1.

Regulatory (control) mechanisms in organisms are necessary for survival. Choose **THREE** of the following examples and explain how each is **regulated**.

(i) Flowering in plants

(ii) Water balance in plants

(iii) Water balance in terrestrial vertebrates

(iv) Body temperature in terrestrial vertebrates

(each box represents an independent 1 point each)

change in photocycle/photoperiod	long day (short night) plants flower only if night is shorter than a critical duration - - - or - - - short day (long night) plants flower only if night exceeds a critical duration	phytochromes $P_r \Leftrightarrow P_{fr}$ (night) (day) unknown "florigen" converts shoot-meristem to floral-meristem or breaks bud dormancy leaf is photoreceptor organ gibberellins → ↑flowering auxins, ethylene, or abscisic acid→ ↓flowering
change in temperature pattern (vernalization)	specific duration of cold exposure - - - or - - - specified sequence of temperature changes initiate flowering	can be independent of (day neutral) or dependent on photocycle changes unknown "florigen" transitions shoot meristem to floral meristem or break bud dormancy gibberellins → ↑flowering auxins, ethylene, or abscisic acid→ ↓flowering
nutritional status	plant has enough nutritional resources to support flowering	can be independent (day neutral) or co-dependent of photocycle changes unknown "florigen" transitions shoot meristem to floral meristem or break bud dormancy gibberellins → ↑flowering auxins, ethylene, or abscisic acid→ ↓flowering

(ii) Maximum 4 points

Regulatory mechanism (must earn one "explanation point" before awarding a second "mechanism point")	**Explain how the regulatory mechanism affects water balance:** (2nd point must come from explanation before 3rd point can be awarded)	**Elaboration** (max 1 point)
- stomates/guard cells	closed ≈ ↓water loss (evap/transpir) open ≈ ↑water loss (evap/transpir)	ion, water influx/efflux from guard cells; turgid/flaccid (stomates: open/closed)
- altered stomate location or "sunken stomates"	stomates more abundant in more humid, cooler regions of the plant	
- cuticle thickening	↓water loss (evap/transpir)	waxy polymers resist water movements, cutin
- increased succulence	water storage	
- smaller leaves	↓water loss (evap/transpir)	
- drop leaves	↓water loss (evap/transpir)	abscisic acid
- altered leaf angle	↓water loss (evap/transpir)	less surface area directly exposed to sun's heat
- water potential in roots lower than that of soil	permits water uptake, even in saline soils	production of organic osmolytes in roots
- deeper root growth	reach deeper water	
- altered metabolic pattern (e.g., CAM)	stomates open only at night: ↓water loss (evap/transpir)	cooler, more humid conditions during the night
- increase cellular turgidity	opposes osmotic force	cell wall resists influx until pressure gradient offsets osmotic pressure

(iii) Maximum 4 points

Hypothalamus is water-regulation center (1 point max)	***Hypothalamus regulates neural circuits in behavior of thirst (1 point max)***	
Regulatory mechanism/ detector/ signal (must earn one "explanation point" before awarding a second "mechanism point")	**Explain how the regulatory mechanism affects water balance.** (2nd point must come from explanation before 3rd point can be awarded)	**Elaboration** (1 point max)
Hyperosmotic conditions result in increased secretion of **Vasopressin (a.k.a. Anti-Diuretic Hormone = ADH)** from the hypothalamus/ (posterior) pituitary (gland) [[hyposmotic opposite]]	reduces water loss in urine [[hyposmotic opposite]]	↑ water permeability in descending limb of loop of Henle, distal tubule, or collecting duct causes greater reabsorption of water [[hyposmotic opposite]]
Hypovolemic conditions activate RAAS system (renin angiotensin activating system), especially **Ang II** from kidney/blood	Ang II increases (Na^+) and water reabsorption in proximal tubule; less urine	decreased renal blood pressure and filtrate flow increase renin release; renin activates angiotensinogen to Ang I, which is readily converted to Ang II juxtaglomerular apparatus (JGA)
Hypovolemic/ RAAS active Ang II stimulates **hypothalamic thirst** center	Ang II increases thirst	"dry mouth" perception
Hypovolemic/ RAAS active Ang II stimulates secretion of **aldosterone** from adrenal (cortex) gland	Aldosterone increases (Na^+) and water reabsorption (& K^+ secretion) in distal tubule	
Hypervolemic conditions (excess blood volume) cause increased secretion of **Atrial Natriuretic Peptide (ANP)**	decreases (Na^+) and water reabsorption in distal tubule	inhibits renin and aldosterone release; causes vasodilation of afferent arterioles

