此爆發動作，而 (*Cardamine hirsuta*) 的果瓣在其果實是新鮮且膨大的情況下爆發性地彎曲並捲起，則是受到機械性的刺激(如：被動物所刺激) (圖 1)。

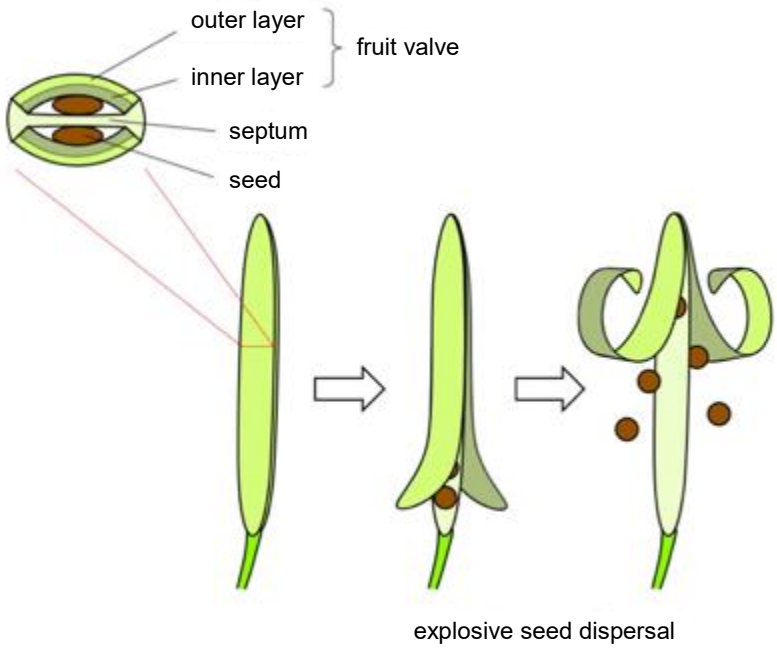


Figure 1. Explosive bending and coiling of a fruit valve of *C. hirsuta*

圖 1. *C. cirsuta* 果瓣爆炸性彎曲的過程

To study how the fruit valve of *C. hirsuta* builds up energy for bending, researchers examined effects of various treatments and conditions on the bending of fruit valves (Table 1). In this experiment, bending of living intact fruit valves with all layers combined was observed in air, pure water, and 4 M NaCl solution. Fruit valves killed by freeze-thaw disruption of cell membranes and living fruit valves separated into outer and inner layers were also tested for bending in pure water.
為了探討 *C. hirsuta* 果瓣如何累積能量以供果瓣彎曲，研究人員測試與果瓣彎曲有關的不同處理及條件，結果如表 1 所示。本實驗中，觀測新鮮且所有細胞層次都相連的果瓣在空氣中、純水以及 4 M NaCl 溶液中、以及藉由快速冷凍而將果瓣的細胞膜破壞以殺死的果瓣等四組之彎曲情形；或將活的果瓣分出內、外兩層，然後也同樣觀測其在水中的彎曲情形。

Table 1 Bending of fruit valves after various treatments and in various conditions
表 1 在不同處理及不同條件下，果瓣的彎曲情形

all layers combined 所有果皮層次				outer layer only 僅有外層	inner layer only 僅有內層
living	living	living	killed	living	living
air	water	4 M NaCl	water	water	water
+	++	–	–	– (shrank longitudinally) 縱向皺縮	– (unchanged in length) 長度不變

++, strong bending(極彎曲); +, bending(彎曲); –, little or no bending(幾乎不或不彎曲).

Choose the most appropriate answer set to fill in the following blanks (A, B and C). 98 (3 points)
從下表 A, B and C 的答案組合中，選出一個最適當者的編號。

- Higher turgor pressure leads to (A) bending of a fruit valve in *C. hirsuta.*
  較高的膨壓會導致 *C. hirsuta* 果瓣彎曲情形(A)。
- A shallow cut made on an intact fruit valve of *C. hirsuta* in the (B) direction would cause the shallow cut to open immediately.
  在完整的 *C. hirsuta* 果瓣上作(B)方向的輕微劃切，會造成此切口立即打開。
- The outer layer cells of fruit valves of *C. hirsuta* are (C) in water as compared to those in air.
  相較於在空氣中，在水中的 *C. hirsuta* 果瓣外層細胞是(C)。

	A	B	C
(1)	increased	longitudinal 縱向	narrower and/or thinner
(2)	increased	longitudinal	wider and/or thicker
(3)	increased	transverse 橫向	narrower and/or thinner
(4)	increased	transverse	wider and/or thicker
(5)	decreased	longitudinal	narrower and/or thinner
(6)	decreased	longitudinal	wider and/or thicker
(7)	decreased	transverse	narrower and/or thinner
(8)	decreased	transverse	wider and/or thicker

Plant biology
植物學

Q33
Many climbing plants have tendrils, a thread-like organ specialized for winding around or clinging to a support. While tendrils are typically modified leaves, some tendrils are modified stems, which can be distinguished by morphological inspection.
許多攀爬植物具有捲鬚(一種會纏繞或攀升至支持物的線狀構造)。雖然捲鬚通常是變態葉，有些捲鬚是變態莖，二者可藉由形態觀察來加以區別。

Vicia sativa

Cayratia japonica

For a tendril sample, answer which of the following observations is most informative for judging whether it is a modified leaf or a modified stem. 99 (2 points)
從捲鬚樣本中，下列觀察方式，何者最足以判斷其是變態葉或變態莖？

(1) Observation of the surface to examine the presence/absence of stomata
觀察表面、檢視有/無氣孔
(2) Observation of the surface to examine the presence/absence of trichomes
觀察表面、檢視有/無毛狀物
(3) Observation of the surface to examine the thickness of the cuticular wax layer
觀察表面、量測蠟質-角質層的厚度
(4) Observation of the surface to examine the shape of epidermal cells
觀察表面、檢視表皮細胞的形狀
(5) Observation of the cross section to examine the positional arrangement of the xylem and phloem
觀察橫切面、檢視木質部和韌皮部的位置排列
(6) Observation of the cross section to examine the number of vascular strands
觀察橫切面、檢視維管束的數目
(7) Observation of the inner tissue to examine the presence/absence of developed chloroplasts
觀察內部組織、檢視有/無已發育的葉綠體
(8) Observation of the inner tissue to examine the presence/absence of the intercellular air space
觀察內部組織、檢視有/無細胞間隙

