Theory

Q1-1

English (Official)

Morning 1st

Q1-2

English (Official)

Cell Biology

Q1

The nematode *C. elegans* develops as either a male having only one sex chromosome (XO) or a hermaphrodite with two sex chromosomes (XX). When maintained in groups containing both sexes, hermaphrodites live significantly longer than males. Two signalling pathways, the IGF-1 signalling and the sex determination pathways play pivotal roles in the control of *C. elegans* aging.

DAF-2 and DAF-16 are elements of the IGF-1 signalling pathway. Loss-of-function mutations in their genes were introduced, and the lifespan of generated transgenic animals of the two sexes were measured (Figure 1)

In all graphs, NS = not significant difference; *** = significant difference.

Q1-3

English (Official)

Fig.1. Axis = Mean lifespan (days). WT = Wild-type.

To test whether the nematode sex-determination cascade is involved in the sex-specific regulation of aging, researchers modified the activity of two elements of this pathway, TRA-1 and TRA-3. The mutations of transgenic hermaphrodites were as follows in Figure 2.

- MUT1 - TRA-1-/-
- MUT2 - TRA-1 low activity, with some function
- MUT3 - TRA-1 hyperactive function
- MUT4 - TRA-3 loss of function

- MUT5 - TRA-1 hyperactive function AND TRA-3 loss of function

Fig.2. Axis = Mean lifespan (days). WT = Wild-type.

TRA-1 was identified as a transcription factor, and to assess the functionality of a potential TRA-1-binding site in the DNA at the DAF-16 gene. The expression of DAF-16 was therefore measured in the various TRA-1 mutants (Figure 3).

Fig.3. Axis = Relative DAF-16 expression level.

Q1-6

English (Official)

Q.1.1 Based on the information above, create a model of protein interactions that affect lifespan (LS). Use the options below (A-D) to fill in the boxes in the flowchart and indicate in the circles by the arrows whether the interaction is stimulatory (put **+**) or inhibitory (put **-**). 0.0 pt

Options:
A. TRA-1
B. TRA-3
C. DAF-2
D. DAF-16

Q2

The ATP content of an average muscle fibre at rest is very low. Under short, high energy demand exercise (e.g. a 100 m sprint), the initially very low ATP levels in the muscle fibres are buffered by phosphocreatine (PCr, Figure 1).

Fig.1

We can measure levels of phosphocreatine and ATP in a working tissue using 31P NMR spectroscopy, through the height of the corresponding NMR peak. Figure 2 shows the NMR-spectroscopy results of muscle intracellular fluid from a subject who had done 2 minutes of vigorous exercise. A: before exercise, B: first minute of exercise, C: last minute of exercise, D: after exercise; I, II and III are peaks that represent the three phosphate groups in ATP molecules, IV: PCr, V: Pi, VI: phospho-monoesters.

Fig.2

Immediately when the actin-myosin interaction starts producing ADP, the activity of the enzyme adenylate kinase, which catalyses the near-equilibrium reaction 2 ADP ↔ ATP + AMP becomes significant. Besides the generation of the negligible amount of available ATP, the reaction is essential because both ADP and AMP can allosterically upregulate glycolytic enzymes – and therefore prepare the muscle for longer exercise.

Based on the information above, indicate with an X if each of the following statements is true (T) or false (F).

Q.2.1	Hydrolysis of the high energy bond of PCr can be used directly as energy source of enzymes.	0.0 pt
Q.2.2	The relatively constant ATP concentrations shown on the NMR results are due to the buffering effect of PCr.	0.0 pt
Q.2.3	The phosphocreatine system is the main energy source in marathon runners.	0.0 pt
Q.2.4	AMP and ADP levels are similarly sensitive indicators of energy status (as shown by ATP concentration).	0.0 pt

Q3

Abscisic acid (ABA)-and salicylic acid (SA) are involved in stomatal closure. It's known that the Ca2+-independent protein kinase OST1 and Ca2+-dependent protein kinases (CPK3 and CPK6) are key for abscisic acid induced activation of an anion channel SLAC1 and stomatal closure. SLAC1 has two phosphorylation sites: S59 and S120 are both serines. Coexpression of the CPKs or OST1 together with SLAC1 genes in an observed cell leads to the following result:

Table 1. Col 1 = Expression of . Col 2 = Phosphorylation of . Col 3 = Current. An = Anionic. '+' = expressed; '–' = not expressed; '@' = not happens; '***' = happens

Q1-10

English (Official)

The effect of salicylic acid (SA) on stomata closure of wild type (WT) *Arabidopsis thaliana* was determined in a standardized way. Salicylic acid was added to a leaf fragments and stomata opening was measured. The stomatal assay was also carried out with some KO-mutant lines. The results are shown below. (*– significant change, ns – non-significant change)

Fig.1. Axis = Stomatal aperture (μm). WT = Wild-type.

