THEORETICAL EXAM
ANSWER KEY WITH EXPLANATIONS

Theory Part A (Q1–Q31)

1. Answers are marked with a green **X** in the same tables used on the question paper.

2. A short explanation follows each question so the reasoning can be checked and used in class.

3. Where the question paper is missing a figure (Part A Q1 Figure 1, Part A Q9 pollen images, the RR formula in Part A Q26), the answer is given from the remaining data and the source study, and this is stated.

Theory

Part A

Cell Biology

Q1

	Statement	True	False
A	According to Figure 1, the Dual ICI therapy is significantly more effective at reducing tumor size compared to no treatment at all.	X	
B	Data in Figure 2 suggest that the signaling molecule TNF is a primary driver for the migration of various inflammatory cells into the heart tissue.		X
C	Based on Figure 1, adding a TNF-receptor blocker (αTNFR2) to the treatment successfully reduces heart inflammation but completely cancels out the anti-tumor effects of the ICI drugs.		X
D	The results in Figure 2 indicate that the heart damage is likely caused by a complex inflammatory response involving multiple cell types (such as macrophages and monocytes), rather than a single type of immune cell.	X	

Explanation. Figure 1 did not print on the question paper, so A and C are answered from the source study. Dual ICI strongly suppresses tumour growth, and adding the TNF-pathway blocker *preserves* this effect. That is the main point of the study: myocarditis can be uncoupled from anti-tumour efficacy. So C is false. B: Figure 2 compares *treatments*. αCTLA-4 or αPD-1 alone recruit almost no leukocytes even with normal T cells, so the large infiltrate depends on the dual treatment. The figure does not isolate TNF as the driver. D: the Dual ICI bar is made up of macrophages, inflammatory monocytes, neutrophils and dendritic cells, which is a multicellular response.

Q2

	Statement	True	False
A	After COPII loss-of-function, the secreted protein is expected to accumulate in the ER, and the amount of protein detected in the extracellular medium should decrease.	X	
B	After COPII loss-of-function, the secreted protein is expected to accumulate in the Golgi, because COPII primarily mediates retrograde transport from the Golgi back to the ER.		X
C	After COPII loss-of-function, the secreted protein is expected to accumulate in the cytosol, because an ER signal peptide causes proteins to be retained on cytosolic ribosomes.		X
D	COPII loss-of-function directly reroutes newly synthesized secretory cargo to lysosomes, so lysosomal accumulation is the most consistent outcome.		X

Explanation. COPII coats vesicles for *anterograde* ER → Golgi export. COPI does retrograde Golgi → ER transport. The signal peptide still targets the protein co-translationally into the ER lumen, so the cargo enters the ER but cannot leave it. ER-retained misfolded cargo is mainly cleared by ERAD and the proteasome, not rerouted to lysosomes.

Biochemistry

Q3

	Statement	True	False
A	Chitinases are involved in defense against pathogenic bacteria.		**X**
B	Chitinases are involved in defense against pathogenic fungi.	**X**	
C	Chitinases participate in the breakdown of chitin present in blood vessel walls.		**X**
D	Human chitinases are involved in chitin biosynthesis rather than its degradation.		**X**

Explanation. Chitin is absent from vertebrate tissues and from bacteria. It is found in fungal cell walls and in the coverings of nematodes and arthropods. Human chitotriosidase (from macrophages) and acidic mammalian chitinase (AMCase) are hydrolases that degrade chitin as part of innate defence against chitin-containing pathogens such as fungi, and in allergic and Th2 responses. They do not make chitin.

Q4

1	2	3	4	5	6	7	8
		X				**X**	

Explanation. Lipid 1 = 1,3-dioleoyl-2-palmitoylglycerol (oleate $C_{17}H_{33}COO–$ at sn-1 and sn-3, palmitate at sn-2). Pancreatic lipase is sn-1,3 specific. It releases the two outer fatty acids as free **oleic acid (3)**, ×2, and leaves **2-monopalmitoylglycerol (7)**. Palmitate stays esterified at sn-2, is absorbed as a monoacylglycerol, and therefore cannot form insoluble calcium palmitate. Lipid 2 instead releases free palmitic acid (2).

