Life and the Chemical Ocean – Tutorial Script

Almost all organisms on planet Earth require oxygen to survive. Whether on land or in the oceans, through lungs, gills, or other processes, the primary mechanism for getting that oxygen into our bodies is diffusion. **Diffusion** is a process in which most molecules can move freely across boundaries and do so constantly, eventually achieving equal concentrations of all diffusing molecules on both sides of the boundary. Diffusion is the key process at work in the lungs of mammals, including humans and blue whales.

When we inhale, we take in air that is, as you know, 21% oxygen with less than 0.04% carbon dioxide. That air travels through our lungs and into tiny airways that have a high surface area and come in contact with our blood. Oxygen-poor, carbon-dioxide rich blood that has resulted from respiration processes through our bodies is carried to the lungs where the carbon dioxide diffuses out of the blood and into the lungs, while the oxygen diffuses out of the lungs and into the blood. This now-oxygen-rich, carbon-dioxide-poor blood returns to the body where it is available for further respiration. Our lungs have an efficiency of 25% -- meaning 25% of the available oxygen in the air we breathe is transferred to the blood stream.

Fish have an even more efficient process for extracting oxygen. They use **gills**, which have a surface area ten times greater than the surface area of the fish's body. The gills consist of a number of gill arches, along which run blood vessels that feed millions of gill filaments. Water that passes through the mouth of the fish is deflected across the gill filaments and out the back of the **operculum** or gill covering. Across these filaments, oxygen-poor, carbon-dioxide-rich blood moves against the current of water, allowing maximal diffusion and extracting 85% of the available oxygen from the seawater. This blood is then circulated through the body of the fish for respiration and returns to pick up more oxygen as needed. Bony fish and cartilaginous fish can be distinguished by the presence of an operculum – most bony fish have one, and it covers most of the gills. Cartilaginous fish have gill slits – like portholes in the side of a ship. This picture of a Chinook salmon caught in Northern British Columbia shows the individual gill arches and filaments quite well. It also shows the path that water takes from the mouth through to the back of the operculum.

Not only is diffusion an important process in gas exchange for all marine organisms, but it is also the primary mechanism for autotrophs to absorb nutrients and for many organisms to eliminate their wastes. Seaweeds, sponges, and all single-celled organisms in the oceans do most of their molecular exchanges through diffusion from and to the surrounding water. In fact, one of the major differences between marine autotrophs and most land autotrophs is that on land, autotrophs get their nutrients and water through diffusion through their roots, while in the ocean diffusion can happen across all outer cell walls at any part of the organism, including all stipes and blades on kelp and other seaweeds.

Pause now.

This image shows three kinds of molecular transport – all of which are important to marine life. The top image shows diffusion, which we've already discussed. The middle image shows osmosis, which we'll get to in just a moment. The final image shows **active transport**. You can see from this image that the concentrations of molecules are NOT the same on either side of the boundary. Such a situation is not in equilibrium. It must be constantly working against diffusion. It thus requires a lot of energy to maintain. The boundary will open to transport the molecule uphill so to speak, toward an area of higher concentration, but only if energy is provided to the system to make it happen. An example of active transport is what the body does when it stores fat in blubber and other fat-rich cells or when sugar is stored for later use as needed. You can explore active transport processes further in a biology class. For now, it's sufficient to know that active transport requires an energy source and will not happen without it.

Now let's return to the middle image – **osmosis**. In this case, equilibrium is reached on both sides of the boundary, but because the boundary has holes that allow only water molecules through, equilibrium is achieved not by equal numbers of each molecule on both sides, but by water moving toward the side that needs dilution. For example, here is a pail of fresh water. If you put your hands in this bucket, what will happen?

Your skin cells will allow water to move across them, but not ions. The fluid in your body is salty. If you've ever spent too long in the bathtub or swimming pool or hot tub, you know that the water will move across the boundary from the bucket into your hands – attempting to dilute the salty water in the cells of your hands. If you leave your hands in too long, they will swell up with water, and the prune appearance results, which actually means your skin has swollen up larger than your fingers can contain it.

What happens if the pail contains seawater?

The salty fluid in your hands is NOT as salty as the seawater, so the water in your body moves out into the seawater in an attempt to dilute it. Thus, after swimming in the ocean, your body will be dehydrated, and you'll need to drink water to replace what you've lost. This is also why you should never drink seawater. If you do, once it enters your body, it will draw out the water from the surrounding cells, and you'll actually lose vital water from throughout your body.

This image shows how your blood cells respond to osmosis. If your cells are like this bag and contain a salinity of 2%, when you put them into a bucket of distilled water with no dissolved ions, water will move into the bag or cell to dilute the 2% solution inside. That means your cells swell up with water and can burst if this situation persists for too long. Yes, that means that if you drink too much fresh water – and your body can't eliminate it fast enough, you can die from burst blood cells. Such a situation is extremely rare, but has been known to happen when people are forced to drink water beyond their body's comfort levels and capacity. When the cells or bag are in contact with water that is saltier, water in the cell will move outward to dilute the surroundings. Result is that the cells dessicate and eventually break apart. A healthy cell is shown on the right, in which water flow in and out are matched, because the concentrations on both sides are the same.

So how do saltwater fish regulate osmosis and combat the continual water loss? They drink lots seawater, use specialized cells in their gills to remove the salt, and then excrete that salt periodically through very limited, but highly salty urine production. What about freshwater fish? How do they regulate osmosis and combat continual water gain? They do the opposite. They drink no water. They retain as much salt as possible within their bodies, and they urinate frequently mostly pure water. Because these regulation processes are completely opposite, there are very few fish that can do both. For this reason, there is not a large diversity of fish that can survive in estuaries where freshwater and saltwater mix. These are, in fact, the least diverse ecosystems in the oceans—mostly because of the challenges of handling changing osmotic processes.

Pause now.
For more information and more detail, continue on to the next video in this series.

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Living Ocean Video Series:
Part 1: Life and the Ocean's Physical Environment
Part 2: Life and the Ocean's Chemical Environment
Part 3: Marine Life Symbiosis

Life and the Ocean's Chemical Environment
Produced by Katryn Wiese
City College of San Francisco

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