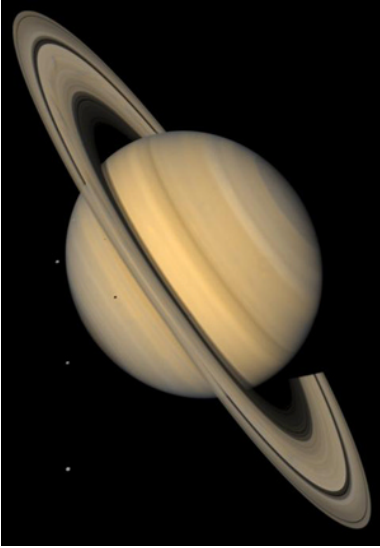


Taking Apart the Light



What is the name of that big, gassy planet in our solar system that has the bright, beautiful rings? If you are interested in space and astronomy, you probably know it is Saturn. And if you are really an astronomy buff, you might know that Saturn is mostly hydrogen and helium and that Saturn's rings are mostly water ice.

How do scientists know what Saturn is made of? How do they also know that the Sun is three-fourths hydrogen and one-fourth helium? How do they know what other stars, planets, comets, and gas clouds in space are made of?

How they know is by using a technique called *spectroscopy* (spek-TROSS-koh-pee). Spectroscopy is a way of studying the light coming from some material (like a star) or passing through some material, like a gas. For example, as the light passes through the gas, the atoms in the gas change the light somewhat so that the light is different when it comes out from when it went in. What makes this technique so interesting is that every different kind of matter produces or changes the light in a different way. So, just by examining the light that comes from something that is burning or has passed through a cold gas, scientists can figure out what the burning material or gas is. Or, if two or more kinds of materials are mixed together, they can tell in what proportions they are mixed—like figuring out the recipe by tasting the stew.

How does this work? Why do different materials all change the light in different ways?

Quantum Mechanics Made Easy (Really!)

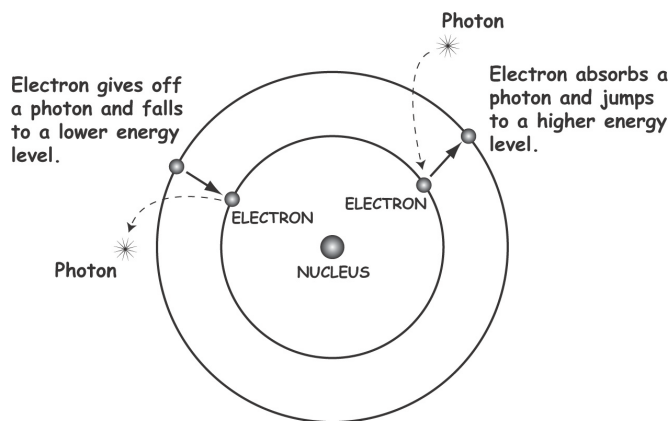
All ordinary matter is made up of atoms. Atoms are the smallest particles of an element. Elements are the simplest substances that can't easily be separated into other substances. For example, oxygen is an element and hydrogen is an element. Water is one oxygen atom and two hydrogen atoms combined. However, water can fairly easily be separated back into oxygen and hydrogen.

Atoms, themselves, are made up of even smaller particles, but when you start breaking those apart, you don't have the element anymore. You have something else, but we won't get into that here.

An atom is made of a *nucleus* (containing *protons* and *neutrons*, also called nucleons), with *electrons* buzzing around it. What kind of atom it is depends on how many protons (the number defines which element it is), neutrons, and electrons there are. Hydrogen, which is the most abundant element in the universe, has just one proton and one electron (and most often no neutrons). The nucleus is just a few quadrillionths (that is, an unimaginably small part) of the total size of the atom, yet a nucleon is nearly 2000 times heavier than an electron. What does this mean? It means atoms are mostly empty space! Yes, even the most solid-looking matter—the chair that is holding you up, the floor you are standing upon—is almost all empty space!

