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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.

<table>
<thead>
<tr>
<th>Macromolecule</th>
<th>Structure</th>
<th>Function (must match selected macromolecule)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phospholipids OR Lipid with phosphate</td>
<td>Glycerol, two fatty acids, and polar head group w/phosphate</td>
<td>Selectively permeable</td>
</tr>
<tr>
<td></td>
<td>Amphilipathic</td>
<td>Fluidity</td>
</tr>
<tr>
<td></td>
<td>Hydrophilic or polar (head) and hydrophobic or nonpolar (tails)</td>
<td>Creates compartment/separates cell from environment; barrier</td>
</tr>
<tr>
<td></td>
<td>Forms a lipid bilayer</td>
<td>Signals, inositol pathway (IP3) diacylglycerol (DAG)</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Ring structure</td>
<td>Moderates fluidity</td>
</tr>
<tr>
<td></td>
<td>Steroid</td>
<td>Stabilizes membrane</td>
</tr>
<tr>
<td></td>
<td>Amphilipathic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Embedded in bilayer</td>
<td></td>
</tr>
<tr>
<td>Proteins OR The following specific types must indicate that they are proteins</td>
<td>General Structure</td>
<td>Transport</td>
</tr>
<tr>
<td>Integral Peripheral Pump Receptor Transport Recognition Tight junction Desmosomes Gap junctions Integrons Enzyme Channel</td>
<td>Polypeptides; amino acids 2(^\circ), 3(^\circ), 4(^\circ) structure description</td>
<td>Enzyme, catalysis</td>
</tr>
<tr>
<td>Specific Structure</td>
<td>Integral, transmembrane, embedded; forms a channel</td>
<td>Signal transduction</td>
</tr>
<tr>
<td></td>
<td>Peripheral, on surface</td>
<td>Attachment: extracellular matrix (ECM)-cytoskeleton</td>
</tr>
<tr>
<td></td>
<td>Structure fit to substrate or ligand</td>
<td>Recognition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cell junction</td>
</tr>
<tr>
<td>Glycolipid/Glycoprotein</td>
<td>Carbohydrate (chains) linked to lipid/protein</td>
<td>Cell recognition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attachment to external molecule or another cell</td>
</tr>
</tbody>
</table>

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Visit apcentral.collegeboard.com (for AP professionals) and www.collegeboard.com/apstudents (for students and parents).
(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 \( \text{Na}^+ \) 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 \( \text{Ca}^{2+} \) released from SR
- \( \text{Ca}^{2+} \) active transport into SR (reuptake of \( \text{Ca}^{2+} \))
- Repolarization or maintenance of membrane potential (\( \text{Na}^+/\text{K}^+ \) 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 \( \text{H}^+ \) across membrane
- \( \text{H}^+ \) gradient established across membrane
- \( \text{H}^+ \) 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, \( \text{IP}_3 \), \( \text{Ca}^{2+} \))
- Antibodies activate immune function
- Descriptions of gap junctions, plasmodesmata (communicating junctions)
Cephalization and the development of a brain were important steps in animal evolution.

(a) **Discuss** the evolutionary origin and adaptive significance of cephalization in animal phyla. *(3 points)*

- **Cephalization (1 point)**
  - **Defined:** The concentration of the nervous system toward the anterior end of the organism
  - **Association:** Cephalization tied to bilateral symmetry development

- **Origin (1 point)**
  - **Origin identification:** (Platyhelminthes/flatworms)
  - **Evolutionary progression** of development

- **Adaptive Significance/Advantage (1 point)**
  - Efficient response to a stimulus (e.g., protection, predation, avoidance, movement toward or away)
  - During movement sensory organs encounter the environment first

(b) **Describe** the development of the nervous system in the vertebrate embryo. *(4 points maximum)*

- **Tissue of origin (1 point)**
  - Ectoderm gives rise to the nervous system.

