POWER SOURCES CHALLENGE

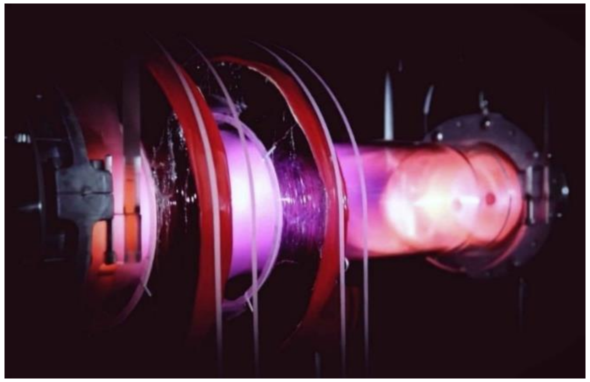
Girls of Energy

HOW CAN YOU MAKE A PLASMA BALL?

Summary: What is plasma? When you think of plasma, where do you think you can find it? How does plasma relate to energy?

How cool would it be if you could make your own plasma ball from the comfort of your home or school?! Princeton Plasma Physics Laboratory (PPPL), a Department of Energy National Laboratory, has devised a way for students of all ages to experience plasma physics—all you need is a computer with internet access. The Remote Glow Discharge Experiment (RGDX) allows remote access and control of the entire experiment including the gas pressure inside the tube, the voltage produced by the power supply that makes the plasma, and the strength of an electromagnet surrounding the plasma.

Did you know that plasma is used to make magnetic fusion energy? Get excited to learn more about how you can actually make your own plasma!



Background: The Department of Energy (DOE) has 17 National Laboratories across the United States, including the PPPL. The RGDX was developed as a way to fill a tremendous gap in online science education, allowing students anywhere in the world to participate in a plasma lab experiment. This development offers a unique opportunity to bring the laboratory to the students. Students can manipulate the three variables that control the creation of the plasma and then watch as the plasma product streams online. This allows students to witness how the changes in conditions of each of the variables changes the product in the glass tube. (https://pppl.princeton.edu/RGDX)

Learning Objectives - After this activity, students should be able to:

- Name and describe the four phases of matter;
- Demonstrate, using magnets, opposite charge attraction and repulsion;
- Participate in a virtual online laboratory experiment creating plasma;
- Understand how gas pressure, electrode voltage and electromagnets affect the physics of plasmas

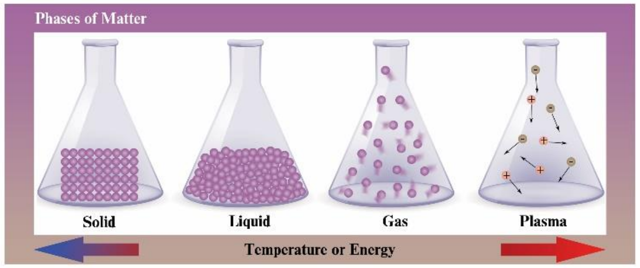
Introduction: The four physical states of matter are solid, liquid, gas, and plasma; a substance can transform its state with an increase in energy.

Solids
- Solids have the lowest energy and are arranged in a regular, repeating pattern with vibrational movement.
- Solids have a definite shape and a definite volume.

Liquids
- Liquids have a definite volume and an indefinite shape.
- Liquids have attractive forces between them that allow them to flow past one another.

Gases
- Gas atoms and molecules (neutral substances) gain enough energy to break free of the attractive forces between them
- Gases have an indefinite shape and an indefinite volume.

Plasma
- Plasma is formed as the energy increases in gaseous atoms to the point of stripping electrons from the neutral gases, and the hot, charged gas becomes a plasma.



- Plasma is produced naturally in the stars and the sun where there is intense heat and a large density enabling fusion reactions to occur.
    - Magnetic nuclear fusion is a clean and abundant energy alternative used to generate electricity.
- In order to create plasma, you must have gases with enough energy, movement of electrons, and a force that enables them to come in close contact with one another.

In order to make the plasma in the virtual experiment, there are three variables that you can control: gas pressure, voltage and electromagnets. We will examine each of the variables before you begin the experiment.

Pressure: Gas pressure is measured as force per unit area. The gas molecules collide with one another and the walls of the container. If you think about pressure in your bicycle tires, what happens when they go flat? You need to add more air and thus more pressure to fill them back to normal. Since temperature is a measure of the average kinetic energy of the molecules, how is gas pressure affected by an increase in temperature? When it gets cold and you leave your bicycle outside, how do the tires feel when you first start to ride your bike?

The air we breathe is actually a mixture of gases, but nitrogen gas (N2) is the most abundant. What other gases might be in the air? The gas used to create plasma in the RGDX is air comprised of nitrogen, oxygen, carbon dioxide and other small amounts of different gases.

By manipulating the controls of the RGDX, you can increase the amount of gas pressure in the tube. How do you think this might affect the creation of plasma?

You can learn more about gas pressure and how it is measured by using the "Gas Pressure Realities" power-up activity.

Voltage: A positively-charged substance (+) and a negatively- charged (-) substance are attracted to one another. This attraction, due to the difference in charge, is called electrostatic attraction. You can explore this attraction the "Smacking Electrons" power-up activity.

