Air, Land, Water, Ice

Remarkable realms and resources engaged by life’s variety

The Earth’s atmosphere at sunset. This picture was taken by astronauts aboard the International Space Station while over the Indian Ocean. It vividly shows the layering present in the atmosphere, starting as the thick troposphere near the surface (the layer with clouds), then thinning out as the stratosphere and mesosphere at higher altitudes. The air is a mix of different gases – mostly nitrogen and oxygen.

Air

Atmosphere

Our atmosphere is the only thing that protects life from the extremes of outer space. Without an atmospheric shield, the surface would have no protection from unfiltered, direct sunlight. Sunlight would be so intense during the day that surface temperatures would be as hot as 250°F (121°C) – much hotter than boiling water. At night, temperatures would plunge to -250°F (-156°C) and all water would be frozen. There might be a short period of time during dawn and dusk when water could be in a liquid state. But otherwise, it would be a world of extreme temperatures.

In addition to moderating the surface temperature, the atmosphere recycles evaporated water back to the planet’s surface in the form of rain or snow. This hydrologic cycle prevents the water from being lost to space. Without an atmosphere, the planet’s oceans of water would evaporate to space and the surface of Earth would be utterly dry.

How Earth might look without an atmosphere.
Panel: Estimating the surface temperature without an atmosphere

This operation uses the Stefan-Boltzmann law for a black body exposed to our sun at one astronomical unit (the distance of the Earth from the sun).

The law is represented by the following expression:

\[ S_{\text{Sun}} = \sigma T^4 W/m^2 \]

Where

- \( S_{\text{Sun}} \) is the irradiance output of the sun.
- \( \sigma \) is Stefan’s constant (derived empirically).
- \( T \) is the temperature in degrees Kelvin.
- \( W \) is a measure of energy in watts.
- \( m \) is meter, a unit of linear distance.

Filling in values, we get...

\[ S_{\text{Sun}} = 1360 \text{ W/m}^2 \]
\[ \sigma = 5.67 \times 10^{-8} \text{ W/(m}^2\text{K}^4) \]

Rearranging the original expression, we get

\[ T^4 = \frac{S_{\text{Sun}}}{\sigma W/m^2} \]

Substituting, we get

\[ T^4 = \frac{1360 \text{ W/m}^2}{5.67 \times 10^{-8} \text{ W/(m}^2\text{K}^4)} \]

Turning the crank, we get

\[ T^4 = 2.4 \times 10^{10} \text{ K}^4 \]

Taking the fourth root, we get

\[ T = \sqrt[4]{2.4 \times 10^{10} \text{ K}^4} = 394\text{ K} \]

To get degrees Celsius...

\[ 394\text{ K} - 273\text{ °C} = 121\text{ °C} \]

To get degrees F...

\[ ^\circ F = \frac{121\text{ °C} \times 9}{5} + 32 = 250\text{ °F} \]

So, without an atmosphere, the daytime surface of the Earth would be as hot as 250°F.
radiation.” All those lovely constructions of DNA and chlorophyll? SLICE! Ionizing radiation splits them, and once they’re broken they don’t work anymore. The atmosphere provides a good measure of protection against ionizing radiation, by filtering much of it out before it reaches the ground. More about this later.

In short, Earth’s atmosphere results in moderate temperatures on the surface, and keeps temperature fluctuations within a narrow range. And by recycling water back to the surface, the atmosphere conserves the planet’s oceans of water reserves.

Gases in the Air

The planet’s atmosphere mainly is composed of the following gases:

- Molecular nitrogen (N\textsubscript{2}) 78%
- Molecular oxygen (O\textsubscript{2}) 21%
- Argon (Ar) 0.9%
- Carbon dioxide (CO\textsubscript{2}) 0.040%
- Water (H\textsubscript{2}O) 0.4%

The atmosphere contains smaller proportions of neon (Ne), helium (He), methane (CH\textsubscript{4}), molecular hydrogen (H\textsubscript{2}), ozone (O\textsubscript{3}), and more. Many gases in the atmosphere are significant in terms of life on the planet. I am going to address several of them below.

Biological significance of nitrogen (N)

Atoms of nitrogen contribute interesting forms of reactivity to biological molecules. Examples include: amino acids, proteins, RNA, DNA, and specialty molecules such as vitamins (vitamin B\textsubscript{1} - thiamine, vitamin B\textsubscript{2} - riboflavin, vitamin B\textsubscript{9} - folic acid), hemoglobin, and chlorophyll. Nitrogen atoms also are found in notably active molecules such as caffeine, cocaine, morphine, and lysergic acid diethylamide (LSD).

Nitrogen fixation. Molecular nitrogen (N\textsubscript{2}) in the atmosphere is the ultimate source of nitrogen in all biological molecules. But there is a problem. The problem is that N\textsubscript{2} (called molecular nitrogen, or atmospheric nitrogen, or nitrogen gas) resists chemical reactions. Because of N\textsubscript{2}’s low chemical reactivity, plants, animals and most bacteria cannot use the nitrogen atoms in N\textsubscript{2} directly to make new biological molecules. In order to use nitrogen in the chemistry inside cells, N\textsubscript{2} must first be converted into a more reactive form. That’s what the energy-expensive biochemical process of nitrogen fixation does. Nitrogen fixation converts molecular nitrogen (N\textsubscript{2}) into ammonia (NH\textsubscript{3}) (or ammonium salts, such as ammonium chloride, NH\textsubscript{4}Cl).

A short reaction equation for nitrogen fixation is represented below.

\[ N_2 + H_2O + sugar \xrightarrow{\text{nitrogen fixate}} NH_3 + CO_2 \]

Ammonia is very chemically reactive. If you have ever sniffed an open bottle of ammonia, you have experienced the high reactivity of nitrogen in this form.

Once nitrogen is in the form of ammonia or ammonium, it can be easily used by a variety of biosynthetic pipelines to make the kinds of molecules mentioned above.

On Earth, there are several special kinds of bacteria that fix nitrogen and use the resulting ammonia to make their own nitrogen-containing molecules. Generally, these bacteria are referred to as “nitrogen-fixing bacteria.” Cyanobacteria are a special kind of nitrogen-fixing microbe and are worth noting here. They can fix nitrogen in addition to performing photosynthesis. Nitrogen-fixing bacteria and cyanobacteria can be free-living forms, and symbiotic forms (living with another kind of organism). Free-living nitrogen-fixing bacteria and cyanobacteria generally reside in the soil or mud often associated with other kinds of bacteria in tight, multilevel economies. See the diagram below.
In this arrangement, different kinds of bacteria live in close association with each other. Sometimes they organize into discrete layers in the soil. The products of one type of bacteria are consumed by other types, whose products are consumed by additional types. Ultimately, the raw materials get recycled – in this case, molecular nitrogen. These basic economic principles form the main organizing force in nature.

Some nitrogen-fixing bacteria live only in special root nodules of certain kinds of plants, mostly legumes including soybeans, peas, alfalfa, beans and peanuts. In this arrangement, the relationship is more structured. The symbiotic nitrogen-fixing bacteria live within the cells of the plant that make up the root nodule. There, they have access to a steady supply of cell resources, including surplus sugar “shipped down” to the roots from the leaves. Remember, the leaves produce the sugar by photosynthesis. Roots can’t photosynthesize because they exist in the dark soil. So, roots persist because surplus sugar made in the leaves is transported through a system of tubes in the stem (phloem) down to the roots. Since it takes a great deal of chemical energy to fix nitrogen, being attached to a pipeline of sugar results in active ammonia production... as long as the leaves continue to photosynthesize. Which leads me to discuss the other end of the “bargain.”

As leaves support a high amount of biosynthetic activity – not just photosynthesis, the leaf cells are constantly consuming molecular resources, especially nitrates and ammonia. Photosynthesis involves a huge enterprise of complex biochemistry including abundant side reactions. And all the reactions in this enterprise are “moderated” by a variety of very large enzyme molecules – their composition of which includes lots and lots of nitrogen. The problem is that these molecules eventually wear out and need to be replaced. Or as the leaf grows by adding new cells, the cells need to be furnished with a new set of nitrogen-containing molecules. If the leaf cells experience a shortage of fixed nitrogen, photosynthesis will be reduced. If the leaf cells can obtain a steady supply of fixed nitrogen, photosynthesis will increase. Nitrogen-fixing, symbiotic bacteria in the root nodules produce a surplus of ammonia. This surplus gets transported from the roots, up to the leaves by an additional system of tubes (xylem). The leaves use this steady supply of ammonia to build new biological molecules to maintain themselves and grow.

So, to the extent that the leaves produce a surplus of sugar, the bacteria in the root nodules will produce surplus ammonia. And to the extent that bacteria in the root nodules produce a surplus of ammonia, the leaves will produce a surplus of sugar.