- **Processes of development (2 points)**
  - Neurulation described (neural tube formation) **Note:** The notochord does not become the nerve cord.
  - Other nerve development processes
    - Neural crest cells migrate to form the peripheral nervous system
    - Anterior portion of the neural tube/cord bulges to become the brain or brain regions

- **Endpoints** with structures described at the end of a process step of development *(1 point)*
  - The ectoderm folds into the neural crest/tube or dorsal nerve/spinal cord
  - Neural tube expands or develops into developmental brain region (e.g., fore-mid-hind brain, prosen-mesen-rhombencephalon)
  - Spinal column/vertebrae/cranium that protects the CNS

- **Signaling (1 point)**
  - Notochord (mesodermal in origin) signals or directs development of neural tube (ectodermal in origin)
  - *Hox* genes, morphogens (diffusible developmental signal)
Question 2 (continued)

(c) At the sound of shattering glass, people quickly turn their heads. **Discuss** how the human nervous system functions to produce this type of response to an external stimulus. *(5 points)*

- **Stimulus/Intermediating Structure of Receptor Action (1 point)**
  Stimulus (sound waves, pressure, heat, etc.) producing an appropriate receptor action (eardrum vibrating, cochlear hairs vibrating or bending, pressure receptors firing, heat receptors firing, etc.)

- **Input/Sensory/Afferent (1 point)**
  Signal direction toward the central nervous system

- **Integration (1 point)**
  Processing/Interpretation by CNS
  Interneurons/Association/Communicating/Internuncial

- **Output/Motor/Efferent Response (1 point)**
  Signal direction toward effectors (peripheral NS) **or** description of the response or autonomic nervous response (e.g., increase in blood pressure or heart rate, muscle contraction **but not just** turning of head)

- **Possible Elaboration (1 point)**
  Neural electrophysiology (e.g., action potential, neurotransmitters, synapse)
  Neuron structure and impulse pathway
  Sensory physiology
Compared with other terrestrial biomes, deserts have extremely low productivity.

(a) **Discuss** how temperature, soil composition, and annual precipitation limit productivity in deserts. **(3 points maximum)**

<table>
<thead>
<tr>
<th>Abiotic factor (description)</th>
<th>How abiotic factor limits productivity (must be linked) (1 point per factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>Lowers photosynthetic rate</td>
</tr>
<tr>
<td>Increase in transpiration/evaporation</td>
<td>Lowers plant growth</td>
</tr>
<tr>
<td>Desiccation</td>
<td>Lowers biomass production</td>
</tr>
<tr>
<td>Loss of water from tissues/guard cells</td>
<td>PS/metabolic enzymes/proteins hindered</td>
</tr>
<tr>
<td>Not optimal temperatures</td>
<td>Lowers photosynthetic rate/plant growth</td>
</tr>
<tr>
<td>Lowers plant growth</td>
<td>Poor root anchorage limits plant growth</td>
</tr>
<tr>
<td>Lowers photosynthetic rate</td>
<td>Root limitations decrease photosynthesis</td>
</tr>
<tr>
<td>Lowers plant growth</td>
<td>Period of high productivity/wildflowers</td>
</tr>
<tr>
<td>Soil composition</td>
<td>Lowers photosynthetic rate/plant growth</td>
</tr>
<tr>
<td>Low organic content/nutrients</td>
<td>Lowers photosynthetic rate/plant growth</td>
</tr>
<tr>
<td>Low water retention</td>
<td>Poor root anchorage limits plant growth</td>
</tr>
<tr>
<td>Sandy</td>
<td>Root limitations decrease photosynthesis</td>
</tr>
<tr>
<td>Compacted soil</td>
<td></td>
</tr>
<tr>
<td>Annual precipitation</td>
<td>Lowers photosynthetic rate/plant growth</td>
</tr>
<tr>
<td>Low rainfall</td>
<td>Lowers plant growth</td>
</tr>
<tr>
<td>Seasonal rainfall</td>
<td>Period of high productivity/wildflowers</td>
</tr>
</tbody>
</table>

Clear definition/discussion of productivity: e.g., a measure of the amount of biomass produced by autotrophs/photosynthetic organism/plants...amount of light energy converted to chemical energy by autotrophs per unit time...reduced community productivity **(1 point)**

(b) **Describe** a four-organism food chain that might characterize a desert community, and **identify** the trophic level of each organism. **(2 points)**

