宇宙通信에 있어서의 Plasma의 應用

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要旨 : 宇宙에 99% 以上을 차지 하고 있는 Plasma를 아주 基本的인 概念으로 說明하고, 現在 硏究가 繼續되고 있는 問題와 MHD, 推進(propulsion)等 廣範한 領域에 걸친 Plasma 應用 問題를 紹介하는 同時에 筆者가 지금 Plasma의 溫度와 傳播特性을 硏究하고 있음을 言及하고 있다.

Dean, faculty members and students.

I come to you with a great deal of pleasure to say a few words about a subject that I find very interesting and I hope that perhaps you will find also.

I would like to present some material perhaps in a more general way than implied in the title as given.

I would ask the indulgence of those of you who have already studied plasma physics, as I know you have a very fine faculty member who is interested in the study of plasma physics.

Now before even writing down what a plasma is, I think you should know that fully 99%, greater than 99% of the whole universe, is made up of matter in a plasma state.

The sun, all stars, and all matter outside of the earth as we know it are really composed of a state of matter called plasma. As you well know, of course, that we have the liquid state, gas state, solid state and it is fashionable to think of the plasma sometimes as a fourth state of matter.

In a formal sense, a plasma can be considered as a hot gas with appreciable ionization it really exhibits the properties of a gas and sometimes the properties of a fluid, but it is unique in that it consists almost entirely of charged particles.

If, by some process we slip an electron from an atom, the atom will remain in a positive or ionized state and a group of these ions or elections is what we refer to as a plasma.

Before talking further about the nature of a plasma, I'd like to just show you that you have a frame of reference. I'd like to mention a few man-made and naturally occuring plasmas that you can recognize, aside from the sun. The simple current arc, and the fluorescence arc are plasma sources with variations, of course, in the properties of plasmas as I will indicate; and there are other examples.

To show that a current arc is indeed a plasma, one need only to open a switch in a conventional inductive circuit to get an arc, and if before hand the switch is placed in a magnetic field you will observe that the arc actually moves diagonally or at right angles to the current flow.

As a matter of fact, the simple application of this principle is used in the so-called "plasma circuit braker" or "magnetic circuit braker", that is, the magnetic field is present to divert the arc

I started to call your attention to a hot gas. Actually to a plasma physicist or an electrical engineer working in plasma physics, hot gas corresponds to something quite different from what we normally think of. The temperature of a gas in order to qualify as a plasma, is approximately $\frac{3}{10}$ of an electron volt and since 1 ev is 10,000°K we see we're talking about a temperature of 3,000°K. This, however, for a plasma physicist is a cold plasma.

A hot plasma to someone who's studying in this area is one that has a temperature something like 10 ev or greater.

This type of plasma is the type necessary for "controlled fusion" as I will illustrate later for you need temperatures hotter than the interior of the sun. So then hot gas at 3,000°K it's still fairly hot

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but to someone who is classifying or studying physics it's called a cold plasma.

A highly ionized plasma would be perhaps 99% ionized and in this type of plasma the ions would be universal and so, in one sense, neutral.

Now here perhaps we can get some sense of the difference between gases that are slightly ionized and others that are highly ionized.

Historically, it was Erving Langmuer at G.E. in America who in about 1920 first started to study slightly ionized gases because fluorescent lights are discharges, and classify as slightly ionized gases. It wasn't until 10 or 15 years ago that a great deal of interest was shown in highly ionized plasmas, the reason for which I will now mention in a qualitative way.

Recall that with a slightly ionized plasma 99% of the plasma is made up of neutral highmass particles. Therefore in attempting to analyze the behaviour of a plasma the analysis is greatly complicated by the fact that you must consider collisions. There are a great number of collisions of electrons with large neutral particles. This is a very complicated mathematical phenomenon to handle.

If one is looking for very high temperatures in order to bring about such an exciting process as controlled fusion, I will discuss this later. However for high temperatures, one needs to heat the electrons and ions, that is, to accelerate them and cause them to move fast and therefore energy must not be expended or wasted in collisions with neutrals, so if one requires a very hot plasma one must have a highly ionized plasma with few collisions.

