Studying the Electric Field Near a Plasma Globe

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

Robert Reiland, Shady Side Academy, Pittsburgh, PA
Chair, Plasma Activities Development Committee of the
Contemporary Physics Education Project (CPEP)

Editorial assistance: G. Samuel Lightner, Westminster College, New Wilmington, PA and Vice-President of Plasma/Fusion Division of CPEP

Advice and assistance: T. P. Zaleskiewicz, University of Pittsburgh at Greensburg, Greensburg, PA and President of CPEP

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

The activities "Studying the Electric Field near a Plasma Globe" and "The Physics of Plasma Globes" 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 flames 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 result of being scattered by one another or as the result of oscillating motion, and since occasional recombinations of electrons

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

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.

Additional General Information specific to the activity *Studying the Electric Field near a Plasma Globe.*

The plasmas in the plasma globe act as "radiating antennas" in the same sense that the antennas on top of radio towers and cell phone towers are radiating electromagnetic waves. We study this radiation with "receiving antennas" which are similar to those on radios and cell phones.

The radiated electromagnetic waves are actually travelling oscillating electric and magnetic fields set up by the oscillating (accelerating) charges in the plasma. The electric and magnetic fields are at right angles to each other and are at a right angle to the direction the wave travels. In the case of waves from a plasma, these waves contain information that can be used to learn how energetic the emitting plasma system is and how the plasmas are oscillating. For a plasma globe it is possible to determine the frequency of the oscillations in the plasma from the frequency of the electromagnetic waves emitted.

Our "receiving antennas" need to be able to detect these electric or magnetic fields in the electromagnetic waves coming from the plasma globe. Fortunately, the frequencies are in a range such that the electric field is relatively easy to sense and measure. In some cases the field is strong enough that, using a simple "probe," a spark can be made to jump indicating the presence of the field. More careful measurements of the electric field can be made with a metal "antenna", oriented so that the oscillating electric fields will cause oscillating currents that are detected with a voltmeter or oscilloscope. All of these methods are used to detect the electric field in the activity "Studying the Electric Field near a Plasma Globe," however, only the oscilloscope can be used to measure the frequency of the electromagnetic field.

PROCEDURES FOR "STUDYING THE ELECTRIC FIELD NEAR A PLASMA GLOBE" ACTIVITY

The small sparks that you may have seen in the activity, "The Physics of Plasma Globes," are evidence that whatever produces the plasma streamers also produces electric fields that extend beyond the globe. In this activity you will study these fields to determine as much as you can about their characteristics and their source.

Procedures:

1. Make a simple "probe" of the electric field that extends beyond the plasma globe. Glue or tape a disk of metal to the end of a Popsicle stick with the surface of the disk parallel to the stick. The disk could be a quarter, a circle of about the size of a quarter cut out of aluminum foil or any other metallic disk close to this size. Connect one end of a wire either into the ground hole of an outlet or attach it to a large metallic object such as a metal table or metal pipe. The disk and the wire are your "probe".

   The basic method is to hold the disk on or near the globe with the plane of the disk parallel to an imaginary plane that would be tangent to the nearest point on the glass globe while bringing the end of the wire very slowly toward the center of the disk. In some cases a spark will form between disk and wire (see Figure 1).

