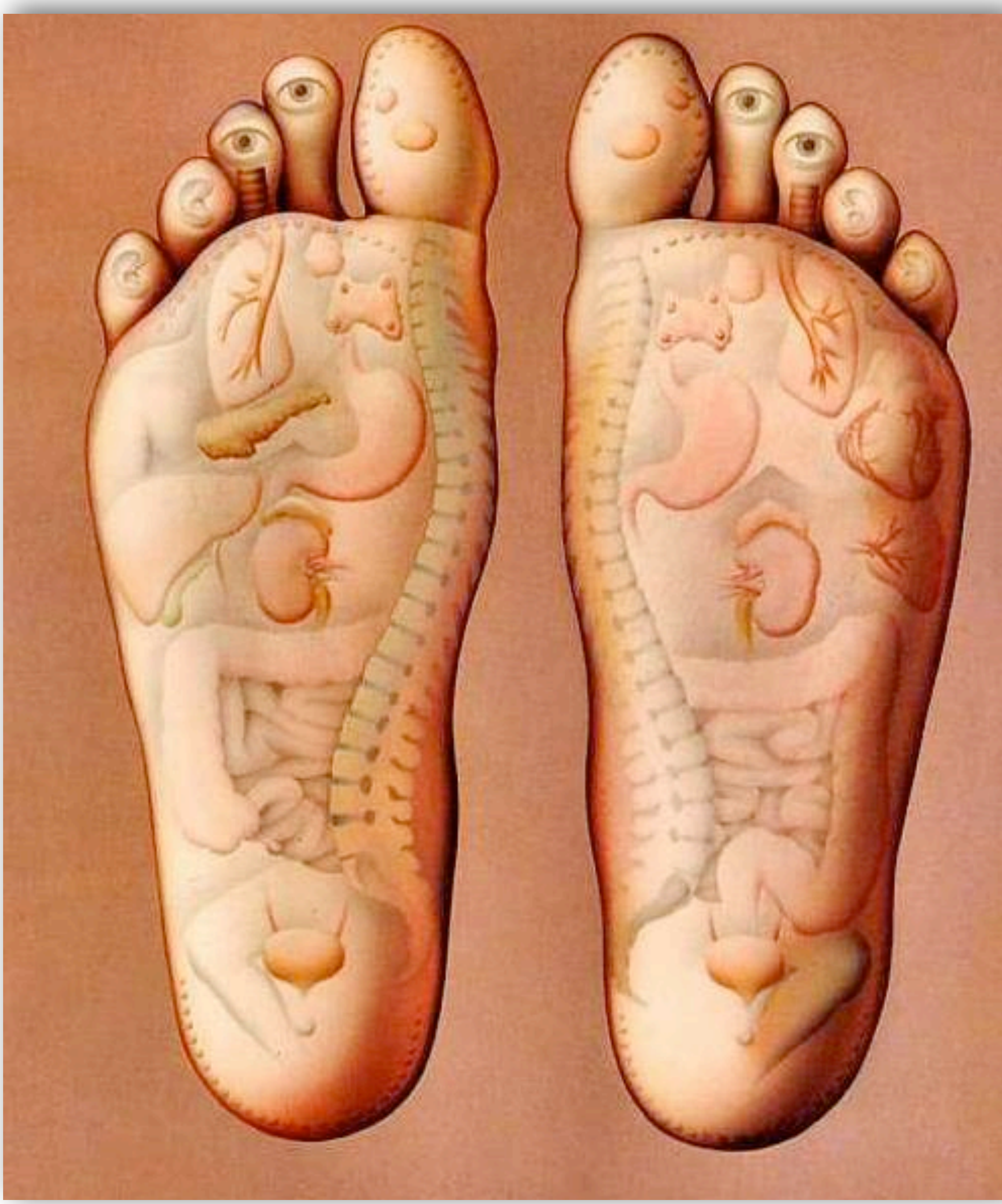
Running on Chemistry

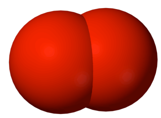
Module 5 • i2P • La Ruta de Sal



Source: Apangshusaha

"Dancing and running shake up the chemistry of happiness."