Q5

	Statement	True	False
A	Cell culture + C_2H_5OH		**X**
B	Cell culture + CH_3COOH		**X**
C	Cell culture + C_2H_5OH + Fomepizole (ADH inhibitor)		**X**
D	Cell culture + C_2H_5OH + CVT-10216 (ALDH inhibitor)	**X**	

Explanation. The question asks which culture has the *highest* steady-state acetaldehyde level. That is D: ADH keeps producing AA while ALDH, the step that removes it, is blocked. A gives some AA, but ALDH clears it. B: acetate is downstream of AA and the reaction is not reversed. C: blocking ADH stops AA formation.

Plant Biology

Q6

	Statement	True	False
A	These results indicate that flowering duration can be shortened in response to both increased temperature and extended photoperiod; however, day-length-sensitive genes play the major role in this process.	**X**	
B	Experiments A and B are designed to analyze the effects of high temperature and long photoperiod on the plant, and these results were used to select appropriate conditions for conducting experiments D, E, and F.	**X**	
C	Similar results would be expected for light wavelengths to which the ft-10 gene product (or the gene itself) is not sensitive.		**X**
D	In plants that overexpress the FT gene, the reproductive period will be significantly prolonged.		**X**

Explanation. Panels A and B show flowering duration shortening as photoperiod and temperature rise. D–F were then done under the selected inductive conditions (16 h, 22 °C). Under these conditions, loss of the day-length gene *FT* (ft-10) lengthens flowering, raises silique number on the primary inflorescence and keeps the IM larger. So the FT photoperiod pathway is the main driver of inflorescence arrest, and panel G shows a second FT peak just before PI arrest. C: FT is not itself a photoreceptor. Its expression depends on light quality perceived by phytochromes and cryptochromes, so different wavelengths would not give the same result. D: FT promotes PI arrest, so overexpressing it would *shorten* the reproductive period.

Q7

	Statement	True	False
A	The enzyme PEP carboxylase has a very high affinity for CO_2 and does not accept O_2 as a substrate. This enables C4 plants to function efficiently even at low CO_2 concentrations.	**X**	
B	The lower CO_2 compensation point in C4 plants compared to C3 plants is due to their RuBisCO enzyme functioning with higher efficiency than PEP carboxylase even at low CO_2 concentrations.		**X**
C	The higher net photosynthetic rate of C3 plants to the left of the 25 °C intersection point is explained by the fact that, at these temperatures, the energetic cost of photorespiration is lower than the cost of the CO_2 pump (ATP consumption) in C4 plants.	**X**	
D	Because the decarboxylation process in the C4 pathway occurs within the chloroplasts of mesophyll cells, photorespiration does not take place even if the partial pressure of oxygen increases in the bundle sheath cells.		**X**
E	The fact that the net photosynthetic rate of C4 plants at 40 °C is lower than its maximum potential is primarily caused by a sharp increase in photorespiration.		**X**

Explanation. PEPC acts on HCO_3^-, has no oxygenase activity and has a high affinity. That is why C4 plants have a low compensation point (B wrongly credits RuBisCO). At low temperature, O_2/CO_2 solubility and RuBisCO specificity favour carboxylation. Photorespiration is then small and costs less than the extra 2 ATP per CO_2 of the C4 pump. D: decarboxylation happens in *bundle-sheath* cells. E: C4 plants have almost no photorespiration. The fall above about 35 °C is due to heat damage to enzymes and membranes (RuBisCO activase, PPDK).

Q8

	Statement	True	False
A	In the process of gravitropism, the auxin concentration increases sharply in the lower part of the root. Although auxin releases ARF factors in root cells under this condition, it does not stimulate cell elongation but rather stops it; this is because ethylene induced by auxin in the root blocks elongation.	**X**	
B	The ethylene hormone enhances the auxin gradient at the root tip by increasing the gene expression of PIN2 transporter proteins. Thus, auxin stimulates ethylene synthesis through its high concentration, forming a "positive feedback" loop that indirectly accelerates its own transport.	**X**	
C	Based on the figure, at an IAA concentration of 10^{-8} M, while shoot elongation is positive (stimulated), root elongation is negative (inhibited). This confirms at the graphical level that root tissues are approximately 10000 times more sensitive to the effects of auxin than shoot tissues.		**X**
D	Strigolactones (SL) support the apical dominance of the plant by inhibiting the growth of lateral buds. Logically, when a plant encounters unfavorable conditions (nutrient deficiency), strigolactone synthesis should decrease, allowing the plant to branch more and increase its chances of survival.		**X**

