Formation of Aurora
- A New Concept

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Abstract

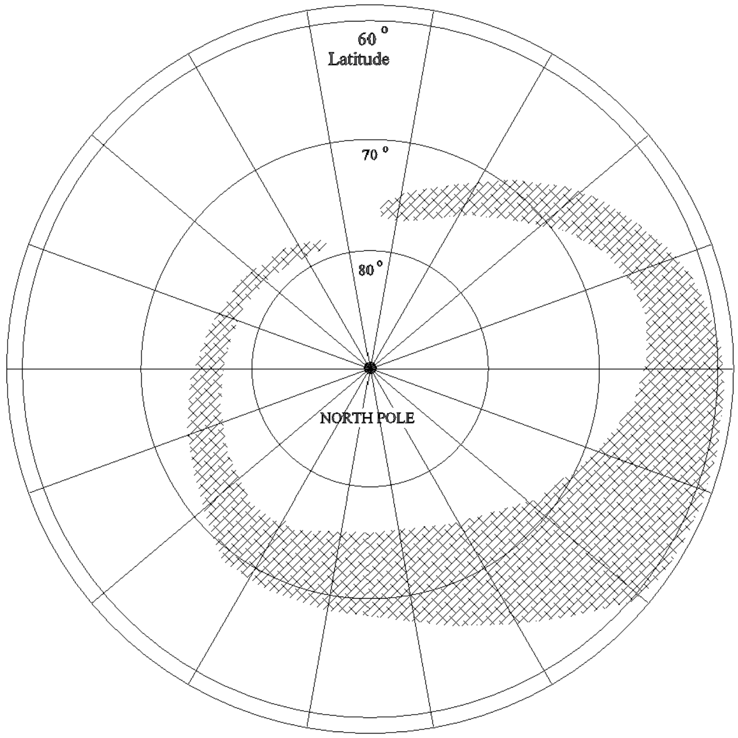
The earth and its atmosphere (including the ionospheric shells) are now found to be electrically charged. The crust of the earth is negatively charged with respect to the core and the atmosphere. Recently the sun also is found to be positively charged with respect to the earth. The natural charge state of earth and the sun provides the exact analysis of the features of ionosphere of the earth and the nature of geomagnetism which are discussed in separate articles in this issue of the journal. The existing understanding of the aurora is complex and has many limitations. It is natural to think that the ionosphere, geomagnetism and aurora in earth's atmosphere have a common cause linking with the charge polarized structure of the earth. The ionospheric shell, subshells have a definite pattern of electric charge potential caused due to charge polarization. The potential difference between negatively charged shell and the adjasent positively charged shells due to polarization is not a measure to cause charge flow across shells because the standing potentials are caused by charge polarization. If somehow the potential of any shell or subshell goes up or down from the equilibrium polarized potential then the shell tends to exchange charge with neighbouring shells to attain the equilibrium polarized potential. Solar flares cause changes in solar spectra and composition of solar wind that produce changes the polarized potential structure of ionospheric shells. The nonpolarized component of potential difference produce electromotive force for the flow of electric charge across the ionospheric shells and sub-shells. The dielectric constant of the intervening medium of the shells being high very weak current is discharged across the shells. However, the charge flow is enhanced when assisted by geomagnetic field lines (magnetic field aligned current). The geomagnetic field lines cross the ionospheric charge shells between 60^0 to 85^0 latitudes. The occurrence of aurore are confined to these latitudes which conforms the new mechanism of formation of aurora. The new mechanism explains also other features of aurore in a clear conceptual manner and the same is discussed in the paper.

Subject key words: *aurora, auroral oval, auroral potential, auroral generator, aurora borealis, aurora Australis.*

Introduction

Formation of a great luminous oval in the upper polar atmosphere is known as aurora. When it forms around the North Pole it is called aurora borealis and its counterpart around the South Pole is named as aurora Australis. The auroral oval centres on geomagnetic poles. The oval has two distinct parts: one facing the equator and the other facing the poles. The pole-ward part consists of curtain like forms of luminosity while the equator-ward part is wide with diffused glow. The complete view of the auroral oval can be obtained from a satellite while looking down the earth from a position above the polar region. One such view is shown in Fig.1. The average size of an auroral oval is about 4000 km. Though the oval always centers on each geomagnetic pole, it does not exactly confirm to any geomagnetic latitude in a strict sense. The mid-day part of the auroral oval is located at 76^{o} of the geomagnetic latitude while that corresponding to the mid- night part is 67^{o}. At times the oval can contract poleward or equatorward within the rough limits of 82^{o} to 70^{o} in the mid-day part and 72^{o} to 55^{o} in the mid-night part.