Fig.2. Axis = Stomatal aperture (μm). WT = Wild-type.

For the following questions indicate your answer with an **X.**

A. CPK3

B. CPK6

C. OST1

D. either CPK3 or CPK6

E. either CPK3 or OST1

F. either CPK6 or OST1

G. CPK3 and CPK6

H. CPK3 and OST1 I. CPK6 and OST1

Q.3.1 Which of the kinase(s) (A-I) are required for the phosphorylation of the two sites in SALC1? 0.0 pt

Q.3.1.1. S59	
Q.3.1.2. S120	

Q.3.2 Which of the kinase(s) (A-I) is required for salicylic acid dependent stomata closure? 0.0 pt

Q.3.3 Which site or sites need to be phosphorylated to open the SALC1 anion channel? 0.0 pt

A. S59
B. S120
C. S59 or S120
D. S59 and S120

Q4

Each year, the WHO forecasts which H and N antigens the dominant flu strain is likely to carry to make vaccines. In 2017, an outbreak of strains H1N1 and H3N2 was forecast for the following year. However, in 2018, H1N2 actually became dominant

Three people (1-3) are vaccinated, and their antibodies are used in immunodiffusion assays. Virus and antibodies are loaded into neighbouring wells of an agar plate according to the table below. They diffuse towards each other and precipitate in a visible band if they crosslink.

Antibody	Well A	Well B
1	H1N1	H1N2
2	H1N1	H3N2
3	H1N1	H1N2

The results of the experiment are presented in Figure 1.

Fig.1

Indicate with an X if each the following statements are true (T) or false (F).

Q.4.1	The developed vaccine provided protection for antigens predicted by the WHO.	0.0 pt

Q.4.2	Antibody 1 and 2 can from the same subject.	0.0 pt

Q.4.3 Patient 2 is protected against the new H1N2 influenza outbreak. 0.0 pt

Q.4.4 Based on the available information mark antigens the patients are definitely immunised against with an X. Mark all other boxes with O. 0.0 pt

Antibody	H1	H3	N1	N2
1				
2				
3				

Catumaxomab is a new anti-cancer antibody, unlike natural antibodies, binds two different antigens.

Indicate with an X if each the following statements are true (T) or false (F).

Q.4.5 Catumaxomab in an immunodiffusion assay with purified CD3 protein in both antigen wells will give precipitation similar to Antibody 1 in Figure 1. 0.0 pt

Q.4.6 The different specificity chains of Catumaxomab are held together by covalent bonds. 0.0 pt

Q5

In 1963, a series of experiments were performed by John Cairns and peers to test the mechanism of DNA replication. An experimental organism with circular dsDNA chromosomes was grown for several generations in a medium containing radiolabelled [^3H] thymidine. The organism used these bases to replicate their circular dsDNA chromosomes and therefore the subsequently synthesised DNA became radiolabelled. Samples were rapidly frozen during DNA synthesis and then observed so radiolabelled bases appeared as a line of dark beads on a string in SEM photographs. They found that each circular chromosome contains a single “eye” during replication, resembling the Greek letter θ (theta structures, Figure 1).

Fig.1. Autoradiogram and its interpretive drawing of a replicating chromosome. Legend 1 = Replication eye

In a second experiment, researchers grown the cells in a medium that contained both non-labelled and [^3H] thymidine but the latter was only present at low concentrations. Then, during the replicative period, they increased the concentration of [^3H] thymidine in the medium and immediately isolated samples to freeze and photograph. The results are shown in Figure 2.

Fig.2. Radiograph of the DNA

Indicate with an X if each the following statements are true (T) or false (F).

Q.5.1	The experiments show that there is a single replication origin in this organism.	0.0 pt
Q.5.2	The experiments suggest bidirectional replication.	0.0 pt
Q.5.3	Which of the following theories of DNA replication is consistent with the results above? Indicate with an X. A. Conservative B. Semi-conservative C. Dispersive D. None of the above	0.0 pt

Q.5.4 What can you conclude from the results on the relative abundance of thymidine? Indicate with an X. 0.0 pt

A. Thymidine is more abundant in the replication origin(s), than in other area of the DNA.

B. Thymidine is less abundant in the replication origin(s), than in other area of the DNA.

C. Thymidine is equally abundant in the replication origin(s) and in other area of the DNA.

D. Relative thymidine abundancy of the replication origin(s) cannot be inferred from these results without doubt.

Q6

During DNA replication, RNA primers are synthesised, which are then extended by DNA polymerase. On the lagging strand, DNA polymerase is then released, forming an Okazaki fragment, and the process repeats. The lagging strand was immobilised at one end to a flow cell. The other end is attached to a florescent bead. Liquid is moved across the cell to stretch the DNA and the position of the bead is measured and plotted as 'DNA length change'.

