Respiration Study Question Sample Solutions

Note: Make sure to also try the "Possible Exam Wording" for each clicker question. These are all posted in the Clicker Questions folder on Connect.

Study Question 1

Consider the tadpole (larva) and adult life cycle stages of the pacific tree frog (*Pseudacris regilla*). The tadpole uses a dual pump to ventilate its gills with water, while the adult uses a buccal force pump to ventilate its lungs with air. (They are both capable of some cutaneous respiration.) Imagine that it is a hot summer afternoon (relatively high temperatures, but not hot enough to be lethal). Explain <u>two</u> challenges of respiration experienced by the tadpole compared to the adult frog when temperatures are relatively high. (6 marks)

1. Amphibians are ectothermic – on a hot day their body temperature will also be high **(0.5)**. Metabolic rate increases with body temperature, so both the hot tadpole and adult frog will require more oxygen per minute **(0.5)**, so they must both increase ventilation (and perfusion) **(0.5)**. Because water is much more dense (about one thousand times more dense) than air **(0.5)** the respiratory pump of the tadpole must do more work to pump water than the respiratory pump of the frog to pump air **(0.5)** so increasing ventilation requires relatively more energy for the tadpole than for the frog **(0.5)**.

2. The oxygen content of water is much lower than the oxygen content of air **(0.5)**, and as water temperature increases, the amount of oxygen dissolved in the water decreases even further **(0.5)**. For the tadpole, the partial pressure of oxygen in the water (P_1) decreases but P_2 (the partial pressure of oxygen in the blood) will be similar **(0.5)**, so the partial pressure gradient (P_1-P_2) will be lower **(0.5)**. Since, if other factors remain constant, the diffusion rate (dV/dt) of oxygen from the water into the blood decreases as P_1-P_2 decreases **(0.5)**, dV/dt is lower in the tadpole, making it difficult for the tadpole to obtain enough oxygen in these conditions **(0.5)**.

Study Question 2

Consider the spotted gar (*Lepisosteus oculatus*) and the South American lungfish (*Lepidosiren paradoxa*). The gar usually uses the gills to breathe water. However, in hypoxic water (water with low levels of dissolved oxygen), it is capable of breathing air, ventilating its gas bladder using a four-stroke buccal force pump. . The South American lungfish ventilates its lungs using a two-stroke buccal force pump. The South American lungfish (unlike the African lungfish we discussed in class) always breathes air, whether the water is hypoxic or normoxic (water with normal levels of dissolved oxygen).

a) Predict in which one of these two fish the gills would have a larger surface area. Explain your choice. (3 marks)
b) Describe two similarities and two differences in how the four-stroke and two-stroke buccal force pumps ventilate the lungs or gas bladder with air. (4 marks)

a) The gar is a facultative air breather **(0.5)**. Because it usually breathes water, the gills must be specialized for efficient diffusion of gases **(0.5)**, so they would have many secondary lamellae to increase surface area **(0.5)**. This lungfish is an obligate air breather **(0.5)**, which means that its gills are not capable of sufficient gas exchange to meet its metabolic needs **(0.5)**. The gills would have a greatly reduced surface area to minimize diffusion of oxygen from the blood into the water **(0.5)**.

b) Similarities (1 mark each for any 2 of the following):

- Both of these pumps generate suction by expanding the buccal cavity **(0.5)**, sucking air into the mouth from the lungs or gas bladder and/or from the environment **(0.5)**.
- Both of these pumps generate high pressure by compressing the buccal cavity **(0.5)**, which forces air into the lungs or gas bladder and/or out into the environment **(0.5)**.
- Both of these pumps use branchiomeric muscles **(0.5)** to expand and compress the buccal cavity **(0.5)**.

Differences:

- In the four-stroke pump, refreshing the air in the gas bladder requires two expansions and two compressions of the buccal cavity **(0.5)**, while in the two-stroke pump, refreshing the air in the lungs requires only one expansion and one compression of the buccal cavity **(0.5)**.
- In the two-stroke pump, fresh air from the environment and spent air from the lungs can mix in the buccal cavity **(0.5)**, while in the four-stroke pump, at any given time, the mouth contains only spent air or fresh air, so no (or minimal) mixing **(0.5)**.

