The water was too calm to have any fun. By noon, Oscar had already eaten his fill of clams, and his parents were busy searching the kelp beds for abalone. With the sun sparkling off the turquoise bay and his little belly full, Oscar was on the lookout for adventure.

Unfortunately, so were Alicia the Albatross and Orlando the Orca.

“What’s up?” Alicia asked Oscar as she hovered overhead. “You look bored!”

“Yeah!” added Orlando with his New Jersey accent as he swam in slow circles around the little otter. “How about we play a little Vertical Game?”

“What’s that?” asked Oscar. He shouldn’t have.

“Easy!” said Alicia. “All you have to do is hold on - Orlando and I will do the rest!

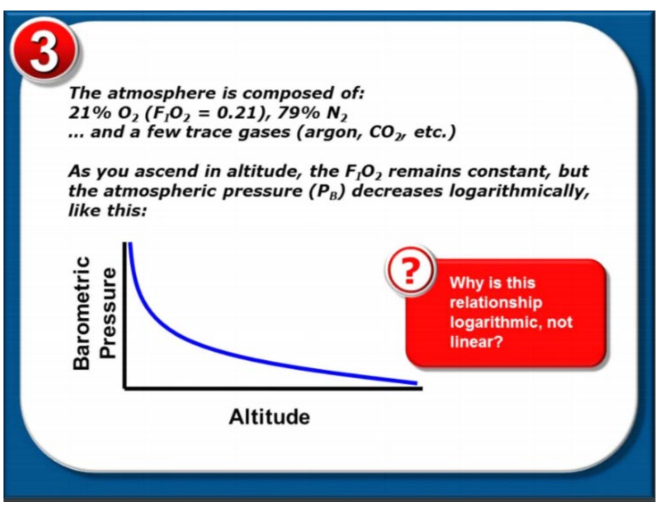
No sooner did Oscar say, "Sure – I'll try anything once!" than Alicia had him aloft.

As the bay got smaller and smaller and the seagulls turned into little dots far below, Oscar found the heights more thrilling than he ever imagined. But then he felt a little lightheaded… and then a little short of breath… and then a ***lot*** short of breath.

"Alicia!" he yelled as loud as he could, but even that effort took all his breath away.

"Alicia!" he tried again. "I think I need to go back down!"

Now, if Oscar had access to your set of flashcards, he would have seen that the barometric pressure (P_B) was dropping while he was rising:



And, further, he would have been able to calculate from the Alveolar Air Equation just what that meant for his alveolar O_2 levels (P_AO_2):

