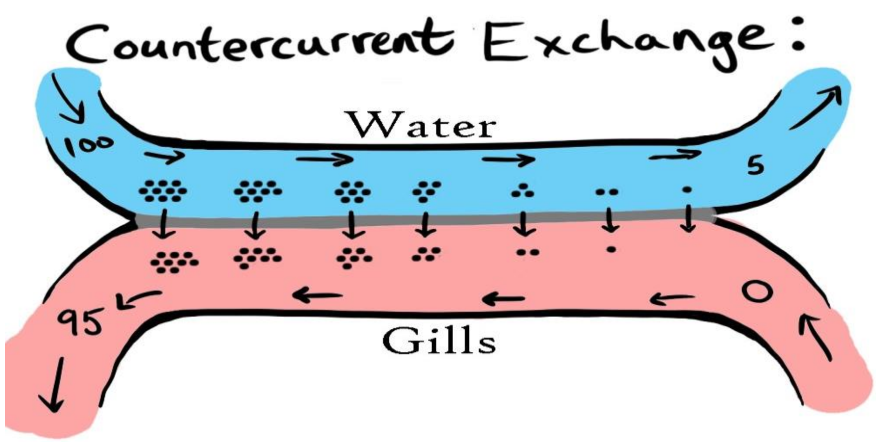
1.

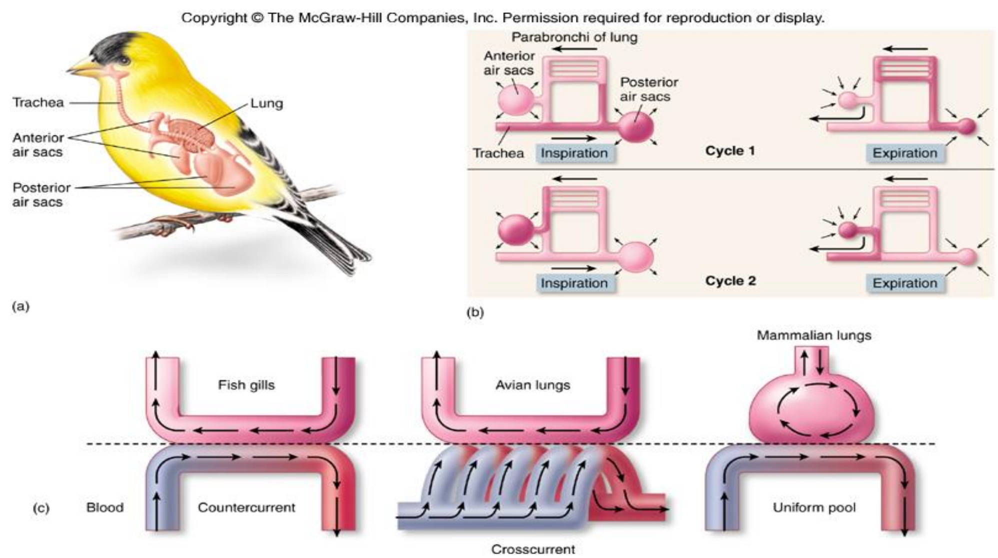
a. The main comparison between the artic fish and the predators is that the fish are ectothermic and the predators are endothermic (mammals and birds). Being ectothermic, fish do not create their own heat and have much less energy/ oxygen needs compared to the endothermic predators. Since the ectothermic fish are subject to the external temperature, they are unable to work their organs and muscles as fast or efficiently as an endotherm would. All biological reactions that occur within the cells happen at a faster rate at warmer temperatures, but not too hot that the proteins catalyzing these reactions denature. This is a threat and reasoning for the endothermic predators being fast enough to catch the fish prey. However, this also means that the metabolism (energy demands) of the fish are also lower than warmer climate fish. They are not able to work their organs/ muscles as fast and therefore do not need extra energy/ oxygen to fuel these movements like warmer organisms need to do. Fish have evolved a very efficient way of extracting oxygen out of the water around them, countercurrent exchange.