- Mason Cooley



Thin Air

Running a marathon a day for a week is a challenge, even at sea level. Running this distance at 12,000 feet elevation, where there is 35% less oxygen in every breath, the challenge becomes even greater. How will the i2P team react to the decreased atmospheric pressure on the Salar de Uyuni? The answer lies in the chemistry of the body.

In the previous module - The Building Blocks of Life - the chemical composition of life was examined. Human beings - like all life forms - are composed of atoms arranged in molecules that form tissue, organs, a supporting skeleton and skin. The laws of chemistry dictate the manner in which the atoms and molecules interact. The study of the chemistry of living things is called biochemistry.

> Did You Know?
>
> At sea level there is a pressure equivalent to 10 meters of water pressing down on all of us all the time. This is because of the weight of the air above us in the atmosphere. When you travel up a mountain, there is less air above you in the atmosphere so The pressure is less.
>
> see: altitude

Running is a complex set of actions that are a product of coordinated chemical reactions. Studying the chemical reactions that allow i2P team members to run across the Salar de Uyuni provides an ideal opportunity to study human biochemistry. To do so we will focus on two elements common to the local environment: sodium, which forms much of the crust of the Salar, and oxygen that forms 21% of the air. By examining the role of these two elements in human function we can illustrate the fundamental importance of the principles of chemistry to our everyday lives.

Figure 1: The SAlar de Uyuni

The First Breath

When they start off each day on the Salar de Uyuni the i2P team will don their gear in preparation to run. Before setting out the first action they take is to breathe. Breathing is something human beings do automatically. Breathing is triggered by sensors in the bloodstream called *chemoreceptors* that measure chemical byproducts of exercise metabolism that cause the pH (see definition) of the blood to fall. The lower the pH the faster a person will breathe. The harder muscles work - as is the case when one runs - the more the pH falls, causing the sensors to send more frequent messages to the muscles, and increasing the respiratory rate.

Did You Know?

The brain is the most sensitive organ in the body to the lack of oxygen. Blockage of the main arteries to the brain either during surgery (or by strangulation!) will result in unconsciousness within three to four minutes and cell death or a stroke will occur shortly after that.

see: brain

Definition: pH

pH is a measure of the acidity or basicity of an aqueous solution.

Each breath of air draws oxygen into the lungs. The oxygen crosses thin lung membranes and dissolves into the bloodstream, where it is picked up by red blood cells and carried to all tissues of the body. The steady flow of oxygen to the trillions of cells in the human body follows clearly defined properties of chemistry. Gasses such as oxygen are always equally distributed in space. When there are two adjoining spaces with different amounts (partial pressures) of oxygen, the oxygen molecules automatically flow from the area of high concentration to the area of low concentration. An example of this occurs when oxygen flows from the air in our lungs into the blood, and from the blood into our working muscles.

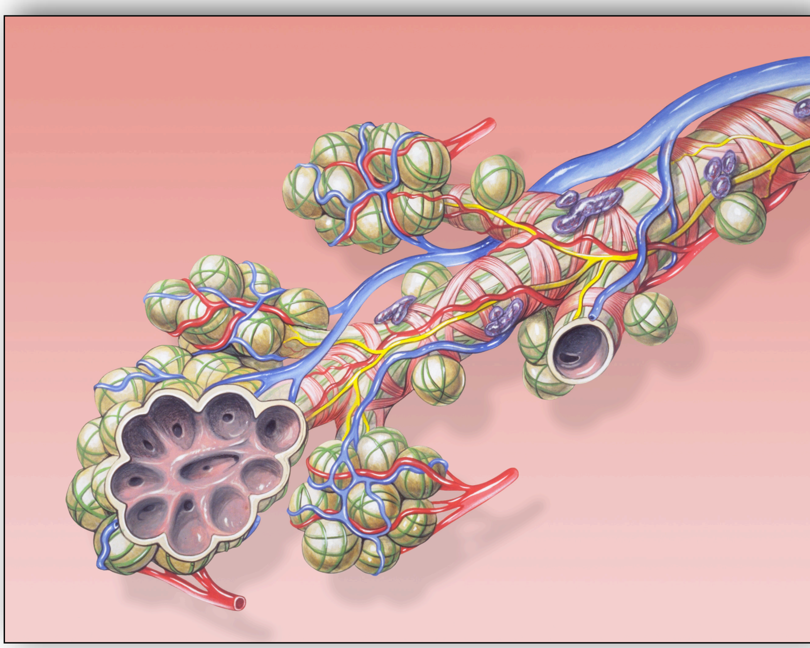


Figure 2: The air humans breathe travels down into sacks called alveoli from which oxygen crosses into the blood stream (red) and is carried to all the tissues of the body (source: Patrick J. Lynch, medical illustrator; C. Carl Jaffe, MD, cardiologist)

Class Exercise:

Calculate the partial pressure of O2 at your school by inserting the elevation where you live in the following calculator.

see: altitude

Did You Know?