Keep in mind that the leaves are not purposefully producing sugar for the symbiotic bacteria; and the bacteria are not purposefully producing ammonia for the leaves. But to the extent that both produce surpluses in this configuration, both will persist.

Symbiotic nitrogen-fixing bacteria inside the cells of a soybean root nodule.
Panel: Diagrams of biologically active, nitrogen-containing molecules.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td>Alanine: a simple amino acid. Living things use 20 or more different types of amino acids. Amino acids are strung together in different sequences to make different kinds of proteins, including the worker molecules – enzymes.</td>
</tr>
<tr>
<td>Triosephosphate isomerase</td>
<td>Triosephosphate isomerase: an enzyme. This large enzyme is part of the energy extraction process of glycolysis.</td>
</tr>
<tr>
<td>Adenine</td>
<td>Adenine: a nitrogenous base. Nitrogenous bases form the rungs of the DNA double helix. They represent individual “bits” of digital data.</td>
</tr>
<tr>
<td>DNA</td>
<td>DNA: a digital data storage and transcription device. DNA forms the foundation of the information management system in living things.</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>Riboflavin: a vitamin (B2). Riboflavin is essential for normal metabolism (energy use) in cells.</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Caffeine: a secondary compound produced by some plants. Has insecticide properties; also a stimulant in higher animals.</td>
</tr>
<tr>
<td>Heme group</td>
<td>Heme group: part of the larger hemoglobin molecule. Hemoglobin carries O₂ in the blood.</td>
</tr>
<tr>
<td>Cocaine</td>
<td>Cocaine: a secondary compound produced by the coca plant.</td>
</tr>
<tr>
<td>LSD</td>
<td>LSD: Lysergic acid diethylamide. Modified from naturally-occurring molecules.</td>
</tr>
</tbody>
</table>
**Biological significance of oxygen (O)**

Atoms of oxygen are among the most interactive and chemically reactive objects in the cosmos. We find oxygen atoms in nearly every kind of biological molecule. Oxygen’s high reactivity translates into higher activity levels in the chemistry of life – higher activity in living things.

Unlike molecular nitrogen (N₂) and carbon dioxide (CO₂) which were abundant in the Earth’s earliest atmosphere, O₂ wasn’t – even for a billion or so years after the first simple living things appeared (or so the rocks tell us). But today we have lots of O₂ in the atmosphere. The atmosphere is 21% O₂. So, where did all this oxygen come from? Short answer: it was produced by photosynthesis. The biochemical process of photosynthesis uses an oxygen atom as a carrier of hydrogen atoms and electrons (in the form of water, H₂O).

Photosynthesis strips away the water molecule’s hydrogen atoms and electrons for its own purposes, then spits out a molecule of oxygen (O₂) as a waste product.

Photosynthesis.

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{light} \xrightarrow{\text{reorganize to make}} \text{fixed carbon} + \text{O}_2 \]

Although molecular nitrogen (N₂) and carbon dioxide (CO₂) have low reactivities, molecular oxygen (O₂) has a very high reactivity. O₂ (called molecular oxygen, or atmospheric oxygen or oxygen gas) easily combines with other elements to make oxides. For example, O₂ reacts with iron to make iron oxide (rust). You would think that if a given amount of O₂ were present in the atmosphere, it should eventually disappear because of its tendency to combine with materials in the Earth’s crust. But despite the tendency for O₂ to combine with solids on the Earth’s crust (which should decrease the amount of O₂ in the atmosphere), it is constantly replenished by photosynthesis.

Cellular respiration. The biochemical process of cellular respiration is a good example of oxygen’s usefulness.

\[ \text{fixed carbon} + \text{O}_2 \xrightarrow{\text{reorganize to make}} \text{CO}_2 + \text{H}_2\text{O} + \text{ATP energy} \]

I discussed cellular respiration in detail in chapter 2, Food. To recap, the process of cellular respiration disassembles molecules of fixed carbon and liberates the chemical energy they contain. The disassembly process results in a lot of waste hydrogen atoms that tend to accumulate in and around the mitochondria – the organelles where cellular respiration happens. If the waste hydrogen atoms are not removed, they will clog up the system and possibly halt cellular respiration. If cellular respiration were to stop in a cell, efficient access to energy would stop and less efficient energy extraction operations (like fermentation) would take over. This would be a bad thing since certain cell operations cannot continue without access to abundant energy. As a result, the cell could fail. O₂ keeps the system from clogging up because it enters the cell and reacts with the accumulated, waste hydrogen atoms to become water.

\[ 4\text{H}^+ + \text{O}_2 \xrightarrow{\text{reorganize to make}} 2\text{H}_2\text{O} \]

So, by sweeping up the hydrogen debris, molecular oxygen allows the energy machinery inside the cell mitochondria to keep pumping out useful biological energy, and power-consuming cellular operations can proceed.

Many people naturally praise the “life-giving” properties of O₂. But there is an interesting twist. Because it is so highly reactive, O₂ can be very destructive to the molecules of life. If O₂ is not controlled, it can break biological molecules apart. So, on the one hand, the high reactivity of oxygen can speed up the chemical reactions of life and add interesting reactivity to biological molecules, thereby increasing the overall activity level of living things. But on the other hand, oxygen’s high reactivity has a tendency to destroy things. What to do... what to do...

Mitochondria. What we see in living things are interesting ways that exploit oxygen’s reactivity while protecting the delicate and vulnerable molecules of life. For example, the mitochondria are dispersed throughout the cell interior, surrounding the nucleus. O₂ molecules enter the cell and, instead of heading toward the hydrogen-rich DNA in the nucleus, they are drawn toward the collection of waste hydrogen atoms around the mitochondria (O₂ diffuses down an O₂ concentration gradient toward the mitochondria). Once there, the O₂ molecules rapidly combine with the hydrogen ions to become H₂O (water). If the mitochondria did not “intercept” the incoming O₂, the O₂ molecules would proceed to the nucleus where they would...
“feast” on the fragile DNA molecules (stealing hydrogen atoms from the DNA), eventually disintegrating them and causing the cell to fail (oxygenic stress).

Hemoglobin. In addition, getting the O$_2$ molecules from the atmosphere, into the body and then to the cell without O$_2$ wandering off and destroying molecules along the way – that’s another issue. Vertebrate animals and some invertebrate animals have a special O$_2$ escort molecule called hemoglobin. The way it works is, hemoglobin resides inside red blood cells. Hemoglobin has a very high attraction for O$_2$. As red blood cells enter the lungs or gills, hemoglobin combines with O$_2$ (from the air or from the water) and becomes a hemoglobin-oxygen complex (HbO$_2$). Hemoglobin keeps a tight hold on the O$_2$ as the blood later leaves the lungs (or gills) and winds its way through the circulatory system. When the blood encounters cells with high amounts of waste hydrogen atoms (slightly acidic), hemoglobin loses its grip on O$_2$. Then, O$_2$ enters the nearby cell where it combines with accumulated hydrogen atoms to become water. Carried by its red blood cells, the hemoglobin then returns to the lungs and collects another O$_2$ molecule.

Hemoglobin escorts O$_2$ through the circulatory system. Mitochondria surround the vulnerable nucleus.

Stratospheric ozone. Once O$_2$ began to accumulate in the atmosphere starting about 2.5 billion years ago (according to the rocks), there was one very interesting side effect – the appearance of ozone (O$_3$). Ozone is a molecule of interest because it can block dangerous ultraviolet radiation coming from the sun. It turns out that O$_2$ and O$_3$ are especially interactive with ultraviolet radiation. This is how ozone is made. Ultraviolet radiation hits an O$_2$ molecule and splits the oxygen atoms apart. We now have two independent oxygen atoms (free radicals of oxygen). Each of these oxygen free radicals combines with nearby O$_2$ molecules to become O$_3$.

Step one: 

\[
O_2 + UV \rightarrow O: + O:
\]

Step two: 

\[
O: + O_2 \rightarrow O_3
\]

Ozone also interacts with ultraviolet, getting split and then re-forming. All the while consuming UV energy and thereby reducing its overall intensity at the planet’s surface.

Ozone concentrations tend to be greatest in the stratosphere (starting about 20 miles up). This is the “sweet spot” for ozone formation – where the combination of O$_2$ abundance and UV intensity are optimal. The result is the stratospheric ozone layer.

