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Effects of solar activity on the formation of the ionosphere and magnetosphere －The effect of high-speed charged particle acting magnetically as a current－

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Abstract Magnetic reactions due to the motion of charged particles are described by vector potential. Vector potential is an attribute of the space, it is able to deal with the action of magnetism due to any motion of charged particles. Sun's electromagnetic waves generate free electrons in upper atmosphere on daytime-hemisphere, and form ionospheres. The ionosphere orbits the Earth by Earth's rotation of counterclockwise rotation, forming geomagnetism from south to north outside of the Earth, because the charged particles that exercise have magnetism. In Jupiter and Saturn, the polarity of the magnetosphere is opposite of the Earth's magnetosphere, because positive charges of protons sent from Sun are added to upper atmosphere of hydrogen, and orbits in counterclockwise direction by rotation of the giant gas planet.

Keywords Aharonov-Bohm effect, Solar wind, Ionosphere, Magnetosphere, Parallel current, Vector potential, Aurora belt

1. Introduction

There is a lot of research on solar wind fluctuations in the magnetosphere-ionosphere interactions [1]. The author reported in 2019 that moving charged particles move in parallel by its magnetic effect, so that the same particles are magnetically bonded and repel between charged particles of different polarity that run side by side [2][3].

The charged particles that run are accompanied by magnetism, and when there is a rounding of charged particle in a plasma, parallel currents are induced, and the circular currents are aligned in a line. As a result, charged particles are running around the magnetic field line.

If a magnetic field is assumed at first, electrons moving into the magnetic field are taken in, but magnetic repulsive force works between moving proton and captured electrons, and the movement of the proton is ignored. But this is a paradox. Moving charged particles are accompanied by moving magnetism. The geomagnetism is a combination of magnetism from many moving charged particles. Since a proton controls movement of electron, the form of magnetics depends mostly on the movement of protons.

Magnetic field lines are a useful tool for considering magnetic action. However, **Aharonov–Bohm effect** [4] shows that the local **E** and **B** fields do not contain full information about the electromagnetic field. That is, when charged particles pass left and right outside the solenoid, the interference fringe caused by the phase difference of the material wave changes with the current of the solenoid of which coil is surrounded by a superconductor.

<u>According to **A–B effect** the local effects caused by charged particles on move should be considered the vector potential without using the magnetic force line.</u>

In the Electromagnetism, the relationship between current and vector potential is shown by an equation corresponding to Poisson's equation. That is, the point charge on move has a vector potential, and if the motion of the point charge is parallel to the motion of the other point charge, the energy between them is lower.

There is a magnetic reconnection theory based on electromagnetic fluid theory. In this theory, energy taken into the magnetic field line is emitted when the connected magnetic field line is cutting off [5].

However, we can explain this phenomenon by considering behaviors of charged particles those accompany magnetism. Since escape velocity from the Sun is 617.5 km/sec, the most of charged particle are pulled back by the gravity of the Sun and route of the movement form an arc. The surface of the Sun can be explained by the magnetic coupling of the charged particles that exercise.

In the past, it was considered that there is little influence of the solar wind on earth, because the geomagnetism of the earth captured electrons, and by the electrons block the protons of the solar wind. Indeed, the high-speed protons of the solar wind repeatedly collide with the earth's atmospheric molecules and do not reach the Earth's ground.

Despite that Earth's gravity cannot hold hydrogen, there continues to be a peak in the density of hydrogen atoms around 80 km above the sky [6]p872. It is the kinetic energy of protons in the solar wind that moves atmosphere from west to east faster than the rotation of the Earth.

The protons in the solar wind those had escaped from the Sun have about speed of several hundred km per second, and they collide with and mix with the atmosphere. As the results, the protons those pass through the eastern side of the planet hydrodynamically accelerate the atmosphere that rotates in the counterclockwise direction. This accelerating effect of the east side has larger power more than the deceleration effect at western side. So, the atmosphere of the planet goes around from west to east.

