The Physics of Plasma Globes

Part of a Series of Activities in Plasma/Fusion Physics
to Accompany the chart
Fusion: Physics of a Fundamental Energy Source

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Preface

This activity is intended for use in high school and introductory college courses to supplement the topics on the Teaching Chart, ***Fusion: Physics of a Fundamental Energy Source,*** produced by the Contemporary Physics Education Project (CPEP). CPEP is a non-profit organization of teachers, educators, and physicists which develops materials related to the current understanding of the nature of matter and energy, incorporating the major findings of the past three decades. CPEP also sponsors many workshops for teachers. See the homepage **www.CPEPweb.org** for more information on CPEP, its projects and the teaching materials available.

The activity packet consists of this student activity and separate notes for the teacher. The Teacher's Notes include background information, equipment information, expected results, and answers to the questions that are asked in the student activity. The student activity is self-contained so that it can be copied and distributed to students. Teachers may reproduce parts of this document for their classroom use as long as they include the title and copyright statement. Page and figure numbers in the Teacher's Notes are labeled with a T prefix, while there are no prefixes in the student activity.

Developed in conjunction with the Princeton Plasma Physics Laboratory and funded through the Office of Fusion Energy Sciences, U.S. Department of Energy, this activity has been field tested at workshops with high school and college teachers.

We would like feedback on this activity. Please send any comments to:

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The Physics of Plasma Globes

Part of a Series of Activities in Plasma/Fusion Physics to Accompany the chart *Fusion: Physics of a Fundamental Energy Source*

General Introduction to "The Physics of Plasma Globes" and "Studying the Electric Field near a Plasma Globe" Activities*

The activities "The Physics of Plasma Globes" and "Studying the Electric Field near a Plasma Globe" use a plasma globe to study some of the characteristics of plasmas and the nature of the energy they radiate. As stated on the Chart, *Fusion: Physics of a Fundamental Energy Source*, plasmas are "collections of freely moving charged particles" and are referred to as the fourth state of matter. You might ask "Why study plasmas?" The other three states of matter-solids liquids and gases-make up our bodies and over 99% of the matter on earth. If we were only concerned with the human body and the most typical things on and in the Earth, the study of the plasma state of matter would be of no interest. However, the Sun, which is necessary for our continuing existence, is nearly entirely in the plasma state, as is over 99.9% of the entire observable universe! It seems that we and our local environment are in the uncommon states of matter, and now the better question becomes, "Why isn't it common to study the dominant state of observable matter in the universe?"

With the availability of plasma globes there is now a safe and affordable device for the study of plasmas. There are other plasma systems that you can study including fire and the plasma inside a glowing fluorescent bulb. (The characteristics of the plasma in a fluorescent bulb are studied in the activity "Properties of a Plasma: Half-Coated Fluorescent Bulbs."*) But one nice feature of the plasmas inside plasma globes is that they are more similar to the plasmas that make up solar flares than are any of the other plasmas that you might see or work with up close.

In many cases plasmas are produced by the ionization of atoms or molecules into electrons and ions at temperatures that can destroy most measuring instruments. This is one source of problems if we want to study plasmas by means of sensors that are inside the plasmas. Another difficulty is getting sensors inside of the plasmas that we want to study since many of these plasmas are too far away, as is the case with plasmas associated with interstellar nebulae.

There is a surprisingly simple way around this problem. It is to use the radiation from the plasma. Plasmas radiate electromagnetic energy and measuring the characteristics of this radiation is one of the most important ways to gain information about the plasma. What makes this possible is that any charged particle that accelerates will radiate energy as electromagnetic waves and also anytime an electron recombines with an atom, a pulse of electromagnetic radiation is produced with a wavelength characteristic of the particular ion. These two things happen in a plasma, since the charged particles of any plasma will experience accelerations as a

* Part of the series of activities in plasma/fusion physics to accompany the CPEP chart *Fusion: Physics of a Fundamental Energy Source.*

result of being scattered by one another or as the result of oscillating motion, and since occasional recombinations of electrons with ions will also occur. Therefore, plasmas continuously send out information about their internal processes in the form of electromagnetic radiation.

In the activity "The Physics of Plasma Globes," it is the characteristic radiation (emission spectra) from the recombination events that is observed. Most of this radiation is in the visible part of the electromagnetic spectrum and so the analysis in that activity uses optical spectrometers or diffraction gratings and eyes. However, in the activity, "Studying the Electric Field near a Plasma Globe," the radiation is primarily due to the acceleration of charges and at wavelengths long enough to be detected by electrical means.

