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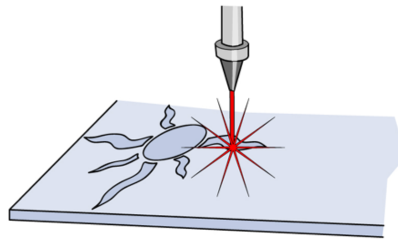
SOLVE THE MYSTERY OF THE GASES!



What do CD and DVD players, grocery store bar code readers, metal cutting and welding tools, and ultra-delicate eye surgery tools all have in common? Right! They all make use of lasers. The laser was invented in 1958, and at first, people didn't think it would be good for much. How wrong they were!

Cutting through hundreds of layers of fabric at once to make clothing. Carrying TV and telephone signals over fiber optic cable. Measuring distances for surveying tracts of land. These are just a few of the ways lasers make our daily lives easier, less expensive, healthier, more interesting, or just more fun.

Lasers have also found great uses in space. For one thing, they can be used in a device called a spectrometer.

A SPEC-WHAT-O-METER?

WHAT IT CAN DO:

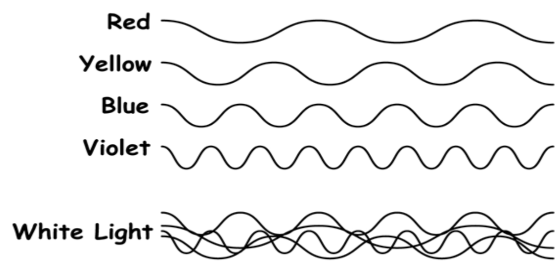
A spectrometer (spek-TROM-met-er) uses light to identify the chemical composition of matter.

For example, a spectrometer "looking at" sunlight that has passed through the air above a city can detect what gases the air contains (like carbon dioxide, nitrogen, oxygen, carbon monoxide, and pollutants like ozone and methane). A spectrometer can also tell us what materials are in the atmospheres of other planets, like Mars and Venus, or their satellites, like Saturn's moon Titan or Jupiter's moon Europa.

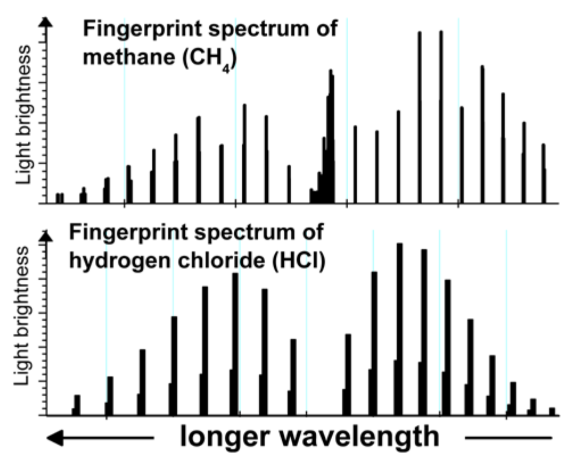
HOW IT WORKS:

So, how does a spectrometer identify material just by looking at light?

Remember that photons, or light particles travel in waves. Different colors of light have waves of different lengths. For example, red light waves are longer than blue light waves. White light is made up of all the wavelengths mixed together. Even light from the Sun or a light bulb contains many different wavelengths.



Atoms and molecules in solids, liquids, or gases produce or change light in a unique way. When very hot, each *emits* a unique color of light of an exact wavelength. For example, hot sodium street lights are yellow and mercury athletic field lights are blue. When vaporized, or in the form of a gas, each *absorbs* that unique color of light, of an exact wavelength. In other words, every atom or molecule leaves a unique "fingerprint" as its spectrum.



Emission spectrometers (like prisms) analyze light emitted, or coming from some source, like sunlight, starlight, or light from a hot, glowing gas. Strong colors of an exact wavelengths reveal what kinds of matter the source is composed of.

Absorption spectrometers look for missing, or *absorbed* colors in light that has passed through a gas or vapor. Colors of an exact wavelength that are missing from this light reveal what kinds of atoms and molecules the gas contains. The light source could be the Sun or a laser.

A laser spectrometer is a special type of absorption spectrometer that shines a laser light beam through the gas. More on lasers later.

Spectroscopy then, is a way of studying the wavelengths of light coming from some material (like a star or a very hot metal) or passing through some material, like a gas. With this technique, scientists can tell what materials are burning (like in a star or a firework) just by examining the wavelengths of light produced. Or, they can identify a cold (that is, non-glowing) gas by seeing what wavelengths are missing after light has passed through it.

What's more, if two or more kinds of materials are present, they can tell in what proportions they are mixed.

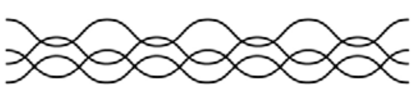
If you want to know more about how spectroscopy works, check out The Space Place article entitled "Taking Apart the Light," from the March 2002 issue of *The Technology Teacher*, now available on The Space Place web site at http://spaceplace.nasa.gov/teachers/eo3_spectroscopy.pdf.