Sun's electromagnetic waves ionized molecules in the upper atmosphere over the Earth's daytime hemisphere, and dense electron layers form ionosphere layers. The clock-rotating current due to the transfer of the electrons forms geomagnetism of the Earth. The direction of the Earth's magnetic line is from the South Pole to the North Pole.

On the other hand, the geomagnetism of Jupiter and Saturn goes from the North Pole to the South Pole in the opposite direction to the earth's magnetic field. Because protons in the solar wind collide with hydrogen atoms of upper atmosphere of Jupiter and Saturn, and great number of positive ions orbit at fast speed in the counterclockwise direction.

2. Interaction between charged particles on move

2.1 Demonstration test of Aharonov–Bohm effect

The Aharonov–Bohm effect [4] (A-B effect) requires that a charged particle on move in a magnetic field must be treated with vector potential rather than magnetic field.

This effect is a theoretically derived effect in which the material waves of moving electrons appear in a space without magnetic fields on the path, where Hamiltonians are different due to differences in vector potential, causing phase differences, and interference fringes of material waves appear where material waves overlap. Fig.1 illustrates the demonstration experiment of the **A-B** effect.

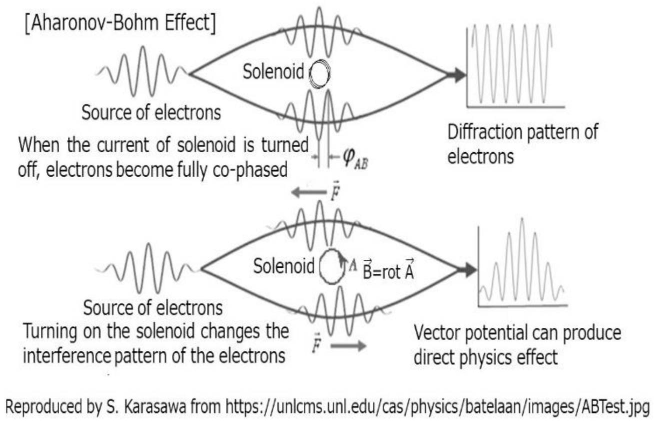


Fig.1 Method for verifying the **A-B** effect (observing interference fringes due to the phase difference generated by electron waves passing outside the solenoid interacting with the motion of the charged particles those are responsible for the excitation current of the coil)

Experimental demonstration of the A-B effect was demonstrated in 1986 by Akira Tonomura [7]. That is, by using a very small doughnut-shaped magnet is surrounded with a superconductor, preventing from leaking out of the magnetic field from donut-shaped magnet, the interference fringes of eelectron holography were observed between a through hole of the donut-shaped magnet and a through outside of the magnet.

So, the vector potential to handle the magnetic action between the moving charged particles, the vectorpotential **(A)** is introduced by expression (2. 1).

$$\mathbf{B} = \mathrm{rot}\ \mathbf{A} \qquad (2.1)$$

This definition satisfies div **B**=0, which is the nature of closed circuits. Maxwell's equation is a differential equation, and the potential *equation uses* a gauge transformation to take in integral constant terms.

When a charge (q) is placed at the electrostatic potential (V), the energy(U) of the position is given by (U=qV). Similarly, an equation (2.2) is given as the energy for a charge particle on move in the magnetic field.

$$U= -q\mathbf{v} \cdot \mathbf{A} = - q(v_x A_x + v_y A_y + v_z A_z) \quad (2.2))$$

If there is a current (q**v)** of charged particles in a magnetic flux density **(B)**, due to the potential energy (U) shown in equation (2.2), the current [q**v]** in the same direction as **[A]** is forced to line up to reduce magnetic energy. The [q**v]** is received repulsive force in case opposed direction for **A**.

The vector potential consists of the principle of stacking. When a charged particle (q) moves at velocity **(v),** a magnetic field on move is generated. If the charged particles flow continuously, they become a static magnetic field. The strength of the magnetic field by a current (q**v)** is expressed by Ampere's law [H= q**v**/(2πR)]. The magnetic field decreases in inverse proportion to the distance. Even though this law is considered for a macroscopic system, it also is available for the motion of the point charge.