At the end of the glass tube are two metal plates called electrodes. Electrodes make contact with a nonmetallic part of a circuit. The higher the voltage, the more opportunity there can be for the electrons to be stripped from the neutral gas and the gas now becomes plasma.

If you look at the power outlet in your home or school, you might see the value 110v or 120v.Voltage is measured in volts (v) and these two amounts are the most common for household electrical outlets. When you go outside and look at the power lines that provide electricity to homes and businesses, keep in mind that those lines provide 1000 times more voltage than your normal outlet. The voltage for power lines start at 110,000v or 110 kilovolts (kv).

Electromagnets: Electromagnets are used to create a magnetic field inside of the glass tube. A magnetic field helps align charged particles and keep them in closer proximity to one another. How do you think the electromagnets will change what you see inside of the tube?

You can feel the force of magnets by experimenting with individual magnets. How are they attracted and repulsed? What types of things are magnets attracted to?

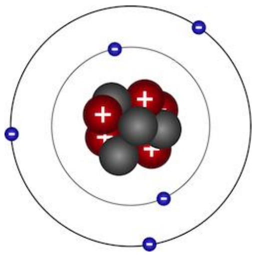
Materials Needed for an Activity:

- Computer with internet access
- Notebook for making predictions and testing hypotheses.

Now that you are a little more familiar with how you will interact with this website, go to the [Remote Glow Discharge Experiment (RGDX)](http://scied-web.pppl.gov/rgdx/) http://scied-web.pppl.gov/rgdx/ and click on the "What is Plasma?" tab. This tab contains information about the structure of an atom and how plasma is made.

The following information is provided by PPPL RGDX website (1).

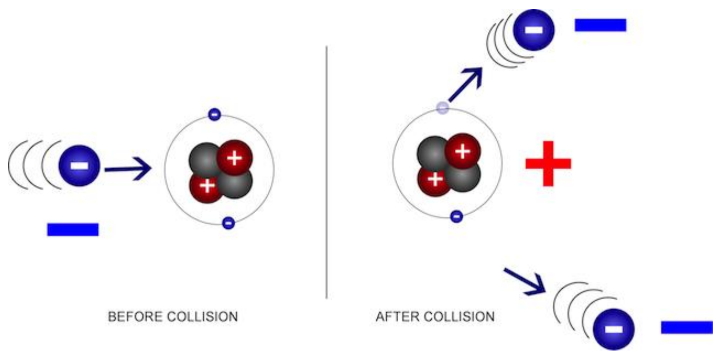
What is Plasma?



All matter is made out of atoms which are composed of a nucleus and electrons. The nucleus has protons and neutrons. Around the nucleus, are the electrons.

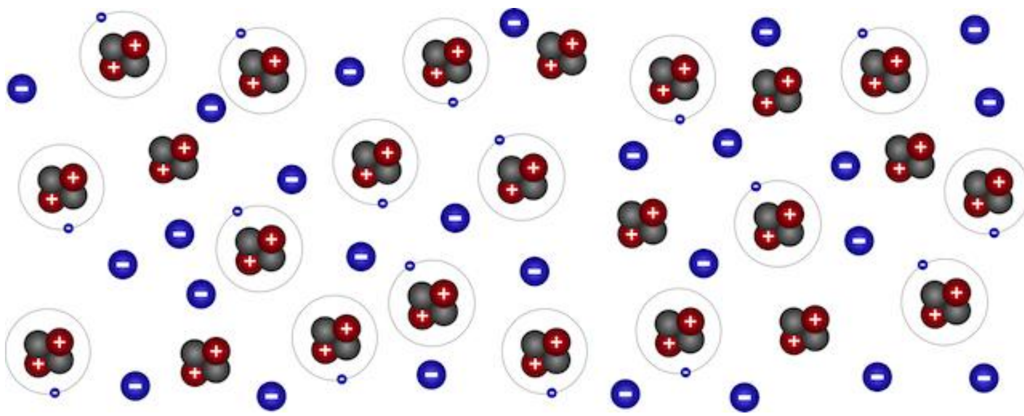
The **protons** are charged POSITIVELY, the **electrons** are charged NEGATIVELY and the **neutrons** are neutral. Most of the matter around us, solids, liquids and gases, are made out of neutral atoms and molecules (collection of atoms), that is, there are the SAME number of protons and electrons.

If for some reason, like collisions with a fast electron, an atom ejects an electron, then the neutral atom will now be POSITIVE and the free electron is NEGATIVE (for simplicity, we'll use Helium (He) atom, with 2 protons, 2 neutrons, 2 electrons, as the gas. Helium is very commonly used in laboratory plasma experiments):



The positively charged atom is called an ION. The more electrons are ejected, the more positively charged it is. This process is called **ionization**.