Although electrons do not exactly go around the nucleus like the planets orbit the Sun, it sometimes helps to think of electrons that way in order to understand how they behave. But unlike planets orbiting the Sun, electrons cannot orbit at just any orbits that the electrons can occupy. (These "orbits" are sometimes called *shells*, since the electrons can be anywhere on an imaginary sphere a certain distance from the nucleus.) The electrons can jump from one orbit to the

next, however. If a little packet of energy comes their way, they may use it to jump to the next higher orbit (that is, farther away from the nucleus). Or, they may fall back to a lower orbit (closer to the nucleus), and give up a little packet of energy. For this reason, these orbits or shells the electrons occupy are also called *energy levels*.



Hydrogen Atom

These packets of energy the electrons are grabbing or giving up are called *photons*. Photons are the smallest units of light energy. Each kind of atom prefers photons of certain colors, or wavelengths. For example, in the range of light that we can see with human eyes, hydrogen atoms like a certain shade of red, a certain shade of blue, and a certain shade of violet.

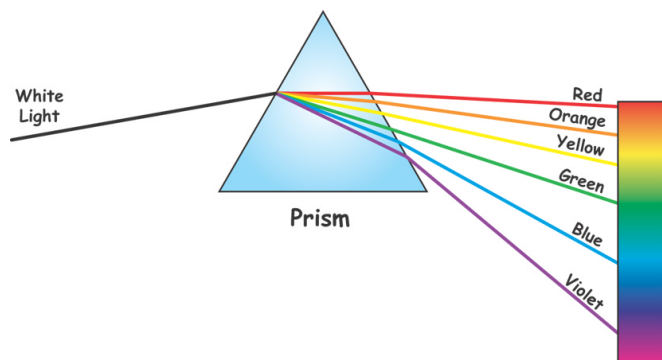
Everyone Has a Favorite Color

What makes light different colors? It is the wavelength of the light.

Like energy passes through the ocean and breaks in waves upon the shore, light energy also travels in waves. Some waves are long and slow and lazy. Others are short, choppy, and energetic. When it comes to waves of light energy, our eyes are sensitive to only a very small range of these wavelengths. This range we call *visible light*, because it is the light that is visible to us.

Whoa! Haven't we been talking about photons of light being little packets? So how can little packets travel in waves? Good question! Well, the universe is a strange and wondrous place. Light seems to be both particles and waves.

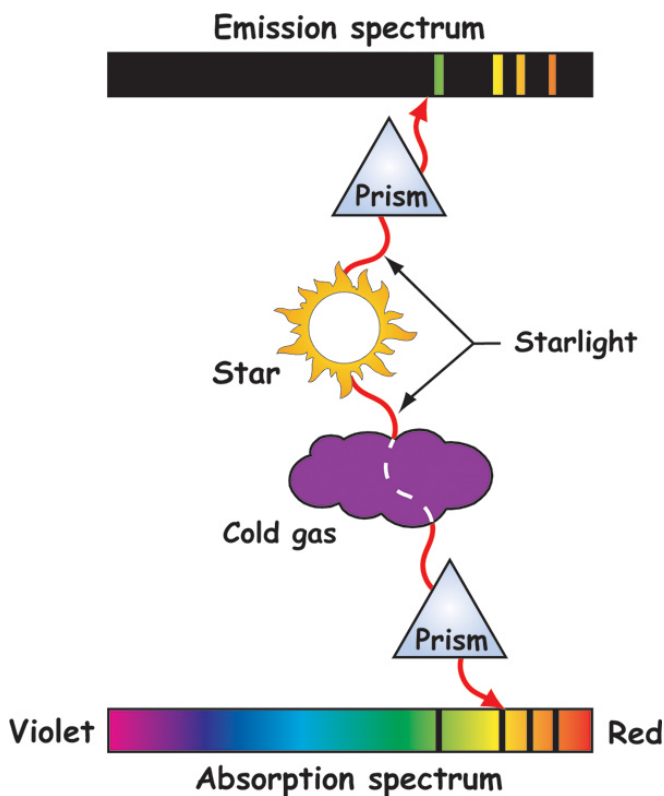
Normally, light from the Sun doesn't seem to be any particular color—it's just white light. But sometimes we are lucky enough to see a rainbow. A rainbow is formed when water droplets in the air act like little prisms and bend the sunlight so that the different wavelengths get separated out. Then we see that sunlight is really made up of all these different colors. When we see all the different colors separated, like a rainbow, we call it a *spectrum*.