Fig.2 shows magnetic field **B** & vector potential **A** caused by a current.

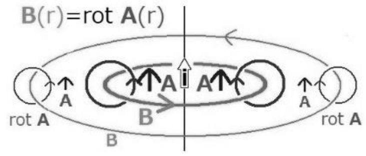


Fig.2 Relationship between magnetic field **(B)** and vectorpotential (A) associated with current **(i)**

Since the magnetic coupling between the moving charged particles is in the vertical direction, and inversely proportional to the distance, the maximum magnetic coupling acts momentarily in inverse proportion to the distance between the particles. On the other hand, coulomb force decreases in inverse proportion to the square of the distance. So, action of the magnetic coupling is stronger than coulomb force at the long distance [2].

A Maxwell equation shown in eq. (2.3.a) corresponds to a change in the magnetic field by adding microscopic charge transfer changes (∂D/∂t) to the current density (j). Since both are charge transfers in a vacuum field, all currents can be expressed by equation (2.3.b) by using of charge density (n).

$$\mathrm{rot}\ \boldsymbol{H} = \mathbf{j} + \partial \mathbf{D}/\partial t \qquad (2.3.a)$$

$$\mathrm{rot}\ \boldsymbol{H} =(n) (q \ \ \boldsymbol{v}) \qquad (2.3.b)$$

The rotating electric field E expressed by equation (2.4) is induced by a change of the magnetic flux dense **B** due to point charge current also.

$$\mathrm{rot}\ \mathbf{E} =-\partial \mathbf{B}/\partial t \qquad (2.4)$$

By the way, in Electrostatics, **Poisson's equation** is given by △V= -ρ/ε as a relationship between charge and potential (V).

For microscopic representation on **j**=rot **B**, the point charge current is transformed to the average value of a uniform sphere volume ($4\pi R^3$)/3. So, Eq. (2. 5) for the relationship between moving charge and vector potential is obtained by using eq. (2.3) and (2.1) [8]pp.305.

$$\mathrm{rot}\ \mathbf{B} = \mathrm{rot\ rot}\ \mathbf{A} = \mathrm{grad}(\mathrm{div}\ \mathbf{A}) - \triangle \mathbf{A}$$
$$= (q\ \mathrm{v}\ )\mu_0\{3/ (4\pi R^3)\} \qquad (2.5)$$

The grad(div **A**)is not always 0. By using a relationship of div (grad **Λ**) = 0, adding effect of the other vector of (grad **Λ**) to **A**→(**A** + grad **Λ**) in order to get div (**A**) =0, the equation (2.5) becomes $\triangle \mathbf{A} = -(q\mathbf{v})\mu_0\{3/ (4\pi R^3)\}$. This equation is the same expression as **Poisson's equation.** If twice of integrals on the equation are carried out, we can get the relationship that the vector potential **A** is inversely proportional to R is obtained. So, the vector potential of charged particle on move works strongly in the vicinity.

3 Behaviors of charged particles in the Sun's plasma

3.1 Equilibrium state in a central force field

The sum of kinetic energy and potential energy in an equilibrium state is maintained according to the energy preservation law. And a state of confined space, such as in an atom or a box, is quantized in quantum mechanics.

As shown in Fig.3, if the quantum state is specified and the size is reduced in the center force field, the potential energy decreases, and the kinetic energy increases, but the overall energy decreases. The half of decrease of the potential energy is changed to increase of kinetic energy and the remained half of the energy is released to the outside. That is the Virial theorem.

When the center of a celestial body is compressed, the temperature is high.