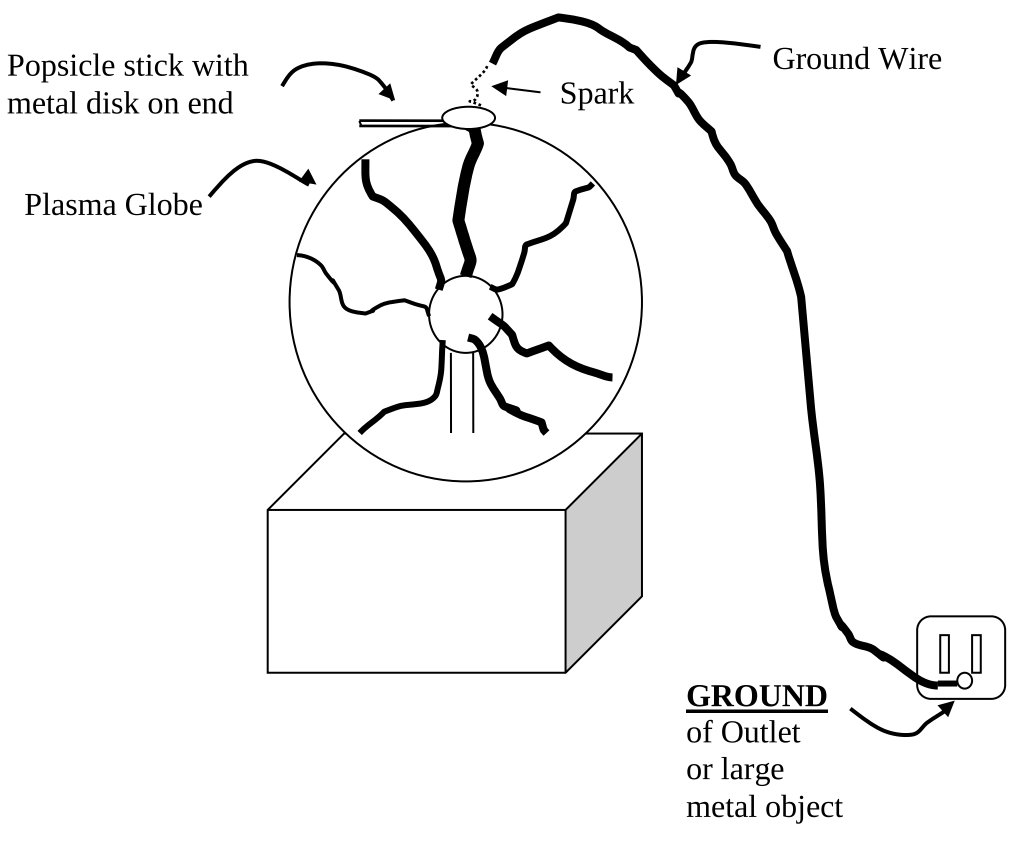

Figure 1: "Popsicle Stick-Disk" and wire "probe" of electric field near a plasma globe

2. In a darkened room, have the disk touching the globe and then record the approximate lengths of sparks you can get to form between the center of the disk and the wire as you slowly move the wire toward and away from the disk. Try this on the top of the globe and at several different heights on the sides of the globe.

Do you notice any differences in spark lengths achieved as a function of location on the globe?

You can touch the globe with your hand and get all of the streamers on one side of the globe. If you do this and have someone else tests for sparks on the disk, is there any variation in spark length depending on whether the disk is on the side with the streamers or on the other side?

If there is a large streamer ending on the top disk as a result of someone having a hand there, does this affect the length of sparks that can be produced either at the top or at the sides?

What do you conclude about electric field strengths near the ends of streamers vs. elsewhere on the globe?

3. Test for spark length as a function of probe distance by holding the disk a few millimeters from the globe while bringing the end of the wire toward its center. Repeat this at greater distances from the globe until you can no longer see a spark form. Qualitatively describe the size of the sparks as a function of disk distance from the globe.

If you have a digital multimeter with an a.c. volts setting or an oscilloscope, you can do a rough quantitative test of electric field strength in relationship to distance and direction from the globe. In this case you will use an "antenna" connected to the meter or oscilloscope. To start with, your antenna will just be the end of wire opposite to that plugged into the meter or oscilloscope (See Figure 2). The following descriptions of procedures are written for a multimeter. If you don't have a multimeter and do have an oscilloscope or if you want to use both a multimeter and an oscilloscope, the antenna for the oscilloscope is used in the same way as the antenna for the multimeter. If you use an oscilloscope, you will be recording the height of the pattern on the oscilloscope screen from bottom to top instead of numbers on a meter. Check with your instructor for the adjustment to the oscilloscope.