EVOLUTION		
- loop of Henle	loop length α urine osmolarity	
- type of nitrogenous waste	use less water in excretion	compare ammonia, urea, and uric acid for water solubility or toxicity
- development of specialized transport epithelia, e.g., salt glands	less water loss in osmoregulation	
- cloaca development	use less water in excretion	
- large intestine/ colon	greater surface area for water and ion absorption	
- water-resistant body surface	decrease water loss from body surface	
- behavioral avoidance of dessicating conditions	nocturnal habits reduce water loss due to heat	

2.

Prokaryotes are found throughout the biosphere. Answer two of the following.

a) Provide three examples of adaptations found in various prokaryotes. Explain how these three adaptations have ensured the success of prokaryotes.

b) Discuss how prokaryotes early in Earth's history altered environments on Earth.

c) Discuss three ways in which prokaryotes continue to have ecological impact today.

a) Provide three examples of adaptations found in various prokaryotes. **Explain** how these three adaptations have ensured the success of prokaryotes. **(Max. 6 points)**

- 1 pt for each example of an adaptation (3 are asked for)
- 1 pt for each explanation of how that adaptation ensured success

Some sample answers are:

Sample	Explanation
• fast reproduction	• out-compete other organisms
• asexual reproduction	• no need to risk change if environment constant
• genetic transfer (conjugation, transduction, transformation)	• can increase species variation
• plasmids	• provide new phenotypic capabilities
• diverse metabolism (N_2 fixation, anaerobes, chemoautrotrophs, variety of substrates)	• can colonize habitats inhospitable to others
• extremophiles	• can colonize habitats inhospitable to others or explanation (thermophiles have altered enzymes so can live at high temperatures, halophiles have altered cell wall and compatible solutes to live in high salt concentrations)
• endospores	• resist harsh conditions
• cell walls	• protect from osmotic lysis, protect from some chemicals
• small	• high SA/Vol ratio, large number in small space
• restriction enzymes	• protection from viruses

b) **Discuss** how prokaryotes early in Earth's history altered environments on Earth. **(Max. 6 points)**

- 1 pt for each identification of an impact on early Earth
- 1 pt for explanation of how environment was altered
- 1 pt for elaboration

Some sample answers are:

Early Impact	Explanation	Elaboration
• provided oxygen	• cyanobacteria produced oxygen that was previously not present	• discussion of how photosynthesis produces oxygen, discussion of ozone
• production of usable organics	• converted CO_2 (or methane) to sugars, proteins, etc.	• discussion of Calvin cycle
• nitrogen fixation	• converted N_2 to usable form	• discussion of nitrogen cycle
• origin of organelles	• endosymbiotic origin of mitochondria/chloroplasts	• discussion of evidence for endosymbiont theory

c) **Discuss** three ways in which prokaryotes continue to have ecological impact today. **(Max. 6 points)**

- 1 pt for each impact on Earth today (3 are asked for)
- 1 pt for explanation

Note: Most answers for part B will also work here. *Some* sample answers are:

Current Impact	Explanation
• chemical cycling (decomposition)	• explanation of role in a specific cycle (N, C, O, etc.)
• pathogenesis	• specific example; example linked to ecology
• biotechnology	• food industry, bioremediation; example must link to ecology

3.

Homeostasis, maintaining a steady-state internal environment, is a characteristic of all living organisms. Choose three of the following physiological parameters and for each, describe how homeostasis is maintained in an organism of your choice. Be sure to indicate what animal you have chosen for each parameter. You may use the same animal or different animals for your three descriptions.