Fig.1. Axis 1 = Time (s). Axis 2 = DNA length change (kb). Legend = Primer.

Q1-18

English (Official)

Q.6.1 Indicate with an X which position on the graph (I-III) may correspond to which step of DNA replication (A-C). 0.0 pt

Q.6.2 How many base pairs long is the Okazaki fragment based on the figure (to the nearest 500bp)? 0.0 pt

Q.6.3 What is the rate of DNA synthesis? (in bp/sec) 0.0 pt

Q.6.4 1U of Taq polymerase is defined as the amount of enzyme required to incorporate 10nmol dNTP into DNA in 30 minutes under optimal conditions (72°C). In a PCR mixture (25µL) made with 1U of Taq pol, assuming unlimited template DNA and optimal conditions throughout, how long would it theoretically take for dNTPlevels to drop from a starting 400µM concentration to 200µM in minutes? 0.0 pt

Q7

You find a mutation in p53 ('the guardian of the genome') at nucleotide 42. In your sequence, it is an adenine (A), whereas it is usually guanine (G) in the wild-type, as shown in Figure 1.

Fig.1

Q.7.1 You design a test for the mutant allele using restriction enzymes. Indicate with an X which enzyme (A-D) can be used to distinguish patient samples? 0.0 pt

A. MboII
B. BglII
C. DpnI
D. HgaI

A clinician uses the appropriate enzyme to carry out restriction fragment length polymorphism analysis. Results for patient A-G are shown in Figure 2.

Fig.2

Q.7.2 Determine the genotype of the patients by marking in it with an X. The letters in the table refer to the nucleotides found at position 42. 0.0 pt

Nucleotide 42	A	B	C	D	E	F	G
GG							
AG							
AA							

Following genotyping you look at p53 transcript and protein levels as seen in Figure 3.

Fig.3. Legend 1 = RNA. Legend 2 = Protein.

Q.7.3	Indicate with an X whether the mutation affects: A. p53 transcription B. p53 translation C. Both	0.0 pt

Q.7.4	Normally, when the genome is damaged, four molecules of p53 form a complex which can then bind to DNA as a transcription factor. In an experiment a cell is heterozygous for a mutation which produces p53 that prevents DNA binding. If the amount of transcription is proportional to the level of active p53, what fraction of transcription occurs in this cell compared to normal cells?	0.0 pt

Animal Anatomy and Physiology

Q8

In an experiment, the breathing tube of the spirometer was filled with oxygen and fitted with a carbon dioxide absorber that removed all exhaled CO_2, as illustrated in Figure 1. Test subject "A" was allowed to breath from the apparatus for 4 minutes. The result of this experiment is presented in Figure 2.

Fig.1. Legend 1 = Kymograph. Legend 2 = Water level. Legend 3 = Mouthpiece. Legend 4 = Nose clip. Legend 5 = Carbon dioxide absorber. Legend 6 = Counterpoise. Legend 7 = Spirometer chamber.

Fig.2. Spirometer experiment. Axis 1 = Time (min). Axis 2 = Spirometer volume (L).

Q.8.1	What is the tidal volume of test subject “A”? (in mL)	0.0 pt
Q.8.2	What is the breathing frequency of test subject “A”? (in breaths/min)	0.0 pt
Q.8.3	What is the oxygen consumption of test subject “A”? (in mL/min)	0.0 pt
Q.8.4	In an experiment where the CO_2 absorber is removed, how would the test subject’s breathing frequency change? Indicate your answer by putting an X in the appropriate box on the answer sheet. A. Increase B. Not change C. Decrease	0.0 pt

In a different spirometry experiment, we measured the volume and speed of air during normal and forced exhalation and inhalation.

Fig.3. Axis = Volume (ml/kg).

- TLC - Total lung capacity: the volume in the lungs at maximal inflation, the sum of VC and RV.
- TV - Tidal volume: that volume of air moved into or out of the lungs during quiet breathing
- RV - Residual volume: the volume of air remaining in the lungs after a maximal exhalation
- ERV - Expiratory reserve volume: the maximal volume of air that can be exhaled from the end-expiratory position
- IRV - Inspiratory reserve volume: the maximal volume that can be inhaled from the end-inspiratory level
- VC - Vital capacity: the volume of air breathed out after the deepest inhalation.
- FRC - Functional residual capacity: the volume in the lungs at the end-expiratory position

Consider test subject "B" who had the following results:

- VC = 5,200 mL
- IRV = 3,300 mL
- FRC = 2,500 mL
- RV = 1,300 mL

Q.8.5	Calculate the tidal volume of test subject "B" and give your answer on the answer sheet in millilitres (mL).	0.0 pt

Test subject "C" was also tested. After several measurements, researchers found that her tidal volume is 500 mL and respiratory rate is 15/min when resting. During intense exercise her O_2 consumption rises leading to a 3-fold higher volume of air inhaled per minute and an increased respiratory rate of 25/min.