From the image above you can see that the water and the blood are moving in opposite directions. This maintains a partial pressure gradient throughout the entire time that water and the gills are in contact. The gradient makes the oxygen move from the water and into the blood of the gills. This gradient will always want to achieve equilibrium between the two liquids. However since the currents are traveling in opposite directions, the ocean water will always maintain a higher oxygen concentration than the blood it is in contact with. My first hypothesis is that because these arctic fish are ectothermic they do not need extra oxygen to maintain a normal body temperature. The resulting colder body temperature of the fish means they are unable to maximize the functions of their organs/ muscles and therefore use less oxygen to fuel them. All of these observations in combination with the efficient oxygen delivery system into the blood mentioned earlier, provides enough oxygen in the body without the need for a more efficient delivery system such as hemoglobin.

The second hypothesis involves the previous physiological differences mentioned in the last one but instead of the ectothermic vs endothermic differences, I will focus on the oxygen availability in water compared to air. All the predators mentioned retrieve their oxygen from the air and not water. This is important because there are differences in the amount of oxygen available to these organisms. The following equation describes the concentration of a gas into a liquid, Cx = AxPx. Ax is referred to as the absorption coefficient of a gas. Ax varies between different gasses and temperature. It turns out that as temperature increases, the Ax or solubility of oxygen into water decreases. This then means that there is more oxygen absorbed into colder temperature waters than compared to warmer waters. Therefore, the artic fish living in these colder waters have a much richer source of oxygen around them compared to warmer climate fish. This is also true for the predators mentioned, because they only have adapted to breath air, they are unable to retrieve this high quantity of oxygen in the water. This would explain why the artic fish do not need to rely on hemoglobin, because they have such a high amount of oxygen around them to absorb in addition to the efficient gill system and ectothermic behavior.

b. The predators in question are either mammals or birds, each of which rely on oxygen in the air no water. The lungs of seals and whales (mammals) rely on a system called tidal ventilation. The muscles around the lungs will increase and then decrease the volume of the lungs, pushing the air in and out. This results in air coming in and exchanging close to half of its O2 with the blood flowing through the lungs. Then the used air leaves out the same way with more than half of its O2 still. Penguins (birds) on the other hand utilize a more efficient respiratory system than mammals. Birds use cross current exchange, from the figure below you can see that there is a constant flow of oxygenated air going through the lungs by one of the sacks within the organism.