The reduction of incoming UV radiation by the stratospheric ozone layer is important to biological systems because UV radiation can tear biological molecules apart. If too many molecules within a living cell are destroyed by ultraviolet radiation, the cell will fail. If too many cells in a tissue fail, the tissue operations become suppressed and distressed.
Sunburn is a useful example of the damaging effects of ultraviolet. This is how it works. High intensity ultraviolet radiation penetrates skin cells and breaks pieces off of important molecules within (like DNA). At some point in the exposure, millions of skin cells fail (die). In response to sudden failure of epidermal cells (skin cells), blood flow to the epidermal region (the skin) is significantly increased, delivering added resources and speeding up repair operations (healing). This increased blood flow is what turns the skin red and makes it feel hot. The peeling skin that follows several days later represents the cells previously killed by the UV radiation – now replaced by newly-built cells underneath.

Sunburn is an acute effect of UV over-exposure. But UV also can cause long term harm to biological systems. For example, the development of cataracts is linked to lengthy exposure to ultraviolet radiation. UV radiation can cause mutations in skin cell DNA. In rare cases, mutations can transform the cell programming to result in a cancer cell. Melanoma, or skin cancer, is an example. Cancer cells are different from normal cells in that they perform no useful operations. As cancer cells spread within the tissue, they consume resources and crowd out normal cells. The organ of which they are a part gradually loses performance and ultimately fails.

Ultraviolet radiation can harm other living things. Overexposure can damage crop plants and reduce crop yields in soybeans, wheat, corn and rice, for example. It can reduce the photosynthetic output in phytoplankton in the oceans.

Despite the harmful effects of ultraviolet radiation, there are some benefits. For example, ultraviolet radiation drives the synthesis of vitamin D in plants, animals and microorganisms. In vertebrate animals, vitamin D improves bone mineral density.

This discussion about O₂ has come a long way. Let’s summarize. If “controlled” in biological systems, O₂ can increase the activity level of cells (by increasing activity levels of the cell’s biochemistry). This is good. If uncontrolled, O₂ can be disruptive (by damaging or destroying important molecules in the cell). This is bad. As O₂ is abundant in the atmosphere, it is converted to ozone (O₃) in the stratosphere. Stratospheric ozone filters out incoming ultraviolet radiation thereby reducing the amount of UV radiation that strikes the Earth’s surface. This is good because at high exposures UV radiation can damage biological systems.

**The biological significance of methane (CH₄)**

Methane. Now having made the case about O₂ as a double-edged sword to life, let me fortify this argument with a discussion of methane (CH₄). Previously, I mentioned that O₂ can be destructive to biological molecules. The plants, animals, fungi, and algae you and I see have useful ways to channel and contain O₂’s high reactivity. The abundant mitochondria in their cells, for example. But some kinds of microorganisms have no such methods to control O₂. If O₂ reaches them, they will perish. This group of O₂-phobic organisms is generally referred to as **obligate anaerobes**. The word, “anaerobic,” is used by biologists to mean “without oxygen.” Obligate anaerobes include a sampling of different kinds of bacteria, archaea and protozoa. (Archaea are somewhat similar to bacteria.) Regarding methane, I want to focus on one particular kind of archaea, the methanogens (methane producers).

Methanogen archaea live in a variety of oxygen-free (anaerobic) environments including the deep muds in wetlands, swamps, and oceans. They are part of the microfauna in the oxygen-free space inside the guts of animals where they participate in a daisy chain of digestive chemistry involving a mix of different kinds of microorganisms. For example, methanogenic archaea in ruminating herbivores, like cattle and sheep, produce large amounts of methane gas which gets burped out. In humans and termites, methanogens reside in the lower gut and produce methane gas that gets emitted out the rear end.

Similarly to O₂, methane is very reactive and its stay in the atmosphere is relatively short-lived. Methane will spontaneously react with O₂ to become CO₂ and water. So, like O₂, in order for methane to be present in the atmosphere, it must be continuously produced.

\[
\text{reorganize} \\

\ce{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}
\]

**The biological significance of CO₂**

CO₂ in the atmosphere is the ultimate source of carbon in all living things. As mentioned before, the biochemical process of photosynthesis converts gaseous CO₂ into a solid chain of carbon atoms.
Later biosynthetic operations couple carbon chains to make longer chains, and then add a selection of other elements to make huge varieties of new molecules. But why carbon? Why are biological molecules composed mainly of carbon?

Versatility and strength. The carbon atom has a very interesting configuration that makes it extremely flexible, adaptable, strong, light and easy to use. Carbon atoms have high versatility, high strength, and high usability.

Carbon atom. Nucleus of protons and neutrons at the center; electrons surrounding.

Carbon atoms are relatively light atoms, having only six protons and six neutrons in their nucleus. Versatility is the result of the carbon atom’s four readily available bonding sites. In the above image, the four outer electrons quickly share their orbital space with electrons of other atoms; the act of sharing results in a strong chemical bond (covalent bond) that connects the two atoms. The drawing below illustrates an example of carbon’s bonding style.

2-D carbon matrix; diamonds are composed of a 3-D carbon matrix.

The high strength of these bonds is because they form close to the carbon nucleus. Diamonds are the best demonstration of this strength. Industrial engineers create carbon fibers to make lightweight, high strength carbon-composite materials. Carbon fiber materials are increasingly being used to make aircraft and cars lighter, thereby improving performance and fuel efficiency. For example, the new Boeing 787 Dreamliner aircraft uses carbon fiber composite materials extensively in its construction, making it the most fuel-efficient commercial aircraft today.

Fuselage of Boeing 787 made with carbon fiber composites.

Consumption and recycling. Although CO₂ is removed from the atmosphere by the process of photosynthesis, it is recycled back to the atmosphere by the process of cellular respiration. The below flow diagram illustrates the recycling results of these two biochemical operations.

Greenhouse effect. The presence of CO₂ in the atmosphere results in an increase in the Earth’s temperature. This “warming” phenomenon is referred to as the greenhouse effect. Here is how it works. Surfaces, warmed by absorbing incoming sunlight, re-radiate energy toward space in the form of infrared radiation. Molecules of some gases like CO₂, methane, chlorofluorocarbons (CFCs) and nitrous oxide (these all are greenhouse gases) intercept and interact with outbound infrared and become warmer. This causes the planet to retain heat that would otherwise escape to space if the greenhouse gases weren’t there. Like glass in a greenhouse, greenhouse gases in a planet’s atmosphere are transparent to light but opaque to infrared. In general, the more greenhouse gases in a planet’s atmosphere, the more infrared gets trapped, and the warmer the planet gets.
If the atmosphere had no greenhouse gases, climatologists estimate that the Earth's average temperature would be about 0° F (-18° C). An average temperature this cold would render large portions of the Earth under ice. So, a certain amount of greenhouse gas, like CO\(_2\), helps keep the planet from freezing.

**The Greenhouse Effect**

The planet surface is illuminated and warmed by incoming sunlight.

Infrared radiation interacts with greenhouse gases, causing them and the atmosphere to get warmer.

Reflected light radiation passes through the atmosphere and escapes to space.

Warm surfaces radiate infrared.

Illuminated surfaces reflect light.

This weather map indicates the distribution of high pressure air masses (H) and low pressure air masses (L).

Pollen dispersal. Wind is the primary means of pollen dispersal in pine and fir trees (gymnosperms), oak trees, grasses and many other kinds of plants. Pollen grains are microscopic objects that contain two plant sperm cells.

Pollen from many different plant species.

Plants are stationary and cannot directly transport their sperm cells from place-to-place. Sperm cells inside a pollen grain from one plant individual have the ability to fertilize the egg of another plant individual. The result of such fertilization is the development of a new plant embryo, and eventually a new plant individual. The problem is transportation. The stout casing of pollen grains provides durable and lightweight packaging for the otherwise delicate sperm cells. Wind picks up pollen from cones or flowers and disperses the pollen randomly along its path. Rarely, a pollen particle lands on the female part of flower or cone of the same species and sticks (pollination). Once there, the pollen grain germinates and sends its sperm cells into the ovary of the receiving plant and completes the fertilization operation.

**The biological significance of wind**

Wind is the movement of air from a zone of high pressure in the atmosphere toward a zone of low pressure. The distribution and composition of air in the atmosphere is constantly changing. Meteorologists observe these changes by tracking the movement of the atmosphere’s fluid air masses. Atmospheric pressure is caused by the total mass of air above a given point. The air is weighing down on that point. But because air is fluid, this distribution of mass changes, and as it changes, so does the atmospheric pressure. When an air mass of high pressure is adjacent to an air mass of low pressure, wind results. This is because the air from the high pressure mass rushes toward the low pressure mass as the system tries to balance itself. Living things interact with the wind in interesting ways.
Grass is wind-pollinated.

Wind-pollination increases persistence of a species when it is accompanied by a large production of pollen. Which is why hay fever sufferers have it so bad. Their sinuses are allergic to seasonally abundant pollen carried by the wind. Wind-pollination works best within dense stands of plants of the same species, like a forest or a field of grass. It is not as effective for plant species that tend to be widely separated in the environment.