Now you know where the word *spectroscopy* comes from. It is the study of *spectra* (which just means more than one spectrum).

If all the colors are present in the spectrum, it is called a *continuous spectrum*. However, if you had a particular kind of prism that was very, very good at separating out all the different wavelengths in the light, you might notice that some of the wavelengths were missing! Even the light coming from the Sun would have some wavelengths missing. Where are these missing photons? Most likely, they were absorbed by atoms or molecules of the gases in Earth's atmosphere. Electrons in those gases used their favorite wavelengths of photons to boost themselves to a higher orbit. These missing wavelengths in their spectra are called *absorption lines*.

While looking for absorption lines is a good way to find out what kind of stuff the light has passed through (like gas clouds), we can also use spectroscopy to examine the source of the light—like a star. When the star burns, the electrons in the star's atoms are jumping from higher to lower orbits, releasing photons like mad. If we use a particular kind of prism that is very, very good at separating out the wavelengths of light coming from the star, we will see bright bands at certain wavelengths. These bright bands are called *emission lines*. They allow scientists to identify what's cooking on the star.



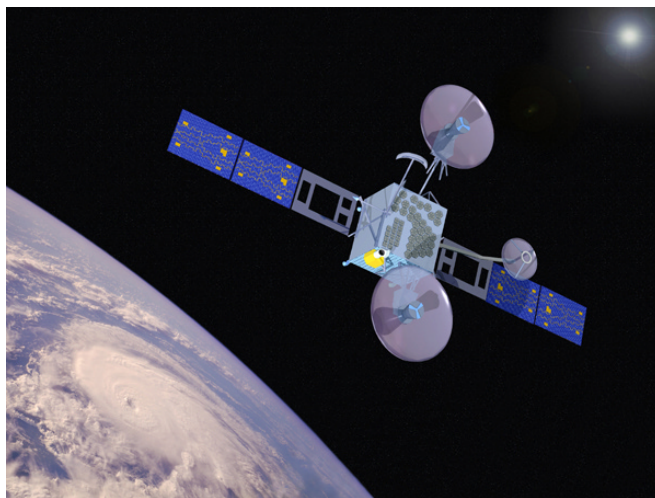
It's Elementary, Watson!

Be a detective and try identifying some elements by their absorption spectra.

On the last page of this article, in the left-hand column, you will find a list of elements, along with a selection of some of the wavelengths at which each element's atoms absorb light. In the right-hand column, you will see some graphs that represent absorption spectra (sorry they're not in color). Each graph is labeled at the bottom with a scale that includes the wavelengths of visible light, that is, waves from about 400 to 750 nanometers (nm) long. (A nanometer is one-billionth of a meter; a visible light wavelength is about the size of a germ, far too small to see without a microscope.) Each graph then shows where the absorption lines would be for some element. Match the elements on the left with their absorption line spectra on the right. Answers are upside-down at the bottom.



New Spectroscopy Technology



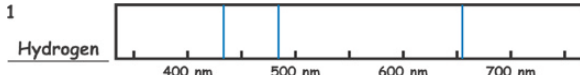
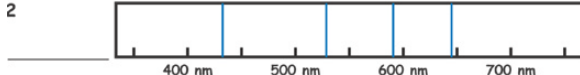


