

USA Biology Olympiad Answers to Semifinal Exam

Question Set 1: Cell Biology

a)i)

Any drawing of a mitochondria or chloroplast is sufficient, as long as the position/location of the ATP synthase is correct (as below):

In the mitochondrion, the ATP synthase is located in the inner membrane. **+2 point**

In the chloroplast, the ATP synthase is located in the thylakoid membrane. **+2 point**

a)ii)

Protons flow through the ATP synthase from the intermembrane space to the matrix in the mitochondrion, or from the thylakoid space to the stroma in the chloroplast. **+3 point total, 1.5 points for each mitochondria, chloroplast**

a)iii)

Since $\text{pH} = -\log[\text{H}^+]$, a two pH unit difference is a 10^2 difference (100-fold) difference in $[\text{H}^+]$. For example, $1 \times 10^{-5} \text{ M}$ vs. $1 \times 10^{-7} \text{ M}$ H^+ concentrations. **+3 point for PH difference! ALL OR NOTHING (No points awarded for difference in H^+ concentration alone)**

Figure 10.14 p179

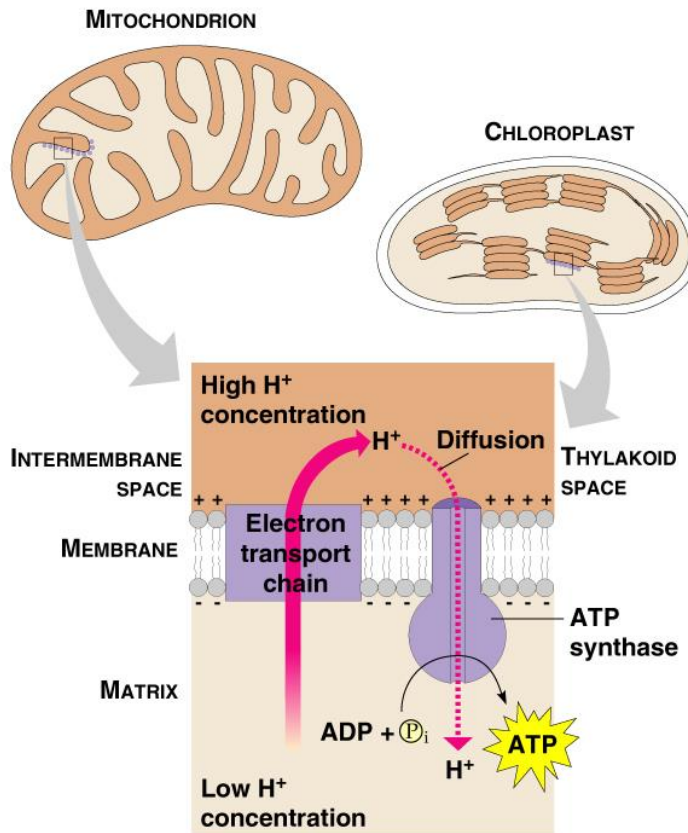
b.

i) oligomycin

Loss of ATPase activity => blocks
+1 point

Buildup of H^+ gradient => blocks
coupled)
+1 point

Blockade of ETC => lower O_2 con
+1 point



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ii) 2,4 dinitrophenol

Any mention of loss of coupling between H⁺ and ETC

+1 point

ETC can pass electrons to pump H⁺ into intermembrane space, and H⁺ gradient is automatically diffused by DNP => EXCESSIVE ETC activity

+1 point

Excessive ETC activity => excessive electrons passed down to oxygen => HIGHER O₂ consumption

+1 point

iii) cyanide

Any mention of loss of coupling between H⁺ and ETC

+1 point

ETC can pass electrons to pump H⁺ into intermembrane space, and H⁺ gradient is automatically diffused by DNP => EXCESSIVE ETC activity

+1 point

Excessive ETC activity => excessive electrons passed down to oxygen => HIGHER O₂ consumption

