Nature Physics: A Change of Seasons – Fall Colors

Autumn in eastern Idaho means dwindling daylight hours, bull elk bugling in the high country, and leaves changing colors. You likely know why the days are shorter (the northern hemisphere tilts farther from the sun during the fall than during the summer) and why bull elk bugle (they're trying to advertise their dominance over other bulls and attract a mate). But do you know why leaves change colors?

Fall colors on display in Teton National Park (photo courtesy of GeekPhilosopher.com).

The Ingredients of Fall Colors

To understand this process, you'll first need to know about four substances involved in the process of leaves changing colors each autumn:

- First, there's *chlorophyll*. The chlorophyll that's present in plants during the warm-weather months makes leaves appear green. Chlorophyll facilitates one of the most miraculous processes on earth—photosynthesis. The process of photosynthesis allows plants to convert water, carbon dioxide, and the energy from sunlight into our primary source of bodily fuel, which is glucose (a type of sugar). All animals and humans obtain their life-sustaining energy either directly or indirectly from plants, making photosynthesis one of the sources of all life. Without photosynthesis, there would be no life (Sacred Source Nutrition 2014).

A green substance called chlorophyll gives leaves their green color during spring and summer (photo courtesy of GeekPhilosopher.com).

- You also need to know about xanthophylls and carotenoids. Yellow-colored xanthophyll pigments and yellow- to orange-colored carotenoid pigments are, like chlorophyll, also present in leaves during the warm-weather months and are used for photosynthesis. But you don't see these pigments during the summer because they're masked by the green color of the chlorophyll. These pigments are also commonly found in such things as corn, carrots, daffodils, rutabagas, buttercups, and bananas (Science Buddies 2014).

- And finally, there are anthocyanins. These are red pigments that are not present in leaves during the warm-weather months, but they do appear in the leaves of some trees after chlorophyll production stops. Anthocyanins are intense color molecules. In addition to some autumn leaves, they give color to such familiar things as cranberries, red apples, concord grapes, blueberries, cherries, strawberries, and plums (Science Buddies 2014).

How the Change Happens

Throughout the summer, leaves are green because they are flush with green-colored chlorophyll as trees take advantage of the long hours of sunlight and plentiful water to make food via photosynthesis. During the growing season, chlorophyll is replaced constantly in the leaves because it breaks down with exposure to light in the same way that colored paper fades in sunlight. So leaves must manufacture new chlorophyll to replace that which breaks down (The United States National Arboretum 2014). Small tubes carry water from the tree to the leaves and then shuttle food back from the leaves to the tree. But as daylight hours decrease during autumn, trees begin to shut down their food production. Leaves aren't able to continue photosynthesizing during winter because there's not enough sunlight.

At the base of each leaf is a special layer called an "abscission" or separation layer. As daylight hours decrease during the fall, the cells of this layer begin to swell and eventually form a dry cork-like material. This material reduces, and finally cuts off, the flow of the small tubes between leaf and tree.

Consequently, glucose and waste products are trapped in the leaf. And without fresh water to renew the chlorophyll, the chlorophyll begins to break down and disappear in a relatively short period (Science Made Simple 2014).

Likewise, the supplies of yellow-colored xanthophylls and the yellow- to red-colored carotenoids in the leaf are eventually cutoff completely. But these pigments are different from those in the green-colored chlorophyll because they don't break down as quickly. So as the green fades away relatively fast, the longer-lasting yellow, orange, and red pigments become visible, and the leaves take on these colors instead of green.

The red hues that come from the pigments called anthocyanins are slightly more complicated. All trees contain chlorophyll, carotene, and xanthophyll, but not all of them produce anthocyanins. Even the ones that do have anthocyanins only produce it under certain circumstances (How Stuff Works 2014).

As the days grow shorter, trees shut down their production of chlorophyll (green pigments), xanthophyll (yellow pigments), and carotenoid (yellow to orange pigments) production. All three substances eventually fade from the leaves, but the green chlorophyll fades faster than the other two, resulting in the leaves' yellow and orange hues (photo courtesy of GeekPhilosopher.com).

The pH of the trapped glucose (sap) also has an effect on the colors of leaves. The pigments are sensitive to pH. If the sap is slightly acidic, the leaves will turn redder in color. If the sap is caustic (on the base side of the pH scale), the leaves will turn more purple or blue color before the pigments start to break down.

Remember that layer of cells at the base of the leaf stem? Its purpose is to protect the tree during the cold winter months and prevent it from drying out. When the separation layer is complete, the leaves fall off in the tree's attempt to conserve energy. But before the leaves fall off and the tree closes up shop for the winter, the tree wants to pull in as much sugar and nutrients as possible from its leaves, which is where the anthocyanin comes in.

Scientists offer several different reasons for why some trees produce anthocyanins and autumn leaves change color, but the prevailing theory is that anthocyanins protect the leaves from excess sunlight and enable the trees to recover any last remaining nutrients. The reason we see more vibrant reds during some years is that lots of sunlight and dry weather increase the sugar concentration in tree sap, triggering the tree to release more anthocyanins in a last-ditch effort to gather up energy to get through the winter. In addition, near-freezing weather, low nutrient levels, and other plant stressors seem to trigger increased levels of anthocyanins (How Stuff Works 2014).

Other Factors Affecting Color

By far, the biggest factor affecting the changing color of leaves during the fall is the decreased daylight hours, as discussed above. But temperature and soil moisture also influence of the fall foliage display.

Weather plays a part in displays of fall colors, but the greatest influence is decreased daylight (photo courtesy of GeekPhilosopher.com).

According to The United States National Arboretum website, "Abundant sunlight and low temperatures after the time the abscission layer forms cause the chlorophyll to be destroyed more rapidly. Cool temperatures, particularly at night, combined with abundant sunlight, promote the formation of more anthocyanins. Freezing conditions destroy the machinery responsible for manufacturing anthocyanins, so early frost means an early end to colorful foliage. Drought stress during the growing season can sometimes trigger the early formation of the abscission layer, and leaves may drop before they have a chance to develop fall coloration. A growing season with ample moisture that is followed by a rather dry, cool, sunny autumn that is marked by warm days and cool but frostless nights provides the best weather conditions for development of the brightest fall colors. Lack of wind and rain in the autumn prolongs the display; wind or heavy rain may cause the leaves to be lost before they develop their full color potential" (The United States National Arboretum 2014).

Experiment

If you want to find out which pigments (or colors) are present in leaves, try re-creating an experiment shown in a YouTube video titled Chromatography: Why Do Leaves Change Colors? at this link: http://www.youtube.com/watch?v=lKnH6576ixM.

In this video, two working scientists demonstrate something called chromatography. The word chromatography originates from the Greek language and translates roughly into “color writing.” Chromatography is a set of laboratory techniques used to separate the individual substances that make up a mixture. In the case of this experiment, the mixture of chlorophyll, xanthophylls, and carotenoids in leaves will be separated from each other so that the individual pigments are visible.

The process works by using a solvent to extract chemical compounds from a substance. Once the chemicals of interested are extracted, we need a way to separate them into the individual components. In this video, the scientists use a coffee filter. The coffee filter paper acts as a separating agent. The different pigments travel up the filter paper at different rates. This is caused by the chemical reactions between the pigments and the paper. As a result, different color “bands” form on the paper representing the different pigments. As can be seen in this experiment, many different pigments are present in the green leaves. As the leaves turn color in the fall, the green chlorophyll pigment is reduced, allowing the other pigments to be seen.

References

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