- Blood-glucose levels
- Body temperature
- pH of the blood
- Osmotic concentration of the blood
- Neuron resting-membrane potential

Homeostasis of 3 parameters (Maximum of 4 points for each parameter chosen). Within each Parameter:

- mechanism appropriate for organism (1 point)
- explanation appropriate for mechanism (1 point)

Parameter 1 Blood glucose level		
Example of an organism	Mechanism	How homeostasis is maintained.
Any appropriate animal	Insulin	Lowers blood glucose
	Glucagon	Raises blood glucose
	Hunger	Changes behavior (finding food)
Parameter 2 Body Temperature		
Example of an organism	Mechanism	How homeostasis is maintained.
Any appropriate animal	Sweating	Evaporative cooling
	Shivering	Generates metabolic heat
	Dilation of peripheral blood vessels	Increases surface of blood vessels exposed
	Constriction of peripheral blood vessels	Increases surface of blood vessels exposed
	Piloerection (not in humans)	Traps air to insulate against heat loss
	Countercurrent heat exchange	Appropriate description for animal choice
An Ectotherm	Behavioral mechanisms	Appropriate link of behavior to change
An Endotherm	Behavioral mechanisms	Appropriate link of behavior to change
Parameter 3 pH of blood		
Example of an organism	Mechanism	How homeostasis is maintained.
Any appropriate animal	Breathing Rate	Altering carbon dioxide concentration
	Hb-buffer	Altering H ion concentration
	Protein buffer	Altering H ion concentration
	Kidney secretion	Altering H ion concentration
Parameter 4 Osmotic concentration of blood		
Example of an organism	Mechanism	How homeostasis is maintained.
Any appropriate animal	Kidney	Filtration, reabsorption
	Secretion of ADH	Water reabsorption in CD
	Take in water through mouth	Replaces water lost (hypertonic environment)
	Excrete dilute urine	Removes water gained (hypotonic environment)
Parameter 5 Neuron resting-membrane potential (Note: either restoring or maintaining resting potential)		
Example of an organism	Mechanism	How homeostasis is maintained.
Any appropriate animal	Na^+/K^+ pump	Restores the ion gradient
	Gated channels	Repolarizes membrane

4.

Membranes are essential components of all cells.

(a) **Identify** THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and **discuss** the structure and function of each.

(b) **Explain** how membranes participate in THREE of the following biological processes:

- Muscle contraction
- Fertilization of an egg
- Chemiosmotic production of ATP
- Intercellular signaling

Membranes are essential components of all cells.

(a) **Identify** THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and **discuss** the structure and function of each. **(6 points maximum; 1 point for each macromolecule + structure, 1 point for each macromolecule + function)**

NOTE: Only first three molecules mentioned will be scored.

Macromolecule	Structure	Function (must match selected macromolecule)
Phospholipids OR Lipid with phosphate	• Glycerol, two fatty acids, and polar head group w/phosphate • Amphipathic • Hydrophilic or polar (head) and hydrophobic or nonpolar (tails) • Forms a lipid bilayer	• Selectively permeable • Fluidity • Creates compartment/ separates cell from environment; barrier • Signals, inositol pathway (IP3) diacylglycerol (DAG)
Cholesterol	• Ring structure • Steroid • Amphipathic • Embedded in bilayer	• Moderates fluidity • Stabilizes membrane

Proteins OR <u>The following specific types must indicate that they are proteins</u> Integral Peripheral Pump Receptor Transport Recognition Tight junction Desmosomes Gap junctions Integrins Enzyme Channel	<u>General Structure</u> • Polypeptides; amino acids • 2°, 3°, 4° structure description <u>Specific Structure</u> • Integral, transmembrane, embedded; forms a channel • Peripheral, on surface • Structure fit to substrate or ligand	• Transport • Enzyme, catalysis • Signal transduction • Attachment: extracellular matrix (ECM)-cytoskeleton • Recognition • Cell junction
Glycolipid/Glycoprotein	• Carbohydrate (chains) linked to lipid/protein	• Cell recognition • Attachment to external molecule or another cell