Get Those Waves Organized!

Laser is an acronym of (short for) "**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation." But what does this mean? What makes laser light so different from ordinary light?

First, the light from a laser contains exactly one color or wavelength rather than a lot of different wavelengths. Scientists say that laser light is "**monochromatic**," meaning of one color.

Mixed wavelength (white light)

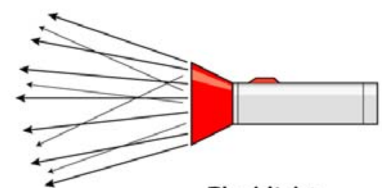


Same wavelength (but not in phase)

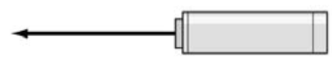
Second, all the wavelengths are in phase. That is, they are all "waving" in unison, like a well-coordinated audience "wave" at a football game. All the wave crests (high points) and troughs (low points) are lined up. Scientists say the laser light is "**coherent**."

Same wavelength (and in phase)

And third, the particles of light, or photons in the laser light waves are all traveling in the same direction, exactly parallel to one another. They are not headed off in different directions. This means that laser light beams are very narrow and can be concentrated on one tiny spot. Scientists say the laser light is "**collimated**."



Flashlight



Laser

Because the laser light is monochromatic, coherent, and collimated, all of its energy is focused to produce a small point of intense power. ·This is the quality that enables laser light to be used in cutting and welding tools. This is also the quality that makes it possible to control it very precisely and make it do all kinds of useful things.

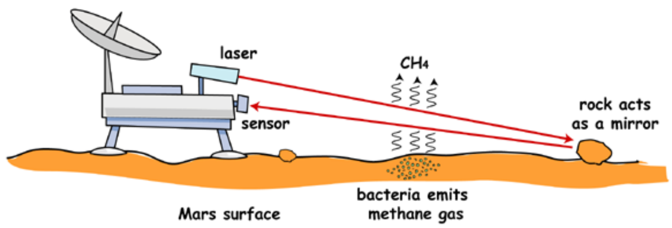
No Escaping the Laser Spotlight

So, what can laser spectrometers do that ordinary light spectrometers cannot?

Absorption spectrometers that analyze ordinary light passing through gases give a pretty good idea which gases (atoms and molecules) are present based on what colors (wavelengths) of light have been absorbed by the gas.

But laser spectrometers, using a beam of laser light consisting of only one wavelength tell scientists a lot more. A laser spectrometer shines this precisely tuned beam though a sample of unknown gas, to a mirror (a part of the spectrometer) where it is reflected back again through the gas, and into a light sensor. The sensor measures the beam for changes in intensity. Any decrease in the laser beam's intensity indicates precisely how much (if any) there is of the gas that absorbs the laser beam's wavelength.

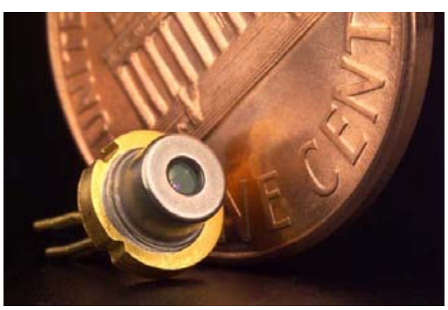
Although spectroscopy lasers can also operate at wavelengths of light that are invisible to our eyes, suppose the laser beam were bright red and the gas absorbs a narrow band of blue or green? In that case, the laser spectrometer would see no gas. But what if a scientist wanted to know if there was any tiny trace amount of, say, methane on Mars being given off by a bacterial life community, and a laser spectrometer could be tuned like a violin to send out a laser beam of exactly a wavelength that methane molecules absorb? Not only would the spectrometer find the methane molecules, but it could practically count them, even if there were only a few, based on the strength of a reflected laser beam, slightly weakened by each molecule as it passed through a particular volume of mixed gases.



A New Way to Make a Laser

NASA is studying a new type of laser spectrometer for possible use in space missions. The new device is called a Quantum Cascade Laser Spectrometer. The very tiny laser device is constructed in a special way that allows it to generate a very powerful laser beam. Not only that, but the laser beam is "tunable." The wavelength of the laser beam can be changed within a certain range of wavelengths. This way, the Quantum Cascade Laser Spectrometer can look for a variety of specific gases in, for example, the atmosphere on Mars or Venus! This special spectrometer is also very sensitive and can detect the tiniest amounts of a gas. Finding even a few molecules of CH_4 (methane), for example, on Mars would be very significant.

This new laser spectrometer is so small and uses so little power it could be put on an atmospheric probe, a lander, a rover, a balloon, or an aerobot.



The Spectrometer's Quantum Cascade Laser is tiny compared to this penny.