Study Question 3

While hiking in the mountains, you find the remains of an unknown vertebrate lying in the grass. You can see that it would have used an aspiration pump to ventilate its lungs with air. It has air sacs connected to the lungs. Your friend thinks that this vertebrate is most likely a turtle (Parareptilia) or a squirrel (Mammalia). Evaluate this classification.

Step 1: Do the described features support this classification? (1 mark)
No. Although both parareptilia and mammalia use an aspiration pump **(0.5)**, neither has air sacs **(0.5)**.

Step 2: Which vertebrate taxa have these features? (1 mark)
Aves

Step 3: List <u>two</u> features of the <u>lungs</u> and clearly explain how <u>each</u> feature will allow you to definitely distinguish between parareptilia, mammalia, and any taxa that you listed in Step 2 – <u>describe</u> what you would look for to recognize each of these features in each of these taxa. (6 marks)

For each taxon, 0.5 marks for naming feature, 0.5 marks for **describing** how to recognize feature, maximum of 3 marks per feature:

1. Site of gas exchange: In parareptilia: faveoli **(0.5)**, in mammalia: alveoli **(0.5)**, in aves: air capillaries **(0.5)**. Faveoli are small, thin-walled compartments lining the walls of the lung **(0.5)**. Alveoli are much smaller than faveoli and are distributed throughout the lungs, not just along the lung walls / alveoli are **(0.5)**. In aves, air capillaries are tiny blind-ending compartments that extend off of the parabronchi **(0.5)**.

2. Connection with the trachea: In parareptilia, the lungs have a hollow central air chamber (or multiple central chambers) **(0.5)** that the trachea opens directly into **(0.5)**, while in mammals, the trachea divides into bronchi and bronchioles **(0.5)**, a series of branching tubes of smaller and smaller diameter **(0.5)**. In birds, the trachea connects (after dividing into two bronchi) with the parabronchi **(0.5)**, one way passages running from the posterior to the anterior of the lungs **(0.5)** (and also connects with the posterior air sacs).

Study Question 4

Consider *Oligocottus maculosus*, commonly known as the tide pool sculpin, a marine teleost (Actinopterygii) which lives in shallow waters off the coast of British Columbia. Sculpins can exchange gases using their gills and their skin (cutaneous respiration). They are facultative air breathers – they usually breathe water, but when the water becomes hypoxic (low levels of dissolved oxygen), they will switch to breathing air. At low tide, these sculpins live in tide pools. Imagine that a sculpin is in a tide pool during a hot summer night, breathing water using its gills. As the water temperature increases, the amount of dissolved oxygen in the water decreases. Explain, using Fick's Equation, how the diffusion rate of oxygen into the blood will change when the sculpin switches from breathing water (the water in the hot tide pool under the conditions described above) to breathing air. (In your answer, make sure to clearly explain what each of the relevant variables in Fick's equation represents.) (7 marks)

$$\frac{dV}{dt} = \frac{A}{dx} * D * (P_1 - P_2)$$

The partial pressure of oxygen in air (P_1) is much higher than the partial pressure of oxygen in warm water (P_1) **(0.5)**, so when the sculpin switches to breathing air, P_1 will be much higher than when it was breathing water **(0.5)** but the partial pressure of oxygen in the deoxygenated blood entering the gill capillaries (P_2) **(0.5)** will stay about the same* **(0.5)**, so the partial pressure gradient (P_1-P_2) will increase **(0.5)**. The diffusion rate (dV/dt) is directly proportional to P_1-P_2 **(0.5)** so if all other factors were equal, the diffusion rate (dV/dt) would <u>increase</u> when the sculpin switched to breathing air **(0.5)**.

However, when not supported by the water, the gills collapse because of gravity **(0.5)**, greatly decreasing the surface area (A) of the gills available for gas exchange **(0.5)**. The outer surface of the body would not decrease, so A for cutaneous respiration would stay the same **(0.5)**. So overall there would still be surface area for gas exchange, but it would be much less than when breathing air **(0.5)**. dV/dt is directly proportional to A **(0.5)**, so if all other factors were equal, dV/dt would <u>decrease</u> when the sculpin switched to breathing air **(0.5)**.

To determine if overall, dV/dt would increase or decrease, we would need to calculate** whether the increase in P_1-P_2 would be greater than the decrease in A **(0.5)**.