Wind also is the main disperser of fungi spores, the main transportable object in the fungus reproductive cycle.

Mushrooms and other fungi disperse by wind-carried spores.

Seed dispersal. The wind plays a part in dispersing the seeds of plants. Remember, seeds contain the new embryo produced after pollination and fertilization. Seeds generally are much heavier than pollen grains because they include a package of food that the embryo uses to initiate germination of the new plant. Animals unwittingly transport seeds of many flowering plants, which “hide” their seeds in a nourishing mass of fruit. But wind is the main seed dispersal force for some plants, especially grasses.

For example, pampas grass seeds are carried aloft on feathery sails. Although not a grass, the dandelion seed is a lightweight container suspended by a kind of fibrous parasail.

Maple and ash trees make seeds with attached flat blades. When dropped, the seeds spin in the air like little helicopters and the wind can carry them a short distance during their fluttery descent.

Pheromone dispersal. Plants and animals release many different kinds of pheromones to their surroundings. Pheromones are specialty molecules dispersed through the air that influence operations in the receiving organism. Pheromones can act as signals that influence behavior within the species. For example, locusts can emit pheromones that result in faster development from hopper stage to winged stage. Colonial bees can release aggression pheromones. Plants can release pheromones that trigger synchronized flowering or the production of defense chemicals. Pheromones can activate responses in receiving organisms at extremely small exposures. Therefore, wind-borne pheromones can influence synchronized behavior over large areas.

Scent detection. Mammals have well-developed noses that are very good at detecting smells (chemosensory). Predator and prey alike are frequently sampling the air for information about nearby situations. Scavenging animals use their sense of smell to detect decaying biological material including dead animals, animal wastes, and rotting fruit. Although the sense of smell is not highly developed in birds in general, several vultures possess this trait: the turkey vulture,
lesser yellow-headed vulture and greater yellow-headed vulture.

Turkey vulture.

Long range dispersal. We have seen some of the typical localized effects of wind. But wind also can transport items on a global scale. For example, winds stirring up dust across the Sahara Desert in Africa can carry that dust, rich in iron and phosphorous, over 3000 miles westward to be deposited on the Amazon rain forest (Bristow, Hudson-Edwards, & Chappell, 2010). As the soils in the Amazon basin are nutrient-poor, the Saharan dust represents a significant subsidy to the ecological systems there.

Birds, flying insects, pollen, wind-dispersed seeds, bacteria, and fungal spores can be transported far out to sea by storms. Occasionally, these castaways settle on remote islands far from the mainland. Examples of remote islands so colonized include the Canary Islands west of Africa, Easter Island, the Galapagos Islands west of South America, and the Polynesian Islands (including Hawaii) in the middle of the Pacific Ocean. Because these islands rarely receive storm-blown immigrants, their stranded biota is effectively cut off from mainland genetic influences. As a result, the genetic trajectories of these isolated species take unique and surprising new directions. This is why remote islands are extremely productive environments for investigating genetic evolution.

Wind and rain weather patterns. Global scale winds operate within generalized patterns moving across the oceans and continents along consistent and repeating paths. For example, in North America, air usually moves from the west towards the east across the continent. The pattern is wavy and often dips southward across the interior then up again as it makes its way east. The below image of the Jetstream illustrates this general pattern.

Jetstreams aloft influence general direction of global surface winds.

These large surface winds carry moisture-rich clouds into the continental interiors. The moisture is collected while the air masses move over oceans.

Rain approaches the usually dry Arizona desert.

Without this kind of air movement and water distribution, the interiors of continents would be very dry. Plants and animals organize themselves depending on the pattern of precipitation across the continent. Areas that receive high amounts of rain every month of the year tend to be dominated by forests. At the other extreme, regions that experience many months without any rain (drought) may be occupied by dry grasslands (savanna) or desert scrub.

Forest: rain every month. Desert scrub: little rain.

Subtropical high. Apart from horizontal movements of air across the planet, there are vertical patterns of air flow. Vertical circulation patterns result in
interesting bands of dryness around the planet. The below drawing labels these vertical patterns as Hadley cells. Without getting into the total mechanism, please notice that air is rising at the equator and descending along two bands, about 30° north latitude and 30° south latitude. At the equator, the moisture-laden air dumps its moisture load on ascent – because of cooling, cloud formation and rain. After reaching the top of its ascent, this air (now dry) is pushed aside by more rising air from below. The dry air travels away from the equator and begins to descend at 30° north or 30° south. As it descends, the temperature of the dry air increases – which reduces its relative humidity and makes the air feel drier still. Near the surface, this dry air mass has few clouds and fewer prospects for rain. These zones of dryness are known as the “subtropical high zones” and they account for the bands of aridity on either side of the tropics. Most of the world’s deserts lie in the subtropical high zones.

Vertical circulation patterns. Subtropical highs.

The significance of air as a medium for flight

Insects, birds, bats and even some spiders use the air as a medium for flight. Flight enables animals to rapidly move through all levels of the 3-dimensional forest, or travel distances that would not be practical by walking or running. Flight provides so many productive alternatives to slithering, crawling, walking, running and hopping.

Hunting and foraging. Tiny bees can travel many miles a day harvesting nectar and pollen before returning to the hive. Beetles fly for many miles roaming the terrain in search of food. Bats leave their dark caves to snap up flying insects from the night air. Owls swoop down on silent wings, talons extended, to nab a deer mouse in the darkness. Peregrine falcons streak downwards at 180 miles-per-hour intent on breaking the wing bones of a duck in flight far below. A northern goshawk dodges speedily through the canopy to ambush startled doves. Pelicans, terns, kingfishers, ospreys and bald eagles can soar high over the water in search of unsuspecting fish near the surface.

Northern goshawk in hurried search for prey.

Migration. Monarch butterflies can fly thousands of miles from Canada to Mexico in their autumn migration. Plagues of locusts swarm across hundreds of miles of countryside eating everything edible. Strands of delicate silk act as balloons that lift petite young spiders and carry them from their hatching site to distant destinations. Arctic terns fly 20,000 miles each year from Arctic to Antarctic and back again. Canada geese and sandhill cranes fly thousands of miles to over-winter in California and Texas, then back to Canada come springtime. And the swallows make their spring arrival in San Juan Capistrano to feast on abundant flying insects before returning to South America in the fall.
Earth’s atmosphere is more than just a layer of gas encircling the planet. It is a reserve of building materials with which living things construct themselves; a lens for sunlight and a source of reactive molecules with which life energizes itself, an enveloping blanket that provides warmth against the cold of space and a barrier against harmful radiation; a fluid medium that transports giant clouds and the tiniest pollen; a supportive medium that gives balloon rides to young spiders and tenders the hopeful cries of red tail hawks soaring in the heavens. I never, ever take it for granted.

**Land**

![NASA image composite of Earth during June, 2004. It is summer in the northern hemisphere.](image_url)

Land is a spherical encrustation of rock and soil protruding above Earth’s large oceans and submerged under the planet’s shroud of gas. Regarded as the “terrestrial realm,” land presents a firm and defined surface upon which any kind of thing can stand or sit or rest without sinking endlessly toward planet center. Neither Jupiter nor Saturn has such a thing as land; their rocky cores are buried so deep that the planets’ crushing atmospheres congeal into thick, mushy gels far above. Even with a magic pressure suit, you cannot stand on Jupiter. On Earth, the surface of the land is a definitive boundary that separates crust from atmosphere. There is no zone of transition.

Land lies at the bottom of the gaseous sea of the atmosphere. As the air is transparent to light, land receives daily doses of warming radiation from the planet’s host star during the day, and the cooling benefits of deep space at night. The most abundant living things on land (plants) interact with realms above and below the land surface.

Land is not uniformly presented on planet Earth. It is not an even smearing of rock equitably distributed across all quadrants. Instead, the distributions, compositions, 2-dimensional shapes, and topographies of land masses are highly variable. This variability presents living things with numerous kinds of environmental circumstances.

**Life on the rocks**

Solid rock is the basic material from which land is composed. Virgin crustal rock is a result of deep, hot magma rising from the Earth’s mantle towards the surface. The process takes many forms and produces a variety of rock types including basalt (cooled lava) and granite (magma that cooled while still just below the surface). These rocks can be
eroded, the particles of which can mix together as sediments. The sediments can undergo compression and heating to form new layered rocks – sedimentary rocks. Sandstone and limestone are examples. All kinds of rocks can experience more compression and heating which results in metamorphic rock such as marble (metamorphosed limestone) and quartzite (metamorphosed sandstone).