Plant biology
植物學

Q34
Plant leaves are arranged around the stem in regular patterns. A typical example is the Fibonacci spiral, where the angle between successive leaves is near the golden angle of 137.5 degrees. Such regular pattern of leaf arrangement reflects the positional relationship of a new leaf to the existing leaves when it arises at the periphery of the shoot apical meristem. It is considered that the position of new leaf formation is determined under the epidermis-transmitted inhibitory effect from existing leaves. To characterize this effect, the following microsurgical experiments were performed using tomato plants.
植物葉片在莖上的排列呈現規律模式。典型的例子是費伯納契氏螺旋，其在相鄰葉片間的角度將近完美的 137.5°。葉片排列模式如此規律反映出：當新生葉片從莖的頂端分生組織周圍突起時，其與既存葉片間的位置關係。新生葉片形成的位置被認為是由既存葉片表皮釋出抑制作用來決定。為了具體呈現此作用，利用番茄植株來進行以下顯微操作實驗。

Researchers made a shallow cut on the surface at the adaxial side of the incipient leaf P_0 to isolate it from the apical region (Figure 1), and measured the angles between successive leaves after the next leaf P_1 and the second next leaf P_2 were formed (Figure 2).
研究人員在葉片 P_0 近軸側的表面劃出淺切口，以將其與頂端分開(圖 1)，並在接著形成的葉片 P_1 以及隨後形成的葉片 P_2 之後，測量 P_1、P_2 兩者間的夾角(圖 2)。

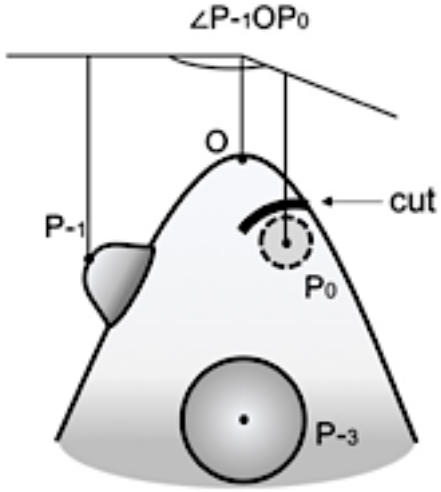


Figure. 1. Schematic drawing of microsurgical experiment P_{n-1} indicates the leaf immediately preceding to P_n and O represent the center of the stem. P_{-4} and P_{-2} are not shown in this drawing. 顯微操作實驗示意圖。P_{n-1} 代表緊接在 P_n 之前的葉片，O 代表莖頂；圖中未顯示 P_{-4} 和 P_{-2}。

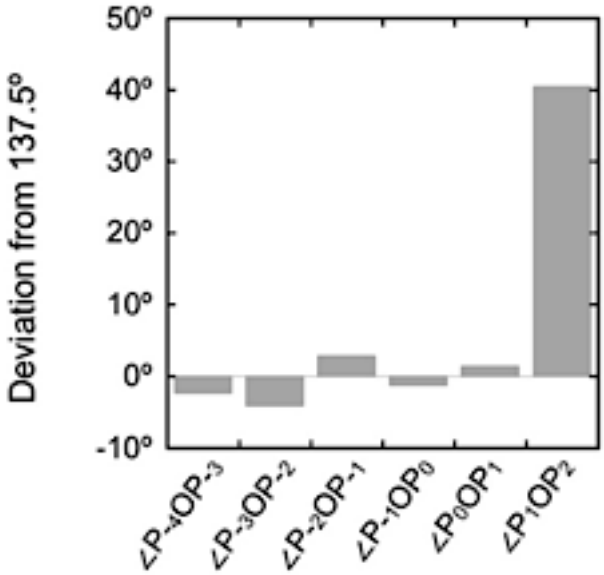


Figure 2. Deviation of the angle between successive leaves from 137.5 degrees
相鄰葉片間的夾角和 137.5°的偏差。(縱軸：137.5°的偏差)

What can be speculated from the above experiment? **Choose the most appropriate set of reasonable speculations.** 100 (3 points)

由以上實驗，其推測為何？**從下列合理的推測，選出最適當的一組。**

A. Among existing leaves, only the immediately preceding leaf is critical for the determination of the position of a new leaf formation.
在既存的葉片中，只有緊鄰的前一片葉是決定新生葉片形成位置的關鍵。

B. Among existing leaves, two preceding leaves are critical for the determination of the position of a new leaf formation.
在既存的葉片中，前兩片葉是決定新生葉片形成位置的關鍵。

C. When a leaf is newly arising, the position of the next leaf is not determined yet.
當新葉片剛突起時，下一片葉的位置尚未被決定。

D. When a leaf is newly arising, the position of the next leaf is already determined but the position of the second next leaf is not determined yet.
當新葉片剛突起時，下一片葉的位置已被決定，但接著的第 2 片葉則尚未被決定。

E. If n is sufficiently large, the deviation of the angle $\angle P_nOP_{n+1}$ from 137.5 degrees is close to 0.
倘若 n 夠大，夾角$\angle P_nOP_{n+1}$和 137.5°的偏差會近於 0。

F. If n is sufficiently large, the deviation of the angle $\angle P_nOP_{n+1}$ from 137.5 degrees is close to 42.5 degrees.
倘若 n 夠大，夾角$\angle P_nOP_{n+1}$和 137.5°的偏差會近於 42.5°。

(1) A, C, E (2) A, C, F (3) A, D, E (4) A, D, F
(5) B, C, E (6) B, C, F (7) B, D, E (8) B, D, F

Plant biology
植物學

Q35
Nitrogen assimilation is a process that requires considerable amounts of reducing power. In leaf cells under moderate light conditions, this process competes with carbon assimilation in the Calvin cycle for reductants supplied by the photosystem, if these reactions are coexistent (Figure 1). Such competition influences the carbon assimilation quotient (CAQ), defined as the ratio of the CO_2 absorption rate to the O_2 evolution rate. Additionally, CAQ is also influenced by the nitrogen source applied to plants. This effect is expressed by ΔCAQ, which is calculated as the difference of CAQ between plants grown with ammonium and plants grown with nitrate.