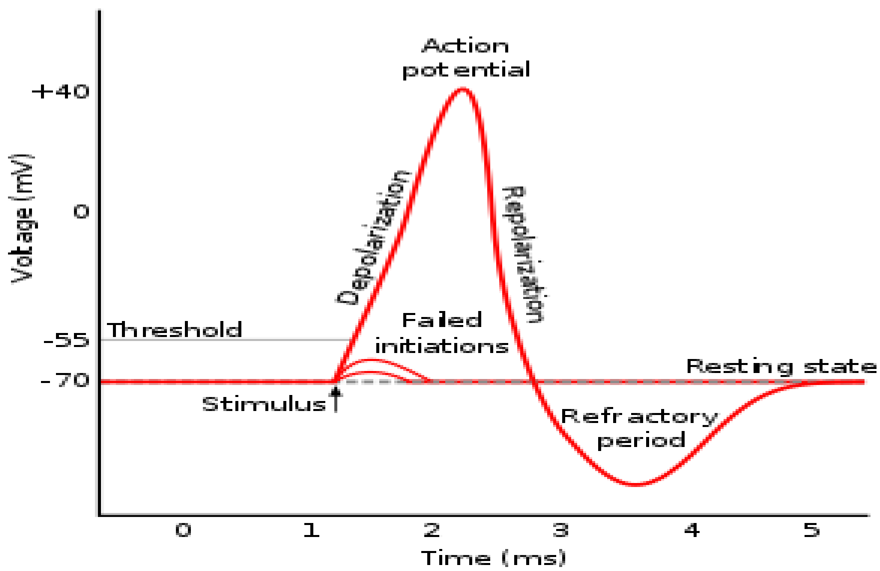


This allows birds to extract more O2 at a time and maintain a partial pressure gradient because the air is in contact with multiple currents of deoxygenated blood at a time. Countercurrent used by the artic fish is still more efficient than cross current or tidal. The first hypothesis would be that the predators must extract oxygen only from the air, in a less efficient manner and therefore need to rely on a much greater density of hemoglobin to store enough oxygen in the body during the time the predators are in the water.

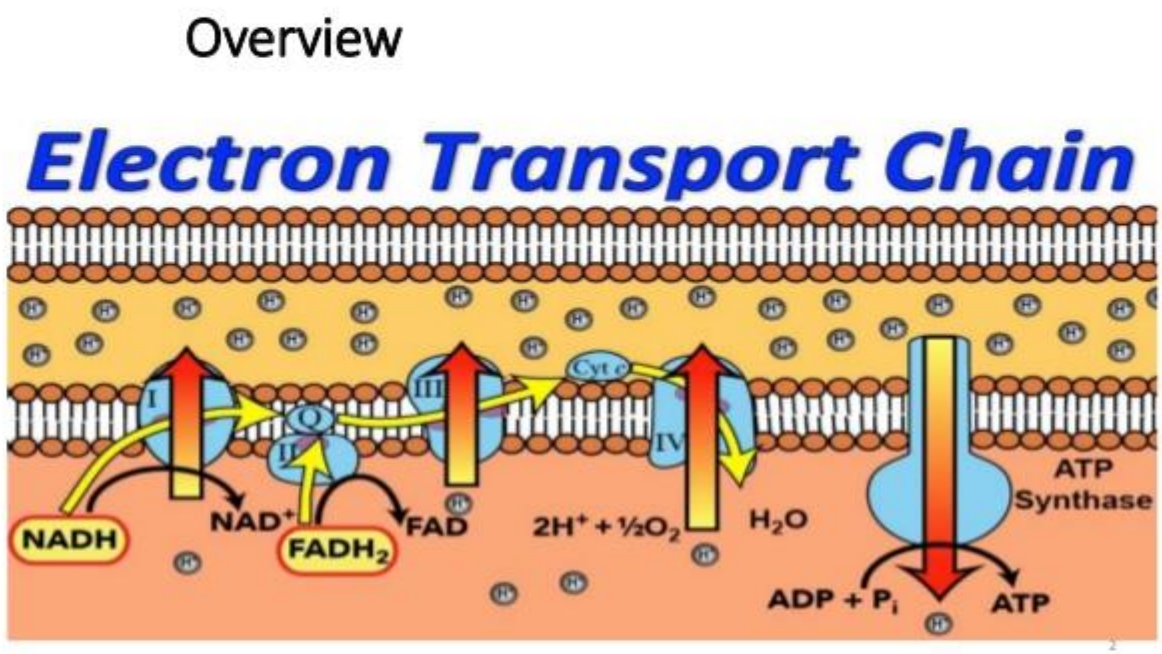
The second hypothesis focuses on these predators evolving to work anaerobically (without oxygen) with certain body functions and therefore invest into oxygen storage for the vital organs that need it (heart and brain). These predators have evolved to have a much greater number of mitochondria in their muscles than compared to the traditional land counterparts. During a dive, the animal's body responds with the vasoconstriction of the muscles. This means that much less blood is delivered to the muscles and therefore the hemoglobin containing the oxygen is not wasted in the muscles. The muscles will instead rely on anaerobic respiration which produces energy without oxygen, however this produces much less energy. The large amount of mitochondria is produce as much energy as possible during this time without oxygen available. Because these predators can't breathe underwater, they must invest in these strategies to reserve oxygen during dives. The extra hemoglobin allows for more oxygen to be stored in the blood before a dive and all this oxygen is reserved for the brain and heart of these predators (high endothermic demands) and the rest of the organs will function/ survive just enough to allow the predators to capture food.