Explanation. A, B: high auxin on the lower side of the root induces ACS, and the resulting ethylene inhibits elongation, so the root bends down. Ethylene in turn upregulates auxin synthesis and transport (PIN2, AUX1) in the root tip. C: on the graph, root elongation at 10^{-8} M is still *positive* (about +18%). It only becomes negative near 10^{-7} M. So the premise is false, even though the optima (10^{-10} vs 10^{-6} M) do differ by about 10^{4}. D: phosphate or nitrogen deficiency *increases* SL synthesis, which suppresses branching and promotes mycorrhizal symbiosis.

Q9

	Pollen morphology	wind	insects	water
A–F	Small, light, smooth/thin-walled, dry pollen, often with air sacs (e.g. pine) or with simple pores (grasses)	**X**		
	Large, sculptured (spiny/echinate or reticulate/netted) exine, sticky with pollenkitt		**X**	
	Thread-like or elongated pollen with very thin or no exine (e.g. *Zostera*, seagrasses)			**X**

Explanation. The six pollen images (rows A–F) did not print on the question paper, so each row cannot be keyed individually. Classify each image by the rule above. Smooth, small, dry grains, or saccate grains with air bladders, are wind-dispersed. Spiny (echinate) or netted (reticulate) sticky grains are insect-dispersed. Filamentous grains with reduced exine are water-dispersed (hydrophily).

Animal Physiology

Q10

	Statement	True	False
A	The first carriage represents the signal coming from the brain, the second carriage represents the sinoatrial node, and the third carriage represents the atrioventricular node.		**X**
B	Condition C can only maintain a very immovable state; this type of heartbeat is associated only with a comatose state.		**X**
C	To treat conditions B and C, an artificial pacemaker is implanted in the heart, and the impulses generated by this device restore the heartbeat to normal.	**X**	
D	Condition D occurs more frequently as a result of recurrent anxiety, insomnia, or excessive intake of caffeine, nicotine, or alcohol.	**X**	
E	In condition C, although the signal passes from the atrioventricular node to the Purkinje fibers, the connection between the sinoatrial node and the atrioventricular node is interrupted.		**X**

Explanation. The Sherwood analogy: 70 mph = SA node, 50 mph = AV node, 30 mph = bundle of His and Purkinje fibres. The heart beats on its own (myogenic), and the brain only modulates the rate. B = SA node failure, with the AV node taking over at about 50 beats/min. C = complete heart block. The atria follow the SA node at 70, the ventricles follow the Purkinje fibres at about 30, and conduction *through* the AV node to the ventricles is lost (the 50 mph carriage is derailed). So E is false. A ventricular rate of about 30 supports only sedentary activity, not only a coma (B false). Both B and C are treated with artificial pacemakers. D = ectopic focus (premature beats), which is promoted by anxiety, lack of sleep, caffeine, nicotine and alcohol.

Q11

	Statement	True	False
A	Generally, in all animals, due to α-neurotoxin binding with the nAChR, the receptor fails to detect acetylcholine in the synaptic cleft. As a result, contracted muscles cannot relax, leading to spastic paralysis.		**X**
B	The presence of IgG antibodies in the honey badger's blood is a product of directional selection resulting from a constant struggle for survival with snakes; it is common to all individuals of the species and is hereditary.		**X**
C	Both honey badgers and mongooses have evolved nAChR mutations that confer resistance to cobratoxin through changes at different amino acid positions, what represents a remarkable example of convergent evolution.	**X**	
D	It is highly likely that the nAChR mutation will facilitate the survival of the organism during tetrodotoxin poisoning.		**X**

Explanation. α-neurotoxins are competitive nAChR *antagonists*. The muscle cannot depolarise, so the paralysis is **flaccid**, not spastic, and it also does not occur in animals with resistant receptors. Specific IgG is acquired by each individual after exposure. It is not inherited (only transient maternal IgG is passed on). Honey badger, mongoose, hedgehog and pig evolved resistance independently, through substitutions at positions 187/189 of the α1 subunit. Tetrodotoxin blocks voltage-gated Na^+ channels, which is unrelated to nAChR.