氮素同化作用是需要相當大量還原力的過程。在中度光照下的葉肉細胞中，氮素同化作用會和卡爾文循環的碳同化作用競爭光系統所提供的還原劑，倘若這些反應同時在進行(圖 1)。此競爭會影響碳同化作用商數(CAQ)，其定義為碳吸收率對氧衍生率的比值。此外，CAQ 也會受到供給植物的氮源所影響，此作用以ΔCAQ 表示，亦即植物分別在供給銨鹽和硝酸鹽環境下生長，計算其 CAQ 的差異。

$$CAQ = CO_2 \text{ absorption rate} / O_2 \text{ evolution rate}$$

$$\Delta CAQ = CAQ_{\text{ammonium}} - CAQ_{\text{nitrate}}$$

* CAQ_{ammonium} : CAQ of plants grown with ammonium as the only source of nitrogen (銨鹽是其唯一氮源)

* CAQ_{nitrate} : CAQ of plants grown with nitrate as the only source of nitrogen (硝酸鹽是其唯一氮源)

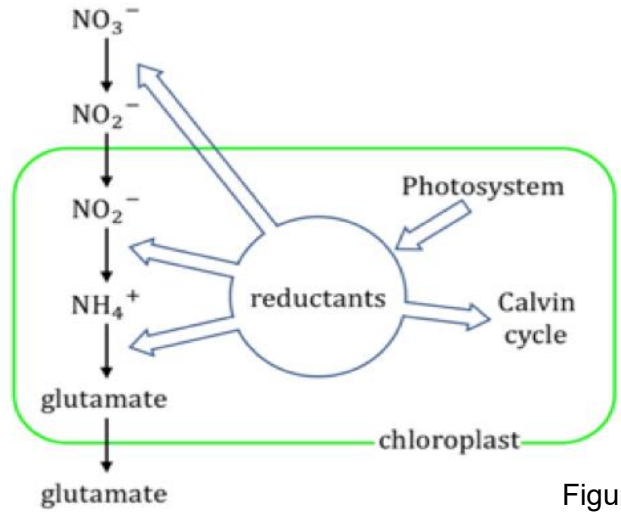


Figure 1

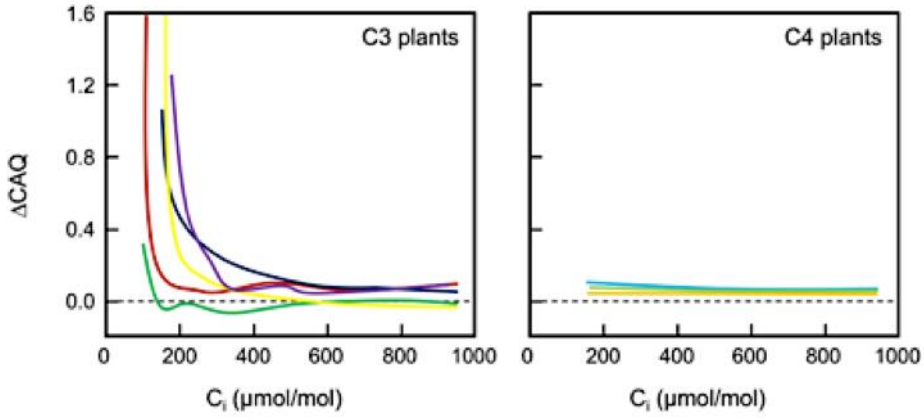


Figure 2

Figure 2 shows ΔCAQ values as a function of the leaf internal CO_2 concentration (Ci) measured in various C3 and C4 plant species. Different colors indicate different species.

圖 2 顯示在不同 C3 和 C4 植物種類中，ΔCAQ 因葉內部的 CO_2 濃度(Ci)改變之結果。不同顏色曲線代表不同的植物種類。

Q35-1 Choose the appropriate answer set to fill in the following blanks (A and B). 101 (2 point)

選出適當的 A and B 填空組合，以其編號作答。

Competition for reductants between nitrogen assimilation and carbon assimilation (A) CAQ. As application of ammonium skips its upstream steps of nitrogen assimilation, ΔCAQ correlates (B) with the activity of the nitrate-to-ammonium conversion process of nitrogen assimilation.

氮素同化作用和碳同化作用間的還原劑競爭會(A) CAQ，由於添加銨鹽可跳過其在氮素同化作用的上游步驟，ΔCAQ 和氮素同化作用中的硝酸鹽-銨鹽轉換過程之作用情形呈現(B)相關。

	A	B
(1)	raises	positively
(2)	raises	negatively
(3)	lowers	positively
(4)	lowers	negatively

Q35-2 In C4 plants, which cell is likely to be responsible for the nitrate-to-ammonium and ammonium-to-glutamate processes of nitrogen assimilation? 102 (2 point)

在 C4 植物中，哪一種細胞可能會是負責氮素同化作用中的硝酸鹽-銨鹽以及銨鹽-麩胺酸鹽之過程？

	nitrate-to-ammonium 硝酸鹽-銨鹽	ammonium-to-glutamate 銨鹽-麩胺酸鹽
(1)	mesophyll cell 葉肉細胞	mesophyll cell
(2)	mesophyll cell	bundle sheath cell 束鞘細胞
(3)	mesophyll cell	cannot determine from the data provided 無法從數據判斷
(4)	bundle sheath cell	mesophyll cell
(5)	bundle sheath cell	bundle sheath cell
(6)	bundle sheath cell	cannot determine from the data provided
(7)	cannot determine from the data provided	mesophyll cell
(8)	cannot determine from the data provided	bundle sheath cell
(9)	cannot determine from the data provided	cannot determine from the data provided

Evolution

演化學

Q36

In a hypothetical organism, a male is known to transmit about 40 *de novo* mutations to his offspring when he mates with a female at the age of 20. In addition, the number of mutations in the germline cells of a male for each year is known to be about two. In this condition, **what is the expected number of deleterious mutations an offspring receives from a 20-year-old and a 40-year-old father, respectively?** Note that the genome size, the number of genes, the average length of a gene, and the probability that a mutation in a gene is deleterious are 1 Gbp, 10,000, 1 kbp, and 70%, respectively. Also note that all deleterious mutations are assumed to remain in the offspring genomes.

假設有一種生物，當 20 歲的雄性和雌性交配後，會將其 40 種新生突變傳給子代。此外，雄性每年形成的生殖細胞大約具有 2 種突變。在此情況下，**子代從 20 歲父親和 40 歲父親得到有害突變的預期數值分別為何？**注意：基因體大小為 1 Gbp、基因數目為 10,000、基因的平均長度為 1 kbp、以及在基因中發生有害突變的機率為 70%。此外，假設所有的有害突變都會留在子代基因體中。

Age 20: 0. 103 104 (2 points)

Age 40: 0. 105 106 (2 points)

Evolution
演化學

Q37
During the evolutionary history of vertebrates, they experienced several instances of whole-genome duplications that are believed to facilitate genome diversification and dynamic evolution.
脊椎動物的演化史中，牠們歷經多次的全基因體複製，其被認為會促使基因體分歧和活躍多變的演化。

A. Figure 1 shows the phylogenetic tree of broad range of vertebrates and lancelet (ancestor of vertebrates) with the timing of whole-genome duplication (black arrowheads). The lancelet possesses one Hox gene cluster in the genome.
圖 1 顯示大多數脊椎動物和文昌魚(脊椎動物的祖先)的親緣關係樹，並標出全基因體複製的時間(黑色箭頭)。文昌魚基因體具有 1 個 Hox 基因群。