2.

a. The first gradient I will be describing involves the neurons of our cells and how they produce action potentials, the signals they send to other neurons or cells in the body to produce a desired response. At rest a neuron is always working/ using energy to maintain a negative voltage inside the cell and a positive one outside the cell. This is maintained by having a high concentration of Na+ ions outside of the cell and a high concentration of K+ ions inside the cell, in addition to large negatively charged proteins within the cells. The Sodium potassium pump works to organize these ions into this gradient, moving 3 Na+ ions out and 2 K+ ions into the cell at a time. This movement of ions uses energy stored in ATP to function. The ATP is usually produced within the body from the process of glycolysis. The sodium potassium pump will move these ions in and out until the electrical and concentration gradients of the ions reach around equilibrium, at about -70mv in the membrane. When an external signal, like another action potential, comes in contact with the neuron and is strong enough, it will push the voltage of the membrane past the threshold (around -55). This all or none mechanism will trigger the opening of voltage gated Na+ channels, flooding the neuron with positively charged sodium, depolarizing the membrane (changing the membrane voltage more positive towards +40). At this point the K+ gated channels will be triggered to open, releasing potassium out of the neuron and repolarizing the membrane to lower than -70 mv. This action potential will trigger the same reaction down the axon of the neuron, sending a wave of electrical signal to wherever the axon is connected to. The neuron is now below its resting potential of -70 mv and must again use the sodium potassium pump and ATP to rearrange the ions back into the gradients used before to produce an action potential. This process can be seen in the image below.



b. The second gradient is oxidative phosphorylation or the electron transport chain.



I will walk through and describe what the figure above is showing. NADH and FADH2 are both products formed from an earlier process called the krebs cycle or citric acid cycle. These two products essentially act as electron carries and will give up their electrons to the proteins inside the cellular membrane (I and II). When these electrons are removed from NADH and FADH2, the H+ ions will detached and be pumped through the protein channels into the intermembrane matrix. This results with an increased concentration of H+ ions on one side and NAD and FAD as byproducts to be reused by the cell in other reactions. These acquired electrons will be accepted by ½ O2 and 2H+ ions to produce H2O as a byproduct. Finally, there is still a buildup of H+ ions in the intermembrane matrix. When this gradient reaches ATP synthase, it releases the built up H+ ions through and back into the cell. This change in gradient produces electrical energy that an attached ADP and Pi will store into a bond on a newly synthesized ATP. The leftover H+ ions are accepted by NAD, FAD, and 1/2O2 mentioned earlier, allowing for the reaction to be initiated once again.

3. N/A
4.
    a. The reaction time of an individual should not be altered that much by being in a dive response. The dive response works to prepare the body for long period of time underwater without oxygen availability. This is done by inhibiting respiratory muscles (so you don't start attempting to breath underwater), vasoconstriction of limb, skin, intestine, and kidney arteries (redirecting oxygenated blood flow to crucial organs like the heart and brain), and finally the parasympathetic nervous system kicks in to reduce heart rate and therefore reduce the oxygen consumption of the heart. The reaction time of the hand to flex relies on the signal (action potential) sent from the brain to the hand to flex the needed muscles. Since the brain is being prioritized with oxygenated blood, it would function normally in sending this signal. The signal would travel at a normal speed even if the hand was subjected to cold temperatures, because the nerve containing the signal to tell the hand muscles to flex is in the arm, and not the hand. Therefore, I hypothesize that since the brain is still functioning normally, the hand would be able to react in the same amount of time, as this does not involve any continuous muscle constriction or maximum use of muscular power.
    b. Grip strength differs from hand reaction time because it involves the majority of the hand muscles to constrict over a period of time to produce the greatest amount of muscular force possible for those muscles. As mentioned earlier, the dive response reduces the heart rate and restricts blood flow from the limbs of the individual to conserve oxygen for the brain and heart. Different skeletal muscle cells are either adapted to work aerobically (red fiber/ slow twitch, investment in blood vessels and mitochondria for steady/ long lasting energy production) or anaerobically (white fiber/ fast twitch, investment in actin/ myesin, structures that produce the mechanical force in muscles). But when oxygen is