Q.8.6	Based on the graph above and the data provided, calculate the tidal volume of test subject “C” during exercise. Give your answer on the answer sheet in millilitres (mL).	0.0 pt

Q9

In the brainstem there is a neuronal regulation network which maintains the rhythmic breathing as it can be seen in the list below.

Pneumotaxic center (PC):

- Controls the duration of inhalation by signalling to inspiratory area
- Strong activity $\longrightarrow$ length of inspiration < 0.5 seconds
- Weak activity $\longrightarrow$ length of inspiration > 5 seconds

Apneostic center (AC):

- Promotes inhalation by stimulating the DRG
- Inhibited by pulmonary stretch receptors
- Inhibits PC

Dorsal respiratory group (DRG):

- Controls the basic rhythm by triggering respiratory impulses
- Vagal and glossopharyngeal nerves bring peripheral chemosensory information to it

Ventral respiratory group (VRG):

- Inactive during normal baseline respiration
- High DRG activity (increased need for ventilation) stimulates it
- Has neurons for both inhalation and exhalation
- Inhibits AC

Central chemosensitive area (CC):

- Stimulated by high blood pCO_2
- Excites other respiratory centres

Decide if the following treatments would result in an increase , no change or decrease in the described feature. Indicate your answer by putting an X in the appropriate box on the answer sheet.

- A. Increase
- B. No change
- C. Decrease

Q.9.1	Respiratory rate upon damage to pneumotaxic center	0.0 pt
Q.9.2	Blood pH after a stroke affecting central chemosensitive area neurons	0.0 pt
Q.9.3	Ventral respiratory group activity upon a deep inhalation	0.0 pt
Q.9.4	Central chemosensitive area neuron membrane hyperpolarisation upon voluntarily holding one's breath	0.0 pt

Q1-28

English (Official)

Q.9.5	Length of inhalation upon overstimulation of apneostic center	0.0 pt

Q10

Pressure–volume work (or PV work) occurs when the volume of a system changes. It can be calculated as the product of Δ volume and Δ pressure. The work of breathing is mainly determined by the compliance of the lungs, which is defined as:

Compliance = Δ volume (mL) /Δ pressure (cm H_2O)

Compliance itself is dependent on two main factors, (1) the elastic characteristics of the lung, and (2) the surface tension generated by the air-liquid interface at the inner alveolar surface. In 1929, von Neergaard excised the lung of a cat which he then inflated and then deflated using air and then inflated and deflated using saline solution. The results are plotted in the figure below.

Fig.1. Axis 1 = Pressure (cm H_2O). Axis 2 = Volume (ml). Legend 1 = Saline inflation. Legend 2 = Air inflation. Empty circles ◦ : inflation. Full dots • : deflation.

For the following pairs of statements (A and B), evaluate the mathematical relationship between the values. Indicate your answers using the following symbols > or < or = in the cells provided on the answer sheet.

Q.10.1	A: Work of inflating the cat lung with saline solution. B: Work of inflating the cat lung with air.	0.0 pt

Q.10.2	A: The compliance of the lung at volumes above 35 mL (upon normal air inhalation). B: The compliance of the lung at volumes below 35 mL (upon normal air inhalation).	0.0 pt

Q.10.3	A: Contribution of intrinsic elastic forces to total lung compliance. B: Contribution of surface tension to total lung compliance.	0.0 pt

Q.10.4	A: Compliance of a healthy, normally functioning lung. B: Compliance of a lung in which surfactant production is abolished by genetic mutations.	0.0 pt

Q.10.5	A: Total lung capacity in a normally functioning cat lung. B: Total lung capacity in the same cat's lung after chemical inhibition of surfactant production.	0.0 pt

Q11

The electromyogram (EMG) is a technique used to measure the collective electrical activity of active skeletal muscle fibres using electrodes placed on the skin. A human subject was prepared for a muscle electrophysiology experiment to test the conduction velocity of their motor neurons. The experimental setup and a trace of one of their measurements are illustrated below.

Fig.1. Legend 1 = Connected to amplifier and detector. Legend 2 = Stick-on electrodes. Legend 3 = Stimulator applied to notch in back of elbow. Legend 4 = To isolated stimulator

Fig.2. Axis 1 = Time (sec). Axis 2 = Force transducer (N). Axis 3 = Electromyogram (mV). *(The spike in the "Electromyogram" trace at "A" (time = 0.03 sec) is added by the computer to show when the stimulus was presented.)*

Q.11.1	Calculate the conduction velocity of the motor neuron. Assume that the initiation and transmission of signalling within the muscle cells take zero milliseconds. The distance between the stimulation electrode and the EMG electrode was 420 mm. Give your answer in m.sec-1 and round it to the nearest whole number.	0.0 pt

For the following questions, answer with the letters of the processes listed below (A-I). Note that not all

of the options are actually involved in the illustrated process. Indicate your answer by putting an X in the appropriate box on the answer sheet.