In general, the auroral form has a discrete curtain like shape with its bottom edge approximately in the range of 100-110 km height while the upper edge is more flexible between 400 to 1000 km and even more. The auroral curtain has several folds ranging from kilometres to hundreds of kilometres in scale. The aurora with small scale folds give rise to the appearance of striations which is called a “ray structure” and that with large scale folds is termed as horseshoe or drapery. The equator ward of the curtain like aurora extends to low latitude giving wide coverage of the sky with having faint, diffuse and Milky Way like glow. This diffuse glow tends to develop east-west structures in the morning part of the sky. Often these structures break up into patches like the cumulus cloud and drift eastward with a speed of 300 m/sec.



THE EARTH

Fig.1 SCHEMATIC OF AURORAL OVAL
(A view from above the geographic north pole
Source : Scientific American, May 1989, p.62

Auroras are dynamic in nature, but at times they exhibit very dynamic features known as auroral sub-storms. A typical auroral sub-storm begins with sudden brightening of auroral curtain in the mid-night sector which then spreads rapidly westward and eastward. Very soon the auroral curtain is developed in the entire dark hemispheres which brighten the dark sky. Beside the east-west motion, the brightening is associated with a poleward motion at a speed of few hundred meters per second and at the same time forming a prominent bulge in the oval. The bulged structure has further its prominent effect in the mid-day sector. The poleward advancement of aurora reaches its limit of high latitude where the auroral sub storm has its peak form. The time taken from its first appearance at mid-night sector to its maximum epoch generally varies between 30 to 60 minutes which is known as the expansive phase of the sub-storm. Thereafter the bulge begins to contract by receding from the lower latitude. This is known as the receding phase of the auroral sub-storm.

Special Feature

The aurora is associated with electromagnetic waves over a wide range of frequencies starting from x-ray down to IR, VLF and ULF radio emissions. Green light at wavelength of 5577 Å and red light at 6300 Å from excited oxygen atoms are the most familiar ones. Images made by Swedish Viking Satellite of extreme ultraviolet emissions show that the aurora is surprisingly active on the sunlight side, often more active than the dark side [1]. The field aligned current forms thin sheet like beams which when gradually gains intensity, a peculiar electric field called an auroral potential structure develops around the beams at an altitude between 10,000 to 20,000 kilometres [2].

The diurnal variation is caused due to rotation of the earth but the aurora is always fixed with respect to the sun [3]· During the occurrence of aurore, magnetic disturbances are invariably seen. The frequency of occurrence is prominently marked from the frequency of sunspot number at lower magnetic latitudes and during the solar flare brilliant auroras are seen. From a survey of the auroral occurrences, it is seen that there is a tendency for the aurora to recur after approximately 27 days (27 days is the rotation period of the sun). During the occurrence of aurore, changes in earth current values are noticed. The vertical electric potential at the ground level increases during the storms from its fair-weather values (100 volts to 130 volts/meter) but, during the auroral display, the vertical gradient is depressed at ground level to a value of 10 volts per meter.

Progressive Understanding of Aurora

Until about the middle of 19th century, it was generally believed that auroral lights arose from the reflection of sunlight by ice crystals in air. This concept was rejected when A.J. Angstrom showed that the auroral spectra consist of many lines and bands instead of one continuous spectrum of sunlight. Therefore, it became clear that visible emissions from an aurora are caused by some excitation process of the atmospheric atoms and molecules. Many popular books on the aurora explain that the aurora is caused by direct impact of solar wind-particles (hydrogen ions and electrons) in the polar region on being deflected by the earth’s magnetic field. It was possible to think of an impact region only for the portion of the mid-day part of the oval called the cusp. This mechanism, however, does not explain how the other parts of the auroral oval corresponding to the dawn, dusk and the mid-night are formed. Moreover, the auroral belt formation around the pole could not be reasoned out properly by using the above said mechanism.