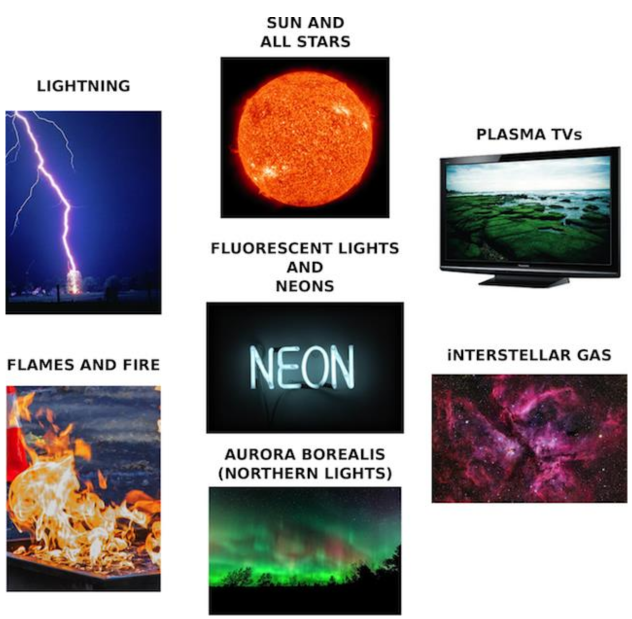
Plasma is the state of matter made out of ionized atoms (i.e. ions) and free electrons:



Since the particles need to be energetic enough to undergo ionizing collisions, and energetic particles simply means that they're hot, plasma is the hottest of the 4 states of matter.

While most of the matter we come in contact with is solid, liquid, or gas, the visible universe is more than 99% plasma.

Here are some examples of plasmas:



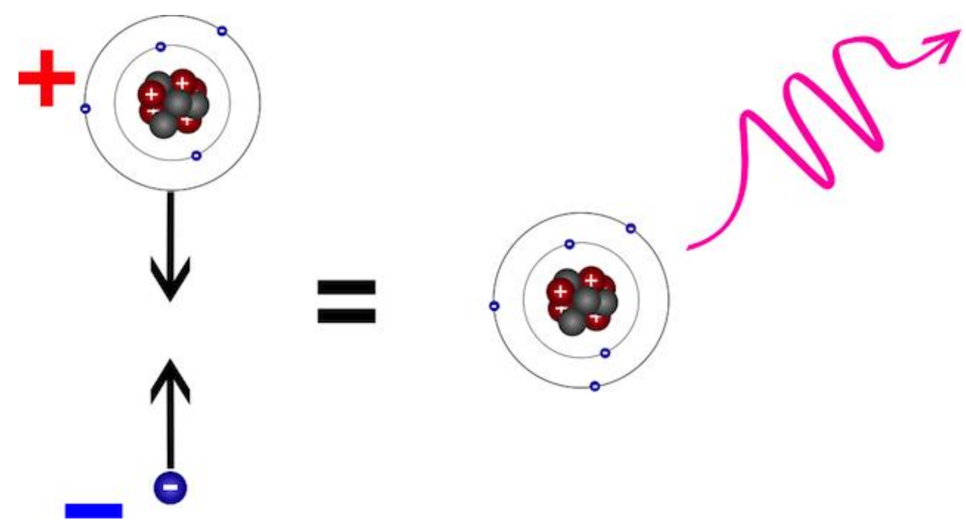
Next, click on the tab that states "Why does a plasma glow?" This illustrated page will help you understand how light is given off when the electrons move to a lower energy level. Remember the 1st Law of Thermodynamics states that energy cannot be created or destroyed, but it can change form. Energy can be given off in the form of light when an electron moves from a higher energy level to a lower energy level.

The following information is provided by PPPL RGDX website (1):

Why does the plasma glow?

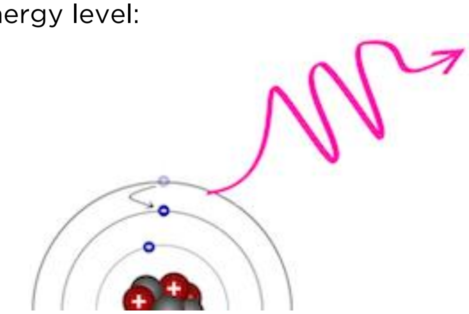
From the "What is Plasma?" page, we saw that the glow is actually plasma, a lot of positively charged ions and negatively charged electrons held at high temperatures.

Sometimes (very often), the electrons RECOMBINE with the ions:

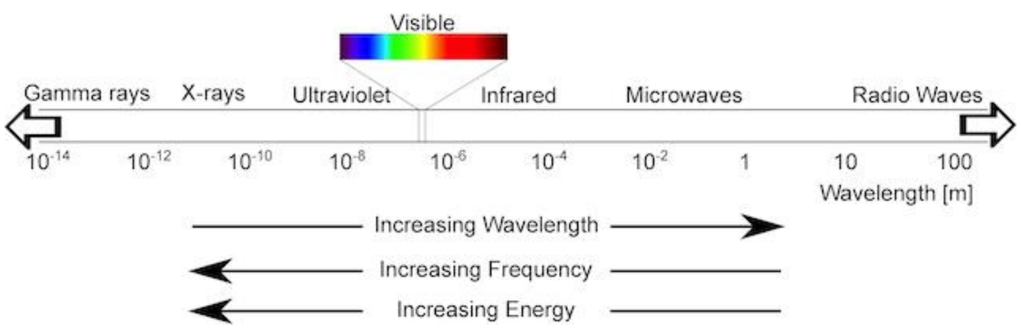


The recombination leads to a neutral (or less ionized) atom. But, in order to conserve energy, the atom releases a photon, which is just light.