By volume the air we breath is roughly 78% nitrogen, 21% oxygen, 0.96% argon and with trace amounts of carbon dioxide, helium, water, and other gasses.

Human cells 'burn' oxygen to generate energy, creating an oxygen deficit in cells. The low oxygen content of cells draws a steady flow of oxygen from the blood stream. The blood stream in turn is always being depleted of oxygen by hungry cells, so a steady flow of oxygen from the oxygen-rich air inhaled into the lungs is drawn to the depleted blood stream. The movement of oxygen is like a river that flows continuously downstream, from the air, to the lungs, to the bloodstream, to the cells, where the oxygen is consumed. This flow is called the *oxygen cascade*.

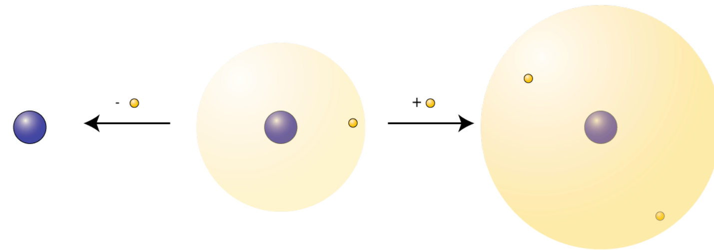
Deciding to Run

Now that the cells of all the i2P team members are rich with oxygen the decision to start running is made. Unlike the muscles of breathing which fire automatically, the use of the muscles of running is a conscious decision. The decision to start running is a complex chemical process that results in a series of messages being sent through nerve cells from the brain to the muscles. One of the principle 'messengers' that nerve cells use to transmit these messages is sodium.

Figure 3: i2P running in Tunisia

Sodium does not occur naturally on earth as a pure element. When found, it is bound to other elements like chloride or dissolved in water. In both these forms sodium exists as an *ion*. Recall from module three that each atom is composed of three components: protons, neutrons and electrons. Both the protons (+) and the electrons (-) have an electrical charge. In its pure form an element is composed of an equal number of protons and electrons and has no charge. However atoms can lose or gain an electron, in which case they are not neutral but have an electrical charge. Atoms with an extra electron have a negative (-) charge and are called *anions*. Atoms missing an electron have a positive (+) charge and are called *cations*. An ion is defined as an atom or molecule in which the total number of protons does not equal the total number of electrons giving it a net positive or negative charge (see: figure 4).

Nerve cells use the charge of ions to send electrical signals. Just like oxygen, ions also flow from areas of high concentration to areas of low concentration. Due to their charge



No. of protons	1	1	1
No. of electrons	0	1	2
Charge	+1	0	-1
Notation	H^+	H	H^-
Classification	cation	neutral (not an ion)	anion

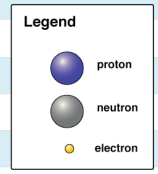


Figure 4: Hydrogen atom (center) contains a single proton and a single electron. Removal of the electron gives a cation (left), whereas addition of an electron gives an anion (right). (source: Jkwchui)

the flow of ions causes an electrical current. It is the flow of an electrical current from one end of a nerve cell to the other (an action potential) that transmits a nervous message.

The two principle ions that nerve cells use to send messages are sodium and potassium. Thus the decision of i2P team members to run occurs when a flow of sodium ions across a series of nerve cell membranes cause a message to be relayed from the brains of the runners to their muscles.

Did You Know?

Oxygen can be toxic to human beings.

see: Oxygen toxicity

Running on Salt

The decision to run having been made, the i2P team sets out, moving one foot in front of the other as they cross the great salt flats of Bolivia. Each step requires the coordination of countless muscle fibers. Similar to nerve function, muscle contraction is also a product of the flow of ions across muscle cell membranes. However the ion used by muscle cells is calcium.