A. Ca^{2+} channel opening in the membrane of the sarcoplasmic reticulum

B. Acetylcholine released

C. Ca^{2+} binding to troponin

D. Action potential initiated in muscle fibre membrane

E. Action potential propagated along motor neuron

F. Actin-myosin cross-bridge cycling

G. Troponin blockage of myosin binding sites restored

H. Active transport of Ca^{2+} across membrane of sarcoplasmic reticulum

I. Ca^{2+} concentration increases in the muscle fibre's cytoplasm

Q.11.2 Which **2** processes happen between time points A and B?	0.0 pt
Q.11.3 What happens immediately at point B?	0.0 pt
Q.11.4 Which process accounts for the observation of the peak labelled C?	0.0 pt
Q.11.5 Which process is most likely to account for the slowness of the fall of the trace after point C?	0.0 pt

Q12

Nitric oxide (NO) plays a role in physiological regulation of the circulatory system. NO is the activator of soluble guanylyl cyclase, leading to the formation of cyclic GMP (cGMP), an important second messenger in vascular smooth muscle.

Fig.1. Legend 1 = Adrenaline. Legend 2 = Endothelial Cell. Legend 3 = Smooth Muscle Cell. Legend 4 = Sarcoplasmic Reticulum.

The contraction of vascular smooth muscle determines the diameter of a blood vessel. The relationship between vessel diameter, pressure, and flow is described by Poisseuille's law.

$$Q = \frac{\pi r^4 \Delta P}{8 \mu L} \tag{1}$$

Where:

- Q is flow in mL/min
- r is the vessel radius
- ΔP is the pressure gradient

- μ is the viscosity of the fluid in the vessel
- L is the length of the vessel

Based on the above, how would the specified characteristics be changed in the following scenarios? For the **next three questions**, decide if the result is increase, no change or decrease. Indicate your answer by putting an X in the appropriate box on the answer sheet.

A. Increase

B. No change

C. Decrease

Q.12.1	Flow in the vessel in case of fight-or-flight response in a living organism.	0.0 pt
Q.12.2	Flow in the vessel upon administration of the drug sildenafil, which inhibits cGMP specific phosphodiesterase (PDE).	0.0 pt
Q.12.3	Membrane potential of the smooth muscle cell upon adrenaline infusion into a perfused vessel preparation.	0.0 pt
Q.12.4	What fold increase of pressure results in an equal increase in flow as a 10-fold increase in radius? Provide your answer in the appropriate box on the answer sheet.	0.0 pt

Q13

The water content of the human body is about 60%. The distribution of this huge amount of fluid and their content are both important to understand the main processes of homeostasis. Figure 1 shows the amount of body fluid compartment and their ionic content.

Fig.1. Distribution of the different fluid compartments in a healthy adult. Axis 1 = Mass (kg). Axis 2 = Osmotic concentration (mOsmol/kg). Legend 1 = Intracellular fluid. Legend 2 = Interstitial fluid. Legend 3 = Blood plasma.

Inadequate supply of water and ions or the abnormal loss of these substances alter the values found in Figure 1. In Figure 2, four physiological conditions with their distinctive values are shown, in which changes occur in the mass and/or osmotic concentration of body fluids. The diagrams only show the intracellular (dark grey) and the extracellular (light grey) fluid compartments and their mass and osmotic concentration values. The areas surrounded by the dashed lines represent the normal values of the compartments shown in the previous diagram.

Fig.2. Axis 1 = Mass)kg). Axis 2 = Osmotic concentration (mOsmol/kg)

Q.13.1	Calculate the extracellular fluid/intracellular fluid mass ratio of sodium ions based on normal values. Assume, that the concentration of sodium ion in the extracellular fluid is 140 mOsm/kg and in the intracellular fluid 10 mOsm/kg. Give your answer to the nearest integer.	0.0 pt

Match the following statements describing different physiological conditions with the letters in Figure 2 (A-D). Indicate your answer by putting an X in the appropriate box (A-D) on the answer sheet.

Q.13.2	A condition typical after drinking large quantities of diluted liquid.	0.0 pt

Q.13.3	A condition typical of dehydration (loss of water).	0.0 pt

Q.13.4	A condition brought about after severe vomiting and diarrhoea.	0.0 pt

Q.13.5	A condition most likely to cause the blood pressure to increase.	0.0 pt

Q.13.6	Which of these conditions will inhibit release of vasopressin (ADH) into the blood?	0.0 pt

Q14

Insulin is a 51-amino acid protein consisting of 2 polypeptide chains linked by disulphide bonds.