Q12

	Statement	True	False
A	In patient B, hypothyroidism symptoms may have developed due to dysfunction of the pituitary gland and thyroid gland.		X
B	In patient A, hypothyroidism may have occurred due to autoimmune damage to the thyroid gland.	X	
C	Patient A may have developed endemic goiter.	X	
D	In a person with T4 levels of 12.8 pmol/L, TSH levels of 25 mIU/L, and TRH levels of 63 pg/mL, subclinical hypothyroidism may have developed.	X	

Explanation. Patient A has low T4, high TSH and high TRH. This is **primary** (thyroid) hypothyroidism, for example Hashimoto thyroiditis or iodine deficiency, where TSH-driven growth produces an endemic goitre. Patient B has low T4 and high TRH, but a TSH that is inappropriately normal. This is **secondary** (pituitary) hypothyroidism. A thyroid defect is not needed to explain it, and a primary thyroid defect would raise TSH. D: normal T4 with raised TSH is the definition of subclinical hypothyroidism.

Q13

	Statement	True	False
A	Individual A exhibits a developmental anomaly of the carpal bones, which is often associated with genetic mutations or congenital anomalies occurring during intrauterine development.		X
B	In Individual B, it is highly probable that the cell cycle checkpoints in the osteoblasts (bone cells) are malfunctioning.	X	
C	Radiogram A belongs to a young child and shows a closed fracture of the radius and ulna of the right forearm.	X	
D	Radiogram A demonstrates a fracture of the cortical layer while the periosteum remains intact. This type of fracture is caused by Vitamin D deficiency.		X

Explanation. A: only a few carpal ossification centres are visible, and open growth plates are seen. This is normal for a young child, not an anomaly. B: an aggressive bone lesion with 'sunburst' periosteal reaction and a Codman triangle, typical of osteosarcoma, a malignant osteoblast tumour, i.e. failed cell-cycle control. C, D: incomplete (greenstick-type) fractures of both forearm bones with no skin breach. The thumb-side radius lies on the viewer's left, which fits a right forearm in AP view. Greenstick fractures result from *trauma* in flexible juvenile bone with a thick periosteum, not from vitamin D deficiency.

Q14

	Statement	True	False
A	The organism with the skull shown in image A has a well-developed cecum, within which numerous bacteria live in symbiosis.	X	
B	The organism shown in image B uses ultrasound to locate and capture its prey.		X
C	If organisms B and C inhabit the same environment, species C could be the predator while species B could be the prey.	X	
D	The reduced development of teeth in species D is a result of feeding on very small food particles.	X	

Explanation. A = beaver (rodent with ever-growing orange incisors). It is a hindgut fermenter with a large caecum. B = herbivorous ungulate (selenodont molars, diastema). It does not echolocate. C = large carnivore (bear-type skull with large canines and carnassial-type cheek teeth), a plausible predator of B. D = baleen whale. Teeth are replaced by baleen plates as an adaptation to filter-feeding on krill and small fish.

Q15

	Statement	True	False
A	During the acute phase of hemolytic jaundice, the increase in serum bilirubin occurs solely due to the unconjugated fraction, while the level of urobilinogen in the urine is significantly elevated.	**X**	
B	Physiological jaundice in newborns (neonatal jaundice) occurs due to insufficient activity of the enzyme glucuronyl transferase. In this condition, phototherapy converts bilirubin-IXα into a form that can be excreted without the involvement of glucuronyl transferase.	**X**	
C	In viral hepatitis A, the number of functionally active hepatocytes decreases, leading to an increase in unconjugated bilirubin in the blood. Additionally, the accumulation of cellular debris from damaged hepatocytes obstructs the bile canaliculi, causing cholestasis and an increase in conjugated bilirubin.	**X**	
D	In a patient with jaundice syndrome, an increase in conjugated bilirubin in the blood plasma may be caused by obstruction of the bile ducts due to helminths.	**X**	

Explanation. Pre-hepatic (haemolytic) jaundice: unconjugated bilirubin rises, and more conjugated bilirubin reaches the gut, so urobilinogen is increased in both urine and stool. Phototherapy turns bilirubin IXα into water-soluble photoisomers (lumirubin) that are excreted without conjugation. Hepatitis raises both fractions (hepatocellular plus intrahepatic cholestasis). Ascaris or liver flukes in the bile ducts cause obstructive jaundice with conjugated hyperbilirubinaemia.