PROCEDURES FOR *THE PHYSICS OF PLASMA GLOBES* ACTIVITY

Using Spectrum Tubes as Reference Sources

In this part of the activity you will first observe (and record) the characteristics of the spectra of known gases contained in spectrum tubes. You will then attempt to identify various unknown gases by comparison with the known spectra. Begin with the observations in the following procedures.

Procedures:

1. In a darkened room each student should observe each spectrum tube while it is being excited with a power supply, Tesla coil or sparks from an electrostatic source. Record the color and relative brightness as seen by the naked eye along with the name of the material in the tube. Then repeat the observation through a diffraction grating and/or spectroscope. With a diffraction grating record the color of every distinct line, or if there are many lines, record the colors of the brightest lines along with a description of the pattern of the weaker lines. With a spectroscope record the colors and the wavelengths of every line that time permits, starting with the brightest lines.

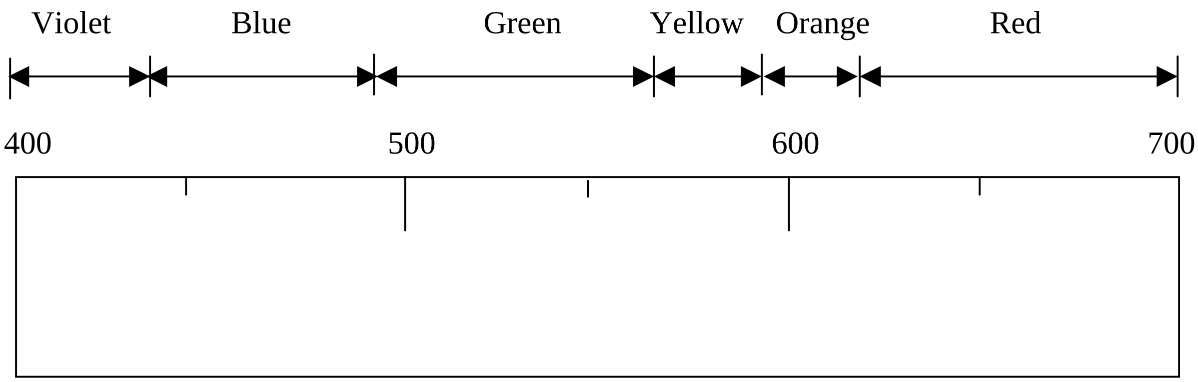
   Use the "Student's Spectrum Sketching Template" to record the lines (see next page). The numbers in this "Template" represent wavelengths of light in nanometers (nm). Notice that the Template is broken up into 6 color regions with approximate wavelengths as follows: violet is from 400 nm to 430 nm, blue is from 430 nm to 490 nm, green is from 490 nm to 570 nm, yellow is from 570 nm to 590 nm, orange is from 590 nm to 620 nm and red is from 620 nm to 700 nm.

   Simply draw a vertical line inside the Template at the approximate location of each spectral line that you see through either a diffraction grating or the student spectrometer. If you have a set of color pencils, you might find it more informative to draw each observed line in colors that match your observations as closely as possible.

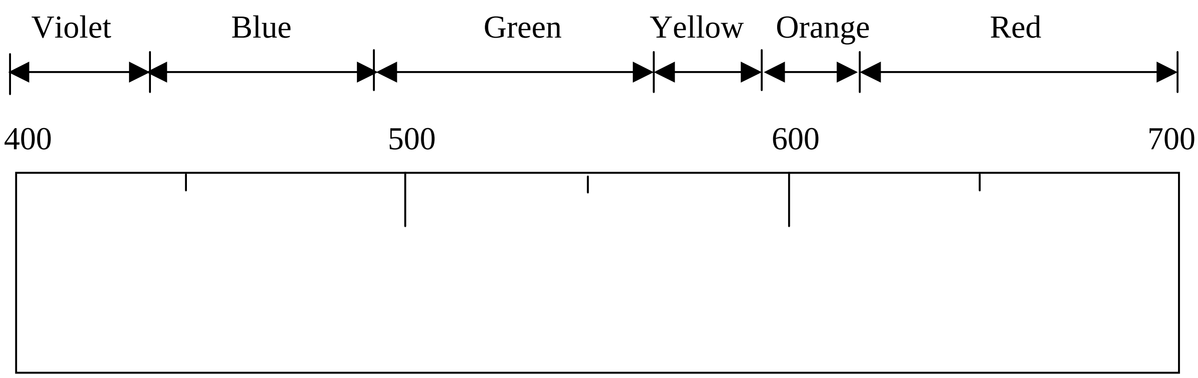
2. As a check on what you have found, observe tubes of unknown gases (have someone else put them in the power supply), and use your record of color, brightness and spectral lines to identify each gas.