+1 point

iv) atractyloside

ATP-ADP exchange blockade => lower matrix [ADP] => no substrate for ATP synthase => lower (or no) ATP synthase activity

+1 point

Lower ATP synthase activity => H⁺ gradient not diffused as well (or at all)

+1 point

H⁺ gradient backs up => no ETC function (because coupled) => lower O₂ consumption

+1 point

v) arsenite

blockade of acetyl CoA (Krebs cycle) => no high energy electrons (FADH₂, NADH)

+1 point

No high energy electrons => no electrons in ETC => lower ETC function

+1 point

Lower ETC function \Rightarrow lower O₂ consumption
+1 point

Question Set 2: Animal Physiology

In this question, we consider the buffering system of the blood, and how both the renal and circulatory systems deal with pH homeostasis. The central buffering system in the blood is based on carbonic acid, according to the chemical equation:



Note that the “ \rightleftharpoons ” signs in the reactions imply reversibility; in other words, carbon dioxide and water can combine to form carbonic acid, and carbonic acid can also decompose to water and carbon dioxide. The first reaction is mediated by the red blood cell enzyme carbonic anhydrase.

a. What is the function of carbonic anhydrase? Does carbonic anhydrase catalyze the decomposition of carbonic acid to water and carbon dioxide, as well as carbonic acid formation? What effect will increasing temperature (e.g. in a fever) have on carbonic anhydrase activity?

It will catalyze both FORWARD AND REVERSE reactions. +1 point

**Increasing temperature will increase the carbonic anhydrase activity.
+1 point**

b. Suppose that we found a small molecule that bound the carbonic anhydrase at its active site. (Assume carbonic anhydrase has only one active site.) What is the mode of inhibition of this inhibitor? Draw the resulting initial reaction velocity versus substrate concentration and a reciprocal plot (1/reaction velocity versus 1/substrate concentration) graphs in the presence and absence of the inhibitor. Will increasing the concentration of CO_2 and H_2O overcome this inhibition? Explain.

**Active site inhibition is COMPETITIVE INHIBITION.
+1 point**

**The reciprocal plot will look like NO CHANGE in V_{max} (y-intercept). The apparent K_m will increase (decrease in x-intercept).
+1 for correct y-intercept
+1 for correct x-intercept**

**Increasing concentration of carbon dioxide and water will overcome inhibition, because they outcompete the inhibitor.
+1 for “outcompetition”**

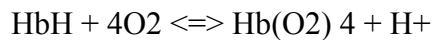
c. Assume you're a doctor. A patient comes to your clinic who has a carbonic anhydrase enzyme deficiency? What phenotype would you expect him or her to have? (To a first approximation, what would you expect the partial pressure of

carbon dioxide in their blood to be?) Explain.

Most CO₂ in blood is transported in form of bicarbonate. If you do not have CA, you cannot convert CO₂ to bicarbonate, because the intermediate (H₂CO₃) cannot be formed. So CO₂ in blood will INCREASE.

**+1 for answer
+1 for carbon anhydrase
deficiency effect (CO₂ increase
because of equilibrium)**

- d. Hemoglobin (Hb) cooperatively binds the oxygen in blood by the following equation:



Draw a curve relating the oxygen saturation of Hb to the partial pressure of O₂ in the blood. Using this curve, explain briefly the concept of cooperativity. Hb is sensitive to changes in the pH of the blood. If we assume that the chemical equation written above completely describes how Hb and pH are related, how would an increased respiratory rate affect Hb's affinity for oxygen molecules? Explain your answer.

Correct saturation curve. +2 points:

**+1 for sigmoidicity
+1 for axes**

Cooperativity. +3 points:

Occurs in enzymes that have QUATERNARY STRUCTURE or MULTIPLE LIGAND BINDING SUBUNITS such that binding of ligand to one subunit increases the affinity for binding of the ligand to the remaining subunits.

**+1 for multiple bind sites or quaternary
+1 for increasing loading affy after each
loaded ligand**

The curve shows a variable slope that indicates increasing O₂ loading affinity at progressively higher pO₂'s. Binding of one O₂ molecule therefore makes binding of the other O₂ molecule's much "easier" (in terms of free energy).