Q16

	Statement	True	False
A	Captivity has altered the giant panda microbiome, which may have unintended negative consequences for the adaptation and ecosystem of giant pandas when they are reintroduced into the wild.	**X**	
B	Antibiotic resistance genes and virulence factors, as well as heavy metal resistance genes, have been identified in the panda microbiomes, which is only due to human intervention.		**X**
C	Wild pandas have been found to have low cellulase activity and high amylase activity.		**X**
D	The reduction in cellulose degradation pathways and enrichment of starch metabolism in captive giant pandas is due to their being fed a variety of products other than bamboo.	**X**	

Explanation. Captive pandas have lower Shannon diversity, a separate Bray–Curtis cluster, fewer cellulose-degradation genes and more resistance genes. B: resistance genes are also present in wild pandas and are ancient and natural, so 'only due to human intervention' is false. C is reversed: wild pandas have *more* cellulose degradation. D: captive diets (bamboo plus starch-rich 'panda cake', fruit and vegetables) explain the shift towards starch metabolism.

Q17

	Statement	True	False
A	This is a restriction site; without it, the gene will not be integrated into the plasmid.		X
B	This is a promoter; without it, the scorpine and phoA genes will not be transcribed.	X	
C	This is a selective marker; without it, the bacterium will become antibiotic-resistant.		X
D	This is a replication point; without it, the plasmid will not replicate inside the cell.		X

Explanation. P*nptII* (bent arrow) is the constitutive promoter of the neomycin phosphotransferase II gene. It drives the signal–scorpine–'phoA fusion. NdeI, PacI and SbfI are the restriction sites, KanR is the selectable marker, pBBR is the replicon and oriT is the origin of conjugative transfer.

Genetics

Q18

	Statement	True	False
A	*Hox* genes begin to be strongly expressed at the gastrula stage.		X
B	Once the expression of a *Hox* gene has been induced, it is not switched off until molluscan metamorphosis.		X
C	The expression of *Hox* genes is probably induced by other transcription factors that begin to function 8–12 hours after fertilization (hpf).	X	
D	Based on the available data, the hypothesis of collinearity of gene expression can be rejected.	X	
E	*Hox* genes are transcription factors that regulate animal morphogenesis.	X	

Explanation. The heatmap is blue (low) through 0–8 hpf (gastrula). Strong expression first appears at 13 hpf, in the trochophore. Expression then switches on and off repeatedly (e.g. *Hox1* falls at 23–30 hpf). Onset between 8 and 13 hpf points to upstream regulators acting in that window. *Hox1*, *Hox4* and *Post1* switch on together at 13 hpf, while *Hox3* and *Lox2* come on late. The order of activation does not follow the order in the cluster, so temporal collinearity is not supported.

Q19

	Statement	True	False
A	Nematodes, mollusks, and flatworms form a monophyletic clade that is sister to the group including arthropods and annelids.		X
B	The moulting animals (Ecdysozoa) form a monophyletic group.	X	
C	The group of animals possessing a distinct excretory system (Nephrozoa) is not monophyletic.		X
D	The group of "true animals" (Eumetazoa) includes all animal phyla except sponges (Porifera) is monophyletic.		X
E	Flatworms and annelids form a monophyletic clade that is sister to the group including arthropods and nematodes.		X

Explanation. In the tree, Ecdysozoa (Priapulida, Onychophora, Arthropoda) form one supported clade, and Nephrozoa (Protostomia + Deuterostomia) is monophyletic, with Xenacoelomorpha as its sister. Nematodes are not in the tree, so A and E cannot be stated 'with confidence'. Annelids and molluscs are both Spiralia, not grouped with arthropods. Ctenophores branch outside the sponge + ParaHoxozoa clade, so a group of all animals except Porifera is not monophyletic.

