THE PLASMA CONNECTION

IEEE NPSS NUCLEAR & PLASMA SCIENCES SOCIETY

FROM THE IEEE NUCLEAR & PLASMA SCIENCES SOCIETY AUGUST 2021

Plasma: The Fourth and Main State of Visible Matter

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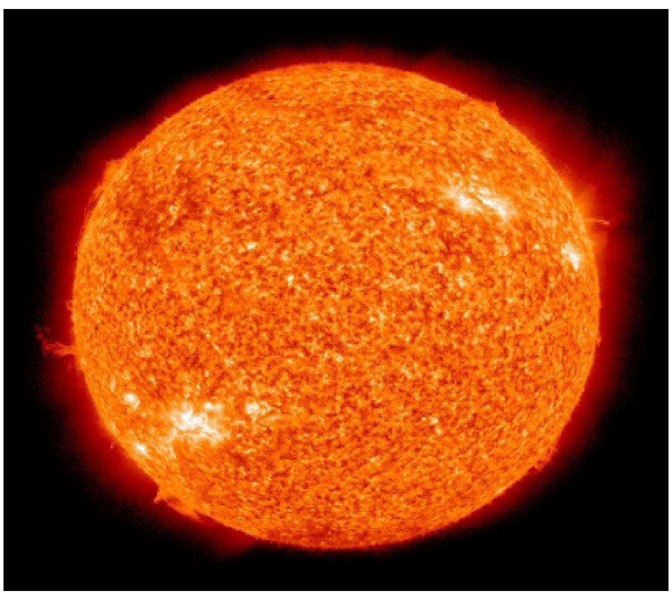
Before defining "plasma" let me set the stage by giving a brief historical background. By the beginning of the 20th century a great revolution in physics took place. In the span of a few years, physicists proposed unprecedented theories about the structure of matter, which were later supported by experimental observations. The basic structure of matter was proposed, and elementary particles, such as the electron (negative charge), the proton (positive charge) and neutron (no electric charge), which are the main elementary constituents of atoms, were experimentally detected. In addition, the mystery of the source of energy of the stars was finally unraveled. It was found that most of the visible universe was not made up of solids, liquids, or gaseous matter, but of a 4th state of matter which Nobel Laureate Irving Langmuir named "plasma".



Our sun is a huge ball of plasma where hydrogen is fused into helium and energy is released. Photograph by NASA/SDO (AIA). http://sdo.gsfc.nasa.gov/assets/img/browse/2010/08/19/20100819_003221_4096_0304.jpg

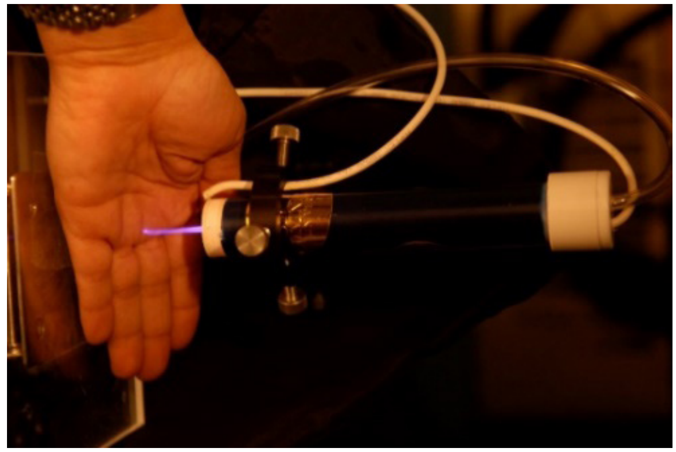
The sun, the stars, and the intergalactic matter are mostly in the plasma state. Our own sun is a huge "plasma reactor" which fuses hydrogen atoms to form helium, and in the process releases a great amount of energy.

A neon sign where the plasma is at a much cooler temperature. https://commons.wikimedia.org/w/index.php?curid=468523

Close to earth, natural plasmas are found in lightning, and in the aurora Borealis (Northern lights). Man-made plasmas are found in lighting devices (such as neon signs), in electrical arcs (such as in arc welding), in Lasers and in several other applications, some of which are described in the following section.