In the early 1960’s solar physicists began to recognise the role of solar wind in stretching and carrying forward the coronal magnetic field far into the solar system. This extended magnetic field extending far into the solar system is known as the interplanetary magnetic field. This concept was further enriched by James. W. Dungey of the Imperial College of Science and Technology, London through the proposition that this magnetic field could join the magnetic field lines originating from polar region of the earth. Such magnetic reconnection proceeds most efficiently when the solar wind magnetic field is antipolar with the earth's magnetic field. The magnetic reconnection mechanism was then accepted to be a stable process. An electricity generating system in the upper atmosphere was then proposed indicating complex interaction between the solar wind and the earth's magnetic envelope to explain various auroral phenomena. This could explain the relation of aurora with the sunspot, the solar flare, diurnal variation responding to the solar cycle of 27 days, fluctuation of earth's magnetic field and the earth current. Towards late 1970's Christopher. T. Russel, University of California at Los Angeles proposed an alternate way of magnetic reconnection. He assumed that bundles of ropes of field lines form, which eventually cleave from magnetosphere and are swept into magneto tail (like the breaking of one string from the bundle of rubber band that brings instability to the bound system) causing instability. This model permits magnetic reconnection even when the interplanetary magnetic field has a steady southward orientation.

Auroral Dynamics (present understanding)

The solar wind particles dashing against magnetospheric barrier glide over the magnetopause thereby it crosses the connected field lines. The flow of solar wind plasma over the magnetopause represents the motion of conductor crossing the reconnected magnetic lines. Electromotive force is produced in the plasma conductor which drives the electrons and ions in opposite direction following Fleming's right-hand rule. The positive ions are driven towards the dawn side of the equatorial plane of the magneto-pause, creating a kind of positive terminal and the electrons are driven to the dusk side of the equatorial plane of the magnetosphere. The rarefied plasma which faces minimum resistance from the magnetosphere enters the magnetosphere and the electrons within the magnetosphere travel along the cork screw trajectories that wind around the field lines. This field aligned current meets the ionospheric E layer at an altitude of 110 km approximately at the magnetic latitude which is connected to the aurora. The field aligned electrons in motion connect the magnetopause to ionosphere. The positive potential of the dawn side of the magnetopause is thereby projected to the dawn side of the oval. Likewise, the negative potential of the dusk side of the magnetopause is projected to the dusk side of the oval. Hence a potential difference of about 100 kilovolts across the oval is generated. Due to greater mobility of electrons as compared to positive ions, all charge conduction takes place by electronic current. By this dynamo mechanism electron current flow downward to the dusk half of the oval and flow upward from the down half. The incoming electrons from the auroral generator collide energetically with the ionosphere and produce excitation and ionisation of atoms which emit radiations over a wide spectral range.

Some Basic Aspects of Aurora Not Explained by the Auroral Generator Theory

An auroral potential structure is seen to develop at an altitude between 10,000 and 20,000 km. The region inside the structure appears to separate into positively and negatively charged layers producing an electric field between them. Investigators at Lockheed Missile and Space Company have confirmed the auroral potential structure and further seen positive ions accelerating upward. The formation of positive and negative charge layers is not understood by the auroral dynamo operation.

It is also interesting to note that the auroral potential field is seen to develop along the magnetic field lines in rarefied plasma. Such observed charge field feature is not expected and it goes against the basic assumption of the dynamo theory. Again, in the light of the alternate positive and negative charge of ionospheric shells, the dynamo operation becomes much more complicated. Against this background, the author has now proposed a new simple auroral theory by considering the ionospheric charged shells.