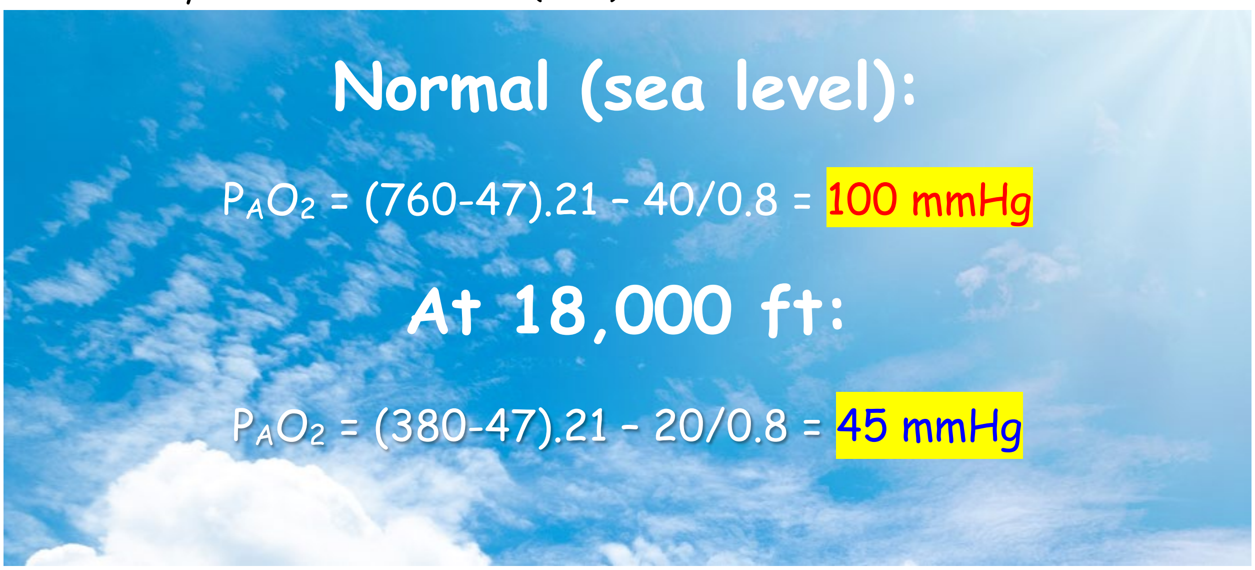
O_2

$$P_AO_2 = (P_B - P_{H2O})F_IO_2 - P_ACO_2/0.8$$
$$P_AO_2 - P_aO_2 = \text{"A-a Gradient"}$$
$$P_aO_2/F_IO_2 = \text{Oxygenation Index}$$

…But what about his alveolar CO_2 (P_ACO_2)? Would that change, too?

Yes, it would! Why? Because as Oscar's oxygen levels fall, his little carotid body chemoreceptors will be screaming about the low arterial PO_2 (P_aO_2), and that will cause his alveolar ventilation to increase, and that, in turn, will cause his alveolar CO_2 (P_ACO_2) to fall. Remember the story of Otto the Elephant and ventilation?

Let's put all this together and solve for the Alveolar Air Equation (the first equation in the red box, above). Assume that sea level P_B is 760 mmHg. But Alicia has kited Oscar up to 18,000 ft, which is only ½ atmospheric pressure (380 mmHg). Let's also assume that water vapor pressure (P_{H2O}) remains 47 mmHg at all altitudes and the fraction of inspired oxygen (F_IO_2) remains the same at all altitudes (0.21) and that the respiratory exchange ratio (R) also remains the same at all altitudes (0.8 – Oscar hasn't changed his diet). Finally, let's bring down Oscar's alveolar CO_2 from its normal level of 40 mmHg to 20 mmHg because his little carotid body chemoreceptors are screaming for him to breath harder because they sense low arterial O_2 (P_aO_2) levels:



Now, while Oscar is negotiating with Alicia to bring him down again, suppose he was wearing a pulse oximeter. What oxygen saturation would it show? To answer that question, you need to know what the relationship is between P_aO_2 (which we'll assume is close to P_AO_2, which we've just calculated) and O_2 saturation. That relationship is depicted in the oxyhemoglobin dissociation curve (OHDC). Why isn't the relationship a straight line? Because hemoglobin binds to O_2 molecules in a non-linear way (something called binding "cooperativity" that you may have learned and forgotten during college). If you plot Oscar's assumed P_aO_2 on that curve (below), you'll see that it corresponds to an oxygen saturation of 75%, which happens to be the same as "mixed venous" saturation when he's at sea level. But he's not at sea level, so his saturation is lower than the usual 100%. It's the same oxygen saturation that the veins would normally have, not the arteries. Not a good day.

