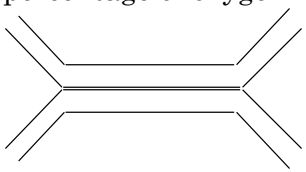
RESPIRATION — PROBLEM SET 5

Useful notes:
Alveolar p_AO_2 is similar in mammals & lizards – 13.8 kPa @ rest.
E = 20 kJ/liter O_2.

1) (3pts) Below is a diagram of a countercurrent exchange gill. Redraw the diagram and fill in the approximate PO2 values of the water and blood as they pass through the gill. Assume that the water enters the gill with a PO2 of 21 kPa and venous blood enters with a PO2 of 5 kPa and exits with a PO2 of 20 kPa. What is the concentration gradient between the water and blood? Be sure to draw arrows depicting the directions of water flow and blood flow. What percentage of oxygen in the water is extracted by the gill?



2) (3pts) The avian respiratory system is capable of extracting more oxygen from the air than the mammalian system, thus allowing birds to fly at high altitudes. Describe (or draw) the anatomy of the respiratory system in birds, and explain how this anatomical configuration allows them to extract a greater percentage of oxygen.

3) (3pts) Diagram the internal structure of a mammalian lung. Use your drawing to define the term "dead space." How does the dead space reduce the volume of fresh air that reaches the alveoli?

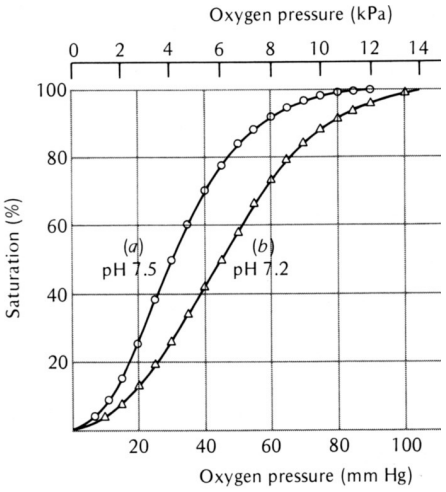
4) For a 1 kg monitor lizard (RMR = 3.7 kJ/hr at 30C). Assume that for active lizards: the lung volume is 210ml/kg, tidal volume at rest is 20% of lung volume, Vt during exercise is 50% of lung volume, and dead space is 8% of lung volume:

a) (1pt) Calculate lung volume, tidal volume (V_t), dead space volume (V_D), and alveolar ventilation volume (V_A).
b) (1pt) Calculate pO_{2ex} (pO_2 of expired air hint – see tidal lung lecture)
c) (1pt) Calculate VdotO2 at RMR (in liters O_2/min)
d) (1pt) Calculate V_E (minute volume) in liters air/minute
e) (1pt) Calculate breathing rate (it will be low – monitor lizards breathe infrequently when at rest).
f) (2pt) Calculate the oxygen flux between the lung and the blood AT REST that would be predicted from measured values of D_{LO2} (table 13-7) and ($p_AO_2 - p_cO_2$). How does this compare with the required O_2? If it does not match, how would the structure of the lungs and capillaries have to change to deliver enough oxygen? (answer this question even if it does match).
g) (4pt) Redo these calculations for maximum exercise – 6x RMR

5) A toadfish (genus *Opsanus*) is a sluggish, bottom-dwelling fish. It is a sit-and-wait predator. A 1 kg toadfish has an RMR of 0.1 kJ/hr in sea water at 10°C. Assume MMR = 3 x RMR and assume that the venous oxygen tension is 5 kPa during exercise.

a. (1pt) Calculate VdotO2 at MMR (in ml O_2/min)
b. (1pt) Calculate fraction of oxygen in inspired and expired water (FO_{2in} and FO_{2ex}; hint: use results from problem #1 and table 12-4.).
c. (1pt) Calculate V_E in liters water/minute (amount of water per minute that must flow over the gills).
d. (1pt) Calculate the tidal volume at MMR. Assume a breathing rate of 30 br/min.
e. (4pts) Calculate the surface area of gills required to support the MMR. Use the diffusion distance for *Opsanus* of 5 micrometers. Use a diffusion coefficient (D) of 5 x 10^{-6} cm^2/s. Hint: remember in your conversions that 1ml = $1cm^3$. How does the calculated value for SA compare with the measured value of 1.9cm2/g (from table 12-8, Withers? -- The calculated value comes out to be about 30% lower than the measured value – not too bad, considering all assumptions.)

EXTRA CREDIT (3pts)



(1) Redraw the hemoglobin (Hb) O_2-equilibrium curves. Label the curve that represents blood at rest and the curve with the Bohr-shift.
(2) If the $pO_{2\_arterial}$ = 100mm Hg and $pO_{2\_tissues}$ = 30mm Hg, how much O_2 is delivered at rest? with Bohr shift?
(3) It turns out that the Bohr shift results from a conformational shift of the Hb tetramer lowering O_2 affinity (allosteric inhibition at binding site). Myoglobin (Mb) does not have a Bohr-shift. Draw the Mb O2-equilibrium curve on your figure (see slides) — Explain some advantages of this system, with examples using numbers from the curves you drew.