Rocks are composed of hundreds of different combinations of minerals. When rocks are exposed to the sun and atmosphere, the exposed surfaces experience “weathering”. Rock weathering can take many chemical and physical forms, but in all cases the rock surface is broken down. This liberates tiny amounts of the rock’s minerals which become available on the rock surface. Living things consume these materials. In addition to the rock’s own weathered materials, tiny particles of dust can collect on rock surfaces.

Panel: Rock Weathering

Rock weathering: Gases from the atmosphere react with minerals in the rocks to produce new substances.

For example, O\textsubscript{2} from the atmosphere reacts with iron minerals in the rocks to make iron oxide (rust). Another example, CO\textsubscript{2} in the atmosphere reacts with calcium minerals in the rocks to make calcium carbonate (chalk).

Bacteria, carried by the wind, land on the rock and use the collected dust and rock-weathered materials for growth and reproduction. The organic wastes from this bacterial growth further accelerate rock weathering. Life on the rocks continues as long as there is moisture. When the surface of the rock becomes dry, surface life halts. With the return of moisture, biological action will resume from bacterial spores left by predecessors, and the arrival of new bacterial colonists.

The combination of rock weathering and associated microbial growth produces an extremely thin layer of mineral and organic material on the rock surface. In arid environments, like the desert, sunlight and heat “bake” this material. The result is called “varnish,” which is a dark and shiny coating on the rock surface.

Life deep in the rocks

Deep underground, in the dark, there is life – barely. “Deep biology” consists of microorganisms (microbes) of various sorts, living an impoverished life in the rocks as deep as a mile underground (Gold, 1992). Some live in close association with petroleum deposits, using the petroleum as a source of food. Others live in deep underground aquifers and hot springs. To fix carbon, they use the rare hydrogen gas (H\textsubscript{2}) and CO\textsubscript{2} percolating upwards in the crust (Kerr, 2002). One line of investigation proposes that the subterranean microbes receive organic matter that trickles down from the planet surface. Resources are so scarce that the microbes cannot reproduce, and their level of activity is greatly restricted. Subterranean biology is an area of great interest because of its diverse implementations of biochemistry and because the total mass of deep biological life has been estimated to be near equal to that of surface life.
**Life in cracks of the rocks**

Back on the surface, living things use cracks in the rocks. Plants anchor in these narrow openings, taking in water and nutrients from the small amounts of dust that settles there. Small animals use the cracks as cover to ambush prey, to avoid predation, and to avoid harsh weather. The desert brittlebush (pictured below) and the apricot mallow are excellent examples of this lifestyle.

![Desert plants rooted in cracks. Brittlebush dominates.](image1)

Snakes and lizards of all kinds take to the cracks in routine fashion. The chuckwalla (below) is a good example.

![Chuckwalla.](image2)

Small mammals take advantage of rock cracks. The wood rat, yellowbellied marmot (both rodents), and pika (a lagomorph – related to rabbits) will make their nests in the cracks.

![Yellow bellied marmot.](image3)

Insect uses the crevices as well. Honeybees will establish a home for their hives in deep rock cracks, building honeycombs there. Scorpions (an arachnid, not an insect) and hunting spiders patrol the cracks in search of insects to eat. Caterpillars attach themselves in protected crevices to carry out undisturbed metamorphosis into butterflies.

**Cave and cavern dwelling**

Caverns represent an unusual set of circumstances for living things. The caverns I am referring to are not little bear caves, but large volumes of space deep underground. The world’s largest caverns occur in limestone rock formations. Limestone is made out of calcium carbonate, which readily dissolves in acid. Large caverns are produced after thousands (if not millions) of years of slightly acid ground water leaching away calcium carbonate rock formations. The acidic ground water comes in, dissolves the calcium carbonate, and then carries the calcium carbonate away. After thousands of years, you get a big pocket of air where there used to be rock. Carlsbad Caverns in New Mexico is a good example of this kind of cavern.

![Carlsbad Caverns, artificially lit.](image4)

Caverns of this sort occur in many places around the world. The interesting thing about these caverns is the constancy of their internal environmental conditions. That is, the cave environment is usually always the same regardless of the changing weather on the surface. Of course this varies from cave-to-cave. But we can generalize and say that caves are always cool and always dark.
In the southwestern desert of North America, summer daytime temperatures can be over 100° F (38° C). But in Carlsbad Cavern, it is always 56° F (13° C). The cool temperatures inside the cavern represent a rewarding refuge from the harsh weather above. The problem is how to deal with the dark.

Bats are flying mammals, many species of which live in caverns. Bats have remarkably well developed ears that allow them to pick up faint echoes from nearby objects. It’s a natural form of sonar, the technology that submarine hunters use in the world's navies. It works like this: bats emit high pitched chirps that echo off of nearby flying insects. The bat receives the echo and determines the direction of its origin. The bat orients toward the source emitting ever more frequent chirps to fine-tune the exact location of the flying insect. The technique is useful day or night, but bats use it mostly at night, when the temperature topside is cooler. During the heat of the day, bats literally hang out in the cave where it is much cooler. They navigate the darkness of the cave using their built-in sonar. Inside, bats perch upside down by clutching the ceiling with their feet. While on the ceiling, bats are inaccessible to large predators who might wander into the cool cave looking for something to eat.

Big-eared Townsend bat.

As the bats spend a great deal of time hanging in the cave and digesting their food, large piles of bat poop begin to accumulate on the cave floor. No living thing likes bat poop more than cockroaches. So while the bats are quietly napping on the ceiling, the cavern floor can be alive with swarms of cockroaches eating the glorious poop falling from their cockroach heaven above.

**Life on and under sand**

Sand is the result of fine fragmentation of rock. Small sand grains are carried along by the wind. Sand particles accumulate against barriers, or simply drop out of the quieting air. Sand deposits represent two different possibilities for living things: 1) sand provides a fairly substantial surface that supports animal locomotion; and 2) sand particles can be quickly pushed aside as animals hastily bury themselves.

Sand dunes in continental interiors are the result of consistent environmental conditions in which strong prevailing winds collect sand particles (often from a dried lake bed) and transport them to the same destination year-after-year. Along with sand grains, the winds also transport seeds, pollen and insects. So although usually dry, sand dunes have pockets of collected biological resources. In other words, food.

![Kelso Dunes in the Mojave Desert.](image)

In the Mojave Desert, pocket mice, deer mice and kangaroo rats scour the dune margins for seeds and insects just blown in. In turn, the rodents are ambushed by sidewinder rattlesnakes which conceal themselves just below the surface, with only their eyes bulging discreetly above. The fringe-toed lizard expertly zips along the shifting sands. It has stiff filaments on its toes that keep its feet from sinking into the sand. Think of snow shoes in snow. These lizards are remarkably fast as they skitter across the dune face. Equally, they are configured for subsurface life in the sand. They can close off their nostrils and ear ports while buried to keep the sand grains out.

![Fringe-toed lizard.](image)
Life on and under the soil

The abundant animal life on land is because of the abundance of plants growing in soil. Soil is a mix of materials from various sources. I am going to focus on the topmost layer of soil, the topsoil. Generally, topsoil is composed of a mixture of:

- Sand
- Clay
- Mineral salts
- Organic particles, including decaying plant and animal material
- Active microbes
- Invertebrates like nematode worms, earthworms and burrowing insects
- Air spaces that allow atmospheric gases to percolate underneath

Soil composition and thickness is highly variable throughout the world. For example, the prairies of North America have topsoil, several feet thick, while the tropical rain forest has topsoil less than one inch thick.

Topsoil often but not always, is underlain by conglomerates of loose rock of varying sizes. Loose enough for roots to penetrate. Plants penetrate into this loose mix of sand, organic debris and small rocks with their roots. In so doing, they anchor themselves firmly in one place, and they absorb available nutrients and water from the soil below.

Burrows. Many animals dig away the soil to make burrows underground. Burrows provide their occupants with privacy and reduced chances of disturbance by other animals. Burrows insulate underground dwellers from harsh weather above. Some animals, like the trapdoor spider, hide in their burrows waiting to ambush unsuspecting passersby.

For example, during the hot and dry season in the desert, most mammals, like the kangaroo rat, pocket mouse, and kit fox hole-up in their deep, cool burrows. This behavior helps them avoid the hot sunlight and the extremely high temperatures on the surface. They emerge at night to forage and hunt after the sun has set and temperatures have dropped.

Pocket mouse emerging from his desert burrow.

Ants construct complex burrows and divide the spaces for the performance of different tasks such as food storage and production, and nurseries. The underground environment gives the collective and their queen a high degree of protection from large predators.

Ground squirrels, prairies dogs, and meerkats construct a network of burrows in close proximity. These animals are usually active during daytime and their burrows tend to be used mostly for quick escape and refuge from daytime predators.

Meerkats. Active in day. Stay close to burrows.