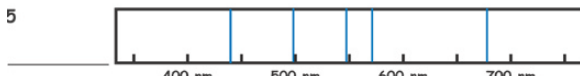
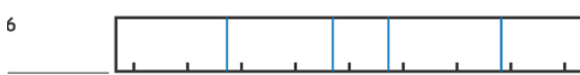
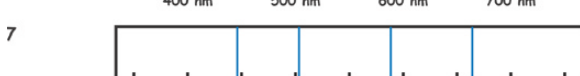
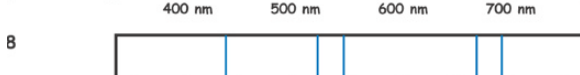
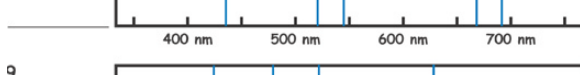
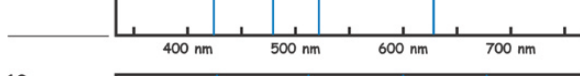
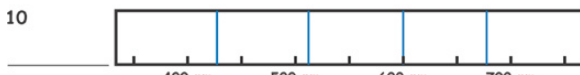


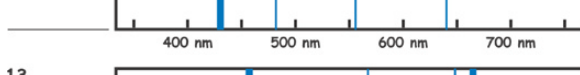
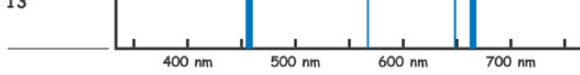

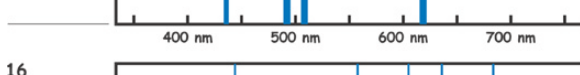
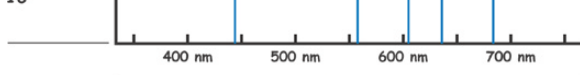
The Earth Observing 3 mission will test the GIFTS instrument by flying it on this satellite.

As part of NASA's New Millennium Program, a very advanced spectrometer will be flown as the Earth Observing 3 mission. The instrument, which will study Earth's atmosphere, is called GIFTS (for Geo-synchronous Imaging Fourier Transform Spectrometer). GIFTS will orbit more than 22,000 miles above the equator. At this altitude, it will take one day (that is, one revolution of Earth) for it to make one orbit, so it will seem to hover over one point on Earth. This orbit will allow it to continuously view a very large area. When GIFTS is used on future weather satellites, its technology will revolutionize weather forecasting by precisely measuring the temperature and water vapor content of the atmosphere at many altitudes.

Earth Observing 3 will be launched around 2005 or 2006. Go to The Space Place at http://spaceplace.nasa.gov/eo3_compression.htm to learn more about Earth Observing 3 and to play a game that shows some new ways that the mission will test for shrinking data down to size.

This article was written by Diane Fisher, Guru of The Space Place website, with help from Sandi Beck, Technical Writer, Sally Urquhart, a high school chemistry teacher and environmental chemist in Richardson, TX, and Alex Novati, Space Place Illustrator. It was provided through the courtesy of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under a contract with the National Aeronautics and Space Administration.

Enter the name of the element from the list on the left beside its spectrum of absorption lines on the right.

Element with selected absorption wavelengths in nm	Absorption Spectrum
Example: Hydrogen 433, 486, 656	1 Hydrogen 
Helium 447, 502, 587, 668	2 
Carbon 427, 515, 600, 678	3 
Nitrogen 460 to 465, 567, 649, 661 to 666	4 
Oxygen 464 to 467, 559, 626, 760	5 
Neon 439, 534, 588, 692	6 
Sulfur 425, 565, 639, 675	7 
Chlorine 438, 522, 545, 669, 692	8 
Iodine 445, 560, 607, 634, 681	9 
Krypton 427 to 430, 482, 556, 642	10 
Xenon 484, 590, 687	11 
Aluminum 490, 528, 600, 669	12 
Calcium 429, 527, 593, 645	13 
Iron 417 to 433, 516, 562, 619	14 
Nickel 440, 499, 548, 572, 677	15 
Copper 435 to 438, 490 to 496, 503 to 508, 618 to 622	16 
Silver 421, 521, 662	17 
Gold 424, 497, 523, 628	18 

Answers:

1. (example given) Hydrogen, 2. Calcium, 3. Silver, 4. Oxygen, 5. Nickel, 6. Neon, 7. Helium, 8. Chlorine, 9. Gold, 10. Krypton, 11. Xenon, 12. Krypton, 13. Nitrogen, 14. Iron, 15. Copper, 16. Copper, 17. Aluminum, 18. Sulfur