(b) **Explain** how membranes participate in THREE of the following biological processes:
(6 points maximum; 2 points maximum per section)

Muscle contraction

- Motor neuron or axon terminal releases neurotransmitter or acetylcholine (ACh)
- ACh binds to receptors
- Depolarization or Na^+ moves in through membrane channels or membrane depolarizes
- Action potential propagates along cell membrane (sarcolemma) or T tubules
- Depolarization changes permeability of sarcoplasmic reticulum (SR) or Ca^{2+} released from SR
- Ca^{2+} active transport into SR (reuptake of Ca^{2+})
- Repolarization or maintenance of membrane potential (Na^+/K^+ pump)
- Smooth or cardiac muscle gap junctions directly transfer membrane potential between cells

Fertilization of an egg

- Part of the acrosomal reaction or sperm acrosome releases hydrolytic enzymes (by exocytosis)
- Sperm binds to receptors on egg
- Fusion of sperm and egg plasma membranes
- Change in membrane electrical charge or fast block (depolarization) to prevent further fertilization (polyspermy)
- Cortical reaction or slow block by exocytosis (prevents polyspermy) or "hardening" of membrane
- Separation of fertilization membrane (envelope)
- Fusion of egg and sperm nuclear membranes or nuclei

Chemiosmotic production of ATP

- Electron transport chain (ETC) in membrane pumps H^+ across membrane
- H^+ gradient established across membrane
- H^+ move through ATP synthase embedded in membrane to produce ATP
- Membrane infolding increases surface area

Intercellular signaling

- Release of chemical signals by exocytosis
- Receptors in membrane bind ligands or chemical signals or chemical signals pass through the membrane (examples: neurotransmitters, hormones, pheromones)
- Ligand-gated ion channels opening/closing
- Cascade of cellular events, including enzymatic reactions and second messengers (examples: G-proteins, cAMP, IP_3, Ca^{2+})
- Antibodies activate immune function
- Descriptions of gap junctions, plasmodesmata (communicating junctions)

5.

Homeostatic maintenance of optimal blood glucose levels has been intensively studied in vertebrate organisms.

(a) Pancreatic hormones regulate blood glucose levels. **Identify** TWO pancreatic hormones and **describe** the effect of each hormone on blood glucose levels.

(b) For ONE of the hormones you identified in (a), **identify** ONE target cell and **discuss** the mechanism by which the hormone can alter activity in that target cell. **Include** in your discussion a description of reception, cellular transduction, and response.

(c) **Compare** the cell-signaling mechanisms of steroid hormones and protein hormones.

Homeostatic maintenance of optimal blood glucose levels has been intensively studied in vertebrate organisms. ***NOTE: Points for parts (a), (b) or (c) may be found in any part of the response**.

(a) Pancreatic hormones regulate blood glucose levels. **Identify** TWO pancreatic hormones and **describe** the effect of each hormone on blood glucose levels. **(4 points maximum)**

Identification of hormone 1 point each (2 points maximum)	**Effect of hormone on blood glucose levels 1 point each (1 point maximum per hormone)**
Insulin (humulin)	• Decreases/lowers blood glucose level.
Glucagon NOTE: A hormone name beginning with "gly-" is not acceptable.	• Increases/raises blood glucose level.
Somatostatin	• Increases/raises blood glucose level.

(b) For ONE of the hormones you identified in (a), **identify** ONE target cell and **discuss** the mechanism by which the hormone can alter activity in that target cell. **Include** in your discussion a description of reception, cellular transduction, and response. **(4 points maximum)**

• **1 point**: target cell • **1 point**: description of reception	• **1 point**: discussion of transduction • **1 point**: discussion of response of target cell