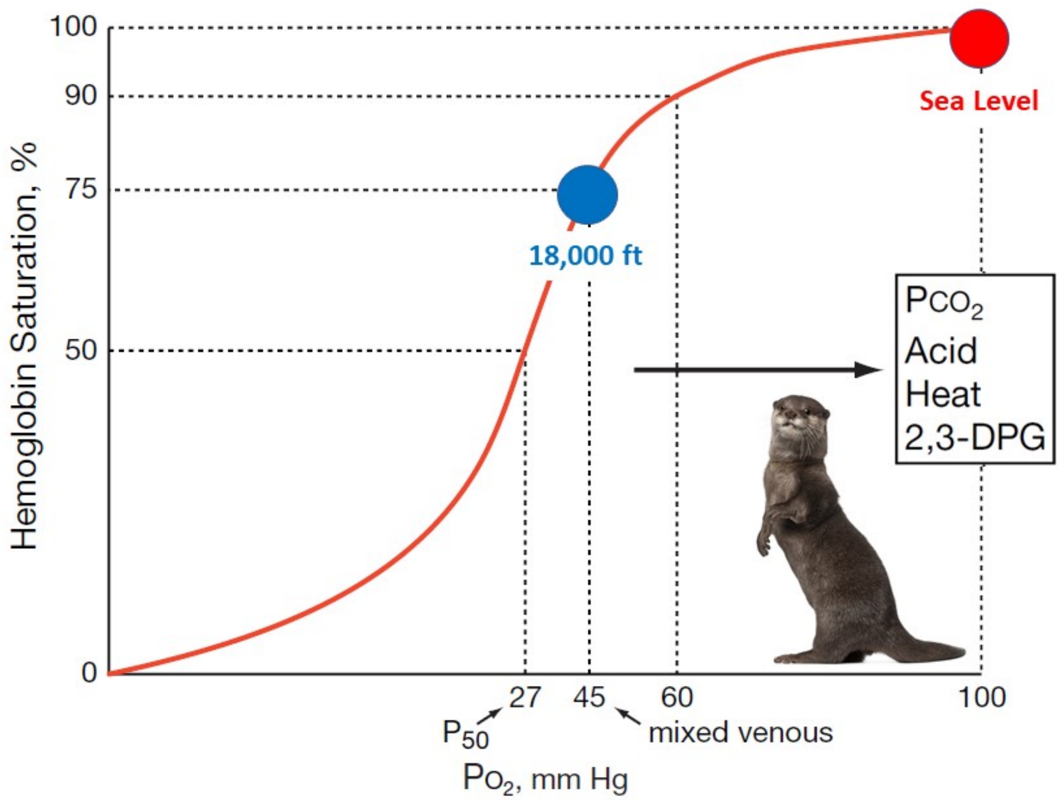


Figure 14.2. Oxyhemoglobin Dissociation Curve.
The curve is shifted to the right by increases in Pco_2, acid, heat, or 2,3-diphosphoglycerate (2,3-DPG).

One other thing, though: you can see from the dissociation curve that several things shift it to the right, including P_aCO_2 and acidemia (low pH). Since Oscar is hyperventilating, though (remember those carotid bodies), his P_aCO_2 is low and his pH is high, so his dissociation curve will be shifted to the left. That means that his actual oxygen saturation will be higher than 75%. But not so high that he's happy.

Alicia finally relents and drops (that's right – drops) Oscar. She can be that way.

Thankfully, even though Oscar achieves terminal velocity on his way down, his body is streamlined and he makes a a 9.0/10 Olympic-level diving entry into the sea. And his alveolar oxugen levels have returned to normal sea-level values. That is, until Orlando comes back into the story.

“How was your flight?” Orlando asks.

“Not so good,” Oscar admits. He’s had enough of the Vertical Game.

“Well, if you don’t like heights,” Orlando says, “let’s see how you do with the depths. Hold on!”

No one ever accused Oscar of being a coward. Gullible, maybe, but not a coward. Down, down, they went, until Oscar’s ears ached from the pressure and his chest felt like it was caving in.

Why did his ears and his chest bother him, but not his arms or his legs, or even his brain? Because the increased water pressure squeezed all the liquid parts of his body by the same amount, and so they don’t even know they’re being squeezed. They can’t get any smaller and the pressures inside them and outside them and all around them are the same. That’s called Pascal’s Principle (not Pascal’s “Princi***pal***” – his school Principal didn’t like him because the boy was smarter than all his teachers, but that’s another story). Not so for the middle ears or the lungs, though. They contain compressibe gas and can be squeezed to smaller volumes when the pressure outside of them rises. That’s called Boyle’s Law.

If you’re thinking ahead, maybe you’re wondering if this increased pressure is a ***good*** thing? “Good” as in increasing the P_AO_2 in Oscar’s lungs because P_B is higher and if you plug a higher P_B into the alveolar air equation, you get a higher P_AO_2. If you’re thinking that, good for you! Unfortuantely, it doesn’t help. The reason is that the total number of oxygen molecules in Oscar’s lungs while he’s holding his breath are the same, whether they at higher partial pressure or not. He’ll use them up at the same rate as if his lungs were bigger and the P_AO_2 was lower.

Finally, Oscar had enough of the Vertical Game and Orlando relented. In fact, when they surfaced, Alicia was waiting for them with a nice sea food buffet.

From: Munis, JR “*Just Enough Physiology*”, Oxford University Press, 2012. & JamesMunis.com