**+1 point (must mention "changing
affinity")**

Respiration and Hb +6 points

+2 points for answer (INCREASED AFFINITY)

+4 points for explanation:

**Increasing respiration rate => increasing minute alveolar ventilation =>
decreased CO₂ concentration in blood. +1 point**

**Decreased CO₂ concentration in blood shifts equilibrium in HCO₃/CO₂ equation to left => loss of protons => pH increases (respiratory alkalosis)
+1 points**

**Loss of protons means that shift the Hb equilibrium to the right => Hb therefore binds O₂ with higher affinity. (REVERSE BOHR EFFECT)
+2 points**

(Any answer referring to a Hb saturation curve in which the saturation curve is drawn shifted to the LEFT, reflecting higher Hb affinities for oxygen, AUTOMATICALLY receives full 4/4 credit on explanation. Need to EXPLICITLY state that AFFINITY INCREASES.)

e. BPG (2,3-bisphosphoglycerate) is a metabolic product of glycolysis found in red blood cells. It decreases the affinity of Hb for O₂. What levels of BPG would you expect in (i) a person living at high altitudes and (ii) a newborn? Explain, using the saturation curve.

**(i) High altitude (+3 points):
+1 for answer (increased BPG)
+2 for explanation:**

**For maximum tissue unloading, you want to be able to unload oxygen at the tissues. To do this, you need to have more BPG so that oxygen affinity for hemoglobin at tissue [O₂] levels is LOW. This way, your Hb will unload more oxygen at the tissues.
+1 points**

**On saturation curve: Must draw normal curve and indicate a RIGHT shift of saturation curve with higher BPG.
+1 point**

Note: Any answer claiming that BPG should be less to promote the oxygen uptake in the lungs (e.g. increase O₂ affinity) misses the point of Hb saturation. Within a reasonable range, high pO₂'s will saturate Hb to the same extent (because the top part of the Hb saturation curve is FLAT). But you want to unload more oxygen in the tissues because saturation HAS DROPPED a little. So you need to reduce the affinity a little.

**(ii) Newborn (+3 points):
+1 for answer
+2 for explanation:**

Fetal Hb has a higher affinity for oxygen than maternal Hb, because it has to “steal” away maternal O₂ from maternal Hb at the chorionic villus (“placenta”) sinuses. You must hence have a lower BPG! +1 point

On saturation curve: Must draw normal curve and indicate LEFT SHIFT with reduced BPG. +1 points

Note: if the student said that in a newborn, fetal conditions do not persist. So the levels of DPG would be the same relative to an adult (or low/moderate), we award 1.5 points overall for part ii.

In retrospect, this question is not totally clear. Really, in newborns, the cycling time for RBCs is 120 days, so it will be a little while (3 months) before circulating BPG in the RBCs is decreased.

Question 3: Ecology and Biosystematics

Answer:

for all of part (a), student receives 1 point for description + 1 point for significance. Only 1 point TOTAL if the explanation is not clear/not completely correct.

a

i) The **amniotic egg** is a shelled egg that contains four internal membranes: the chorion, amnion, yolk sac and allantois. The membranes and shell prevent desiccation, store waste, and provide nutrients, allowing eggs to be laid on land. The amniotic egg first appears among reptiles.

ii) **Bilateral symmetry** is a body plan when bisection to produce mirror image halves is only possible along one perpendicular plan. This body plan is directional (anterior and posterior end) and evolved in conjunction with cephalization or the concentration of sensory organs and brain in a defined head region. This adaptation is important in the development of motile animals where the head and senses are oriented and concentrated in the region encountering new stimuli.

iii) A **coelom** is a fluid-filled body cavity between the gut and body wall that is completely lined with mesoderm. The coelom can serve as a hydrostatic skeleton as in earthworms as well as cushion and protect the internal organs. The coelom also allows the digestive tract to move independently of the body wall and provides space for the complex folding and differentiation of the gut that is seen in many coelomate animals.

iv) In a **closed circulatory system**, blood is confined to the heart and/or blood vessels, which allows directional movement through the body without mixing of oxygenated/deoxygenated blood or filtered vs. unfiltered blood.

v) A **complete gut** is one with a mouth and anus vs. the single opening (mouth) of an incomplete gut. A complete gut allows continuous feeding since intake through the mouth can continue while digestion takes place.

b.

