States of Matter

Solids, liquids, and gases represent the three main states of matter that we find here on earth. We normally think of solids as keeping their shape, liquids as taking the shape of their container, and gases as filling the volume of their container. We also think of solids, liquids, and gases as composed of neutral atoms or molecules, although strictly speaking, this is not always the case. However, others states of matter exist and can be very important in our everyday life. Plasma, or ionized gas, is one such state of matter. The Science Show will present states of matter in a lively, fun, and engaging manner that will serve to increase the interest of your students in science. Topics in states of matter were chosen for the show because the students can readily connect with many aspects of the demonstrations and they provide a comfortable foundation from which to introduce new and more complex concepts and presentations. You are already quite familiar with solids, liquids, and gases, and so we won’t iterate their properties here. However, we will introduce you to plasmas, the fourth state of matter. Please review this material and use it to (re)introduce your students to the fantastic world of solids, liquids, gases, and plasmas!

Gaseous Plasmas are Soooo Coool (Mostly Hot, Actually)!

Plasma discharges and nuclear fusion have been around since shortly after the big bang, some 13 billion years ago. The development of the universe as we understand it today has been shaped, both in terms of time and of space, by the interactions of plasmas with their surroundings and by the hard-to-imagine high temperatures and energies associated with nuclear processes. In the simplest terms, plasma is an ionized gas. Electrons stripped from their parent atom leave the atom positively charged. A mix of electrons and positive ions make up plasma. That these particles are now charged means that magnetic fields and electric fields can influence their behavior. And, being charged, these particles have their own electric fields associated with them, and if moving, will produce an accompanying magnetic field. In a more sophisticated realm, plasmas make up the center portions of stars, lightning discharges, and are partly responsible for the aurora seen on some planets and much of the unseen matter in the universe. We will explore the fundamental concepts of plasma and discover that the science of plasma can be brought into the classroom in many interesting and exciting formats.
Nuclear Fusion is out of this World
(Well, Mostly... But We’re Changing That!)

Nuclear fusion is a process of energy production in stars. However, unlike most energy processes we are accustomed to, such as burning coal or oil, fusion is also responsible for element formation in the universe. Scientists and engineers have been tackling the possibility of fusion on earth to produce electricity for over 60 years. Fusion reactions involve relatively small nuclei, such as hydrogen or helium, that have sufficient kinetic energy that when they slam together, they overcome the mutual repulsive forces associated with being positive charges to produce a larger nucleus. The mass of the newly formed nuclei is less than the mass of the reacting particles; this mass has been converted into energy according to Einstein’s famous formula: \( E = \Delta mc^2 \). Remember, this relationship was not invented by Einstein. Nature already knew about it and followed it without fail. Einstein and others discovered this relationship in their quest to understand nuclear reactions. In this formula, \( \Delta m \) stands for the difference in mass between the products and the reactants and \( c \) is the speed of light. Thus, two hydrogen nuclei, each being only a proton, may come together to form a deuterium nucleus, having one proton and one neutron in its nucleus. Or 4 hydrogen nuclei may come together to form a helium nucleus, with 2 protons and 2 neutrons present. The small change in mass is often of the order of much less than 1/10 of 1 per cent of the mass of the reactants but nevertheless results in the release of a tremendous amount of energy. Elements in the periodic table up to iron (Fe) and nickel (Ni) are also produced in this manner. The nuclei of iron and nickel are so stable that they are not involved in further reactions using ‘simple’ fusion processes. Higher mass elements are formed in significant numbers in the explosions of supernova, where a star catastrophically explodes leading to the release of extremely high energy neutrons and nuclei that can collide with sufficient energy to produce heavier elements. Thus, it is fascinating to contemplate that every atom on the earth and in your body was once inside a star somewhere that exploded with the spewing mass coalescing into another star or star system. Eventually, through life processes, these atoms became you!

What’s a Charged Particle Like You Doing in a Place Like This?