(Notes: * P_2 will stay about the same in this situation because it was not limited by the amount of oxygen that could dissolve in the blood, but by how much oxygen had diffused out of the blood into the tissues of the body in the systemic capillaries.
** This calculation is beyond the scope of this course but the implication is that, for sculpins, breathing air would only be advantageous when the partial pressure of oxygen in the tide pool was very low.)

Study Question 5

Consider the kookaburra (Aves) and the leopard moray eel (Teleost – Actinopterygii). The eel breathes water using gills.

a) **Describe two major similarities of ventilation in the kookaburra and the eel. For each similarity, explain how this feature of ventilation affects the efficiency of gas exchange in these two vertebrates compared to mammals – overall, is gas exchange more efficient in mammals or in the kookaburra and eel? (7 marks)**

EXCELLENT (7 marks)

1. In both the kookaburra and eel, air/water is pumped in only one direction **(0.5)** over the gas exchange surface **(0.5)** while in mammals, air is pumped tidally **(0.5)**. With tidal flow, some air inhaled into the lungs never reaches the gas exchange surface (the air in the dead space of the lungs) **(0.5)** but with unidirectional flow, all the air/water inhaled into the lungs/gill chambers will ventilate the gas exchange surface **(0.5)**. Also, with tidal flow not all the spent air is expelled from the lungs (when breathing passively) **(0.5)** but all the spent air/water is flushed out of the lungs/gills with unidirectional flow **(0.5)**. The partial pressure of oxygen is higher in freshly inhaled air/water than in a mixture of spent air and fresh air **(0.5)**.
2. In both the kookaburra and eel, air/water is pumped over the gas exchange surface during both suction phase and pressure phase **(0.5)** so the flow over the gas exchange surface is nearly continuous **(0.5)**, while in mammals fresh air only flows over the gas exchange surface (alveoli) during suction phase (inhalation) **(0.5)**. Therefore, in the kookaburra and eel, efficient gas exchange can occur for almost the entire respiratory cycle **(0.5)**, while in mammals it only occurs for approximately half of the cycle **(0.5)**

Overall conclusion: gas exchange is more efficient in the kookaburra and eel than in mammals **(0.5)**.

SATISFACTORY (4.5 marks)

1. Air/water is pumped unidirectionally in the kookaburra and eel **(0.5)** but tidally in mammals **(0.5)**. With tidal flow there is dead space, so not all the inhaled air makes it to the gas exchange surface **(0.5)**, but with unidirectional flow all the air/water that is inhaled will be used for gas exchange **(0.5)**. Also with tidal flow some spent air stays in the lungs after exhalation, so mixes with the fresh air inhaled with the next breath **(0.5)**.
2. Air/water flow over the gas exchange surface in the kookaburra and eel is nearly continuous **(0.5)** but not in mammals. This means gas exchange is possible for a larger proportion of the respiratory cycle in the kookaburra and eel than in mammals **(1)**.

So overall, gas exchange is more efficient in the kookaburra and eel than in a mammal **(0.5)**.

REQUIRES ATTENTION (3.5 marks)
Overall, gas exchange is more efficient in the kookaburra and eel **(0.5)**.

1. The respiratory pump of a kookaburra and an eel pumps the air/water in just one direction **(0.5)** but the respiratory pump of a mammal pumps the air in two directions, in and out through the same opening **(0.5)**. This means in mammals some spent air stays in the lungs after the pressure phase, and mixes with the fresh air sucked in during the next suction phase **(0.5)**, so the partial pressure of oxygen is less than if it was just fresh air **(0.5)**. The partial pressure of oxygen affects the efficiency of gas exchange.
2. In the kookaburra and the eel the ventilatory pump generates a flow of air/water over the gas exchange surface during both the suction phase of the pump and the pressure phase of the pump **(0.5)**. Mammals just pump fresh air to the gas exchange surface of the lungs during the suction phase **(0.5)**. So this makes gas exchange more efficient in the kookaburra and eel.

b) Describe one major <u>difference</u> of the ventilatory pumps in the kookaburra and the eel. (2 marks)

The eel uses a dual pump **(0.5)**, expanding and compressing the buccal and opercular cavities **(0.5)**. The bird uses an aspiration pump **(0.5)**, expanding and compressing the thoracic cavity **(0.5)**.

OR The eel uses branchiomeric muscles **(0.5)** to expand and compress the buccal and opercular cavities **(0.5)** while the kookaburra uses axial muscles **(0.5)** to expand and compress the thoracic cavity **(0.5)**.