MENTOR HIGH SCHOOL KITENDE

PROPOSED GUIDE FOR BIOLOGY PAPER 1

EXPANDED GUIDE

BEGINNING OF TERM 11 2025

BY TR. SSEMATIMBA GODFREY (0756341741)

Item 1.

A pharmaceutical company has developed a new drug designed to target a specific protein embedded in the plasma membrane of cancer cells. However, during clinical trials, the drug appears to have reduced efficacy, which scientists suspect is due to changes in the membrane structure caused by elevated cholesterol levels in these cells.

Using your understanding of the fluid mosaic model:

a) Explain how elevated cholesterol levels might alter the structure and function of the plasma membrane.
b) Discuss how these changes could affect the interaction between the drug and its target protein.
c) Propose one modification to the drug design or delivery strategy to overcome the observed issue, and justify your answer.

a) Elevated cholesterol levels insert themselves between the phospholipids in the plasma membrane, reducing its fluidity. This leads to a more rigid and ordered membrane structure. Reduced fluidity can hinder the lateral movement of integral proteins and affect membrane permeability, ultimately influencing how membrane-bound proteins interact with molecules.

b) The drug's target protein may become less accessible due to reduced protein mobility or may cluster into lipid rafts where the drug cannot bind effectively. This reduces the chances of effective drug-receptor interaction, thus lowering drug efficacy.

c) One strategy would be using lipid-based nanoparticles or liposomes to deliver the drug. These systems can fuse with the membrane and bypass cholesterol-induced rigidity. For example, liposomal doxorubicin (Doxil) has been used successfully in cancer treatments for targeted delivery

Item 2.

A team of bioengineers is developing synthetic vesicles to mimic human cell membranes for targeted drug delivery. During testing, they notice that the vesicles are too rigid and do not allow for proper fusion with target cells, limiting their effectiveness.

Using your knowledge of the fluid mosaic model of the plasma membrane:

a) Explain the core principles of the fluid mosaic model and evaluate how this model helps us understand membrane behavior in living cells.
b) Identify two specific components of a natural plasma membrane that the engineers should consider including or modifying in their synthetic vesicles.
c) For each component identified in (b), analyze how it would improve the vesicle's ability to mimic the structure and function of a natural membrane.

a) The fluid mosaic model states that the plasma membrane consists of a phospholipid bilayer with embedded proteins, and both components can move laterally. This fluidity is vital for cell functions like endocytosis, protein transport, and interaction with other cells or molecules.
b) Unsaturated Phospholipids and cholesterol.
c) Unsaturated phospholipids contain double bonds that introduce kinks in fatty acid chains. This prevents tight packing and increases

membrane fluidity, which is essential for mimicking real cell membranes and allowing vesicle fusion with target membranes.

Cholesterol regulates the fluidity and stability of membranes. At high temperatures, it maintains integrity by reducing fluidity, and at low temperatures, it prevents the membrane from becoming too rigid. Including cholesterol helps the synthetic vesicles behave like natural ones under varying conditions.

Item 3.

A group of researchers is studying a newly discovered microorganism found in deep-sea hydrothermal vents. Under the microscope, the organism appears to lack a defined nucleus, but it carries out all essential life processes such as respiration, growth, and reproduction. Some team members argue that it may not qualify as a true living organism because of its simple structure.

Using your understanding of cells and the cell theory:

a) Explain how the principles of the cell theory apply to both simple and complex organisms, and assess their relevance in classifying the microorganism.
b) Analyze how the characteristics of this microorganism either support or challenge the cell theory.
c) Evaluate why structural simplicity does not necessarily exclude an organism from being classified as living. Use examples to support your answer.

a) The cell theory affirms that all living organisms are made of cells, and that the cell is the fundamental unit of life. If the microorganism performs essential life processes (e.g., respiration, reproduction, growth), it supports the claim that it is a living organism, despite being microscopic and structurally simple

b) Evidence includes:

Ability to reproduce (e.g., binary fission in bacteria)

Metabolism (e.g., breaking down glucose to produce ATP)

Response to stimuli (e.g., movement toward nutrients) these are hallmarks of living cells, even in organisms that lack complex structures like a nucleus

c) Structural simplicity does not equate to being non-living. For instance, bacteria lack a true nucleus yet perform all necessary functions of life. Similarly, archaea found in extreme environments like hot springs also lack organelles but are undeniably alive. Viruses, in contrast, are structurally simpler but are not classified as living because they cannot carry out life processes independently

Item 4

In a school laboratory, students conduct an experiment to investigate how temperature affects the activity of the enzyme catalase on hydrogen peroxide. They observe that the reaction is fastest at around 37°C but slows down significantly at both lower and higher temperatures. One group concludes that the enzyme simply "stops working" outside the optimal temperature range.

Using your understanding of enzymes and the lock-and-key hypothesis:

a) Using the lock-and-key hypothesis, evaluate how temperature changes might influence the interaction between catalase and hydrogen peroxide.
b) Explain why enzyme activity decreases at both low and high temperatures, referring to the structure of the enzyme.
c) Suggest how this experiment could be improved to give more reliable results on how temperature affects enzyme activity. Justify your suggestion.

a) **According to the lock-and-key hypothesis, an enzyme's active site is specifically shaped to bind to a particular substrate. At optimal temperature (typically 37°C in humans), this binding is most efficient. If the temperature is too low, molecular motion slows, reducing collisions. If it's too high, the enzyme's structure is**

altered (denatured), distorting the active site and preventing substrate binding

b) At low temperatures, enzymes become less flexible, reducing reaction rates.

At high temperatures, hydrogen and ionic bonds within the enzyme's tertiary structure break, changing the shape of the active site. For example, at 60°C, many enzymes like amylase become denatured and stop working.

c) Use a buffer to control pH, repeat trials for reliability, and maintain exact temperatures with a water bath.

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