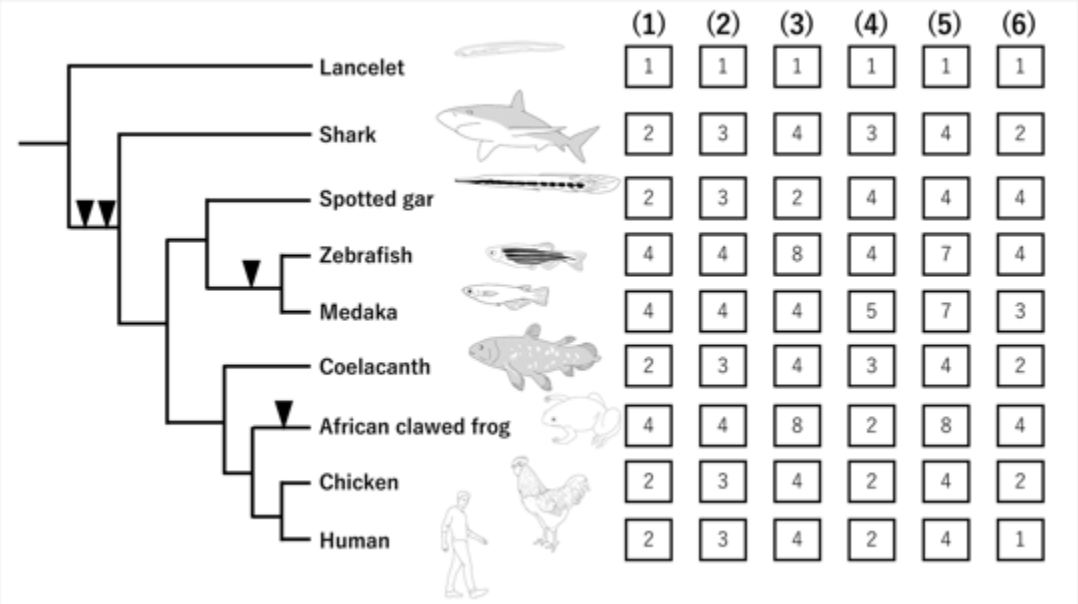


Figure 1. (left) The phylogenetic tree of a broad range of vertebrates and lancelet (an ancestor of vertebrates). (right) The answer options for the number of Hox gene clusters in each species from (1) to (6).
圖 1 (左側) 大多數脊椎動物和文昌魚的親緣關係樹；(右側)每個物種所具有 Hox 基因群的數目，(1) to (6)為答案選項。

Choose the appropriate combination of the numbers of Hox gene clusters (observed) in vertebrates from (1) to (6). It is noteworthy that Hox gene clusters are rarely lost during evolution. 107 (1 point)
從(1) to (6)選出脊椎動物具有 Hox 基因群數目的適當組合。注意：演化期間，Hox 基因群不易喪失。

B. In the phylogenetic tree of species X, Y, and Z, whole-genome duplication occurred two times, which is indicated by black arrowheads (Figure 2 left). As a result, each of the species X, Y, and Z possess X1, X2, Y1, Y2, Z1, and Z2 genes.
X, Y, and Z 物種的親緣關係樹中，全基因體複製發生過 2 次，在圖中以黑色箭頭表示(圖 2 左側)。結果，每個 X, Y, and Z 物種分別具有 X1, X2, Y1, Y2, Z1, and Z2 基因。

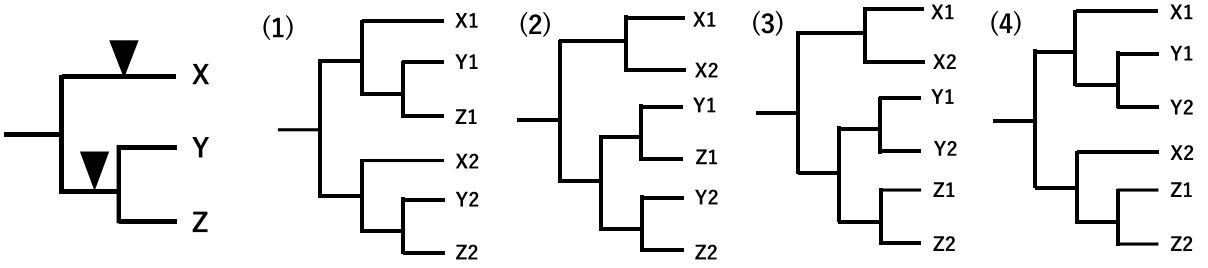


Figure 2 (left) Phylogenetic tree of species X, Y, and Z. (right) The answer options from (1) to (4) for the phylogenetic trees of genes X1 to Z2 of species X, Y, and Z.
圖 2 (左側) X, Y, and Z 物種的親緣關係樹；(右側) 答案選項(1) to (4)為具有 X1 to Z2 基因之 X, Y, and Z 物種的親緣關係樹。

Choose the appropriate phylogenetic tree of these genes (X1 to Z2) from (1) to (4). Enough time has passed between gene duplication and the subsequent speciation. 108 (1 point)
從這些基因(X1 to Z2) 的親緣關係樹(選項(1) to (4))中，選出適當選項。基因複製之後有很充足的時間發生後續的種化。

Evolution
演化學

Q38
Zuckerkandl and Pauling proposed the molecular clock hypothesis, in which amino acid differences in a protein accumulate at a uniform rate among species. The concept was applied to estimate the divergence time between species of various organisms. In addition, rate of the amino acid substitution was revealed to vary among proteins because of the difference in functional importance. Here, we focus on two proteins X and Y. Their lengths (X: 400 a.a., Y: 600 a.a.) and the substitution rates (X: 0.625×10^{-9}, Y: 1.25×10^{-9} substitution/site/year) are both different.

Zuckerkandl and Pauling 提出了一個分子鐘的假說，在一個蛋白質上的胺基酸差異，在不同物種之間是以固定的速率在累積。此概念可用來估計不同物種的分化時間。此外由於不同蛋白質功能的重要性差異，所以不同蛋白質的胺基酸的替換速率不同。在此，我們針對兩種蛋白質 X and Y。它們的長度(X: 400 a.a., Y: 600 a.a.)及替換速率(X: 0.625×10^{-9}, Y: 1.25×10^{-9} substitution/site/year)都是不同的。

A. In each of the proteins X and Y, how many substitutions were expected to be accumulated at a maximum between human and mouse, which was diverged 80 million years ago (MYA).
在每一蛋白質 X and Y，我們預期人與老鼠間，在 8 千萬年分化後至今，累積到最大的替換數為何？

Choose the right choice. 109 (1 point)選擇正確答案
(1) X: 25, Y: 40 (2) X: 40, Y: 100 (3) X: 40, Y: 120 (4) X: 10, Y: 40