A New Theory on Formation of Auroras

The electrical charge structure in the atmosphere of the earth having alternate polarity of the ionospheric shells and again having an orientation with respect to the sun causing a charge density peak in the mid-day and mid-night sky have already been discussed [4]. It is further reported that this nature of ionospheric charge structure is developed by polarisation of atmospheric charges (electrons and ions) due to the effect of the negatively charged earth and positively charged sun [5]. Hence, the noticed charge potential difference between ionospheric layers is not effective in driving electric current since the standing potentials are caused by polarisation due to external charge interaction. For example, when a metallic sphere is charged by induction by an external charge body, the so formed polarized potential difference between different parts of the sphere does not cause charge flow within the conducting sphere. If the external charge body is removed then any potential difference within the body would produce electromotive force for charge flow in the body. However, in polarized state, if some external charge particles shower on metallic sphere it would bring a change in the polarised potential structure and cause charge flow only due to non-polarised component of potential difference (PD). If the polarized PD is x and the PD by charge showering is y then the net PD would be algebraic sum of x and y i.e. (x+y). One, ignorant of the charge polarization source would assume observed PD (x+y) is due to charge showering on metallic sphere, he would then wonder as to how in a conducting sphere such a large PD is feasible. In polarized state the PD is ineffective to cause charge flow. In charge polarized state the charge densities (charge potentials) at different locations corresponds to a state of equilibrium under external and internal charge forces. The equilibrium polarised potentials of the ionospheric shells are subject to change by the solar-wind entering the upper ionosphere by dis-proportionately trapping of selective charge in different ionospheric shells. Charge imbalance also occurs when different degrees of ionisation take place at different levels of ionosphere by selective absorption of solar ionising radiation and selective migration of charge. Both solar wind and the ionising radiations entering the ionosphere cause imbalance in the charge polarised potential structure. Disproportionate loading of one class of charge particles in sun facing side (corresponding to day time) of ionospheric shells and cause charge migration to the far side of the sun through the conducting ionospheric shell. In the process, the charge potential of the shell is raised causing an increased PD across ionospheric shells. But the charge potentials of different ionospheric shells are modulated away from their normal charge polarization potential thereby the non-polarized component of PD would tend to make charge flow across ionospheric shells to attain equilibrium-polarisation-potential. This charge imbalance cause motivation for the cross flow of charge from one ionospheric shell to another. For a cross flow of charge particles from one ionospheric shell to other the electromotive force has to overcome the dielectric barrier of the intervening medium. The cross flow of charge particles will follow a path of least resistance. We notice, the geomagnetic field lines cross the ionospheric shells roughly between 60-85^{o} of geomagnetic latitude Fig.2. The charge particles easily move from one ionospheric shell to another by taking support of the geomagnetic field lines. The ionospheric electrons travel along the geomagnetic field lines in cork screw trajectories that wind around the field lines. The accelerated electrons in their path meet the neutral atoms and ionize/excite them, thereby causing auroral emissions. Electric currents are observed through the satellite borne magnetometer [6]. Referring to Fig.2, the stronger geomagnetic field lines cross the lower ionosphere at higher geomagnetic latitudes. Therefore, the pole-ward aurora has a field aligned current density higher than that of the equator-ward aurora thus having a different pitch of the winding of electrons around field lines. For this reason, the equator-ward curtain like aurora extends to low latitude giving a wide coverage of the sky with a faint, diffused and Milky Way like glow.