available, all these muscle cells can function effectively and contribute to producing a grip strength. During a dive response however, the body has elected to restrict oxygen from the skeletal muscles and therefore they must rely anaerobically for energy to produce the grip strength. This results in less muscle fibers being used (only the white fiber ones able to function) to increase power output and these muscles have inadequate energy production from lack of oxygen, resulting in fast muscular fatigue.

If the individual however becomes distracted, the dive response is lost and the sympathetic nervous system will take over. The sympathetic nervous system acts as the guide for the body to prepare itself for any stressful about to happen, increasing its chances of survival. Acetylcholine is released to activate Joe's adrenal glands. His adrenal glands will then release both epinephrine and norepinephrine. The epinephrine will be released into the blood stream, acting as a hormone, this will have a widespread response to Joe's body, like increased heart rate. Norepinephrine will affect the beta receptors which will signal certain smooth muscles to relax. This will increase blood flow to the lungs and muscles. The opposite effect is now occurring, blood is being pumped to the muscles and therefore more muscle fibers can be recruited to increase the grip strength over a longer period of time. This of course means that oxygen will be used up much quicker by the individual. Which is why it is important for divers to remain calm during dives so that they activate the dive response (conserve oxygen) and not the sympathetic nervous system (increase oxygen consumption), allowing them to stay under water for longer.

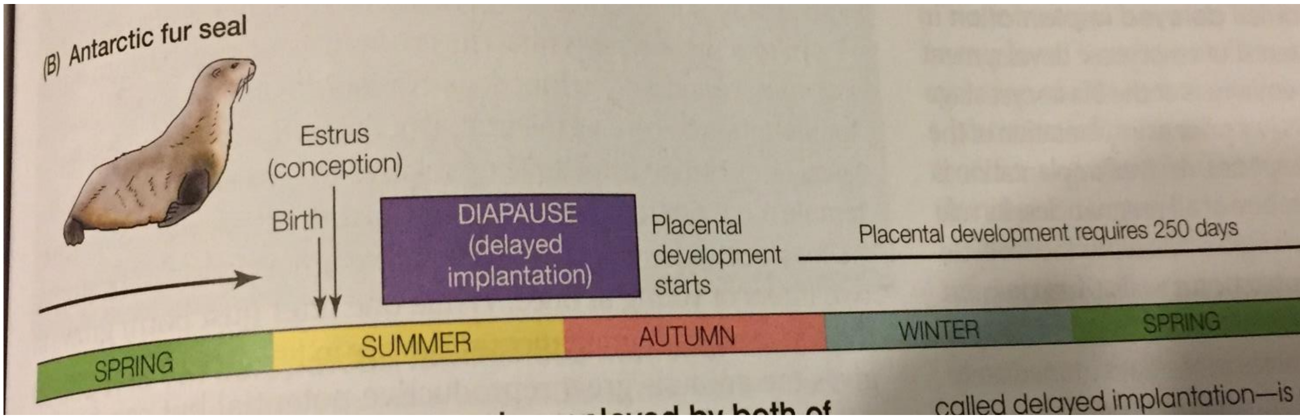
5. Firstly, comparing the differences in terrestrial vs. aquatic environments is important, because water maintains its temperature much more effectively than air does. You can observe this when attempting to boil water, the air around the stove heats up very quickly while the water takes a much longer period of time to increase in temperature. This is important for when day transitions