Fig.1. Legend 1 = A chain. Legend 2 = B chain

In type 1 diabetes mellitus, there is no adequate insulin release due to the loss of beta-cells of the pancreas. Therefore, the only treatment is insulin injection, which is most commonly administered into the fat under the skin. Here it forms hexamers, which then dissociate to be absorbed into the blood stream.

The graph shows the plasma level of three available insulins (1-3) after subcutaneous injection:

1. Human insulin produced in *Saccharomyces cerevisiae* by recombinant DNA technology.
2. An insulin analogue in which swapping one amino acid reduces dimer and hexamer formation.
3. An insulin analogue in which amino acid changes to the A and B chains change the molecule's isoelectric point from 5.7 to a more neutral pH.

Fig.2. Axis 1 = Time. Axis 2 = Relative plasma insulin level

Q.14.1	Match the insulin types (1-3) with the plots (A-C) based on the information above. Indicate your answer by putting an X in the appropriate box on the answer sheet.	0.0 pt

Indicate with an X if each of the following statements is true (T) or false (F).

Q.14.2	Oral administration (e.g. in the form of pills) of insulin is approximately as effective as subcutaneous administration.	0.0 pt

Q.14.3	Stimulation of insulin release from pancreatic beta cells can be an alternative therapy in type 1 diabetes mellitus.	0.0 pt

Q.14.4	Immunosuppressant therapy could slow down the onset of type 1 diabetes mellitus if it is diagnosed early.	0.0 pt

Q.14.5	The long-acting, subcutaneously administered insulins (e.g. plot C) act longer because their degradation in the circulation is slower.	0.0 pt

Q15

An audiometry exam tests a subject's ability to hear sounds at different frequencies. Sound waves travel to the inner ear through the ear canal, eardrum, and the bones of the middle ear (air conduction, empty circles (○) or alternatively, through the bones around and behind the ear (bone conduction, full dots (●).

Figure 1. shows the lowest sound intensity (in dB) at a given frequency (Hz) the test subject can still perceive, where a 0 value is the population average and any positive value suggests that a higher than average intensity is required for the subject to hear the sound.

Fig.1

Q1-43

English (Official)

Q.15.1	What is the highest frequency at which bone conduction is tested? (Hz)	0.0 pt

Match the following conditions with the test results in Figure 1 (A-D). Indicate your answer by putting an X in the appropriate box on the answer sheet.

Q.15.2	Old age related reduced sensitivity to high frequency.	0.0 pt
Q.15.3	Middle ear infection impeding the movement of the auditory bones.	0.0 pt
Q.15.4	Neurological hearing damage causing overall reduction in hearing acuity.	0.0 pt
Q.15.5	Damage caused by an air horn.	0.0 pt

Q16

Fig.1. Title 1 = Day 1 Fertilization. Title 2 = Day 2 Morula formation. Title 3 = Day 5 Blastocyst formation. Title 4 = Day 7 Implantation. Title 5 = Day 9 Inner cell mass differentiation. Title 6 = Day 12 Germ disk and then primitive streak formation.

In each of the following scenarios (Q.16.1-4), decide if the chorion and the amnion are shared or separate. Indicate your answer by putting an X in the appropriate box (A-D) on the answer sheet.

Your options:

A. Both chorion and amnion are shared

B. Chorion is separate, amnion is shared

C. Chorion is shared, amnion is separate

D. Both chorion and amnion are separate

Theory

Q1-45

English (Official)

Q.16.1	Dizygotic twins	0.0 pt
Q.16.2	Monozygotic twins where splitting occurred in the morula stage	0.0 pt
Q.16.3	Monozygotic twins where splitting occurred in the inner cell mass stage	0.0 pt
Q.16.4	Monozygotic twins where splitting occurred between the formation of the germ disc and the primitive streak	0.0 pt

Q1-46

English (Official)

Plant Anatomy and Physiology

Q17

Nutrient availability is thought to be one of the most important conditions influencing stem structure. It is believed to induce changes in the structure of aerenchyma (a spongy tissue of air channels) and the distribution of lacunae (airspaces in aerenchyma tissue). To investigate this, biomechanical parameters of stems of two aquatic plant species (M. s. = M. scorpoides and M. a. = M. aquaticus) were measured under low (↓ in table) or high (↑ in table) nutrient conditions. Data were statistically evaluated and the mathematical relationships between these parameters determined as shown in Table1. (ns = non-significant, more stars show greater significant difference).