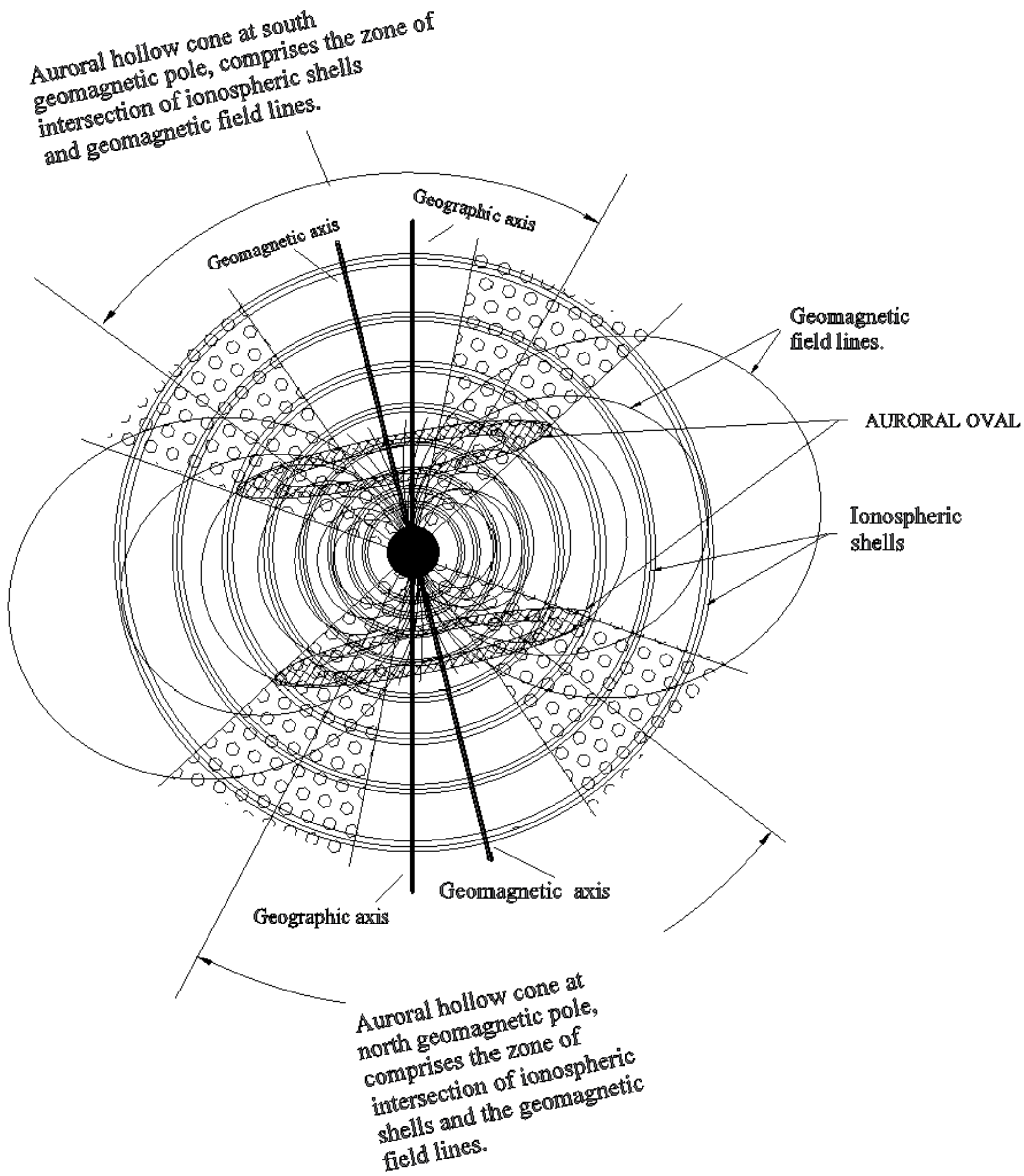


Fig.2 SCHEMATIC VIEW OF GEOMAGNETIC FIELD LINES AND THE POSITION OF IONOSPHERIC SHELLS.
(Auroral discharge occurs where the field lines cross the shell/subshell)

The rotation of the earth causes diurnal variations but interesting enough, the aurora remains fixed with respect to the sun like the electronic configuration in ionospheric shells [4]. Any aurora comprises some portion of the ionospheric shells where the geomagnetic lines cross the shells. Thus, when the entire ionospheric shells (charge shells) remain fixed with respect the sun it becomes natural that the ionospheric sections under the aurora has to remain fixed with respect to the sun.

One would ordinarily expect the aurora that centers around the geomagnetic poles to have also the auroral oval which is symmetrical about the geomagnetic latitude. The oval, in reality, is not symmetrical about the geomagnetic latitude. The day part of the aurora is closer to pole as compared to the night part of the aurora. The electron density in day part of the ionosphere is an order higher than that at the night part of the ionosphere around the equatorial belt. The electron density also decreases from equator to poles. At any given geomagnetic latitude, the day part has a stronger charge polarisation due to the sun, therefore the barrier for electrons in crossing the shells is high. Thus, the electrons find easier to move from one shell to another at higher geomagnetic latitude. The auroral discharge is favoured at locations where there is low polarisation barrier and high geomagnetic field strength. The auroral discharge is more in day part rather than the night part. But due to the day brightness, it is not prominent during the day.

The auroral discharge takes place in a rotating atmosphere, therefore the excited/ionized atmospheric constituents have a group velocity that causes the aurora to move rapidly in eastward direction in the morning sky. Besides this motion, the auroral charge cloud experiences charge forces from the ionospheric charged layers and the positively charged sun which make the aurora to move faster or slower than the tangential velocity of the auroral cloud due to the rotation of the earth.

We find a typical fluctuation of fair-weather voltage at ground level during the auroral discharge. The electrical resistance of the air medium during glow-discharge being less than that of the non-plasma state causes a decrease in the magnitude of potential gradient at ground level

Conclusion

The formation of aurora and its different features are better understood by the new charge polarisation structure of ionosphere which is caused due to the negative charge of the earth and the positive charge of sun. The ionospheric features and the geomagnetism are well understood by the charge polarization concept. Studies also show that the orbital celestial bodies have discrete orbit system obeying definite correlation. In the light of these new developments, one drives towards a complete similarity between the solar system and the atomic system.

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