Some animals will overwinter in burrows. For example, some rattlesnakes that reside in areas with cold winters will gather together underground in the hundreds in a hibernation den. There they enter an extended period of dormancy awaiting the return of milder temperatures. In the meantime, the collective body heat from all those snakes helps keep the entire mass from freezing. Groundhogs and badgers are expert burrow-makers. In winter, badgers become less active and spend much of the winter in their burrows in a reduced physiological and operational state. Groundhogs enter true hibernation (significantly reduced operational state) for about three months.

Last word on burrows. Tarantula hawk wasps are large purple wasps with bright red wings. Wasps are predators. During breeding times, female wasps patrol the ground in search of a tarantula spider. The wasp attempts to sting the big spider, while the
tarantula defends itself by trying to bite the wasp. Sometimes the spider wins, but not usually. Once stung, the tarantula is rendered immobile but still alive. The wasp drags the spider back to her burrow and lays one egg on its abdomen. Once this is accomplished, the wasp departs and covers the entrance to the burrow, never to return. When her egg hatches, the larva feeds on the still-alive, but defenseless tarantula. This behavior of larval parasitism is typical for wasps and it reduces the amount of resources that wasps need to pack in their eggs.

Female tarantula hawk wasp drags a paralyzed tarantula to her burrow.

Panel: Ecological island

An ecological island is a geographic location that has a surrounding environment that is significantly different.

The biological significance of ecological islands

Terrestrial islands occur in two main forms: 1) aquatic islands; and 2) elevation islands. An aquatic island is of an isolated piece of land surrounded by water some distance from the continent. Iceland is an example. An elevation island is a piece of land at given altitude surrounded by land at significantly different altitudes. A mountaintop is an example. Functionally, these are “ecological islands.”

Separation from surroundings. What makes an island and island is that the environment on the island is significantly different from its surroundings – so different that life from the surroundings cannot persist on the island, and vice versa. This is very obvious for aquatic islands; the terrestrial environment is very different from the aquatic environments in the encircling waters. So, the boundary of the island actually is a biological barrier that prevents interactions between life on the island and life adjacent to the island.

Seclusion and genetic isolation. It is possible to travel from island-to-island, depending on the specific situation. For example, if aquatic islands are close together, or not far from the mainland, birds and flying insects can traverse the gap. Pollen and seeds can be carried over by the wind, or float over while carried by water currents. Elevation islands also can be hopped by flying and floating animals, or by airborne pollen and seeds. However, consider the notion of a mountaintop animal walking from one mountain top to another. Let’s take a little pika, for example. Pikas are little furry animals related to rabbits and they live in high mountain elevations. They are about the size of a rat. In order for the pika to make this journey, he would have to walk great distances down the mountain, then along the expanse of terrain between mountains, then up the other mountain. In the process, the pika would encounter very different ecological conditions: different temperatures; different kinds of food; different forms of shelter; different means of accessing water; different predators, different insect pests. Such a journey would require a high degree of behavioral and physiological adaptability. The chances of survival are essentially nil. Because of this, species that can only make the trek on foot are virtually imprisoned on their particular mountaintop.

The farther the islands are separated, the more isolated and cutoff they are from life elsewhere. This isolation means that any genetic developments that occur on the island – stay on the island. It also means that any genetic developments that happen on other islands or the mainland won’t be shared with life on the island. The result is that island flora and fauna often express unique genetic and evolutionary trajectories. This is the explanation to account for many odd species found only on specific islands and nowhere else.
Galapagos Islands. 500 miles west of Ecuador.

For example, the Hawaiian Islands are far out in the middle of the tropical Pacific Ocean. When the first of the volcanic islands protruded above the ocean surface, it was a lifeless piece of basalt and ash. Life began to arrive by accident – blown in by storms. This is a very rare occurrence, such that the surviving colonists and their descendants operated almost entirely without disturbance by visitors. The result is that Hawaii is/was home to many endemic species (species that live in one place and nowhere else). Most of the notable endemic species are birds, many of which are now extinct because of human-caused changes to the islands.

The Galapagos archipelago, the island of New Guinea, Australia and New Zealand are isolated environments with interesting and unique species that occur nowhere else in the world. The birds of paradise on New Guinea have the most varied and peculiar courtship rituals of any birds in the world.

The numerous tepuis (tabletop mountains, or mesas) in the Guiana Highlands are examples of isolated mountaintop ecological islands. They are populated by unique species. The pitcher plant is one of these. Living on nutrient-poor soil, the pitcher plant traps and digests insects as its main source of mineral nutrients.

Mt. Roraima, Venezuela. A tepui and ecological island surrounded by a sea of clouds.

The biological significance of rain shadow

Many islands and continents have prominent mountain ranges. These mountains can influence the movement of cloud-borne moisture as clouds make their way across the land. In most situations, rain and snow come to continents from nearby oceans. Clouds form from evaporating seawater. The prevailing wind patterns carry the clouds across the continents. But what would happen if those clouds had to pass over a high mountain range?

Adiabatic cooling. When any moving air mass encounters a mountain, it rises, passes over the top, then descends down the other side. As the air mass rises, the volume it occupies expands. It expands because there is less air pressure the higher the air...
mass goes. Think of your ears “popping” when you drive up a mountain road. As the air expands, its temperature goes down. This is because the heat energy contained in the air mass is now spread over a larger volume of space. That means there is now less heat per volume – which results in lower temperatures. This process is called adiabatic cooling. As the temperature continues to drop on ascent, it reaches the dew point for the air mass and its water vapor condenses into tiny droplets forming clouds. If the temperature continues to drop even more, rain droplets form (or snow) and the moisture falls to earth. As a result of this process, clouds often form near mountain tops while the surrounding air has none. An extreme example that illustrates this process is the formation of lenticular clouds.

A lenticular cloud forms as moist air passes over the mountain top.

Adiabatic heating. After the air mass passes over the top of the mountain, it has less moisture in it because much of it has fallen out as rain or snow. It begins to compress on descent (because air pressure increases at lower altitudes). As it compresses, its heat content occupies less space, meaning more heat per volume and higher temperatures. This is adiabatic heating. As the temperature increases, the dew point is exceeded and cloud droplets evaporate into water vapor again. When the air mass reaches the bottom of the mountain it is now drier and less likely to produce rain as it continues its journey across the continent.

Deserts of the American southwest. The Sierra Nevada and a series of coastal ranges strip moisture as air masses move eastwards from the sea onto the continent. The result is a large rain shadow that contributes to dry conditions downwind from the mountains.

The land on the downwind side of this phenomenon is in the mountain’s “rain shadow.” The mountain has blocked rain. Land that is in a rain shadow is drier, and sometimes very dry. Rain shadow is a regional phenomenon that significantly contributes to the aridity of deserts and dry zones on continents and many islands. Two good examples of this effect are the Gobi Desert in Asia and the deserts of the southwest United States. In both cases, moist air approaches from the ocean, is forced over tall mountains, is stripped of its moisture, and then descends drier down the other side.
Water

A drop of water impacts a pool of liquid water.

Water is one of the most interesting substances in the universe. Earth is distinguished from other known heavenly bodies because of the abundance of water here. But water is not unique to Earth. Astronomers are finding it on the moon, on Mars, in interstellar space in our own galaxy, and even in distant galaxies. Except that all that other water is in the form of ice. On Earth, water is mostly liquid.

I will refer you to your favorite online encyclopedia for all of the technical details regarding water’s chemical and physical properties. I want to highlight the biological significance of certain aspects of water.

The biological significance of strong cohesive forces in water

Water molecules tend to be attracted to one another electrically. This is because the molecule’s arrangement is not symmetrical. One end has a slight positive electrical charge. The opposite end has a slight negative electrical charge. When water molecules are in close proximity to one another, the slightly positive ends are attracted to the slightly negative ends and vice versa. These attractions are not quite strong enough to form rigid ionic bonds; they are simply weak attractions. Chemists refer to this style of attraction as a “hydrogen bond.”

Several water molecules attracted to one another by hydrogen bonds.

The outcome is that water molecules tend to cohere (stick) to one another. When in a liquid state, these hydrogen bonds are very short-lived, as the molecules jostle around with each other. Still, the property gives water a high degree of cohesiveness. This is why water accumulates on the end of a faucet before finally dropping off, and why the drop self-configures itself into a sphere on descent.

The cohesiveness of water contributes to two other properties: 1) capillary action; and 2) high surface tension. A capillary is a tube with a very small diameter. Water tends to be attracted to the interior walls of such tubes, the xylem vascular tubes in a plant, for example. See image at left for an example. Water will move into and through the tube because of this capillary adhesion – even against the force of gravity. As a result, water tends to move from the roots, up the plant largely because of this physical property. This means that the plant expends no energy pumping water. In addition, because of water’s cohesive forces (hydrogen bonds) when a water molecule evaporates from a leaf, it tugs on an adjacent water molecule still in the leaf and pulls it forward. This starts a chain reaction that ultimately leads down to the roots, where a water molecule in the surrounding soil is pulled into the root. These properties and plant anatomical configurations increase the efficiency and usefulness of water as a transport medium in plants.