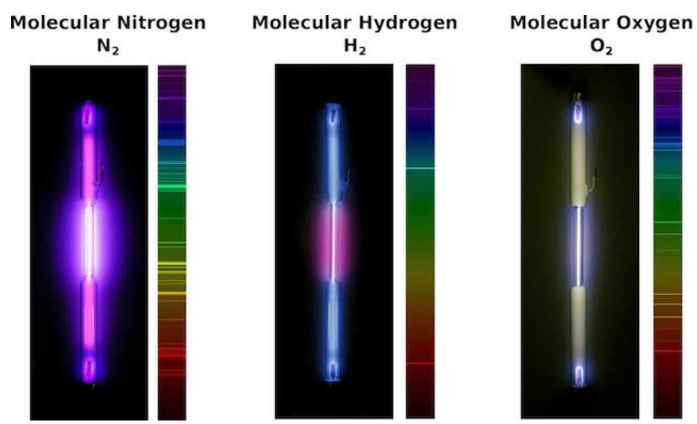
Another way light is emitted is when an electron is at a high energy level (that is, further away from the nucleus) and then transitions to a more favorable, lower energy level:



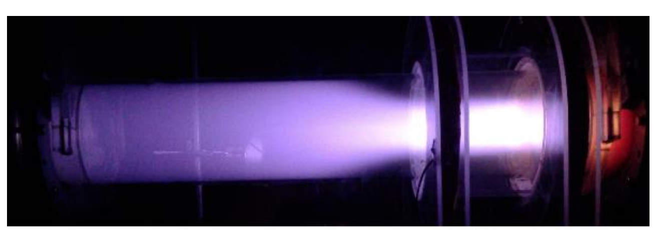
The higher the drop the more energy the photon has to have. The energy of the photon determines its color:



Since each atom and molecule has its own preferred transitions (given by their electronic configuration), each one has an emission fingerprint. You can see a few examples on the right.



Because air is mostly composed of N_2 (nitrogen), O_2 (oxygen) and water vapor, the spectra shown above are the main ones observed in the RGDX, primarily the N_2, as seen here on the right.

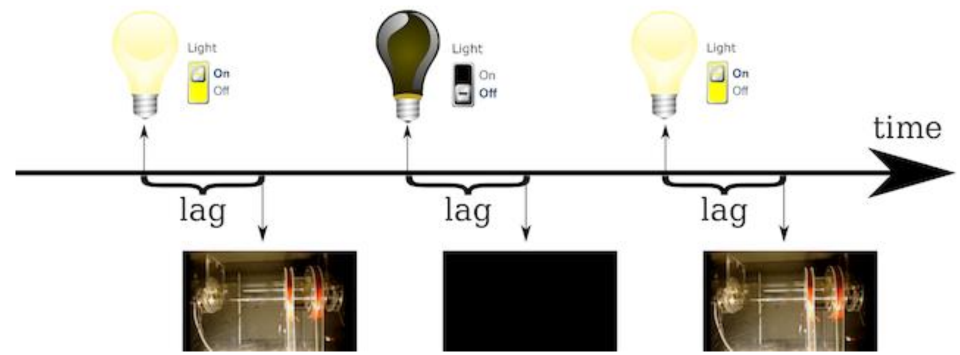


Now you are ready to make the Plasma GLOW! You will proceed to the tab that states “How do I make it Glow?” Read the important information about lag time and settings.

The following information is provided by PPPL RGDX (1):

How can I make it glow?

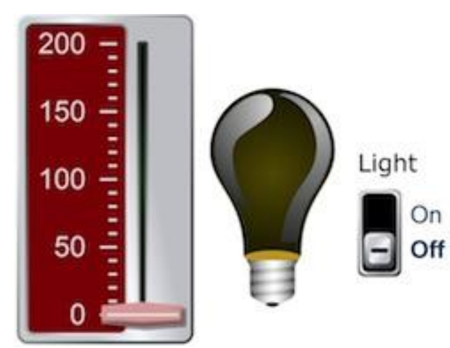
Before we begin, get a feel for the lag time: the video streaming has a few seconds of lag time which you should take into account. By turning the auxiliary light on and off and observing the streaming, you can get a feel for this lag.



If the lag is too long (more than 4 seconds) reload the page. While it may take a little time to get used to this lag, it will not be too much of a problem for the RGDX experience.