B. In Protein X, 6 amino acid substitutions were observed between human and a mammal species. **Choose the right choice for the divergence time between them.** 110 (1 point)
在蛋白質 X，觀察到人與某種的哺乳動物間有 6 個胺基酸的替換。請選擇此二物種正確的分化時間
(1) 3 MYA (2) 6 MYA (3) 9 MYA (4) 12 MYA

C. The rate of amino-acid substitution also varies in the different domains of particular proteins in case that the functional importance is different among domains. Human insulin is a peptide hormone, which is first synthesized as a single polypeptide called preproinsulin (110 a.a.). Preproinsulin subsequently undergoes maturation into active insulin composed of A-B domain (51 a.a.), by releasing predomain (24 a.a.) and C domain (31 a.a.). We can expect that the functional importance varies among these domains.
胺基酸的替換速率，在某些蛋白質中不同的結構區(domains)也會因其功能重要性的不同而產生差異。人類胰島素是肽類激素最先是由單股多肽合成稱為前胰島素原(preproinsulin (110 a.a.))。之後前胰島素原進行修飾成熟，變成有活性的的胰島素包含 A-B 結構區 (51 a.a.)，成熟過程中釋出前結構區(24 a.a.)及 C 結構區 (31 a.a.)我們可以預期，功能重要性在這些結構區是不同的。

Choose the most appropriate choice for the relative values of the substitution rates of a. pre-domain, b. A-B domain, and c. C-domain. 111 (1 point)
從 a. 前結構區(pre-domain)、b. A-B 結構區(domain)和 c. C-結構區(domain)中，選出最適合的替換率相對值。
(1) a < b < c
(2) b < c < a
(3) c < b < a
(4) a < c < b

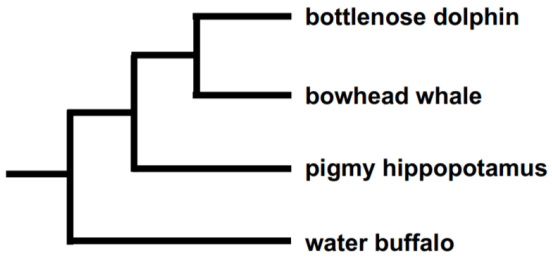
Evolution

演化學

Q39

There is a laboratory storing extracted DNA of diverse mammal species. One day, a laboratory staff investigated stored DNA tubes and found three tubes lacking labels. He also found three labels removed from tubes in the same shelf where the three label-less tubes were stored. These three labels are: “bowhead whale”, “pigmy hippopotamus” and “water buffalo”. There was one more tube stored in the same shelf with a label “bottlenose dolphin”. Here, he sequenced a specific genomic region from the DNA of these three label-less tubes (#2, #3, #4) and the bottlenose dolphin (#1). The phylogenetic relationship of the four species and sequence alignment are shown below. It has been assumed that this genomic region has been evolved under a constant evolutionary rate among cetartiodactyls.

有一個實驗室儲存了由不同哺乳動物萃取的 DNA，有一天實驗室人員檢視這些儲存 DNA 的試管，發現其中有 3 個試管沒有標籤，同時也在放試管架找到 3 個標籤分別貼的是弓頭鯨，侏儒河馬及水牛，在同一置放試管架，另有一試管貼了瓶鼻海豚的標籤。他將這三管沒有標籤的樣本(#2, #3, #4)、以及瓶鼻海豚的樣本(#1)，皆挑選特定基因組區域進行 DNA 定序，並將所得的序列比對結果與 4 個物種的親緣關係呈現如下。假設前提為鯨偶蹄類的此段基因體分析區域的演化速率是穩定的。



Tube #1 bottlenose dolphin	T A A A T A T C G C A T T T A G T T G C C
Tube #2	A T A A T T T G G C A A A T T C A T G T G
Tube #3	T A A A T A T C C C A T A T A G T A G C C
Tube #4	T A T A T T T C G C A T A A T G T T G G C

	Tube #1	Tube #2	Tube #3	Tube #4
(1)	bottlenose dolphin	bowhead whale	pigmy hippopotamus	water buffalo
(2)	bottlenose dolphin	bowhead whale	water buffalo	pigmy hippopotamus
(3)	bottlenose dolphin	pigmy hippopotamus	bowhead whale	water buffalo
(4)	bottlenose dolphin	pigmy hippopotamus	water buffalo	bowhead whale
(5)	bottlenose dolphin	water buffalo	bowhead whale	pigmy hippopotamus
(6)	bottlenose dolphin	water buffalo	pigmy hippopotamus	bowhead whale

Based on the result above, indicate in the answer sheet which is the most likely combination of tubes and labels. 112 (2 points)

根據上述的分析結果，在答案紙上指出何者最有可能是試管與標籤的組合。

Evolution
演化學

Q40
It is well-established that photosynthetic eukaryotes (i.e., algae and plants) acquired plastids through the primary symbiotic uptake of a cyanobacterium. Plastids possess two membranes. Furthermore, it is believed that the ancestors of chlorarachniophytes, which had no plastids, acquired their plastids through the secondary symbiotic uptake of a green alga. The plastids of chlorarachniophytes are bound by four membranes (Figure 1). From which organism is each of the membranes derived?
行光合作用的真核生物（如藻類與植物）的質粒體是由透過初級共生的方式攝入藍細菌而得，這是已經確認的事實。故此質粒體具有兩層膜。並且，一般相信某群藻類 chlorarachniophytes 的祖先原先沒有質粒體，是經由次級共生攝入了綠藻才得到了質粒體。故 chlorarachniophytes 的質粒體被 4 層膜包覆 (Figure 1)。請問每一層膜來自何種生物？

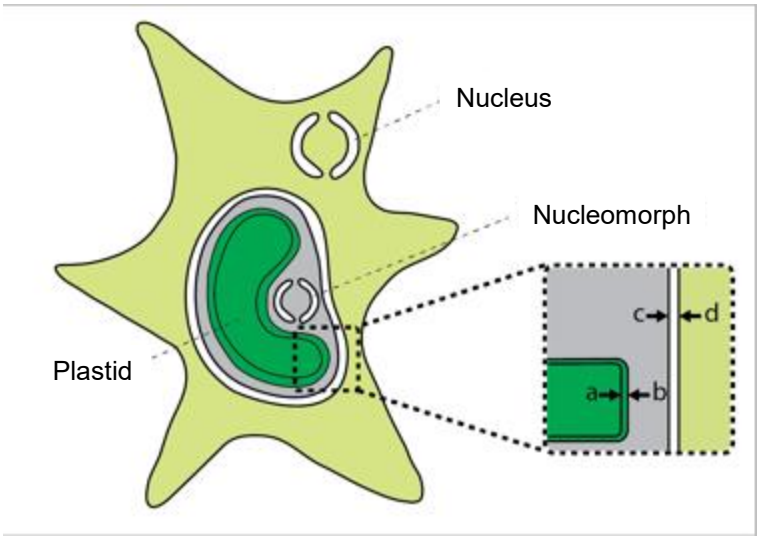


Figure 1. Schematic illustration of the ultrastructure of chlorarachniophytes. The box area is magnified to show that the plastid is bound by four membranes.
圖 1.chlorarachniophytes 的微細的構造圖示。方塊區為質粒體被 4 層膜包覆的放大圖