Insulin

- **Target cells**: Any cell except red blood cells, or brain cells unless specified as neuroglial cells.
- **Reception**: Insulin binds to a specific receptor (tyrosine kinase) on the cell surface.
  - Ligand binding to two adjacent monomers forms an active dimer (tyrosine kinase).
  - Dimer and other proteins become phosphorylated.
- **Transduction**: Binding of signaling molecule alters the receptor protein in some way.
  - Stimulates a cascade pathway/mediated by a second messenger/amplifies signal.
- **Response**: Transduced signal triggers a specific action by the target cell. Specify one of the following:
  - Increases/raises cellular uptake of glucose.
  - Increases formation of glycogen from glucose in liver/(skeletal) muscle cells as intracellular glucose is incorporated into glycogen (glycogenesis).
  - Increases rate of intracellular catabolism of glucose.
  - Increases fat synthesis from glucose in liver cells and adipose tissue.
  - Decreases gluconeogenesis, the conversion of amino acids and glycerol from fats to new molecules of glucose.
  - Phosphorylated transcription factors can alter gene expression.
  - Facilitated diffusion of glucose. (Glucose is phosphorylated into glucose-6-phosphate to preserve the concentration gradient so glucose will continue to enter the cell.)
  - Cells with more glucose transporters increase departure of glucose from blood.

Glucagon

- **Target cells**: Liver cells, (skeletal) muscle cells.
- **Reception**: Binds to a specific receptor on the cell surface (G-protein-coupled receptors on liver cells).
    - G protein-GTP activates adenylyl or guanalyl cyclase.
- **Transduction**: Binding of signaling molecule alters the receptor protein in some way. (G-protein binds to GTP and this activates other signal molecules such as adenylyl cyclase/amplifies signal.)
    - cAMP or cGMP active as second messenger/phospholipase C activation releases IP3 and DAG.
    - Kinase activation by cAMP or cGMP/phosphorylated effector proteins.
- **Response**: Transduced signal triggers the specific action by the target cell. Specify one of the following:
    - Releases glucose into the bloodstream from liver.
    - Increases breakdown (hydrolysis) of glycogen (glycogenolysis) to glucose in liver/(skeletal) muscles.
    - Increases gluconeogenesis, the conversion of amino acids and glycerol to glucose in the liver; new glucose enters the blood.
    - Decreases glucose breakdown/oxidation.
    - Increases glucose formation (gluconeogenesis).
    - Ca^{2+} release.

Somatostatin

- **Target cells**: Pancreatic cells (alpha and beta cells).
- **Reception**: Binds to a specific receptor on the cell surface (G-protein-coupled receptor).
    - G protein-GTP activates adenylyl or guanalyl cyclase.
- **Transduction**: Binding of signaling molecule alters the receptor protein in some way.
    - cAMP or cGMP active as second messenger/Phospholipase C activation releases IP_3 and DAG.
    - Kinase activation by cAMP or cGMP/phosphorylated effector proteins.
- **Response**: Transduced signal triggers the specific action by the target cell. Specify one of the following:
    - Decreases insulin secretion (from beta cells).
    - Decreases glucagon secretion (from alpha cells).
    - Ca^{2+} release.
    - Guanine nucleotide binding protein (GNAI 1) inhibits insulin.

(c) Compare the cell-signaling mechanisms of steroid hormones and protein hormones. **(4 points maximum)**

Steroid hormone (2 points maximum)

- Mechanism of action — to alter gene expression in the target cell.
- Hydrophobic/lipophilic/nonpolar/fat-soluble molecules readily cross cell or nuclear membrane.
- Acts as ligand that binds to cytosol receptors.
- Binding changes the conformation/shape of the cytosol receptor; hormone-receptor complex then enters the nucleus as the activated transcription factor.

- Transcription from the genes is affected:
    - Releases HDACs and recruits HATs — histone acetylases — to end chromosome repression.
    - Complex acts as a transcription factor that binds to a promoter (including HRE, hormone response element).
- Actions are slow but sustained.

Protein hormone (2 points maximum)

- Mechanism of action — to activate biochemical pathways/enzyme systems OR alter gene expression in a target cell.
- Hydrophilic/lipophobic/polar/water-soluble molecules do not readily cross cell membrane.
- Acts as ligand for membrane-bound receptors. Binds to receptor transmembrane proteins (either tyrosine kinase or G-protein receptors).
- Hormone is the ligand and the first messenger.
- Actions are brief but dramatic.