To start out, let's make it glow:

Make sure the electromagnet is set to 0 Gauss and the auxiliary light is turned off



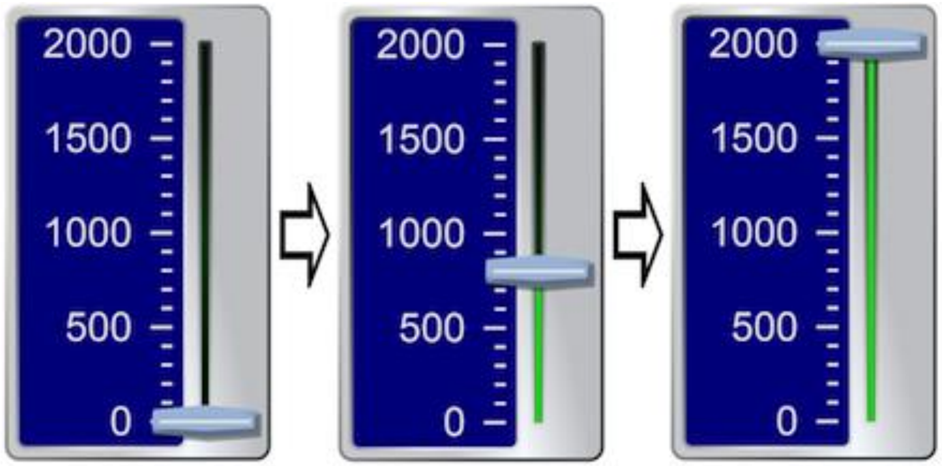
Set the pressure in the tube to about 40mTorr (if not already set)

Wait a few seconds for the pressure to stabilize (between 30mTorr and 50mTorr is fine)

Turn up the voltage between the electrodes

At approximately 800V, a glow discharge will appear.

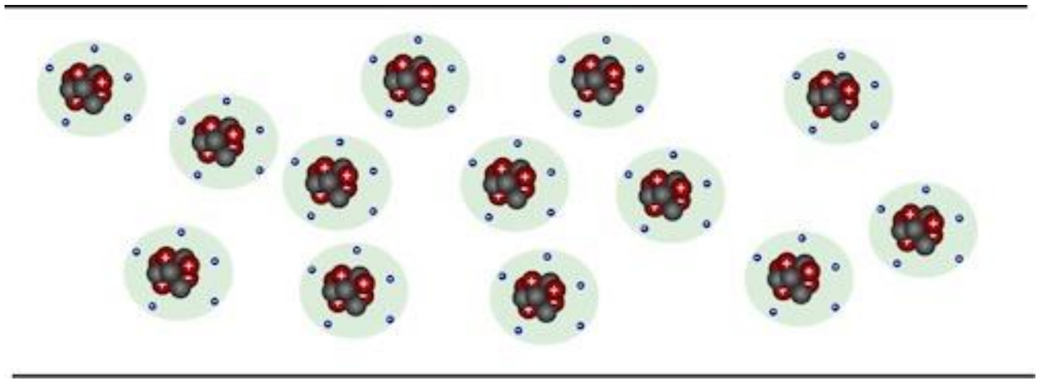
Raise the voltage to 2000V.



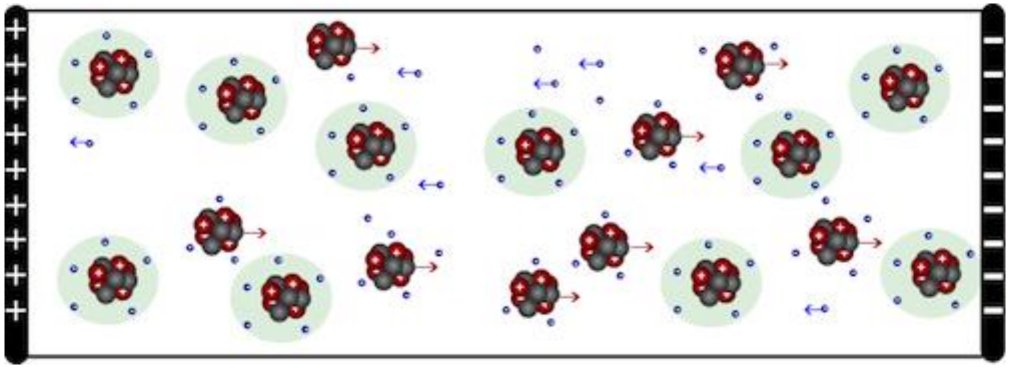
A glow discharge similar to the one below should appear.

What are we looking at?

Before the voltage is high enough, almost all the air is neutral atoms and molecules. In the drawing below the neutral atoms are highlighted just to identify them as neutral.



When the voltage is high enough, the air conducts electricity and the atoms and molecules start to lose electrons...some of the neutral atoms and molecules turn into **plasma**.



Plasma, sometimes referred to as the 4th state of matter, is gas that has positive and negative charged particles.

Once you use the settings provided, take time to experiment with the three variables to see how they make the plasma in the tube change. Think about how each of the different variables, pressure, voltage and electromagnets might change what happens in the tube and change what you see.

Can you predict what might happen? Write down your predictions and then test. Were you correct? If not, how might you change your thoughts about what should happen?

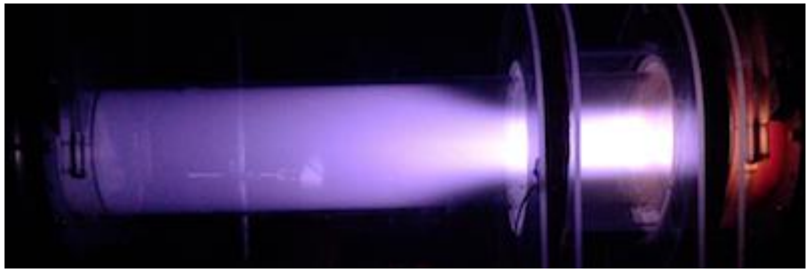
The following information is provided by the PPPL RGDX website (1).