Choose the most appropriate combination in the following. 113 (2 points)
選擇下列何者為最適組合:

(1) (a) cyanobacterium; (b) green alga; (c) ancestor of chlorarachniophytes; (d) ancestor of chlorarachniophytes.
(a)藍細菌 (b) 綠藻 (c) chlorarachniophytes 的祖先 (d) chlorarachniophytes 的祖先

(2) (a) cyanobacterium; (b) green alga; (c) green alga; (d) ancestor of chlorarachniophytes.
(a)藍細菌 (b) 綠藻 (c) 綠藻 (d) chlorarachniophytes 的祖先

(3) (a) cyanobacterium; (b) cyanobacterium; (c) green alga; (d) ancestor of chlorarachniophytes.
(a)藍細菌 (b) 藍細菌 (c) 綠藻 (d) chlorarachniophyte 的祖先

(4) (a) cyanobacterium; (b) cyanobacterium; (c) green alga; (d) green alga.
(a)藍細菌 (b) 藍細菌 (c) 綠藻 (d) 綠藻

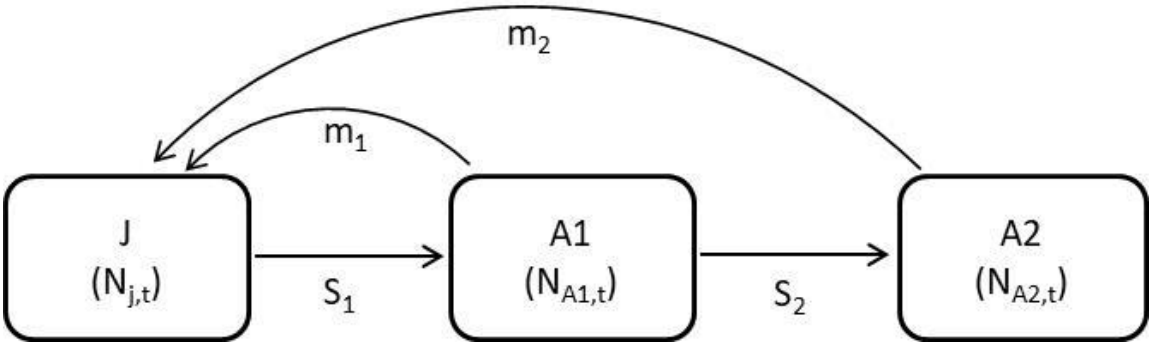
(5) (a) cyanobacterium; (b) cyanobacterium; (c) ancestor of chlorarachniophytes; (d) ancestor of chlorarachniophytes.
(a)藍細菌 (b) 藍細菌 (c) chlorarachniophytes 的祖先 (d) chlorarachniophytes 的祖先

Ecology
生態學

Q41

The population dynamics are principally determined by birth and death rates. The diagram below shows the life cycle of an animal species with three age structures, namely juvenile (J), adult 1 (A1), and adult 2 (A2). The population size (females only) at each stage in a given year (t) is shown in parentheses. S_1 and S_2 denote the survival rates between two successive stages, and m_1 and m_2 show the numbers of juveniles produced by an adult individual at the two stages. All individuals that have survived enter the next stage the following year, and mothers give birth to juveniles immediately after entering the next stage. For instance, the number of juveniles at year 1 ($N_{J,1}$) is the total number of offspring produced by adult 1 ($m_1 \times N_{A1,1}$) and adult 2 ($m_2 \times N_{A2,1}$). All individuals in the adult 2 group die the following year.

族群動態主要取決於出生及死亡率。下圖為一種動物生活史以 3 種年齡層表示，幼體(J)、成體 1(A1)及成體 2(A2)。括弧中顯示在任一年族群中，每一年齡層的數量(以雌性個體數表示)。S_1 和 S_2 表示在二個相連的年齡層之間的存活率，m_1 和 m_2 則分別表示兩個不同成體年齡層中，每個成體所產生的幼體數。假設所有可以存活至第二年的個體，進入下一個年齡層後，可立即產生後代。例如：幼體 1 在第 1 年的數目($N_{J,1}$)是成體 1 ($m_1 \times N_{A1,1}$)與成體 2($m_2 \times N_{A2,1}$)所產生的子代數目總和。所有個體在成體 2 階段之後即死亡。



Q41-1 Given the following demographic parameters and initial population size (year = 0), what will be the number of individuals at each stage class two years later? Note that population size here represents females only.

根據下列所提供族群學的各種變項及初始族群（年 = 0）大小，兩年後，每個年齡層的個體數量為何？注意此處所提到的族群個體數皆只考量雌性。

S_1=0.2, S_2=0.5, m_1=3, m_2=2, $N_{J,0}$=100, $N_{A1,0}$=20, $N_{A2,0}$=20

Choose the appropriate value for each of the following boxes. (2 points if 2 digits are correct)

請將適當的數值填入以下的格子中。(2 分，二格中數字皆正確者才得分)

$N_{j,2}$= [114] [115] $N_{A1,2}$= [116] [117] $N_{A2,2}$= [118] [119]

Q41-2 The population with the above parameters will go extinct in the near future. To prevent extinction, at least one parameter value must be increased. When other parameters are held constant, m_1 should be increased, such that $m_1 \geq$ [120]. **Choose the appropriate value for the box.** (1 point)