into night. On land, day to night usually means a significant drop in the outside temperature, while the ocean will maintain a more constant temperature scale throughout the day. This means that an artic fish will only need to adapt to the usual temperature variation in artic oceans without needing to worry about dropping temperatures at night. On the other hand, on land, a lizard would need to adapt to a dramatic decrease in temperature during night time. This is where endothermic organisms have an advantage. They use extra energy to maintain their own internal body temperature and are able to survive (using additional adaptations such as fur, feathers, etc) in colder environments. An ectothermic lizard however could possibly survive during the day with enough sunlight but once nighttime came, the body temperature would decrease too dramatically for the organs to adapt or function properly. Any internal reaction requires enough heat to function efficiently, if temperature drops too much then the proteins will be unable to function fast enough or the cellular fluids will freeze and burst the cell.

Because the oceans have less variability between day and night temperatures, aquatic ectothermic vertebrates have had the advantage of slowly migrating away from warm waters and becoming more and more adapted to colder water over many generations of many species. These species would have gotten used to a certain temperature for its area of the ocean and through random mutations, they would acquire some gene that allowed for the tolerance of colder temperatures. These mutant offspring would inhabit new colder niches and the pattern would continue into colder and colder waters. This is most likely why many artic fish have adapted antifreeze or glycoproteins that plug up and stop ice crystals from forming inside the cells. I hypothesize that because land provides too much temperature variation from day to night, there is too many survival pressures on terrestrial ectotherms to expand into these colder environments. This is not to say this is not possible for reptiles to adapt anti freezing genes or strategies to survive in these colder environments, as there might have been past extinct species that accomplished this. The problem today is that endotherms have evolved to be far better adapted for the cold and so any reptiles with the potential to produce new adaptations for a colder environment would be quickly outcompeted or eaten by the much more adapted endotherm already occupying that niche.

6.

a. I will be using the Antarctic fur seal as my example for this question.



Based off its name, you can determine that this species of seal are native to the harsh environmental pressures of the Antarctic. This means that during the colder months of the year (autumn and winter) it becomes much more energetically expensive and harder to survive. The fur seal will give birth and then immediately begin estrus (ovulation). The nearby males will complete conception with the fertilization of the egg with his sperm. Even though conception occurs right after birth, the female fur seal will begin diapause to delay the placental development until at least 250 prior to the next summer season. The mechanism that delays the placental development involves the parental care of the newly born seal pup. When the mother seal begins breast feeding, prolactin is produced in the body. Prolactin also acts as an inhibitor to progesterone and estrogen, which allow for implantation of the embryo. Therefore, the mother is able to delay placental development as long as she is caring for a prior offspring. This results in her next birth occurring again during the most ideal season of the year and she won't need to worry about finding a mate at the most ideal time either.

b. Day length is a reliable signal for the time of the year because of the earth's axis. When a location on the earth is in its winter months, it is furthest away from the sun and therefore the nights are longer. The same concept is right but in the opposite direction during the summer months. A mechanism that could allow for an organism to detect day length time is from the secretion of melatonin. Melatonin is the body's way of saying it's time for bed when the daylight is gone. Therefore, during the winter when the nights are longer, there is more of an accumulation of melatonin that could also act as a reproductive signal. This also explains why northern species populations will typically only reproduce 1-2 months out of the year and subtropical populations can breed all year long.

c. Global warming would cause a problem with the seal because of lost for habitat (ice) to raise their young and for reproduction to occur. At first it may seem that the warming temperatures would throw the species off of its reproductive cycle. However, I argue that if day length is the main factor for determining when to reproduce, the species should not be affected. The change in global temperature would begin changing, but the earth will still remain on its usual axis and therefore the amount of sunlight during certain times of the year would remain the same. Although the earth is slowing down very slowly, lengthening the days, it is not fast enough to be noticed by modern species.