Thus we have the difference between the physical phenomena involved in the two types of plasma. Now fortunately for those of us in electrical engineering and plasma physics who are interested in theoretical and experimental verification of plasma investigations, it's a lot easier to handle this analytically than the highly collision dominated type of plasma. However, it's not so easy either, because let us consider what we have. We have a cloud, a mass of charged particles plus and minus in motion. These particles are, as they move, by definition, currents and if they move fast enough, currents produces electric fields, oscillating electric fields produce magnetic fields, magnetic fields produce electric fields; you can see that this is, a very complicated cyclic situation.

In order to analyze the plasma theoretically one is faced with Coulomb forces, that is forces of a type of charge times the electric fields; one must deal with magnetic forces; and one must deal with initial forces. And when one wishes to describe the behaviour of a plasma one uses one of the middle school formulas: $F=m\alpha$ and to describe the force or the force in terms of acceleration with all these forces put in and you combine this equation with Maxwell's equation, because this tells us the relationship between electric oscillation and magnetic fields for electric currents and magnetic fields, so you need a self-consistent solution to this equations in order to completely analyze the plasma. And it's not simply a matter of taking a simple particle because you see really a plasma is made up of many particles each of which is at a different position in space, traveling at a different velocity at the some time.

So you must strictly describe a plasma in terms of a distribution function at some point with velocity v and as time t. I will not carry this any further but this will give you some feeling that you must deal with probability when you analyze a plasma. You must use constants of probability because particles have some sort of distribution which is like the Maxwell's force distribution, for example in velocity space there are distribution functions in velocity space. Any way if one is interested in describing the propagation of electromagnetic waves, that is an oscillating electric field, in a medium consisting of charged praticles it's obvious that there will be a great effect upon a wave that's propagated in a plasma medium.

And the way we describe this in simple form it turns out that for any magnetic field not equal to zero that at no external point the magnetic field will be zero.

For emphasis let me point out that the dielectric constant depends upon frequency. At certain frequencies an object may look like a conductor, at certain frequencies like a dielectric. In the case of a plasma zero may not equal zero, that is, suppose we apply a magnetic field and D C field to a plasma and discuss the propagation of waves. Then you must consider another mathematical frequency called in the plasma field the Cyclotron frequency.

So you can see things get very complicated but in principle, if one wishes to disuss propagation of waves into the ionosphere. One must express the ionosphere dielectric as a constant in terms of some complicated function of density and magnetic field.

I would like now to discuss applications of a plasma.

The first application is MHD. This is an application of plasma medium. When the plasma is such as to be represented as a fluid, this type of a plasma is collision dominated. An MHD is a method of generating voltage with no rotating rotor, so this a method of generating voltage making use of the fact that plasma is a conductor with no rotating conductors and the simple principle is as follows: north pole south pole streams of plasma moving at velocity v, since the plasma consists of positive and negativecharges, let's consider the positive charges, this means current is passing through magnetic field with the result that there will be a voltage set up at right angles. This is just equivalent to the rotor of a motor rotating through a magnetic field only in this case gas streams pass through the magnetic field producing voltage at right angles. This MHD generation is very interesting and potentially very important. Particularly for such applications as so called topping application. For example with a neuclear reactor instead of throwing away used heat, one can use it to ionize gas which you pass through a magnetic field and generate DC voltage by putting electrodes on either side, connecting these electrodes in series or parallel and using this as a DC generator. There are many interesting problems remaining.

The second application is propulsion. If we are interested in traveling in outer space as some people are now and we wish to travel long distances far from the gravitational field of the earth, the amount of force necessary on the rocket is very very small for a modest size rocket, measured in terms of ounces of thrust.

So, if it would be possible to create a jet engine with small thrust that could last for many years perhaps this would be interesting and a simple rocket like that would be made up of some kind of plasma source. Let's say here's a plasma. Let this be minus charge. These are accelerating electrodes minus, so that heavy ions are accelerated out the exhaust of rocket and result in a very slight push in the opposite direction.

So a plasma source with accelerating electrodes causing ions to accelerate and exist out the rear of the rocket produce a force this way, a very small force but enough.

The third application is study of various phenomenon. Let me insert the term extra terrestrial. Does anyone know what extra terrestial means? Extra terrestrial means phenomenon away frome arth, extra-in space-fancy way of saying in space, extra terrestrial.