Surface tension. Surface tension is a property of a liquid in which its surface resists deformation. It is a result of the cohesive forces of the liquid’s molecules. Since liquid water molecules have high cohesion, the surface of any form of liquid water has high surface tension. This is true for a drop of water falling as rain, or a pool of water.
The high surface tension of water contributes to some very interesting biological applications. For example, the water strider is an insect that walks on water. Their legs are covered with thousands of microscopic “hairs” that increase the total surface area of contact with the water. The hairs are so densely packed that they repel water. The combination of these factors permits the water strider to stand and walk on top of the water without sinking in. This ability allows the water strider to move across the water surface and eat dead insects that have fallen into the water but could not escape.

Water strider.

The cohesive quality of water serves the archerfish well. These fish patrol the creek or pond edge just under the surface, scanning the low hung branches for resting insects. Once one is detected, the fish sends out a jet of water that knocks the insect off the branch and into the water. Then the archerfish quickly eats it. The high cohesiveness of water makes the water jet highly precise.

Archerfish uses a jet of water to knock off an insect.

**The biological significance of the buoyancy of water**

Buoyancy is the property in which an object resists sinking while in water. When you are in a swimming pool, your body has buoyancy in that you don’t sink like a rock to the bottom. Most aquatic organisms operate while buoyed to some degree in the water column. Although there are many kinds of aquatic species that operate only on the bottom (benthic), buoyancy doesn’t really affect them, unless some piece of food without buoyancy is sinking toward them. Despite that sharks and beluga whales are interesting beneficiaries of buoyancy, I want to address buoyancy on a microscopic level.

Plankton. Any organism whose movements in the water mainly are the result of water currents, is considered plankton. Taxonomically, plankton can be single-celled organisms (like cyanobacteria), simple multi-celled organisms (like copepods), or complex multi-celled organisms (like sea star larvae, and jellyfish). Regardless, plankton persist because of the buoying properties of water. Normally, plankton occupy the upper levels of the water column. This is important because the greatest mass of planktonic creatures is photosynthetic. The buoyancy of water means that plankton can remain near the surface (where there is more sunlight) with little effort.

Phytoplankton (photosynthetic plankton) account for the overwhelming majority of photosynthesis and biological productivity in the oceans. They form the ultimate basis for marine food webs. In terrestrial environments, plankton exist in ponds, lakes and rivers. But, the productivity of freshwater plankton is greatly exceeded by the productivity of plants on adjacent land. So ecologically, plankton are most important in the oceans. And buoyancy is a critical factor in their productivity – keeping them in the upper, sunlit layers of the water.

Dinoflagellates. Photosynthetic and non-photosynthetic plankton.

Buoyancy is essential in the biochemical reactions of the living cell. Almost all of the operational molecules in living cells are complex, 3-dimensional constructions. DNA and enzymes are examples. Refer to the panel on biomolecules presented earlier in this chapter. But these molecules have no structural strength. Their shape is achieved only because they are buoyed up by the water bath inside the cell. The key to biochemical interaction and chemical reaction is “shape.” If the
cell's large operational molecules lose their shape, they lose their operational characteristics. Think of a jellyfish stranded high up on a beach. Water's buoyant properties make cell biochemical operations possible by helping active molecules maintain their operational shapes.

The biological significance of the chemical reactivity of water

The chemistry of life mainly involves molecules built on a framework of carbon chains. Attached to these chains are atoms of various elements such as nitrogen, phosphorous and sulfur. However, most of the bonding sites on these carbon chains are occupied by hydrogen and oxygen atoms.

From a resource management perspective, this is a very efficient arrangement. This is because biochemistry happens in a water (H₂O) bath. Many reactions use water as not only a reactive medium but also as a source of materials in the building of new molecules. Photosynthesis is a good example.

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{light} \xrightarrow{\text{reorganize}} \text{fixed carbon} + \text{O}_2 \]

In this reaction, hydrogen protons and electrons from water molecules are used to finish the fixed carbon chain. Reactions also produce water as a universal waste product to dispose of hydrogen and oxygen wastes. Cellular respiration is a good example.

\[ \text{fixed carbon} + \text{O}_2 \xrightarrow{\text{reorganize}} \text{CO}_2 + \text{H}_2\text{O} + \text{ATP} \]

So, water not only provides the buoyant bath in which biochemical reactions happen, water also participates in biochemical reactions as a source of building materials and as a means for waste disposal. As water is abundant, and as water is chemically harmless, this is a very efficient and useful arrangement.

Panel: Specific Heat

The capacity of a substance to resist temperature change following the addition or subtraction of heat.

The biological significance of the specific heat of water

The “specific heat” of a substance is a measure of how much the temperature of the substance changes as it gains heat or loses heat. Remember, heat is a form of energy. Temperature is a measure of the internal vibrations of atoms that make up a substance. Adding heat energy to a substance causes the vibration activity of the composing atoms to increase. The more heat, the more vibration. A thermometer measures this.

Not all substances respond to heat changes at the same rate. It turns out that water is somewhat unusual in terms of its specific heat. Water has a very high specific heat – a high resistance to temperature change. To change the temperature of water, a high amount of heat must be added or removed. This means that the temperature of water changes slowly when heat is added or removed. By comparison, copper has a low specific heat. Copper has a low resistance to temperature change when heat is added or removed. This means that copper’s temperature changes more as compared to water, when a given amount of heat is added or removed. Water’s high specific heat has many interesting environmental and biological implications.

Body temperature. Animals have an optimal operating temperature. It is different for each species. The animal’s overall heat content determines the animal's body temperature. If the body’s heat content changes, the body temperature changes. But as animal bodies are about 60% water, body temperature changes slowly despite big changes in the body's heat content.

For example, consider the black collared lizard, a reptile. Reptiles are ectothermic / poikilothermic. Their body temperatures are influenced mainly by external environmental conditions, and their body temperatures will go up and down accordingly.
Black collared lizard.

After a cool night, the black collared lizard, pictured above, was sunning himself early one morning. During this operation, the lizard tries to maximize his exposure to the sun, which maximizes his heat gain. Because of water’s high specific heat, it takes more than a few minutes of heat absorption to register as an actual increase in body temperature. So, the lizard patiently waits. Once body temperature reaches a satisfactory level, the lizard will move on. If the air temperatures are cold, the body will lose heat, but the body temperature will drop slowly because of water’s high specific heat. After body temperature drops sufficiently, the lizard will find another sunny spot and warm up again. Note: this shuttling behavior works well with birds and mammals too.

The point is that by being composed mostly of water, body temperature does not change rapidly despite rapid changes in surrounding temperatures. This characteristic helps stabilize internal physiological operations and internal cell biochemistry – which are sensitive to temperature changes.

I want to consider the topic of specific heat in terms of endothermic / homeothermic animals. These are animals whose body temperatures are influenced mainly by internal processes, and whose body temperatures are held fairly constant. Birds and mammals are endothermic and homeothermic. Blood circulating throughout the body transports heat. The pattern of blood circulation in homeotherms can change during thermal stress.

For example, when exposed to cold temperatures, blood circulation initially is shunted out to the skin. This is why your ears and face turn red when you first go out in the cold. The extra blood carries additional heat to the skin cells whose temperatures are dropping because of heat loss to the cold air. This works fine as long as the core body temperature remains stable, such as when you have a warm jacket and you are not shivering from the cold. If the cold penetrates deeper (because your jacket is too thin), the core body temperature begins to drop (hypothermia - low body temperature). Shivering is an indication of hypothermia and it is one of the ways the body tries to regenerate internal heat. At this stage, blood is shunted away from the skin and the face and ears lose their color. Priorities have changed. Rather than trying to optimize operations in the skin, the body is now trying to save itself from hypothermia. The skin cells are left to fend for themselves.

Here is a hot example. When exposed to hot temperatures, birds and mammals will do two main things. First, shunting blood to the skin and extremities. But instead of trying to keep the skin warm, the body is using the skin to get rid of heat. During hyperthermia (high body temperature) ears and face will turn red (as we saw with the cold example above). Outer ear anatomy (pinna) is a very good region for disposing of heat. The pinna is very thin and has a high surface-area-to-volume ratio... good for heat exchange. Outer ears also are highly vascularized, so large amounts of blood are constantly passing through. Some animals from hot and arid climates have ears that are very efficient at dumping excess heat to the surrounding air.