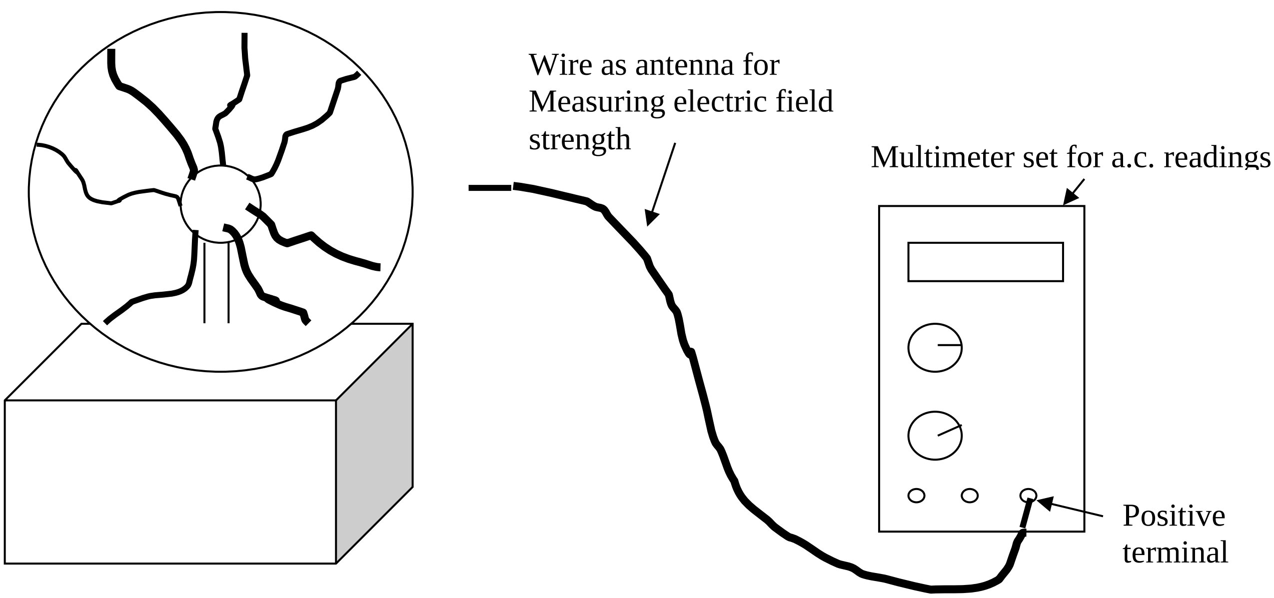

Figure 2: Measuring the electric field radiated from the streamers of a Plasma Globe

Since a.c. devices such as lights, especially fluorescent lights, radiate significant a.c. fields, this will work best if all lights and other a.c. sources in the room are off. The simplest and most effective way to get readings of electrical field radiated from the high frequency plasma in the globe with a multimeter is to use the wire from the antenna in the positive input to the meter and nothing in the negative (ground) input. The internal ground of the multimeter will set the reference voltage for the positive antenna.

The same approach can be used with an older oscilloscope in which wires are separately plugged into a positive terminal and a ground. That is, with such an oscilloscope simply use the wire plugged into the positive terminal, and don't plug anything into the ground terminal.

With oscilloscopes that use probes on the ends of coaxial cables, use the end of the probe as your antenna as it is.

4. Place the antenna on the globe, and move it around on the surface.
   Do you detect any variations with position?

   Keep the antenna in one place for a while. Are there variations in time?

   In particular do the readings depend on whether or not here is a streamer near the antenna? Test this by having someone put his/her hand on parts of the globe away from the antenna. Record a few sample readings.

5. Since your body is a conductor and can affect the electric field strength, it is best for quantitative results if you don't directly hold onto the antenna. An alternative is to tape the end of the antenna (the end of the wire not plugged into the meter) to one end of a wooden dowel or stick that is at least 25 centimeters long. Then, by holding the other end of the dowel or stick, you can change the position of the antenna without getting any part of your body near it.

   Repeat the measurements made in Procedure 4. Note any significant difference between the new readings and those recorded in Procedure 4.

To improve the quantitative results of the next procedures you should modify the antenna by clipping or taping the free end of the wire to the center of a square of aluminum foil ten to twenty centimeters on a side (see Figure 3). To use the antenna, the plane of the foil is kept perpendicular to a line from the center of the plasma globe to the probe, or said another way, the foil should then be kept so that its plane is parallel to the tangent plane of the nearest point on the globe.