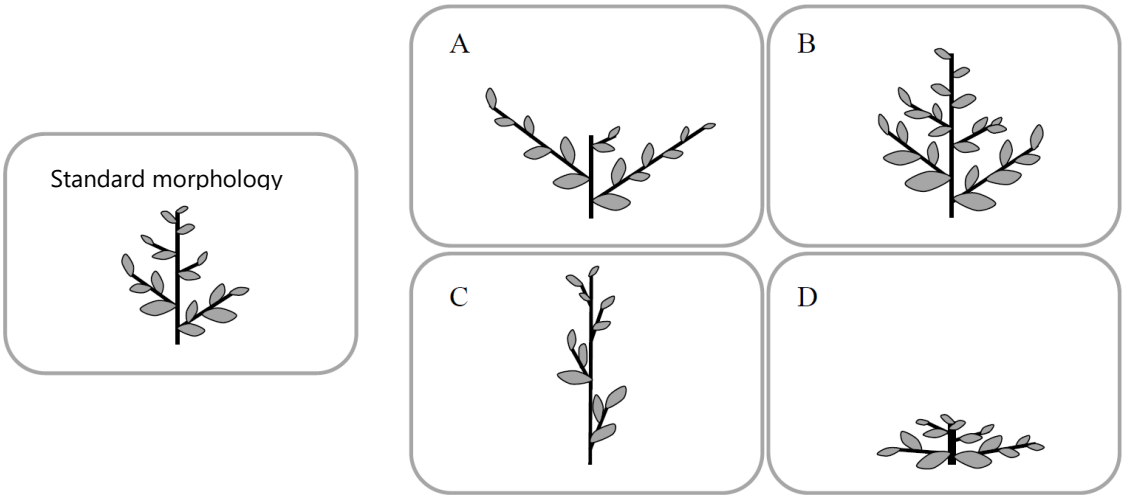
具有上述變項值的族群在不久的將來就會滅絕。為避免滅絕，其中至少一個變項的值必須增加。當其他變項維持不變，m_1 需要增加，其值至少 $m_1 \geq$ [120] **.選擇適合的數值填入**(1 分)

Ecology
生態學

Q42

Plants show morphological plasticity and can change their morphology in response to different environmental conditions. The four figures below (A to D) show simplified diagrams of a plant's typical response to environmental conditions.

植物顯示出形態上的可塑性，能改變其型態以因應不同的環境。下圖 A~D 顯示植物因應不同環境狀況的簡單圖示反應。



Match the following statements (a to d) with the corresponding diagrams (A to D) shown above and choose the appropriate number from the table below. 121 (2 points)

將 a~d 的敘述與上圖 A~D 的關係配對，下表中何者的配對是正確的？

a. Response to soil fertilization 對土壤施肥的反應

b. Response to apical damage 對頂芽缺損的反應

c. Response to shade condition 對遮蔭的反應

d. Response to trampling pressure 對踐踏的反應

	A	B	C	D
(1)	a	d	c	b
(2)	a	c	d	b
(3)	b	a	c	d
(4)	b	d	c	a
(5)	c	a	d	b
(6)	c	a	b	d

Ecology
生態學

Q43
The table below presents data on the reproductive success of four different genotypes, A to D in a Hymenopteran insect. The sex determination of hymenopteran insects (bees and wasps) is haplodiploidy: males develop from unfertilized eggs and are therefore haploid, and females develop from normally fertilized eggs and are diploid. If a female mates with only one male, any two of her daughters will share, on average, 3/4 of their genes.
下表顯示出膜翅目昆蟲四種不同的基因型，其繁殖成功的數據。膜翅目昆蟲(蜂及胡蜂)其個體性別是由染色體單或雙套來決定。雄性的個體是由未受精卵發育而成，為單套染色體，雌性是由受精卵發育而成，為雙套染色體。假設一隻雌性與一隻雄性交配，則其子代中任兩個女兒平均有 3/4 的基因是相同的。(Number of their own offspring 自己的子代數目、Nunber of siblings 手足(姐妹)數目、 Average number of offsprings produced by each sibling 平均每個手足(姐妹)所產生的子代數目)

Females	Number of their own offspring	Number of siblings	Average number of offspring produced by each sibling
Genotype A	12	3	7
Genotype B	2	8	12
Genotype C	8	4	6
Genotype D	9	6	5

Q43-1 Provide the direct fitness of genotype A, assuming that all offspring are females and females with different genotypes do not compete. 122 (1 point)
假設所有的子代皆為雌性而且具有不同基因型的雌性個體並不相互競爭，寫出基因型 A 的直接適存度？

Q43-2 Rank genotypes A to D in descending order of inclusive fitness assuming that all offspring are females. Choose the number from the table below. 123 (1 point)
假設所有的子代皆為雌性，將 A~D 的整體適存度由高到低排序，由下表中選擇正確答案。

(1)	A>B>D>C
(2)	A>D>B>C
(3)	B>A>D>C
(4)	B>D>A>C
(5)	C>A>D>C
(6)	C>D>A>C

Ecology
生態學

Q44
The Figure 1 below shows a simplified food web in temperate forests. Spiders living on shrubs and trees are generalist predators that consume herbivores and detritivores, which belong, respectively, to grazing and detrital food webs. Detrital insects spend their larval period in soil, but move to aboveground as winged adults, becoming potential prey for spiders. Passerine birds are also generalist predators that consume herbivores, detritivores, and spiders. Spiders and passerine birds therefore integrate two pathways from grazing and detrital food webs aboveground.
下圖 1 顯示一個溫帶森林中的簡單食物網。生活在灌叢及樹上的蜘蛛屬於一般性掠食者，捕食草食者以及食碎屑者，此兩者分屬於啃食食物網及碎屑食物網。碎屑食物網中的昆蟲其幼年期生活於土壤中，但是成體長翅膀後便移至地表生活，成為蜘蛛的可能獵捕對象。雀鳥也屬於一般掠食者，會捕食草食者與食碎屑者，以及蜘蛛。因此，蜘蛛與雀鳥的存在，整合了啃食食物網與地表的碎屑食物網。
(圖中 Passerine bird 雀鳥、Herbivore 草食者、 Spider 蜘蛛、 Detriticore(adult)食碎屑者(成體)、Detritivore(larvae)食碎屑者(幼體))。

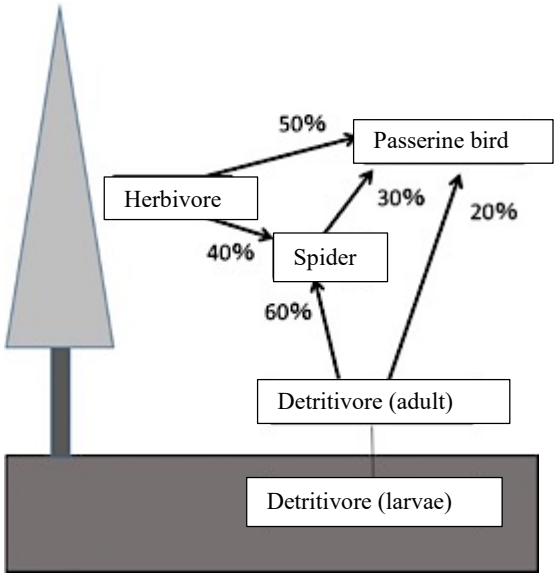


Figure 1

Q44-1 The prey biomass of spiders consists of 40% herbivores and 60% detritivores, while that of passerine birds consists of 50% herbivores, 30% spiders, and 20% detritivores. What is the contribution of the pathway from detrital food web to passerine birds, as expressed by % biomass of detritivores relative to the biomass of herbivores and detritivores combined? Note that the conversion efficiency is assumed to be 10% for any pairs of adjacent trophic levels. **Answer with a 2-digit integer by cutting off numbers after the decimal points.** [124] [125] (2 points if 2 digits are correct)
蜘蛛的獵物的生物量包含了 40%的草食者及 60%的食碎屑者，而雀鳥獵物的生物量有 50%是草食者、30%蜘蛛與 20%的食碎屑者。碎屑食物網貢獻給雀鳥的生物量為何？貢獻度的計算是以食碎屑者相對於食碎屑者加上草食者總和的百分比%。注意：假設在每一營養階層之間的轉換效率為 10%。**答案填入二位整數，小數點都刪除**。(2 分，二格中數字皆正確者才得分)