Student's Spectrum Sketching Template

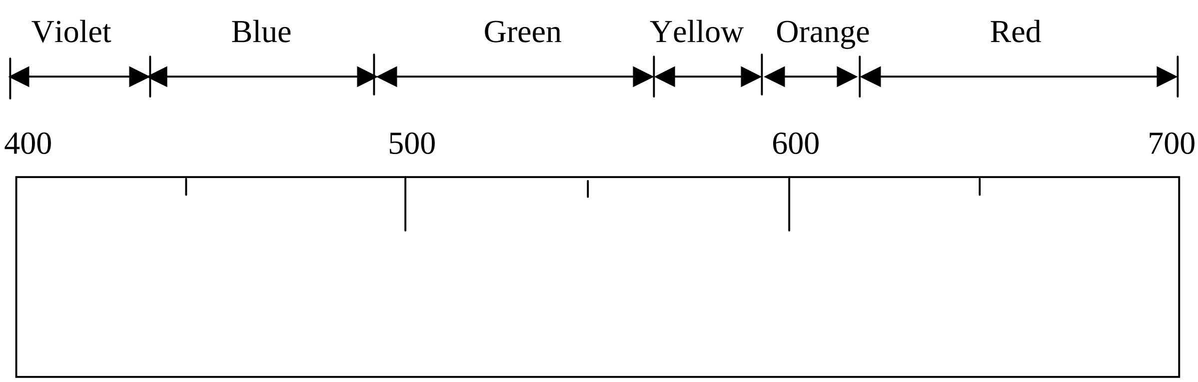
Element Name ________________________



Element Name ________________________



Element Name ________________________



Are there any gases that you could identify by color and/or intensity alone?

Can you be sure that any time you see a plasma glow of this color and similar intensity it will come from the same gas?

3. Next turn on a clear glass light bulb and a fluorescent light and observe these through a grating or spectroscope. If you also have an uncoated fluorescent light or are using a half-coated one, examine the light from the uncoated part as well as from the coated part.

   What is different about the spectra of light bulbs, fluorescent lights and spectrum tubes?

   From your observations of the light bulb with a diffraction grating or spectroscope, how much of the light output do you think is produced by excitation of the gases inside?

General background to help in the interpretation of your observations:

Both spectrum tubes and fluorescent lights produce light by excitation of atoms into the plasma state, that is, some of the atoms are ionized. This makes it possible for the system to carry a current which can continuously excite atoms, but the vast majority of the atoms in the tube are not ionized at any particular time.

With spectrum tubes you can directly observe the light produced as excited atoms return to the ground state. With fluorescent lights, the light that is emitted is absorbed by phosphors that coat the insides of the tubes. These phosphors then radiate most of the energy absorbed at wavelengths different from those of the previously absorbed light. While incandescent light bulbs may have some of the same gases found in spectrum tubes, they do not produce light by exciting these gases, and the gases do not ordinarily go into the plasma phase (this only happens just after a filament breaks and is the cause of the bulb flash when the bulb burns out). They produce light by thermal radiation when the tungsten filament is electrically heated to about 2500 K. Most incandescent light bulbs contain a mixture of nitrogen and argon. These gases reduce the rate of evaporation of tungsten from the filament because of the collisions between gas particles and just evaporated tungsten atoms. The collisions reduce the kinetic energy of tungsten atoms and bounce some back to the filament where they will again bond. Gas particles of greater mass will reduce tungsten evaporation more efficiently, and some more expensive bulbs contain xenon or krypton for this reason.

Using Spectral Analysis to Identify the Gases in the Plasma Globe/bulb

When the plasma globe is turned on, you see colored streamers that often originate near the bottom and the sides and slowly rise. These streamers are formed along ionized paths, or plasmas, and their light is produced by the excited gases in the globe. Assuming that you weren't told what gases are inside the plasma globe you're using (a good bet since most vendors don't provide this information), you are about to find out by analyzing the light produced by these excited gases. Ideally, before you try this you should have examined excited gases in spectrum tubes visually and through diffraction gratings and spectroscopes in the first part of this activity. If this wasn't an option for you, you can look up the spectral lines in reference books such as the CRC *Handbook of Chemistry and Physics* or just consult the abbreviated spectral information provided by your teacher.