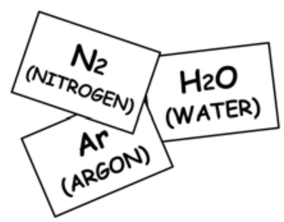
The Quantum Cascade Laser Spectrometer is ideally suited to detecting pollutants in our own atmosphere. Its great sensitivity and small size allow other Earthly possibilities. Doctors could use it to analyze trace amounts of certain chemicals in a person's breath to help diagnose diseases. It could also be used in automobiles as part of a cruise control system to help avoid collisions in conditions of poor visibility.

These Games are a Gas!

Here are some games you can play with your teacher and your classmates to get an idea of how spectrometers work. First you will see how an emission spectrometer using ordinary light works. Then you will see the different approach a laser spectrometer takes to analyzing a gas.

First of all, you will need a collection of "Gas Cards." Use 3x5 cards or whatever is handy. You will need at least twice as many cards as people in the class (or people actually playing the game). On each card, write ONE of the following gases*, including both the name and the formula (how many of which atoms make up a molecule of the gas). Make an equal number (more or less) of each kind of Gas Card. So, for example, if there are 30 people in the class, make 60 Gas Cards, with 6 of each of the 10 gases.

H_2O	Water	CO_2	Carbon dioxide
O_2	Oxygen	N_2	Nitrogen
O_3	Ozone	Ar	Argon
CH_4	Methane	He	Helium
CO	Carbon monoxide	SO_2	Sulfur dioxide



Emission Spectrometer Gas Game (Game #1)

In this game, a prism spectrometer checks emitted (non-laser) light to see whether specific heated gases are present (however, it will not be able to tell how much of each gas there is).

1. Assign roles:
   There are two roles for players:
   Prism—One player (could be teacher)
   Gases—All others in class, each having one Gas Card
2. **Prism** calls the name (or formula) of each gas, including some that are not on the gas cards distributed. **Gases** respond with "yes" if their name or formula is called.
3. **Prism** simply notes which gases received "yes's" (but doesn't count up how many) and summarizes (on board) which gases are present and which aren't.

* C = Carbon, H = Hydrogen, He = Helium, N = Nitrogen, O = Oxygen, S = Sulfur

For example:

H_2O	yes	CH_4	yes
CO	yes	CO_2	no
NH_4	yes	NO	no
He	no		

The Laser Spectrometer Gas Game (Game #2)

1. Assign roles:
   Players have one of three roles:

   Sensor— One player, who records and calculates laser data.
   Lasers— Three (we suggest), one player for each gas type sought.
   Gases— All other class members

2. Except for the **Sensor**, each player draws or is issued one card in a random drawing. (The **Sensor** can be the "dealer"). The cards that the **Lasers** draw will represent the gases that each **Laser** is "tuned" to detect.

3. Each **Laser**, in turn, calls out gas, either by name or formula. As their gas is called, class members ("**Gases**") hold up matching Gas Cards. The **Laser** counts the number of displayed cards and reports to the **Sensor**, who records count. The **Sensor** counts total gas players, then calculates percentage of each gas of the total in the room (see example below).

As a variation, "retune" the **Lasers** by having them draw different Gas Cards or additional Gas Cards. The Laser Spectrometer (**Laser**/**Sensor**) team can calculate the composition of all the gases in the class by eventually calling out and counting all ten gases written on the Gas Cards.

The Binary Variation (Game #3)

1. "**Gas Molecules**" (class members with Gas Cards) move slowly, in single file, past **Lasers**. **Lasers** "test" each **Gas Molecule** by calling out the gas name or formula on their own card. **Gas Molecule** responds with "no" if no match or displays Gas Card if it matches.
2. **Laser** tallies and reports totals to **Sensor**, who records count.
3. **Sensor** counts total **Gas Molecule** players, then for each gas measured, calculates its "volume" as a percentage of all gases in the room.

For example, if there are 27 players with Gas Cards, and Sensor data from three Lasers shows 6 H_2O, 8 CH_4 , 2 CO, then the Sensor would calculate

H_2O	6/27	=	22.22 %
CH_4	8/27	=	29.63 %
CO	2/27	=	7.41 %
Unknown	11/27	=	40.74 % (other gases not checked for).

Discussion

Which of the following problems do you think a laser device of some sort might be able to solve? How? (Hint: It's OK to be stumped on some of these!) Can you think of other uses of lasers?

- Measuring the speed of light in a laboratory.
- Keeping three airplanes or three spacecraft flying exactly the same distance and angle apart no matter what.
- Curing a disease-infested forest.
- Measuring the distance from here to the Moon.
- Creating a 3-dimensional "photograph" of an object (known as a hologram).
- Building a very accurate missile for delivering a bomb to a military target without hurting people.
- Finding and fixing tooth decay.
- Getting rid of an unwanted tattoo.
- Saving our planet from a small asteroid on a collision course with Earth.
- Stopping a runaway train whose brakes have failed.
- Building a mile-long fence in an absolutely straight line.

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