What does the electromagnet do to the plasma?

Have you tried turning on the electromagnet while the plasma's on?

- Set the pressure to 40 mTorr
- Set the electrode voltage to 2000 Volts
- Turn the electromagnet on to 200 Gauss

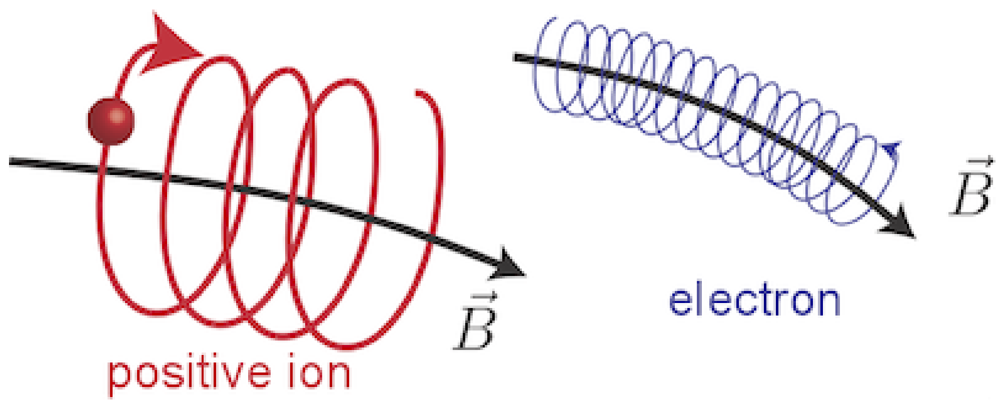
Do you see something like what's shown below?



We have already seen that plasma responds to the voltage across the electrodes, just turn the electrode voltage up and down and see the changes in the plasma.

Now we see that the plasma also reacts to magnetic fields!

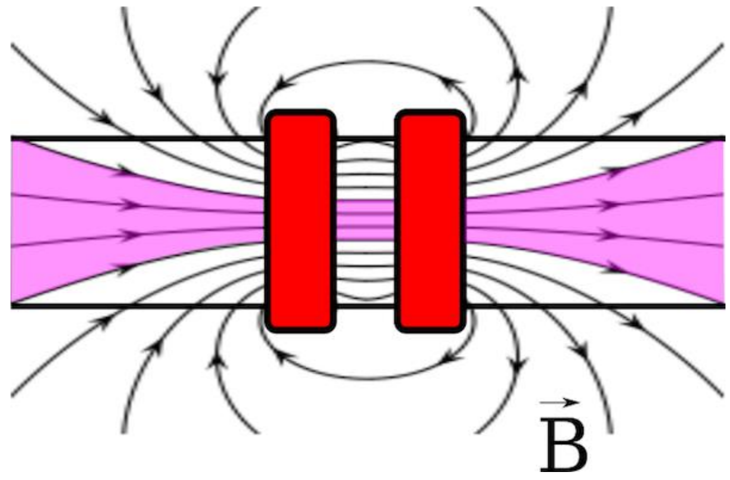
As seen in the figure below, when a negatively or positively charged particle sees a magnetic field, the particle starts spiraling around it.



Now, the radii of these spirals are known as the electron and ion gyroradii and depend on the magnetic field and on the temperature of the plasma.

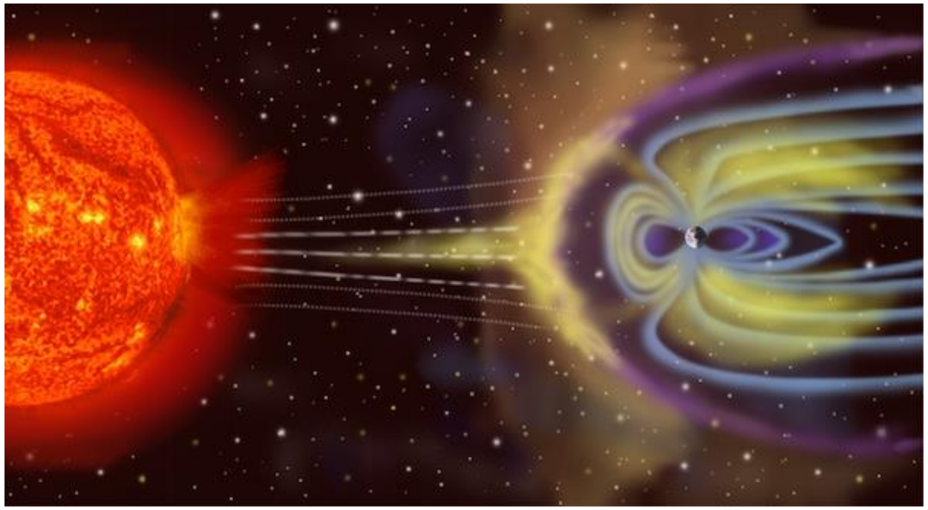
For our case, the sizes are of the order of an inch.