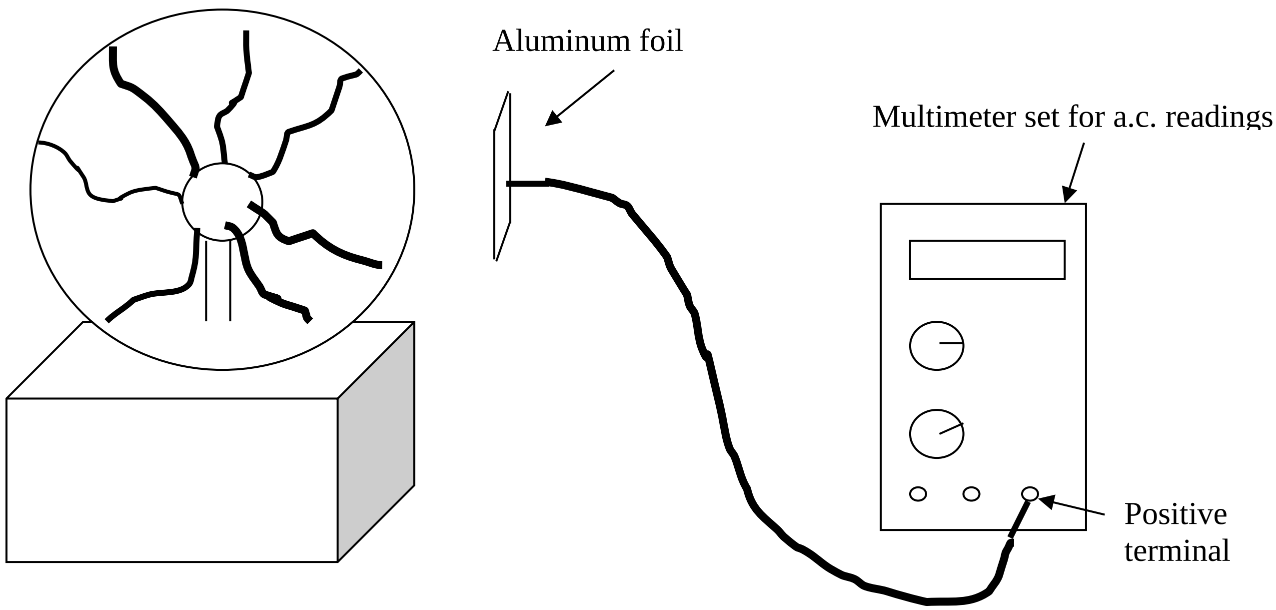

Figure 3: Measuring the electric field radiated from the streamers of a Plasma Globe with a sheet of Aluminum foil attached to the end of the wire (antenna)

6. Starting on one side of the globe, move the antenna horizontally and record meter readings vs. distance from the globe. Before you do this, decide whether it would be best to measure distances to your antenna from the center of the globe or from the nearest surface of the globe. If you decide later that the possibility you didn't chose would have been better, you can easily change all of the measured distances by adding or subtracting the radius of the globe.

Repeat the above starting at the top of the globe and moving the antenna vertically to greater and greater heights.

Does the pattern of readings vs. distance depend on whether the measurements are made horizontally or vertically?

Graph meter readings vs. distance for both sets of data. If you have a graphing calculator or graphing software with a computer, try to find functions that are consistent with the data. Form a hypothesis that might explain your results. If your hypothesis is testable in a simple way, find out how well it holds up.

7. With the antenna at some distance from the globe such that you get stable readings that aren't close to zero find out what happens to the readings when someone touches the globe.

   Are there any additional variations that depend on where this person is standing at the time or what part of the globe her hand is touching?
   Summarize the results.

8. To study the electric fields in more detail you can use an oscilloscope to determine the frequency of the generator in the plasma globe. Use the same antenna that was attached to the multimeter in the previous investigation, and attach it to the oscilloscope leads. Adjust vertical gain until you can easily see a vertical blur at least a few centimeters high with the antenna close to the globe. Then increase the sweep frequency (or time base) and make fine adjustments until waves are clear and stable. Use the sweep frequency (or time) and the

number of complete waves showing on the scope to determine the frequency (or period and then frequency) of the source.

Does this frequency change with location relative to the probe? Do the amplitudes of the waves seem to vary with location in roughly the same pattern as was found using the multimeter?

Questions:

1. What evidence do you now have that the charged particles in the plasmas of plasma globes and fluorescent lights are being driven back and forth as types of "alternating" currents rather than as the type of one-way currents (direct currents) produced by batteries?

2. What evidence do you now have that energy is concentrated in plasmas, especially the plasma streamers inside plasma globes?

3. What are the features of the emitting and receiving antennas that you observed in this activity? Do you know of any reasons that the size of an antenna might be important in determining how easily it can pick up an electromagnetic signal?