Some Hints for Using Spectrum Tube Data to Identify Gases in Mixtures:

The intensity of the light from a spectrum tube or a plasma bulb depends on the type and density of the gas(es) being excited. The particular color seen depends on the mixture and relative intensity of the individual spectral lines which in turn depend on the particular gases and their relative densities. Since many different combinations of spectral lines can produce similar colors, and since in some cases there will not be a strong enough electric field to make the higher energy lines intense, it is often difficult to identify excited gases (plasmas) by eye alone. In identifying the compositions of plasmas with diffraction gratings or spectroscopes we rely on matching patterns of spectral lines from pure samples with those in what may be a mixture. This can still be difficult if one or more of the gases is in relatively low concentration and has several spectral lines that are dim even at higher concentrations. It is then important that the relative intensity of the brighter spectral lines be known for each pure source. Then we can look for a pattern match using some of the brighter lines first, under the assumption that most or all of these come from the gas of highest concentration. Once we have a solid match, we can skip all of the lines that can come from this gas in looking for the next match. For each additional match we may have to use fewer lines, since the dimmer ones will not be visible. In very difficult cases it may be necessary to use a very good spectroscope to find the wavelengths of the lines to high accuracy. On the other hand, if we are working with plasma bulbs, the likely gases are xenon, neon, argon and krypton. With light bulbs they are nitrogen, argon, xenon and krypton. Knowing this narrows the search and the uncertainties considerably.

Procedures:

1. If you have notes or memory of visual color of gases in spectrum tubes, first observe the streamers in your plasma globe/bulb to see if the colors match any of those in spectrum tubes. The best option would be to observe excited spectrum tubes beside your plasma globe/bulb. You can now form a hypothesis about what gas or gases might be in the bulb, but unless there is an extremely good visual match, it's best to be skeptical of this tentative identification.

2. You can then try to make a better identification by carefully observing the spectrum. It is normally difficult to find a streamer that stays in one place long enough for you to see clearly the spectrum through a diffraction grating or a spectroscope. But this can be done by using a vertical streamer that you can hold in place with one end of a grounding wire in contact with the top of the globe. (You could use your finger instead of the grounding wire, but the contact point is soon going to get hot, and burns are possible from prolonged contact). The other end of this wire should be plugged into the "ground" hole of an outlet, as illustrated in Figure 1. A second student should record the spectral information while the first is reporting colors and wavelengths (if they can be seen in the available spectroscopes). Because there may be many observable lines, it is probably best to record the colors and/or wavelengths from brightest to dimmest as much as possible. One additional difficulty is that, even using a vertical streamer, there will be enough motion of the streamer to move it in and out of view, and the streamer will be wide enough to make some nearby lines hard to resolve. Patience and repeated careful observations may be needed to get good results. As earlier, use the following template to record your observed spectra lines.