If we now look at the picture of the magnetic field of the Helmholtz coil, the squeezing of the plasma makes sense! As the plasma spirals around the field lines, it gets redirected due to the curvature of the fields.



You can see that the plasma is kept away from the glass between the coils. This fact is critical to one of the main missions of the Princeton Plasma Physics Lab and other plasma labs around the world: **Magnetically Confined Fusion.**

We mentioned in "What is plasma" that the northern lights are also plasma. Now you can understand why we only see them in the poles:



As solar winds (made out of plasma) reach the earth's magnetic fields, they follow the fields towards the north and south poles. The northern (and southern) lights are seen when the plasma interacts with the atmosphere.

Next Generation Science Standards (4):

Energy:
- Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. (4-PS3-2)
- Ask questions and predict outcomes about the changes in energy that occur when objects collide. (4-PS3-3)

Science and Engineering Practices:
- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships. (4-PS3-3)
- Use evidence (e.g., measurements, observations, patterns) to construct an explanation. (4-PS3-1)
- Make observations to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. (4-PS3-2)

Disciplinary Core Ideas:
- Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (4-PS3-2), (4-PS3-3)
- Light also transfers energy from place to place. (4-PS3-2)
- The faster a given object is moving, the more energy it possesses. (4-PS3-1)

- Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2),(4-PS3-4)
- When objects collide, the contact forces transfer energy so as to change the objects' motions. (4-PS3- 3)

Cross-cutting Concepts:
- Energy can be transferred in various ways and between objects. (4-PS3-1), (4-PS3-2), (4-PS3-3), (4-PS3-4)
- Science affects everyday life. (4-PS3-4)

Structure and Properties of Matter - Students who demonstrate understanding can:
- Develop a model to describe that matter is made of particles too small to be seen. (5-PS1-1)
- Make observations and measurements to identify materials based on their properties. (5-PS1-3)

Science and Engineering Practices:
- Use models to describe phenomena. (5-PS1-1)

Disciplinary Core Ideas:
- Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. (5-PS1-1)

Cross-cutting Concepts:
- Cause and effect relationships are routinely identified and used to explain change. (5-PS1-4)
- Natural objects exist from the very small to the immensely large. (5-PS1-1)
- Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume. (5-PS1-2),(5-PS1-3)

MS. Structure and Properties of Matter

Disciplinary Core Ideas:
- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. (MS-PS1-1)
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. (MS-PS1-4)
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. (MS-PS1-4)
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. (MS-PS1-4)
- The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. (secondary to MS-PS1-4)

MS. Forces and Interactions
- Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. (MS-PS2-3)
- Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. (MS-PS2-5)

Disciplinary Core Ideas:
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. (MS-PS2-3)
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively). (MS-PS2-5)

Cross-cutting Concepts:
- Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-PS2-3), (MS-PS2-5)

MS. Energy
- Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. (MS-PS3-2)

Disciplinary Core Ideas:

- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (MS-PS3-3), (MS-PS3-4)
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)

Sources:

1. Princeton Plasma Physics Laboratory Remote Glow Discharge Experiment (RGDX): http://scied-web.pppl.gov/rgdx/
2. Next Generation Science Standards http://www.nextgenscience.org/

POWER SOURCES CHALLENGE

POWER UP ACTIVITIES – PLASMA BALL LESSON

ACTIVITY ONE:

FEEL THE FORCE

Students will study electron movement using adhesive tape and demonstrate how negative charge and positive charge are affected by movement of electrons.

Question:

What causes attraction between molecules?

Explore:

Tear off two small pieces of adhesive tape. Place the tape pieces' sticky-side down onto a table, allowing 1 inch of overlap hanging off of the table. Now, quickly rip the tape pieces off of the table and bring the two pieces within close proximity of one another.

What do you notice? How do they move? Can you feel a force?

Explain:

Electrons move all of the time, and it is this movement that causes a difference in charge. As electrons move away from an object, it becomes positively charged. If an object gains electrons, it becomes negatively charged. This attraction is called electrostatic attraction and accounts for objects with opposite charges being attracted to one another. When you pulled the tape off of the table, electrons were displaced, so one end of the tape had a positive charge and the other end had a negative charge.

Here is an example of what you might see—make sure you manipulate until you FEEL the force.

ACTIVITY TWO:

ARE YOU BONDED?

Students will use a kinesthetic activity to simulate the movement of particles and their bonds through the four different phases of matter.

Question:

How do particles bond in the different phases of matter?

Explore:

This works best with at least two other people. To simulate the bonding of a solid, stand shoulder to shoulder in a straight line and link arms and cross your feet with the feet of the person on each side of you. Now try to move—and note your range of movement. For a liquid, uncross your feet with the two people standing next to you, keeping your arms linked. How has your range of motion changed? Has it increased or decreased?

To understand the gaseous phase, release your arms and stand all by yourself. Move at a walking and running pace and notice your range of mobility. Now, you will turn into plasma! Plasma is a gas that has lost its electrons and is positively charged. Take the two electrons (a piece of paper with "e- "written on it and place one in each hand). Run as fast as you can and lose your electrons somewhere along the way!