Over the course of a forty kilometer run there will be many modifications in pace, alterations in direction and breaks when the team stop to drink and eat. Every change in direction or pace occurs when a conscious decision in the brain of a runner sends specific signals to their muscles to modify the pattern of contraction. Each runner is also analyzing sensory information from their

Class Exercise

Boil water in your classroom and carefully measure the boiling temperature. What is the elevation of your community in meters? Compare your results to those noted on the expedition graph. What does this tell you about the atmospheric pressure where you live?

eyes, ears, nose, tongue and touch sensors to help them remain upright, balanced, on course, hydrated and well supplied with food energy. All of these functions, from muscle contraction to vision are coordinated by countless messages sent through a web of nerves, and coordinated by the brain. Every nerve signal involves the flow of sodium ions across nerve cell membranes.

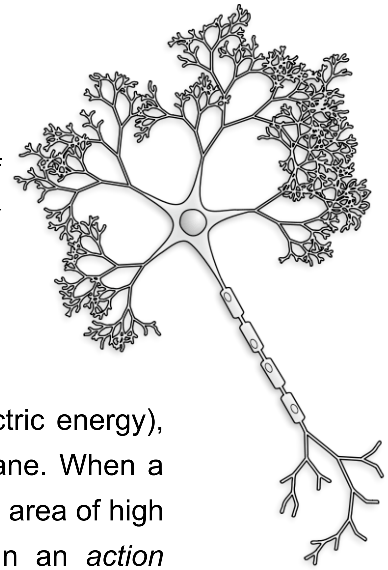


Figure 5: A nerve cell (neuron). (source: Nicolas.Rougier)

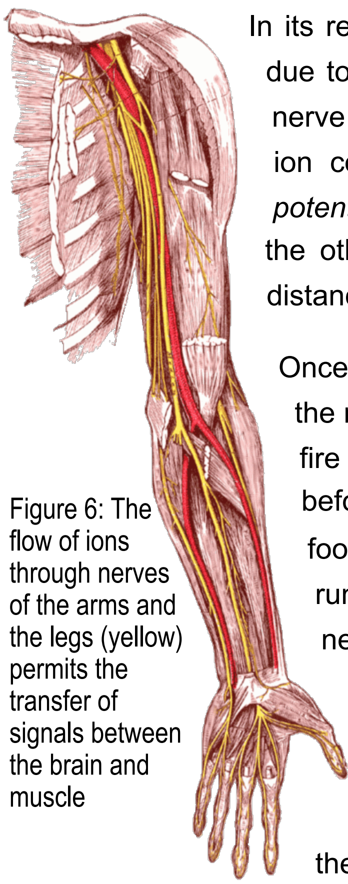


Figure 6: The flow of ions through nerves of the arms and the legs (yellow) permits the transfer of signals between the brain and muscle

In its resting state a nerve cell has a voltage (a potential electric energy), due to an unequal distribution of ions across its cell membrane. When a nerve fires, these ions flow across the cell membrane from an area of high ion concentration, to low ion concentration. This results in an *action potential*, a current of electricity that flows from one end of a nerve cell to the other. In this manner an electrical message is transmitted over the distance spanned by the nerve.

Once an action potential has occurred the flow of ions is complete, and the nerve is said to be *depolarized* and cannot immediately fire again. To fire again all the ions need to be moved back to where they started before the signal was sent (*repolarized*). This is a process that requires food energy and oxygen to carry out. The harder an i2P team member runs, the more nerve and muscle cells will fire, and the greater the need will be to supply food and oxygen to keep nerve cells in a state of readiness. Many other body functions such as waste removal, heat regulation and energy processing also require greater food and oxygen supply during strenuous activities. Thus the decreased oxygen availability on the Salar will affect every part of the runner's body.

A Lot of Altitude

With an increased oxygen demand, and decreased oxygen supply, the i2P runners run the risk of developing an oxygen deficit. The oxygen deficit can cause altitude sickness. Altitude sickness often causes a headache and nausea, but in its severe form can result in fluid collecting in the brain and lungs. At 12,000 feet approximately half of travelers arriving from sea level will experience some degree of altitude sickness.