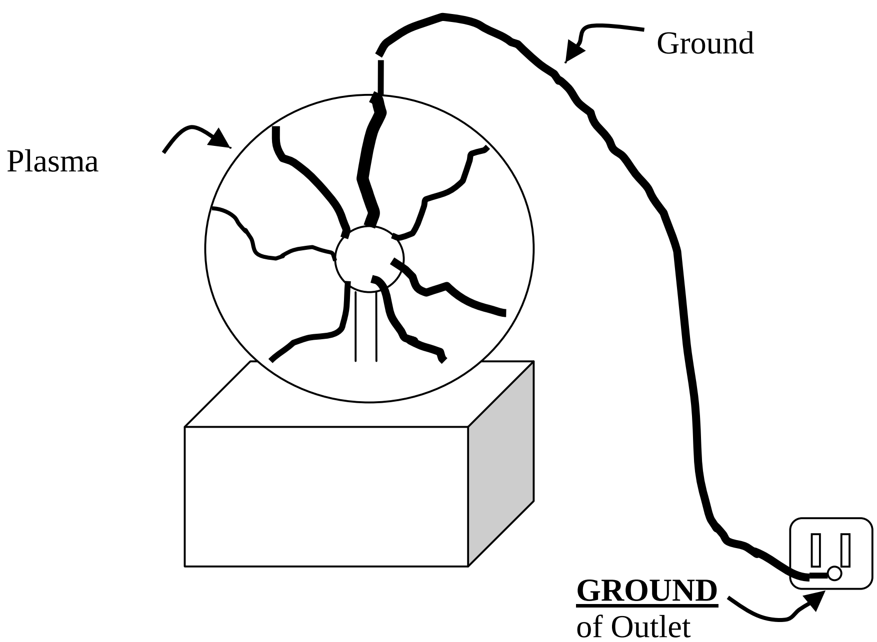
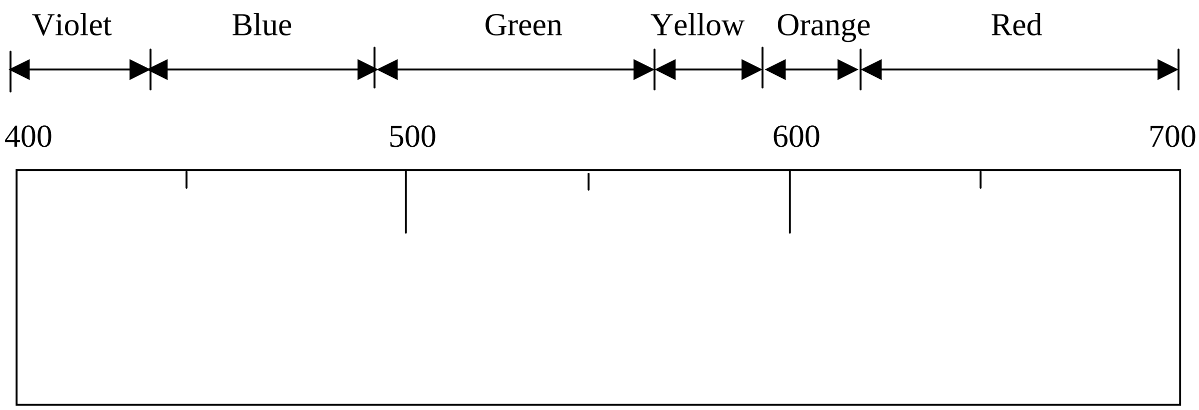


Figure 1: Ground wire used to hold a vertical streamer in place for examination of its spectrum

Student's Spectrum Sketching Template



3. Once the observed lines and patterns of lines have been recorded, try to match them with your information about spectra of pure gases. If you have a very close match, you can conclude that the gas inside your bulb is predominantly that of the match. More likely you will find that one gas dominates the spectrum but doesn't account for all of the lines observed. In that case, record your best conclusion as to the name of the dominant gas and try to use the weaker lines that don't match that gas to determine what other gas or gases may be present.

Question:

Try to come up with a way that doesn't involve spectroscopy to determine what gas or gases is/are present in the globe. Assume that you can do anything that you want and that money is not an object. Be as specific in describing a process as you can. Do you think that it is likely that there is a way to identify gases that is either cheaper, easier to do or more accurate than spectroscopy?

Playing with the Plasma Globe:

The colored streamers that are formed and rise slowly in the plasma globe are produced by high voltage differences between the center electrode and the outer glass globe when a high frequency a.c. voltage is applied to the center electrode.

1. To test that what you are seeing is electrical, place either a coin or a flat disk of aluminum foil on top of the globe and bring a pointed piece of metal such as a key, a nail or the end of an opened up paper clip near the edge of the disk. In a darkened room you should see small sparks.

   Are these sparks the same color as the streamers?

   At this point you might want to more carefully examine the colors of the streamers from the central electrode to the glass surface.

   Is the color uniform?

   Different colors are evidence of different atomic transitions within the same gas or gases.

   How many different color patterns can you observe?

2. You can apparently attract and concentrate some of these streamers by placing your hand or fingers on the bulb. If you put your hand on the top of the bulb, you will see a large vertical streamer that is fairly stable, but, as you will find if you keep your hand on the top, the glass gets very hot in less than a minute. This heating is evidence for a general heating of the gas surrounding the ionized path within the streamers which may explain the fact that streamers rise from the bottom and sides to the top.

   The gas within and surrounding a streamer is heated by the electrical current in the plasma and expands. Being less dense than the surrounding cooler gas, it apparently experiences a buoyant force. Perhaps the biggest surprise is that these streamers don't rise faster. Either the temperature difference isn't very large, the need to continuously create new ionization paths above the old ones to maintain the streamer slows the process, or the lifting force acts mostly on the heated gas surrounding the plasma and not much on the plasma itself. The best explanation may be a combination of these or something more complicated.