Q44-2 A huge amount of radionuclides were released into the environment from the Fukushima Daiichi Nuclear Power Plant accident after the earthquake and subsequent tsunami of March 2011. Cesium 137 (^{137}Cs) is the most worrying radionuclide, which spread from the atmosphere to forests. ^{137}Cs was initially retained on plant surfaces and then entered into soil through rain and defoliation. ^{137}Cs is bound to the organic materials of soil by ion-exchange adsorption, or bound strongly to mica minerals in soil, which makes it difficult for vascular plants to absorb cesium from roots several years later. However, fungi absorb and accumulate a large amount of ^{137}Cs, which is consumed by detritivores. The Figure 2 below presents a schematic representation of how ^{137}Cs concentration changes over the years for three types of organisms after the initial cesium fallout.

在 2011 年三月，由於地震與海嘯造成福島的核能廠爆炸意外，釋放了大量的放射性物質。其中銫 137(^{137}Cs)是最令人擔心的一種放射性污染物質。因為它可以由空氣散佈至森林中。銫 137 最早留在植物表面後，藉著雨水與落葉進入土壤中，銫 137 會與土壤中的有機質藉著離子交換結合，或是與土壤中的雲母更緊密的結合，使得幾年後維管束植物的根由土壤中吸收銫 137 變得非常困難。不過，真菌會吸收並累積大量的銫 137，但隨後真菌會被碎屑食物者所食。下圖 2 為三種不同型態的生物，在接收到銫 137 污染後，幾年來銫 137 的濃度變化。

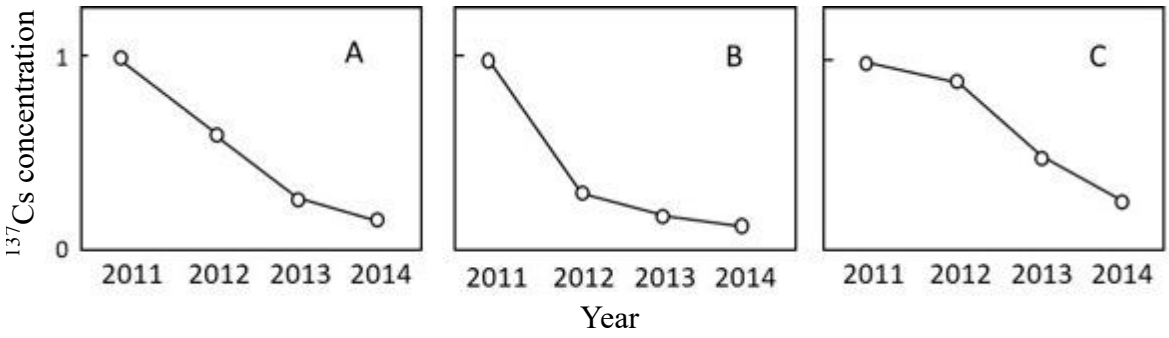


Figure 2 Changes in ^{137}Cs concentration over several years. The concentration represents a relative value, with the value in 2011 being 1.

圖 2 銫 137 在數年間的濃度變化。濃度以相對數值表現，以 2011 時的值定為 1。

Given the above information, organisms in different trophic positions in forest food webs are expected to show different temporal changes in cesium concentrations. The above graphs (A,B,C) represent the responses of three organisms. **Choose the most appropriate combination of organisms from below.** Note that the data were gathered in autumn, and bioaccumulation through trophic levels does not occur. 126 (1 point)

根據以上資料，三種位於森林食物網中的不同的營養階層的生物，其體內銫的濃度預期會依時間而有變化。上圖 A，B，C 分別代表三類生物的反應。由下表中選出最適合的三種生物的排序組合。注意：此資料是於秋天收集獲得，由營養階層而來的生物累積現象是不存在的。

	A	B	C
(1)	Grasshopper	Spider	Earthworm
(2)	Grasshopper	Earthworm	Spider
(3)	Spider	Earthworm	Grasshopper
(4)	Spider	Grasshopper	Earthworm
(5)	Earthworm	Grasshopper	Spider
(6)	Earthworm	Spider	Grasshopper

Ecology
生態學

Q45
Primary succession can begin in a virtually lifeless area, characterized by early-seral plant species followed by the replacement of these species by other late-seral plant species. An example of this process can be seen in Alaska, where glaciers have retreated as a result of climatic warming during the Holocene. Through this succession, key soil properties such as nitrogen (N) and phosphorus (P) content also change. Nitrogen enters into the soil through the biological pathway of nitrogen fixation, the conversion of N_2 to forms that can be used to synthesize organic nitrogen compounds. Phosphorus is added into the soil through the weathering of rocks. Plants in each successional stage use these nutrients for growth and survival. After the death of plants, the elements stored in the plants can reenter into the soil through the activities of microorganisms, which decompose and mineralize detritus. Soil nutrients can be absorbed and utilized by plants again over time, but some are lost through leaching out from ecosystems.
初級消長由一個無生命的區域開始，其特質為由早期消長植物種類逐漸被晚期消長植物種類取代。上述的歷程可以由阿拉斯加的例子來見證。受到全新紀地球暖化的影響，造成冰河消退。在此消長的過程中，主要關鍵的土壤性質如氮、磷的含量隨之改變。氮藉由生物固氮的管道進入土壤，轉化成可以被合成含氮有機物的形式。磷是由岩石的風化進入土壤。植物在不同的消長階段，會利用這些營養鹽來存活與生長。在植物死後，藉由微生物的活動，如分解與礦化有機碎片，這些儲存於植物體內的元素會再度進入土壤中。隨著時間的變化，土壤中的營養鹽可以再度被植物吸收與利用，但某些部分會因從生態系統中散佚而消失。

Choose a panel from (1) to (4) that represents temporal changes in nutrient accumulation in soil through primary succession after glacial retreat in Alaska. The climax stage is boreal forests. In the panels, N and P represent the total amount. 127 (2 points)
由下圖(1)~(4)中，選擇最符合阿拉斯加冰河消退後的初級消長過程中，其土壤中營養鹽的累積變化圖。此處極相為北方森林。在這些圖中，N 與 P 分別代表該元素的總量。