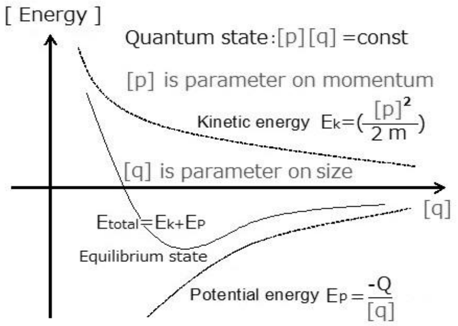


Fig.3 Changes in energy to equilibrium in a quantum state

If there is extra energy in an equilibrium, it swings around the equilibrium point like a pendulum. When that extra energy is greater than the difference in energy from the base state to the excited state, it absorbs the energy of the vibration and transitions from the base state to the excited state. In quantum state transitions, electromagnetic waves in which the electric field responsible for potential energy and the magnetic field responsible for kinetic energy coexist are propagated into space. In the center of the Sun, the kinetic energy of charged particles is very large, and high-speed protons and high-speed protons have strong magnetic coupling, nuclear fusion reaction takes place. As a result, the energy that reaches the Earth from the Sun is about 1.37 kW per square meter.

3.2 Structure of plasma in the chromosphere

Velocity of escape from the Sun is $v_{escape}= (2GM/R)^{1/2}=$ 617.5 (km/sec). Where M is the mass of the Sun and R is the radius of the Sun.

In the photosphere of the Sun, the density of charged particles is high, so protons and electrons are close together and there is little hydrogen in the ions. But the density of electrons (Ne) decreases from10^{-14} ($Å^{-3}$) to 10^{-15} in the transition region of chromosphere, and the temperatures increase remarkably [9]. Here, assuming that the density of electrons and hydrogen ions is equal, and if the collision cross-sectional area is 10 ($Å^2$), the mean free path is$10^3 \rightarrow 10^4$(m). When protons and electrons become separated and move with high speed, a magnetic effect that creates a bunch of moving charged particles in which the same charged particles run side by side takes place.

An elongated protrusion structure reaching a height of 3,000 to 10,000 km from photosphere called "**Spicules**" has been observed. About 60,000 to 70,000 pieces of spicules are constantly occurring, and each spicule is constantly moving, rising from top of the chromosphere and turning downward, but some of them rise, and release from the Sun.

Conventionally, action of electric fields and magnetic fields is affects to the electrons, and the reactions of protons are ignored. However, since the electric field is formed by the charged particles and behavior of electrons depends the movement of protons of its 1836 times of the mass.

High-speed protons are magnetically coupled in bundles, and small populations of protons released form needle-shaped structures of “”. The bundled protons pulled back are affected strongly by horizontal motion at the vicinity of the apex where the movement slows down. Therefore, the group motion of strongly radiated protons draws an "**arc**". A “**sunspot**” is the area of Sun's surface where protons falling by gravity gather.

When high-speed protons with the same direction become huge populations that magnetically coupled each other, it expands horizontally by the selv-replication. A "**flare**" occurs if a population of protons grows huge.

When a group of plasma collides, a re-construction of a magnetic bond that combines a group of electrons and a population of protons occurs, forming a luminescent region.

3.3 State of charged particles in coronal region

The corona's temperature causes its particles to move at very high speeds. These speeds are so high that the particles can escape the Sun's gravity.

It is said that the corona of the Sun is at a temperature of more than 1 million K. The energy of this temperature corresponds to 1.38x 10^{-16} J by using Boltzmann constant $k=1.38x10^{-23}$ JK^{-1}. By using m_p= $1.673x10^{-27}$ and, relation of kT= (1/2) $m_p v^2$, the velocity of proton (v_p) is estimated as, v_p={2x (1.38/1.673)10^{11}}$^{-2}$ = 410 km/sec.

At the smallest activity period in solar cycle, the plasma is emitted radially in the north-south direction, a ling it extends in the east-west direction due to the Sun's rotation.

Fig.4 Corona photographed during a total solar eclipse (Photo by Harutaka Kamiyama (Astro Arts) in Argentina on July 2, 2019 (https://www.astroarts.co.jp/photo-gallery/data/haru-k/56195.jpg)

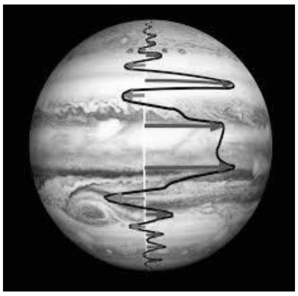
Since an electron has a mass of 1/1836 of proton, it is 42.8 times faster than a proton, and the electron accelerate proton when their high-speed electrons run side by side with the proton. Thus, the Sun's plasma is organized by the magnetic coupling among high-speed charged particles and released with swirl into outer space because Sun is rotating.