+1 point each ALL OR NOTHING; 4 points total

i) Arthropoda has all BUT #1

ii) Cnidaria has none of the traits

iii) Platyhelminthes has #3 only

iv) Mollusca have bilateral symmetry, coelom, and complete gut. Most Mollusks have an open circulatory system, but the class cephalopoda (octopi, squids, cuttlefish) have independently evolved a closed circulatory system.

c.

+8 points total; 2 points for each fate, 2 points / 2 examples per phyla

In protostomes the blastopore, the first opening to form in the ball of the gastrula during germ-layer formation, becomes the mouth while in deuterostomes it becomes the anus. Protostome phyla include: mollusca, annelida, arthropoda, phoronida, bryozoa, brachiopoda. Deuterostome phyla include: echinodermata and chordata.

d.+3 points total, 1 point per difference, but must mention BOTH (e.g. spiral/diagonal vs radial) for credit

Protostomes have spiral cleavage and deuterostomes have radial cleavage. (1pt)

In spiral cleavage the planes of cell division are diagonal to the vertical axis of the embryo so that the each layer of cells is displaced relative to the layer beneath while in radial cleavage the planes are parallel and perpendicular to the vertical axis so the cells are aligned directly above one another. (1pt).

Protostomes have determinate cleavage where the developmental fate of individual cells is determined with the formation of the cleavage furrow. After the first cleavage, individual cells are not capable of producing a complete embryo. (1 pt)

Deuterostomes have indeterminate cleavage where the cells produced early in cleavage can individually develop into a complete embryo. (1 pt)

Protostomes have schizocoelous formation of the coelom where a solid mesodermal block splits and hollow out while deuterostomes have enterocoelous formation of the coelom where there is an outpocketing of the mesoderm from the gut. (1 pt)

Question Set 4: Evolution and Genetics

a)

Hardy-Weinberg equilibrium - sexual shuffling of genes alone cannot alter the overall genetic makeup of a population - allele frequencies will remain the same in a population. It is non-evolving. **+3 point for definition; allele frequencies are INVARIANT in each successive generation, under the assumptions below.**

For Hardy-Weinberg to hold, five conditions (p432) must be maintained in a population:

- 1) very large population size (to minimize genetic drift - chance fluctuation in allele frequencies)
- 2) isolation from other populations (no gene flow in or out of population)
- 3) No net mutations (no new alleles)
- 4) random mating must occur
- 5) no natural selection (no selection for one set of alleles over another)

+5 points total, 1 point for each condition

b)

The frequency of allele B is 0.4 with genotypic frequencies of 0.36, 0.48, 0.16 since $p + q = 1$ and $p^2 + 2pq + q^2 = 1.0$.

allele B freq +2, genotype freq each +1 = 5 points

c)

The allele frequencies in the second generation would be 0.63 and 0.37 with genotypic frequencies of 0.40, 0.46 and 0.13.

Each freq is worth +1 point; 5 points total

Allele B would disappear under these conditions, although it would take many generations for complete loss.

+2 points

If allele B was dominant, it would disappear much more quickly.

+3 points [+2 disappear, +1 for more quickly than before]

With a heterozygotic advantage an equilibrium would be reached and allele B would be maintained in the population at a stable frequency.

+2 points: +1 for equilibrium, +1 B will be maintained, A will decrease/disappear

[Some students may have made assumptions, with the genotype frequencies being 0.46, 0.44, 0.10, AA, AB, BB, with $p=0.68$, $q=0.32$. Hopefully this isn't a problem.]