Class Exercise

Students can follow the expedition and track the altitude that the members are exposed to. Using the calculators and steps provided on the site, students will be able to calculate the PO2 in the air where the expedition is taking place and then predict the levels of oxygen in our blood. We will post the real data so that students can check their predictions against our real data.

web resource: PO2

The best way to prevent altitude sickness is by gradually ascending to altitude. Human beings naturally compensate to decreased atmospheric oxygen through a series of adaptations. Within minutes of arriving at elevation the bodies of i2P team members will start undergoing the following changes:

- Increased *minute ventilation:* the first and most important adaptation to decreased oxygen pressure is an increase in the number of breaths taken a minute.
- Circulatory changes: blood pressure, heart rate, and heart output increase, and the blood circulation to the lungs and brain changes in order to maintain oxygen delivery to these important organs.
- Increased blood count: in response to low blood oxygen, red blood cell counts increase within days of arriving at altitude, increasing oxygen carrying capacity.
- Changes in oxygen delivery and use: adaptations allow oxygen to diffuse quicker from the blood stream to the cells were it is needed.

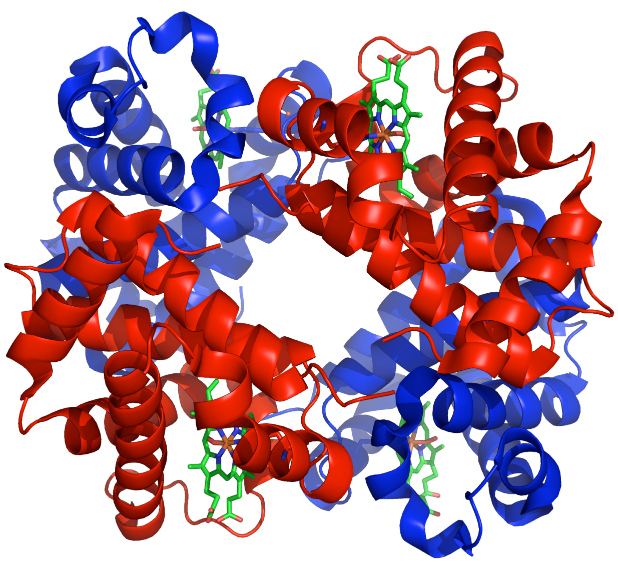


Figure 7: A three dimensional representation of the hemoglobin molecule. Hemoglobin is found in blood cells and carries oxygen. Hemoglobin levels rise in people exposed to decreased oxygen partial pressure at altitude (source:

Class Exercise

Students can take their heart rates at rest, during light exercise (walking in place or around a track) and during more intense exercise like running. Students can compare themselves to each other and draw their own heart rate response on a graph (X-axis = intensity, Y-axis = heart rate)

It takes a number of weeks to fully acclimatize to the high altitude *hypoxia* (low oxygen). Acclimatization never fully compensates for decreased atmospheric oxygen; at altitude there is always a degree of oxygen deficit relative to sea level. To combat altitude sickness i2P team members will be taking acetazolamide, a drug that lowers the pH of the blood and stimulates the breathing rate (see: altitude sickness).

Dr. Greg Wells, i2P team member and physiology professor from the University of Toronto, has designed a series of experiments to observe the effect of altitude. During the course of the expedition he will be measuring a number of physiologic parameters including blood counts (hemoglobin), blood concentration (hematocrit), and blood oxygen saturation. These results will all shed light on the response of i2P team members to elevation.

Artificial Exercise

Forty kilometers across the Salar, the run for the day now complete, the i2P team stops to strike camp for the night. The runners are exhausted, more than expected for a similar run back home. Yet as they adapt to the elevation, team members will notice that running becomes a little easier every day. Measuring the physiologic parameters of the runners will provide insight into why the running becomes easier; insight that offers a fascinating window into the chemistry of the human body.

There is growing evidence of the benefit of prolonged aerobic exercise to human health. However, a detailed understanding of the chemistry that underlies this positive effect is unclear. Some scientists suggest that the identification of the chemical byproducts of exercise could reveal compounds that benefit health. These compounds could be mass-produced as drugs that mimic the positive benefit of exercise (exercise).

Imagine - exercise in a pill!

At i2P exercise in its pure form suits us just fine.

Figure 8: i2P in Tunisia