Another interesting study is the so-colled solar wind study, that is, the sun-earth magnetic field.

There always is a wind traveling at velocity v of ionized gas traveling from the sun to the earth, this is called the solar wind. During certain times, during times of sun spots, intense solar activity occurs and this causes a varying wind.

This wind action compresses the magnetic field on one side of earth and extends it on other side. Well there are a few phenomen associated with the solar wind. For example with very sensitive magnetic instruments, one can study the effect of this plasma on the oscillation of the magnetic field at one position.

Number two, plasma streams hitting the magnetic field lines steps up oscillations and instability which propagates sound, the field lines can be defected near the pole. Low frequency, strange, low frequency radio signals receive down field lines are associated with this solar wind.

Number three, the electrons coming in from here, traveling straight down into polar regions give rise to the so called northern lights.

They're bright lights in the heavens due to the electrons coming from outer space coming in on magnetic fields, in the vicinity of the north pole.

In northern America, sometimes we can see on bright nights lightning flashes and stars which start us, towards the north. Can you see that here, sometimes?

I was at sea during World War II, and very often way out at sea with only dark heavens, you could see intense flash of light toward north pole. That's caused by this type of phenomenon.

Now I would like to slough for you a vast program which is all over the world on cold thermo neuclear fusion. I spent one year leave at Prinston University where a great deal of study is going on this aspect of plasma physics and I did experiments on propagation of electromegnetic waves in a large laboratory for plasma machines.

What is meant by fusion? You all are very familiar with fusion and of course the A-bomb, the explosion associated with fusion and the spliting of uranium. We all realize that this has been controlled with heavy water and in other ways in atomic reactors in the US and you will build one here in a few years. Fusion force involves the so-called H-bomb, And fusion of course deals with the combination of light elements plus other elements.

This of course is many orders of magnitude more powerful than the A-bomb.

Wouldn't it be wonderful if we could control peacefully this energy of the H-bomb like we do this energy here (A-bomb)? Tremendous energy is attained for example in the USA in Florida, Newyork, Hallywood, Chicago, Mississippi etc.

One thermo neuclear plant, with one fuel loading, could supply all the peace cost of America.

One power station in this industrial heart of America to the Mississippi river and you have some idea of industry in America, one plant to control this supply, this whole amount of electricity.

You won't worry about that. By the time this comes about, this will be solved too. So it would seem that one should study the possibility of controling a plasma that's number one motivation. Number two motivation is that people don't understand plasmas anyway and there's a lot of experimental and theoretical research to be carried out.Three difficulties are heat, density and time.

The plasma source, of course, this is a high tempearture phenomenon in any gas that becomes ionized. Then you have a plasma so we talk about hot plasmas. Hot plasma, this hot plasma must reach temperatures of greater than 100 ev that's millions and millions °K.

The density of the gas must be greater than around $10^{10}$to 10^{17} cm^3 particles and the time for reaction must be in milliseconds.

So the principle problem is hot gas, millions °K one cannot contain plasma in a cylinder as in a boilder or something. So you must find other ways to contain hot gas while the reaction goes on for milliseconds. Well studies all over the world are going on an containing gas and they all involve variations on the following principles: magnetic fields, plasma zero tend to stay on magnetic field lines, so that if I had a contain with walls and suppose I put some sort of a diepole here so that plasma wholly went up to diepole, then if I had strong magnetic fields, the plasma would stay in the magnetic field and not here, away from the wall.

Now in Japan, in Russia, in Italy, France and in several places in America, studies are going on with various devices to do this trick.

This was not designed to control fusion but only a step toward control fusion. Many many problems are or yet unknown, but this hope is possible and we hope that within ten years the solution will completed.

My studies involved in the laboratory fundamental studies of propagation of microwaves. Of course that is to study the temperature of plasma and propagation characteristics.

I'd like to thank you again for your kind attention and to tell you that it was a great privilege for me to come to this university and meet with your youngsters.

Thank you very much.

編輯者註：本稿는 去 9月 4日 延世大學校 理工大學 電氣工學科 學生들에게 講演한 內容이다.