Q20

	Statement	True	False
A	The pattern of increase in the number of mutations and in fitness indicates that the overwhelming majority of accumulated mutations are neutral.		**X**
B	The mutations that became fixed early in the populations initially confer a substantially greater selective advantage because they outcompete alternative variants through clonal interference.	**X**	
C	If mutagenesis in *E. coli* were assumed to be completely neutral, the number of accumulated mutations after 20,000 generations would be approximately 15.	**X**	
D	Based on genome size, recurrent bottlenecks caused by serial transfer, and the mutation rate, it can be assumed that most mutations became fixed due to genetic drift.		**X**
E	The increase in fitness most likely follows a hyperbolic model, whereas the increase in the number of mutations over 20,000 generations is linear.	**X**	

Explanation. Under neutrality the substitution rate equals the mutation rate: 4.6×10^{6} bp × 1.6×10^{-10} = 7.4×10^{-4} per generation, × 20,000 ≈ **15**. About 45 mutations were observed, all non-synonymous, and fitness rose, which is the signature of positive selection, not neutrality or drift. With a large population, beneficial mutations compete (clonal interference), so the ones fixed early are those of large effect. Fitness gains then show diminishing returns (a hyperbolic curve), while mutations accumulate at a roughly constant rate.

Q21

	Statement	True	False
A	According to mitochondrial data, the age of the most recent common ancestor of Neanderthals and modern humans (in millions of years ago) is younger than that of Denisovans and modern humans.	**X**	
B	On average, there are approximately 80 differences between the mitochondrial DNA of any two modern humans.		**X**
C	All modern humans differ from one another in mitochondrial DNA to approximately the same extent.		**X**
D	In humans, the age of the most recent common ancestor (in millions of years ago), as estimated from mitochondrial and nuclear genomes, would be the same.		**X**
E	The bimodal distribution of differences among modern humans is due to high mitochondrial genome diversity in indigenous African populations and lower mitochondrial genome diversity in non-African human populations.	**X**	

Explanation. Human–Neanderthal pairs differ at about 200 sites and human–Denisovan pairs at about 385, so the Neanderthal split is more recent. Human–human differences are bimodal, with peaks near 40 and 90 and most pairs in the first peak, so the mean is about 55–60, not 80, and the extent varies. The second peak comes from comparisons involving the deep African lineages (L0/L1). Mitochondrial DNA is a single, maternally inherited, non-recombining locus with a smaller effective population size, so its MRCA date differs from nuclear estimates. (The stem says 'choose one', but both A and E are correct from the figure.)

Q22

	Statement	True	False
A	Purifying (stabilizing) selection acts more strongly on bacterial genes.	**X**	
B	Most human genes evolve neutrally.		**X**
C	Although the medians of the distributions differ, the mean Ka/Ks value is the same for bacteria and eukaryotes.		**X**
D	Most human genes are under positive (directional) selection.		**X**
E	The proportion of genes under positive selection is higher in humans than in bacteria.	**X**	

Explanation. The *Salinispora* curve peaks at about 0.08 and almost none of it lies above 1. The human curve peaks at about 0.3 and has a visible tail above 1. Most genes in both organisms have Ka/Ks well below 1 (purifying selection), and it is stronger in bacteria, which have a large effective population size. The two distributions are clearly shifted, so their means differ.

Q23

	Statement	True	False
A	The heatmap suggests a clear haplotype-block boundary between SNP1–SNP4 and SNP5–SNP8, consistent with a recombination hotspot between SNP4 and SNP5.	**X**	
B	Because SNP4 shows low r^2 with all other SNPs, SNP4 may be a rare variant and that is why LD is low.		**X**
C	The very low r^2 between SNP1 and SNP8 shows that these two SNPs are located on different chromosomes.		**X**
D	High r^2 among SNP5–SNP8 is evidence that these SNPs are under natural selection.		**X**

Explanation. The figure shows two LD blocks with $r^2 \approx 0$ between them, which is the typical signature of a recombination hotspot. SNP4 actually has high r^2 (about 0.75) with SNP1–3, so the premise of B is false. The question states that all SNPs are in the same region, so low LD reflects recombination, not separate chromosomes. High LD within a block arises from low recombination or shared haplotype history and is not proof of selection.