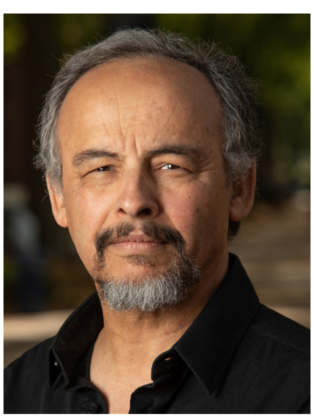
So, what is plasma? In a nutshell, plasma is an ionized gas that contains a mixture of neutral atoms and molecules, molecular fragments, ions, electrons, and electromagnetic radiation spanning a wide frequency spectrum. Depending on how much energy is used to ionize a gas, plasmas can exhibit very high temperatures (referred to as thermal plasma) or relatively low temperatures (referred to as non-thermal plasma). Plasmas can be produced artificially by heating a gas or subjecting it to high electrical stresses until some of the atoms and molecules constituting the gas lose their loosely bound electrons and become ionized. Because of the presence of free moving charged particles, negative (like electrons or an atom with an extra electron) and positive (like an atom missing an electron), plasmas can be affected by electric and magnetic fields. Using this characteristic, scientists are able to control plasmas and can even confine them in given geometrical configurations. Since plasmas are good conductors of electricity, scientists can also drive electrical current through them. For example, in nuclear fusion reactor very high electrical currents are driven into the plasma to heat them to thermonuclear temperatures (millions of degrees). In cooler plasmas, such as in neon light tubes, a current is established between two electrodes to excite the gas molecules, so they emit ultraviolet radiation, which is then converted to visible light by a phosphorus thin film covering the inner surface of the glass tube. Neon tubes are much more efficient in converting electricity into visible light than the conventional incandescent light bulbs where a substantial part of the applied electrical energy is converted to heat, not to light.

What is plasma used for? It may come as a surprise to many readers, but plasma is at the core of many advanced technologies and without it many of the conveniences of modern society would simply not exist. For example, the electronic chips (integrated circuits) in our laptops and cell phones are fabricated using plasma reactors. Here, plasma is used to etch semiconductors and to deposit the thin films necessary for the fabrication of the transistors, which are the main building blocks of integrated circuits. Without plasma we would not have high performance optics used in telescopes and in eyeglasses. Without plasma we would not be able to make efficient solar cells. Without plasma we would not have high efficiency lighting including flat panel displays (like plasma televisions) and light emitting diodes (LEDs). Finally, and to wrap up this section, plasmas have recently entered the biomedical field to help overcome many healthcare challenges. For example, plasmas generated at room temperature and pressure (often referred to as low temperature plasma) are today being used for the inactivation of pathogens such as antibiotic resistant bacteria, biofilms, fungi, and viruses. Low temperature plasma is also used to assist in the healing of chronic wounds, to treat various dermatological diseases, and even to kill some types of cancer cells. It is highly possible that in the very near future plasma-based therapies would be common and available at your doctor's office and nearby hospital. This is already the case in Germany where medically certified plasma devices are now used regularly by dermatologists.



Low temperature plasma jet (plasma pencil) used in biomedical applications. The plasma can safely treat skin/tissue without burning it or causing electrical shock. Photo courtesy M. Laroussi.

To conclude, by understanding and tailoring the characteristics of plasma, the fourth and most prevalent state of matter in the visible universe, scientists and engineers have been able to develop applications with high economical and societal impact. These include harnessing plasma for the production of energy by mimicking the fusion process of the stars, using plasma to manufacture semiconductor devices (computer chips), using plasma to engineer surfaces with specific features, using plasma to make high performance optics, and using plasma for various biomedical applications to overcome persistent healthcare challenges. Many more future technological advances will most certainly rely on this fourth and very special state of matter.



ABOUT THE AUTHOR

Dr. Mounir Laroussi is a Professor at the Electrical & Computer Engineering Department of Old Dominion University (ODU) and is the Director of ODU's Plasma Engineering & Medicine Institute (PEMI). Dr. Laroussi's research interests are in the physics and applications of non-equilibrium gaseous discharges including the biomedical applications of low temperature plasma (LTP). He designed and developed numerous novel LTP devices such as the resistive barrier discharge (RBD) and the plasma pencil. Dr. Laroussi conducted the first pioneering experiments on the use of low temperature atmospheric pressure plasmas for biomedical applications and contributed to the establishment of the interdisciplinary field of "Plasma Medicine". For his scientific achievements in the field of low temperature plasmas and their biomedical applications he was elevated to the grade of Fellow by IEEE in 2009 and was awarded the 2012 IEEE-NPSS Merit Award.