The jack rabbit (a kind of hare) has very large ears. In addition to assisting in sound detection, the highly vascularized pinnae are excellent heat radiators. Jack rabbits are active in the daytime. To cool off on a hot day, jack rabbits will retreat to a shady area while the ears radiate excess heat to the surrounding air.
Jack rabbit. Its big ears are excellent heat radiators.

Birds and mammals have an additional way of using water to dump heat – evaporative cooling.

When water evaporates, individual water molecules at the surface become separated from the adjacent mass of liquid water in the body and become individual water vapor molecules. The rate of evaporation is influenced by temperature and air flow. The higher the temperature and the greater the amount of wind, the faster the evaporation. When a water molecule evaporates, not only does it remove water mass from the system, it also takes a substantial amount of heat with it. Therefore, the remaining liquid water mass has just experienced a reduction in total heat content – which causes a reduction in temperature. This outcome is called “evaporative cooling.”

During hot conditions, birds and many mammals pant in order to speed up evaporation of moisture in their respiratory systems. (It’s actually a little different in birds, an operation called gular fluttering.) Dogs pant while their tongues hang out and drip saliva. The panting increases the airflow over moist surfaces, which speeds up evaporation, which speeds up heat loss, which speeds up cooling.

Some mammals, including humans and horses, produce sweat. During hot conditions, sweat glands in the skin release a salty solution (sweat) onto the surface of the skin. When the sweat evaporates, there is a reduction in heat content on the skin, which results in a cooling sensation.

Kangaroos can’t sweat but they have an interesting alternative behavior. They lick their forearms and apply copious amounts of saliva to them. As the saliva evaporates, blood passing through forearms cools down.

Because of its high specific heat and fluid characteristics, water has remarkable heat-transporting qualities in living things. I want to present this idea of water as a “transportation” medium next.

Water is the master solvent and master transporter on earth

A solvent is a liquid substance in which other substances dissolve. The result is a solution which is a mixture of the two substances. Water is a master solvent because so many different kinds of things dissolve in it. Mineral salts, atmospheric gases, and hundreds of thousands of different kinds of biological molecules (organic) dissolve in water.

Water travels within living things. In vascular plants, water travels from the roots, along the vascular tubes of the xylem, and back to the roots by way of the vascular tubes of the phloem. In animals, blood is mostly water. Many invertebrates and all vertebrate animals have circulatory systems in which watery blood travels.

I previously described how water is a main transporter of heat in living things. As water travels through living things in orderly ways, and as many substances are dissolved in the water (because it is such a good solvent), water is the main transporter of materials in living things.

Looking at the larger environment, water is the planet’s main transporter of heat and materials. These transport activities account for a great deal of the Earth’s planetary surface environment.

We can begin to get at this idea by first considering the hydrologic cycle. The drawing below depicts it. In short, energy from the sun causes water on the ocean surface to evaporate. This water vapor ascends, cools and condenses into clouds. Winds blow clouds onto the continents. Once over the continent, the air mass cools and water falls out as rain or snow. Once on the ground, the water infiltrates into the ground to become groundwater, or it runs off on the surface to be collected in ponds or lakes, or surface runoff joins up in streams, creeks and rivers to return to the ocean.

The hydrologic cycle is driven by the sun. As long as the sun shines down on the oceans, the water on the planet will keep going round-and-round. As
water runs along the surface or below it underground, materials dissolve into it and get carried along. Rivulets of surface runoff water will collect mineral nutrient salts from the mountains and deliver them to the flatlands below. Groundwater also can mobilize underground salts and carry them to new destinations. But water not only carries soluble substances, running surface water also carries suspended materials such as silt, sediments and organic debris. This is especially true during floods.

Floods are very expensive and inconvenient for modern civilization. Many dams have been built in an effort to control them. Before the installation of flood-control dams, floods provided bounties of new, nutrient-rich topsoil to river deltas, such as the Nile River delta in Egypt, or the Mississippi River delta in Louisiana, USA. While flooding or not, rivers carry nutrients to the sea where they fertilize coastal marine ecosystems.

As there are rivers of water on land, there are also rivers of water in the oceans – currents. And though the important objects of transport in continental rivers are dissolved and suspended materials, heat is the most important passenger in ocean currents.

Ocean circulation moves water and heat horizontally and vertically. Heat collected by surface currents in the tropical Atlantic gets transported northwards to bathe Ireland in maritime warmth. This is what the Gulf Stream does. The Gulf Stream Current ends in the North Atlantic after losing much of its heat to the atmosphere above. The warmed air continues east and moderates the winters of Ireland, Britain and Western Europe. Without the influence of the Gulf Stream, these places would have bitter cold winters, instead of the mild winters they now have.
In a similar fashion, the Japan Current originates in the western tropical Pacific Ocean and travels northwards past Japan and Kamchatka to the Aleutian Strait in the far North Pacific Ocean. From there it becomes the North Pacific Current and bends clockwise to the south eventually ending off of southern Alaska as the California Current. The warmth from the Japan Current is the reason Anchorage, Alaska usually has milder winters than the continental interior at the same latitude.

**Ice**

The planet has large regions in which ice is a dominating component. Ice is water in solid form. It achieves this state when its temperature falls below 32°F (0°C). Most substances experience spatial contraction with colder temperatures, but water is different. While liquid, it does contract as temperature is lowered. But upon freezing, it actually expands. This is because the water molecules inside the ice are forced into a strict 3-D lattice according to hydrogen bond alignments.

The result is that ice is less dense than liquid water. This is why ice floats. The implications of this outcome are global. Imagine what planet Earth would be like if ice was denser than liquid water.

The planet’s main ice repositories are Antarctica, Greenland, the North polar ice cap, and mountain glaciers. The ice has formed there as a result of snowfall and temperatures that are permanently below freezing. Fish, penguins, whales, seals, plankton and other invertebrates navigate the periodically rich, freezing waters below floating sea ice. But topside, where there is permanent ice, there is no permanent life. However, we do find living things occasionally associated with ice.

For example, Emperor Penguins are active in the seas surrounding Antarctica. When not swimming and diving for fish in the frigid waters, they collect on the shallow ice or rocky substrate of the continent. Males with mates spend the permadark winters huddled in large, shifting, heat conserving groups in remote inland hideaways. A fold of skin covers a single penguin egg that the male penguins balance on top of their feet. With the return of spring and the sun, the egg hatches. Then chick and male parent make their way to the sea to reunite with the female parent. A summer of intense fishing ensues.
Emperor penguins on the ice in Antarctica.

Penguins are a phenomenon of the southern hemisphere. No operationally similar counterpart exists in the north. But the northern ice has its own unique ice species.

Polar bears have a broad behavioral repertoire. In winter, spring and early summer, males and non-pregnant females move onto floating ice (floes) to hunt for seals. Their favored technique is to stake out a seal breathing hole. When a seal uses the hole, the bear pulls it out of the hole and eats it. Polar bears also will stalk seals perched on the ice. Rarely, polar bears will attempt attacks on walruses.

Pregnant female polar bears have a different behavior. In fall, they dig a deep den into a permanent snow drift. Females occupy the den during winter where they maintain a low activity level accompanied by frequent sleep. Female polar bears in this situation experience a slightly depressed body temperature but not enough for the resting state to be classified as true hibernation (which requires a significant drop in body temperature). The cubs are born during winter in the den where they stay until early spring. Eventually, mother and cubs emerge from the den and make their way to the sea ice in search of seal breathing holes. As spring and summer advance, the sea ice retreats away from the coastline. As a result, polar bears will swim out to them, sometimes several miles.

Glaciers. Glaciers are large masses of ice that move slowly down a mountain. Glaciers have formed on mountaintops at all latitudes, including high mountains in the tropics. Periodic snowfall on mountain tops and permanently sub-freezing temperatures results in an accumulation of snow and ice on the mountaintop. Eventually, the weight of the ice mass begins to push down the mountain, usually down a ravine. As the movement of ice continues for many years, it takes on the appearance of a “river” of ice. This is the glacier. While the glacier moves across the land, it scours away the underlying topsoil and cuts into the bedrock, further carving out the ravine and canyons in its path of transit.

Saskatchewan Glacier.

Lower down the mountain, temperatures are warmer and the glacier ice begins to melt. The melt water continues down streams and creeks, providing moisture for forest and woodland ecosystems associated with the mountain, and on the flat below.

When glaciers melt, their retreat leaves behind piles of rock and debris from the former glacial face (moraines) and a barren of exposed bedrock and large boulders. Useable territory for pikas and marmots, but unrewarding for plants.

The surface environment of planet Earth is an amazing mix of air, land, water and ice. Within each of these environmental realms there is remarkable variety. Bacteria, fungi, plants and animals occupy the world’s complex environmental settings with surprising and beautiful results.
Works Cited


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