Q24

	Statement	True	False
A	Only the peak on chromosome 2 exceeds the genome-wide significance threshold; the signal on chromosome 1 does not pass the multiple-testing threshold (it may be suggestive).	**X**	
B	The peak on chromosome 1 is genome-wide significant, while the peak on chromosome 2 is only suggestive.		**X**
C	The presence of two peaks in the Manhattan plot proves that the phenotype is controlled by exactly two genes.		**X**
D	A higher -log10(p) for a SNP demonstrates that this SNP is causal for the phenotype.		**X**

Explanation. The threshold is $-\log_{10}(5\times10^{-8}) \approx 7.3$. The chromosome 2 peak reaches about 12. The chromosome 1 peak reaches about 6.3, which is suggestive ($p < 10^{-5}$) but not genome-wide significant. GWAS detects association, and a signal can be driven by LD with the true causal variant. Small-effect loci may also stay below the threshold, so the number of peaks does not equal the number of genes.

Ecology

Q25

	Statement	True	False
A	On large islands, the extinction rate is significantly higher because interspecific competition is stronger there.		**X**
B	The rate of successful immigration increases as the number of species on the island decreases, because the number of available ecological niches decreases.		**X**
C	Point 2 represents the equilibrium for the larger island.	**X**	
D	On small islands, the rate of successful immigration is higher because large species that strongly outcompete others cannot establish there.		**X**
E	The main factor determining the differences in the shape of the curves for large and small islands is the number of available ecological niches.	**X**	

Explanation. Large islands have a higher immigration curve (bigger target, more chance of establishment) and a lower extinction curve (larger populations, more habitats). Their equilibrium therefore lies further right, at point 2. B gets the reason backwards: fewer resident species means *more* free niches.

Q26

	Statement	True	False
A	Based on the presented data, Foster's rule does not hold for amphibians inhabiting islands close to the mainland.	**X**	
B	Foster's rule is less clearly expressed on small remote islands than on large islands close to the mainland.		**X**
C	The island rule is most strongly expressed in amphibians.		**X**
D	Based on the presented data, Foster's rule does not apply at all to species capable of prolonged active migration.		**X**
E	Based on the presented data, Foster's rule does not hold for birds inhabiting islands close to the mainland.		**X**

Explanation. The island rule appears as a negative slope of lnRR against log mass (small species get bigger, large species get smaller). Amphibians on close, large islands (purple, panel d) show a flat to slightly *positive* slope, so the rule does not hold. In every group the orange line (small, remote islands) is steeper than the purple, so the rule is *stronger* there. The steepest slope is in reptiles (panel c), not amphibians. Birds (panel b) show a negative slope on both island types, weak on close islands but present, so D and E are false. (The RR formula is missing from the question paper. RR = island mass / mainland mass.)

Q27

	Statement	True	False
A	The shift in nutrient stoichiometry from 1980 to 2010 creates a competitive advantage for nitrogen-fixing cyanobacteria over non-fixing phytoplankton.		**X**
B	The construction of upstream dams contributed to the decline of diatoms by acting as a sink for particulate and dissolved biogenic silica.	**X**	
C	The observed shift in the phytoplankton community will likely increase the efficiency of carbon sequestration to the deep ocean benthic zone.		**X**
D	In 2010, an artificial addition of orthophosphate to the bay would trigger a massive bloom of diatoms.		**X**

Explanation. N:P rises from 10 to 24, above Redfield's 16. Nitrogen becomes abundant, which removes the advantage of N_2 fixation. Si:N falls from 3 to 0.08, against a diatom requirement of about 1. Diatoms become Si-limited because reservoirs trap silica: diatoms bloom and sink in the impounded water. Heavy, silica-ballasted diatoms are the most efficient exporters of carbon to depth, so replacing them with non-siliceous flagellates and cyanobacteria weakens the biological pump. In 2010 diatoms are limited by Si, so adding P would favour non-diatom or harmful taxa instead.