- **Written description** of a minimum of 4 organisms (must include a producer/plant) **(1 point)**
- **Clear identification** of 4 distinct trophic levels of the organisms discussed **(1 point)**
  (producer → primary consumer → secondary consumer → tertiary consumer or top carnivore or decomposer or scavenger)
(c) Describe the results depicted in the graph. Explain one anatomical difference and one physiological difference between species A and B that account for the CO₂ uptake patterns shown. Discuss the evolutionary significance of each difference. (6 points maximum)

**Graph interpretation (3 points)**
- Describe graph (plant A takes up CO₂ during day AND plant B takes up CO₂ at night) (1 point)
- Species B as CAM (1 point)
- Species A as C₃ or species A as C₄ (1 point)

**Anatomical difference (1 point)**
- Species A is C₄ with bundle sheath/wreath/Kranz anatomy
- Stomata location (pits/crypts, underside stems) linked to CO₂ uptake
- Stomata density linked to CO₂ uptake
- In species B/CAM vacuole/mesophyll of organic acids (malate)

**Physiological difference (1 point)**
- Species A stomata open during day
- CAM/species B stomata open at night/closed during day
- Species A uses C₃ pathway; CAM/species B uses C₄ pathway
- C₃ uses Rubisco/C₄ uses PEP Carboxylase
- Organic acids synthesis for CO₂ storage
- Carbon fixation during day vs. night

**Evolutionary significance (2 points)**
Discuss the evolutionary significance linked to each difference (2 points, 1 point per difference)
- e.g., increased evolutionary success due to decrease in water loss in the desert environment
- e.g., C₄ pathway circumvents the problem of photorespiration
A bacterial plasmid is 100 kb in length. The plasmid DNA was digested to completion with two restriction enzymes in three separate treatments: EcoRI, HaeIII, and EcoRI + HaeIII (double digest). The fragments were then separated with electrophoresis, as shown.

### RESULTS OF GEL ELECTROPHORESIS

<table>
<thead>
<tr>
<th></th>
<th>EcoRI</th>
<th>HaeIII</th>
<th>EcoRI + HaeIII</th>
<th>Molecular Weight Standards</th>
<th>Kilobase Pairs</th>
</tr>
</thead>
<tbody>
<tr>
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<td>10</td>
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</tbody>
</table>
(a) Using the circle provided, construct a labeled diagram of the restriction map of the plasmid. Explain how you developed your map.

Construct a labeled map and explain (3 points maximum)

- Restriction sites correctly placed and kilobase sizes shown (2 points)

- Explanation (1 point)
  (NO POINTS for explanation with incorrect or missing map OR for interpreting gel only)
  - trial and error discussion
  - restriction site within larger fragment
Question 4 (continued)

(b) **Describe** how:

- Recombinant DNA technology could be used to insert a gene of interest into a bacterium
- Recombinant bacteria could be identified
- Expression of the gene of interest could be ensured

**Describe how to:** (6 points maximum)

(1) **Insert gene of interest (4 points maximum)**
- Cut gene of interest from source and/or cut plasmid with restriction enzyme
- Use SAME restriction enzyme on both
- Anneal/ligate/mix/combine gene of interest with vector (plasmid/virus/phage)
- “Sticky ends”/bp matches/complementarity
- Treatment for competent cells (CaCl₂/heat shock); incubate together
- Chemical modification can prevent restriction enzyme activity (e.g., methylation)
- Gene = cDNA (without introns) to fit into plasmid

(2) **Identify recombinant bacteria (1 point)**
- Phenotypic selection (antibiotic resistance/blue-white colony selection/“glo” gene, product produced [e.g., insulin])
- Radioactively/fluorescently labeled probe (tag/dye) / mRNA
- Electrophoresis of cut recombinant vs. original (gene/plasmid) OR with sequence comparison of recombinant vs. original (gene/plasmid) *(Not bacterial genome)*

(3) **Ensure expression of gene of interest (1 point)**
- Promoter [for prokaryote]
- cDNA/removal of introns for prokaryotic expression
- Operon (e.g., nutrient/arabinose induced)

(c) **Discuss** how a specific genetically modified organism might provide a benefit for humans and at the same time pose a threat to a population or ecosystem. *(3 points maximum)*

Discuss GM, benefit to humans, and threat to population/ecosystem

- Nonhuman organism with specific, heritable GM trait
- Plausible benefit to humans related to the GM trait
- Plausible or unknown threat to population/ecosystem related to GM trait/modified organism