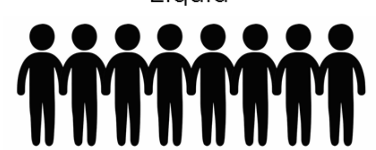
Explain:

Solids move at the slowest pace, they have the least kinetic energy (energy of movement). Liquids do not have as many bonds between molecules, so they can move freely and have more kinetic energy. Gases have no bonds, (they are neutral) so gas molecules can move about independently; they have a higher kinetic energy than solids and liquids. Plasma has the highest kinetic energy, and it has a charge since it loses electrons. Plasma moves at an increased speed and can combine with other things once it loses its electrons.

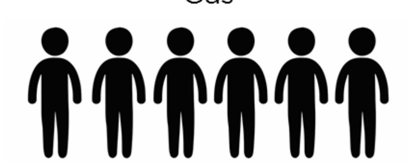
Here is a visual way to demonstrate using stick figures.

Solid

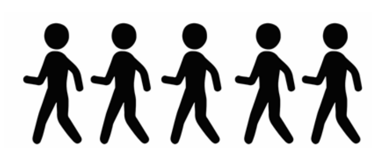
Liquid



Gas



Plasma



ACTIVITY THREE:

GAS PRESSURE REALITIES

Students will learn what gas pressure is and how it affects the plasma in the tube.

Question:

What is gas pressure and how does it affect plasma?

Explore:

Because some gases are invisible to the naked eye, we will look at the effects of a gas (carbon dioxide- CO_2) in water to understand how concentration affects gas pressure. Take a bottle of sparkling water and go to a place that can get wet (maybe outside or in your bathtub).

Look at the bottle—do you see any bubbles?

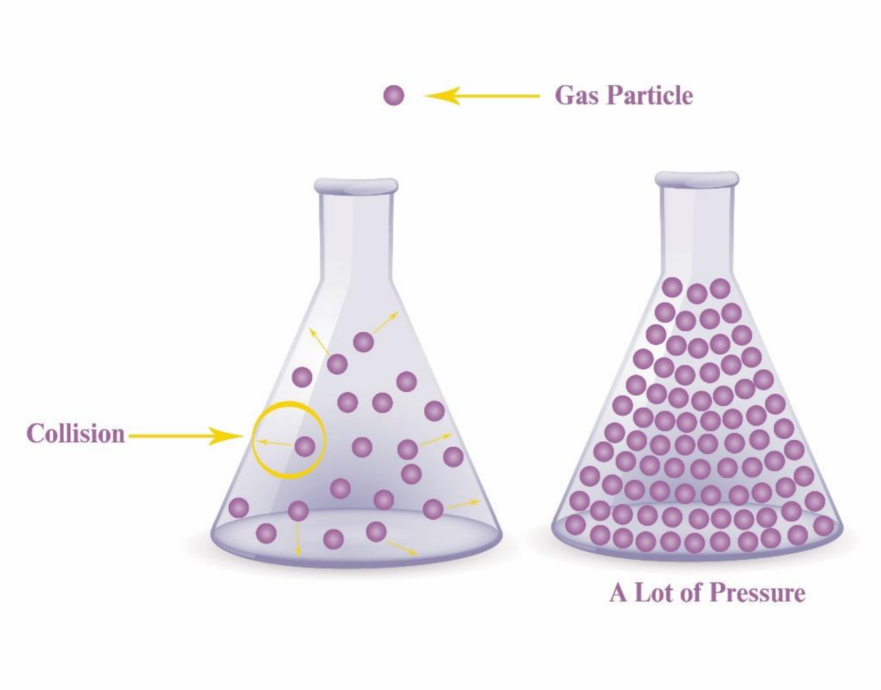
Those bubbles create gas pressure when they collide with the interior surface of the bottle. Now shake the bottle gently—what do you see?

Carefully point the bottle away from you and uncap. What happened?

Now let the bottle remain unopened overnight. Come back the next day, replace the top and shake again. What happened? What did you see? How does it compare to the result you experienced the day before?

Explain:

Gas pressure is defined as the force produced by the gas per unit area. Many different variables can affect gas pressure but we will focus on the concentration or amount of gas. If we think about the force of the gas bubbles on the sides of the container, they exert a certain pressure. The more bubbles that are present, the higher the gas pressure. In order to form plasma, there must be a certain amount of gas that is present in the tube. The more gas that is present in the tube, the higher the probability that the reaction will take place.



ACTIVITY FOUR:

VOLTAGE AND ELECTROMAGNETS

Students will be able to answer the question--how do these two variables help make plasma?

Question:

How do voltage and electromagnets affect the synthesis of plasma?

Explore:

You can think about voltage in terms of the flow of a water stream. Take an open bottle or glass of water and tilt at a slight angle. As you begin to pour the water out, when does it flow out with the greatest speed? Try it again and turn it upside down rather than pouring slowly. What did you observe?

Now take 10 paperclips and place them on the table. Using a magnet, pick up the paperclips that are randomly scattered about. What happened? How are they ordered differently?

Explain:

Voltage helps electrons move from one electrode at one end of the tube to another electrode at the far end of the tube. It is this movement of electrons that helps charge the gas to produce plasma. Electromagnets concentrate the charged particles to a confined space so more of the charged particles can interact.