Q1-47

English (Official)

Table 1. M.s. ↓ = M. scorpoides in low nutrient conditions. M.s. ↑ = M. scorpoides in high nutrient conditions. Sign. = Statistical significance. M.a. ↓ =M. aquaticus in low nutrient conditions. M.a. ↑ = M. aquaticus in high nutrient conditions. BF = Breaking force.

$$I(M.s.) = \frac{\pi R^4}{4} \tag{2}$$

$$I(M.a.) = \frac{l^4}{12} \tag{3}$$

$$Icor = I(1 - P) \tag{4}$$

Where:

- **Second moment of area** (I) = describes the geometry of the stem cross section
- **Breaking force** (Fmax)= the maximum force (F) the stem fragment could withstand before breaking
- **Porosity** (P) = the ratio of total lacunar area and total cross-sectional area of stem
- **Icor** = I corrected by porosity
- **Radius** of a circular stem cross section (R)
- **Side length** of a rectangular stem cross section (l)

Calculate the mean porosity of the stems of both plant species for both nutrient conditions using two significant figures for your result.

Q.17.1 Mean porosity of M.s. in low nutrient conditions	0.0 pt
Q.17.2 Mean porosity of M.s. in high nutrient conditions	0.0 pt
Q.17.3 Mean porosity of M.a. in low nutrient conditions	0.0 pt
Q.17.4 Mean porosity of M.a. in high nutrient conditions	0.0 pt

Representative cross sections of the stems of M.s. and M.a. are shown below.

Fig.1

Q.17.5 Match the following cross sections (1 and 2) with the two species (A and B, as specified below). Indicate your answer by putting an X in the appropriate box on the answer sheet. 0.0 pt
A. if the species is M. scorpoides, and B. if the species is M. aquaticus.

Q.17.6 0.0 pt

Q18

Two transcription factors, GNC and GLK, have been implicated in regulating chloroplast development. Three mutants with different combinations of knock-out mutations in these genes were created in *A. thaliana* as follows: *GNC* or *GLK* only and *GLC-GNK* with mutations in both genes. These mutants and the wild type plant (WT) were then analysed with respect to various parameters associated with chloroplast development as shown in Figure 1. (different letters indicate significantly different values; NPQ = non-photochemical energy quenching, quantifies the ability of photosystems to dissipate excess excitation energy, higher values indicate greater ability)

Fig.1. i) Average chloroplast fluorescence. ii) Chlorophyll a content (ng/mm2 $\pm$ SD). iii) Chloroplast relative fluorescence intensities. iv) Microscopic images of chloroplasts

Q.18.1 Select the microscopic techniques which have been used to take the images shown in Figure 1A and Figure 1B. Indicate your answer by putting an X in the appropriate box on the answer sheet. 0.0 pt

Microscopic techniques:
A. Bright-field light microscopy
B. Fluorescence microscopy
C. X-ray microscopy
D. Atomic force microscopy
E. Transmission electron microscopy
F. Scanning electron microscopy

Q.18.2 Which of the GLK and GNC transcription factor families is the stronger positive regulator of chloroplast development? Indicate your answer using the symbols, > or < or = in the appropriate box on the answer sheet. 0.0 pt

Q.18.3 Select the single best statement describing the contribution of the GLK and GNC genes to chlorophyll biosynthesis. Indicate your answer by putting an X in the appropriate box on the answer sheet. 0.0 pt

A. The GLK and GNC genes modify the expression of chlorophyll biosynthetic genes in separate pathways for chlorophyll biosynthesis.
B. GLK genes modify the expression of chlorophyll biosynthetic genes more upstream than the chlorophyll biosynthetic genes controlled by GNC.
C. GNC genes modify the expression of chlorophyll biosynthetic genes more upstream than the chlorophyll biosynthetic genes controlled by GLK.
D. The relative contribution of the GLK and GNC regulated chlorophyll biosynthetic genes cannot be determined based on the data above.

Q19

Two transcription factors, GNC and GLK, have been implicated in regulating chloroplast development. Three mutants, GNC single-, GLK single-, and GNC-GLK double mutants were analysed for the expression of nine genes (PSAE-2, PSAF, PSBY,CHLM, LHCA2, LHCB3, rbcL, psaC and psbA) using reverse transcription quantitative PCR (RT-qPCR).