Let’s look closer at charged particles. While we will not concern ourselves with the composition of protons, neutrons, and electrons in terms of the number of quarks they possess, we will concentrate on the characteristics such as mass and charge of each of these particles, and the influence that electric and magnetic fields have on such particles.

http://fusioned.gat.com  rick.lee@gat.com
In a plasma discharge, electrons and ions are relatively free to move about and their trajectories are influenced by the presence of electric and magnetic field forces. An example of a simple discharge is a spark; a large example would be lightning. Thus, when electrons are stripped from nitrogen and oxygen molecules in the air when your feet shuffle across a carpeted floor on a dry day a spark is made between you and the metal doorknob; a small electrical current is establish for a short time and we see it as a spark and may feel a little tingling sensation from the energy transfer between your high voltage body and the lower energy of the doorknob’s atoms. A Tesla coil is a high voltage source that easily strips electrons from atoms and can easily produce a lightning-like plasma in the classroom. Fluorescent lights also are great examples of plasmas in the classroom, although unless you’ve seen a half-coated fluorescent tube, you need to use your imagination regarding the argon and mercury plasma inside the tube.
And now...... If you DARE!

Topical discussions regarding states of matter can be introduced by asking the following questions (choose the appropriate level for your students):


2. What is a major difference between a solid and a gas?

3. As you heat up an ice cube, where does that energy go?

4. Your freezer at home is like a reverse heater: it removes heat from your food and eventually your food turns rock-hard. From where is the heat being removed? What does the freezer do with the removed heat?

5. Adding energy to a solid can make it a liquid. Can a gas be made if we add energy to a liquid?

6. Provide pro or con support for this statement: Gaseous CO2 molecules are more energetic than molecules of dry ice.

7. Nitrogen liquefies from gas at –196 °C (77K). Suppose you had, in the classroom, an open container of liquid nitrogen. Would it gain energy from its surroundings? What would happen to the liquid state? I’ve heard you can see “steam” associated with the liquid nitrogen. Where does this steam come from? Why are observations made that the “steam” goes downward towards the floor and not up towards the ceiling?

8. What is the sun made of? Can we go to the sun and grab a handful of it, say, in an insulated container? What would happen to the sun material if we did? What might happen to our spaceship?

9. Can we call the dissolved ions in liquid water as being in a plasma state?

10. What three things are necessary for a planetary aurora to happen?

11. Why do icebergs float? How might the earth be different if icebergs sank rather than floated? What role does this seemingly minor chemical arrangement difference play in your life? In the life of organisms that live in the ocean?
True, False, or Otherwise...

1. Lightning is a combination of gas and plasma.  T  F  O

2. Magnetic fields influence the path of a neutral atom.  T  F  O

3. An electric field influences the speed of a moving neutral atom.  T  F  O

4. Fusion is both an energy process and a method nature uses to produce atoms other than hydrogen.

5. On the moon, a kilogram of feathers has less mass than a kilogram of water, but has more mass than a kilogram of nitrogen gas.  T  F  O

6. The density of an object that has sunk in water is greater than that of a same sized object made of a different material that floats.  T  F  O

7. A balloon filled with air is placed into a very cold liquid. After a moment or two, the balloon begins to shrink. Answer the following:
   a. The balloon shrinks because the gas molecules inside of it are shrinking.  T  F  O
   b. The balloon shrinks because the energy of the molecules inside it is being reduced due to the cold surroundings.  T  F  O
   c. The balloon’s shrinking has nothing to do with the air molecules inside. It is the plastic of the balloon itself that is shrinking.  T  F  O
   d. Air molecules are leaking out of the balloon.  T  F  O
   e. Chemical changes are occurring to reduce the volume.  T  F  O

8. A planetary aurora requires a planet with
   a. An atmosphere only
   b. An atmosphere, a magnetic field, and some available plasma source
   c. Only a magnetic field
   d. A magnetic field and a plasma source
   e. No magnetic field, but with an atmosphere

Bonus

Can you explain why air injected into the mid plane of a column of cooking oil will bubble “up” but injected water will bubble “down”? What happens to an ice cube placed in a column filled half way with water and the rest with cooking oil? What happens to a balloon half filled with water and half filled with oil?