Biotechnology

Q28

	Statement	True	False
A	*Lactobacillus paracasei*, *L. acidophilus*, *L. casei*, and *Bifidobacterium* cultures lower the pH, and in a salty environment, the CO_2 produced by *L. delbrueckii* subsp. *bulgaricus* dissolves in the fat and aqueous phases at 10 °C, resulting in a sweet and porous cheese.		**X**
B	*Streptococcus thermophilus* and *Lactobacillus helveticus* convert lactose into lactic acid; *Propionibacterium*, in turn, utilizes this lactate ($C_3H_6O_3$) to produce CO_2 and propionate ($C_3H_5O_2^-$), and therefore holes develop in the cheese.	**X**	
C	The lactate produced by *L. rhamnosus*, *L. buchneri*, and *L. curvatus* promotes the growth of *Penicillium roqueforti*, resulting in CO_2 production and the formation of holes in the cheese.		**X**
D	*L. helveticus* and *L. delbrueckii* break down lactose into lactic acid, while the holes are formed due to the polysaccharides produced by *Streptococcus thermophilus*.		**X**
E	Due to the fermentation of lactate produced by *L. acidophilus* and *L. casei*, *Clostridium tyrobutyricum* produces gases, including CO_2 and H_2, which results in the formation of holes in the cheese.		**X**

Explanation. Emmental eyes form when thermophilic starters (*S. thermophilus*, *L. helveticus*) make lactate and *Propionibacterium freudenreichii* ferments it during warm-room ripening: 3 lactate → 2 propionate + acetate + CO_2 + H_2O. *L. bulgaricus* is homofermentative, so it produces no CO_2. *P. roqueforti* makes blue veins, not eyes. *S. thermophilus* exopolysaccharides affect texture, not eyes. *C. tyrobutyricum* causes 'late blowing', a spoilage defect with butyric off-flavour and cracks, not the characteristic Emmental eyes.

Q29

	Statement	True	False
A	Cationic AMPs bind to the bacterial surface and disrupt the outer membrane's integrity. This allows the hydrophobic NPN dye to penetrate the membrane's lipid layer, which leads to a significant increase in fluorescence.	**X**	
B	An increase in the DiSC3(5) signal is a classic indicator of membrane hyperpolarization. When AMPs create pores in the membrane, the ion gradient is strengthened, causing the dye to be absorbed more deeply into the membrane, which leads to a significant decrease in the fluorescence signal.		**X**
C	Propidium Iodide (PI) is a large, membrane-impermeable molecule that can only enter cells with a compromised membrane. Once inside, it binds to DNA with higher affinity than SYTO 9, effectively quenching (suppressing) the green SYTO 9 signal and staining the cell red.	**X**	
D	SYTOX Green is a membrane-permeable dye that easily enters healthy bacterial cells via active transport. Once inside, it binds to the lipid droplets in the cytoplasm, and its fluorescence increases only when the membrane remains perfectly intact and undisturbed by AMPs.		**X**

Explanation. NPN fluoresces strongly in a hydrophobic environment, so outer-membrane damage raises its signal. DiSC3(5) collects in polarised membranes, where it self-quenches. Pore formation *depolarises* the membrane, the dye is released and fluorescence *increases*. SYTOX Green, like PI, cannot cross intact membranes. It enters only damaged cells and fluoresces on binding nucleic acids.

Q30

	Statement	True	False
A	They can signal from the outside without disrupting the cell membrane.		X
B	They have the ability to stably integrate genetic information (scFv antibody gene) into the host cell genome.	X	
C	They recognize and reanimate only dead cells.		X
D	They deliver antibodies only to the nucleus, not to the cell surface.		X

Explanation. Lentiviruses (retroviruses) reverse-transcribe and integrate the scFv gene into the host genome, in both dividing and non-dividing cells. This gives stable, inheritable expression, so each scFv stays linked to its cell's phenotype through selection, differentiation and in vivo migration. The scheme shows antibodies expressed both inside the cell and on the cell surface.

Q31

	Statement	True	False
A	Cluster XII enzymes have sequence similarity to proteases (protein-degrading enzymes).	X	
B	Proteases can degrade PLA plastic because its chemical bonds (ether bonds) are similar to peptide bonds in proteins.		X
C	According to the figure, the ability to degrade polyesters is specific to only one type of microorganism (for example, only Bacillota).		X
D	The change in distance and color of lines in the SSN network indicates the differences in amino acid sequences between enzymes.	X	

Explanation. Cluster XII is labelled 'Proteases'. PLA is a poly*ester*: its ester bonds, and the chiral α-carbon of lactate, resemble the amide (peptide) backbone and alanine. It has no ether bonds. Polyester-hydrolase clusters I–IX contain several bacterial phyla, archaea and fungi. In an SSN, edges and clustering distance reflect pairwise sequence similarity, and edge colour shows BLASTp % identity.