Fig.1. Axis = Relative expression

Q.19.1 Arrange the following experimental steps in the appropriate order and fill in the flowchart to summarise the workflow of a RT-qPCR. Put one letter in each box. You do not have to use all the letters. We already put letter A in the correct position for you. 0.0 pt

- ***A. Reverse transcribe into cDNA (complementary DNA) using reverse transcriptase***
- B. Add primers of random sequence and DNA-dependent DNA polymerase
- C. Analyse the results by determining the number of PCR cycles needed for each sample to reach a threshold fluorescence and compare these to one another
- D. Take plant tissue samples
- E. Purify total mRNA
- F. Add a sequence-specific probe containing a quencher and a fluorophore, primers for the sequence of interest and DNA-dependent DNA polymerase
- G. Measure the fluorescence intensity at the end of the PCR amplification with a spectrophotometer
- H. Purify total DNA with RNase
- I. Incubate in a thermocycler under the appropriate conditions to allow for the amplification of the sequence of interest and the release of the fluorophore from the probe. Simultaneously, computationally quantify the increase in fluorescence due to the fluorophore release
- K. Create cell lysate

Q.19.2 Given that GNC and GLK act as transcription factors, determine if they are positive or negative regulators of each of the the nine target genes (PSAE-2, PSAF, PSBY,CHLM, LHCA2, LHCB3, rbcL, psaC and psbA). Select the genes that are **upregulated** by GNC and GLK and indicate your answer by putting X in the appropriate boxes on the answer sheet. 0.0 pt

Q1-54

English (Official)

Q20

The following question concerns the electron transport chain of photosynthesis. Note that NADP+/NADPH is at a higher free energy state than the manganese cluster of the oxygen evolving complex but lower than the central chlorophyll pair of photosystem II in the excited state.

Q.20.1 Put the following oxidised/reduced pairs in an order of increasing redox potential. Put one letter in each box on your answer sheet. We already put letter F in the correct box. 0.0 pt

- A. Oxidised/reduced central chlorophyll pair of photosystem I in the excited state
- B. $NADP^+$ or NADPH
- C. Fully reduced/fully oxidised manganese cluster of the oxygen evolving complex
- D. Oxidised/reduced central chlorophyll pair of photosystem II in the ground state
- E. Oxidised/reduced central chlorophyll pair of photosystem II in the excited state
- ***F. Oxidised/reduced electron carrier Tyr residue***

Q21

Not all flowers use the ABC model of genetic regulation. Nigella species have spiral flowers and variable numbers of sepals (C), petals (D), stamens (E) and carpels (F) under the control of a genetic system different from that of ABC.

Fig.1 Genes involved in flowering (leftmost column) were silenced and their morphology was assessed. The number of each organ (C-F) was measured and results are indicated in the bar charts (right column). Bar G shows the sum of all the numbers (C-F).

Fig.1. WT = Wild-type. Legend 1 = Naturally occurring gene 1 KO mutant + genes 6 and 7. Legend 2 = Naturally occurring gene 1 KO mutant + gene 10.

Q1-56

English (Official)

Q.21.1 Each gene is expressed according to one of the following patterns (darker = more expression). Match the genes (1-13) with the patterns (A-H). Indicate your answer by putting the letters A-H in the appropriate boxes on the answer sheet. Each letter is only used once! 0.0 pt

Q1-57

English (Official)

Q22

Venation and size of leaves are important factors influencing plant physiology. Veins can be categorised hierarchically into four groups: midvein (1°), secondary (2°), tertiary (3°) and quaternary (4° or minor veins) as indicated by arrows on Figure 1. Scaling between vein density (= vein length per total leaf area) and leaf area as well as vein diameter and leaf area were determined for 500 species of dicotyledons. [● = data from species with branched veins; ◦ = data from species with parallel veins]

Fig.1. Axis 1 = Leaf area (cm^2). Axis 2 = Vein density (= vein length per leaf area; $cm \cdot cm^{-2}$). Legend 1 = Midvein. Legend 2 = Minor veins.

Based on these data, a model was created (Figure 2) which is generally true for most of the species examined. It details the change of various structural features during the development of a dicotyledonous leaf.

Fig.2. Axis 1 = Days of leaf expansion. Axis 2 = Leaf area (cm^2). Axis 3 = Vein development. Axis 4 = Vein density ($mm \cdot mm^{-2}$). Axis 5 = Vein diameter (mm). Legend 1 = Cell division growth. Legend 2 = Cell expansion growth. Legend 3 = Minor veins.

Determine the relationship between the following pairs (A and B). Indicate your answer on the answer sheet by using the symbols > or < or =.

Q.22.1 A. Vein density scaling with leaf surface area for midvein and 2°. 0.0 pt
B. Vein density scaling with leaf surface area for 3° and 4°.

Q.22.2 A. Vein density scaling with leaf surface area in species with branched veins. 0.0 pt
B. Vein density scaling with leaf surface area in species with parallel veins

Q.22.3 Identify how density of veins of different hierarchical levels change over time and label Fig.2.c below accordingly. Match the letters below (A-D) with the appropriate roman numeral on your answer sheet. Indicate your answer by putting an X in the appropriate box on the answer sheet. 0.0 pt

A. 1° veins
B. 2° veins
C. 3°veins
D. Minor veins

Fig.3. Axis 1 = Days of leaf expansion. Axis 2 = Vein density ($mm \cdot mm^{-2}$)