4 Effects of the Sun on planetary weather

4.1 Orbiting atmosphere of Jupiter by solar wind

Since the uppermost atmosphere in Jupiter and Saturn is covered with hydrogen, the orbiting current by protons surpasses the orbital current by electrons, and the magnetic field line goes from the North Pole to the South Pole outside the planet. The geomagnetic of Jupiter and Saturn is inverse direction of Earth's geomagnetism.

Fig. 5 shows the air currents orbiting Jupiter. Jupiter's equatorial region from 7°south to 7° N has high-speed air currents flowing from west to east. This air flow is driven by a solar wind that blows through the east side of the daytime hemisphere. Directly above the equator, the solar wind collides head-on and contains the rotational components associated with the Sun's rotation, so the clockwise motion is added to the air flow to cause a small slow area in the center of the equatorial zone of air flow.



The solar wind passing west near Jupiter's equator passes in the clockwise direction and slows down the current that orbits from west to east. So, the air flow in the east-west direction is distributed in a stripe shape, and the vortex is created in the boundary region where it crosses.

Fig.5 Latitude distribution of Jupiter's east-west wind by cloud tracking
http://www.r2.div.jps.or.jp/symposium/AngularMomentum/4_Imamura.pdf

The vortex generated at the boundary of the crossing air flow maintains each air flow. There is a large vortex of counterclockwise rotation called the Great Red Spot at the boundary between the first east-to-west air current in the southern hemisphere and the west-to-east air flow next to the south.

The effect of the solar wind that drives the orbiting air flow becomes weak at high latitude and disappears at polar region. On the other hand, in Jupiter and Saturn, the atmosphere delays compared with the rotation of the ground at a place away from the axis of rotation. There are air flows in the clock rotation direction. But the lower latitudes cause counterclockwise air currents. So, resulting in multiple vortices of two types of public relations.

Jupiter, on the other hand, it is observed that auroras appear only in the North Pole. This is explained as follows. Protons orbit outside of Jupiter at high speed together with Jupiter's geomagnetism, and those collide with Jupiter's satellites, generating ions by sputtering. Since the magnetic energy decreases when ions rotate the same direction, charged particles rotating in the same direction extend in one direction and are sucked into a polar vortex.

4.2 Driving air flow around the Earth by solar wind

The solar wind that hits the earth has an anti-clockwise motion component of 1.89 km/sec due to the solar rotation. It drives the atmosphere above the equator in the daytime hemisphere in the clockwise direction and becomes a trade wind. In the mid-latitudes, the solar wind passing through the side of the earth with the movement of the atmosphere due to the turn slows down in the west side, but accelerates more strongly on the east side, so a westerly wind blows.

The Earth's surface rotates in the counterclockwise direction due to Earth's rotation, and it has a velocity of 463 m/sec at near the equator. In the sea, Equatorial counter current in the sea flows from west to east with a 463m/sec near the Earth's equator. This flow of sea water decreases in proportion to cos θ as latitude θ increases. Since the rate of change is sin θ, there are north and south equatorial currents those flow in opposite directions of the equatorial counter current. Therefore, bottom of the cumulonimbus cloud in the northern hemisphere creates ascending air current that rotates counterclockwise.

On the other hand, there is the flow of cold air that swirls with clockwise rotation by westerly wind together with trade wind in the upper sky, and a tropical cyclone (such as a typhoon) is developed due to a decrease in atmospheric pressure due to rainfall.

In the North and South Poles, the rotational effect of the solar wind driven by the westerly wind decreases, and cold air creates a polar zone of high-pressure and the wind blows toward the low latitude side.

Since the rotational speed becomes insufficient at the place away from the rotation axis, polar easterlies blow. A vortex occurs at the boundary where the extremely east wind meets the westerly wind, and when the rows of the vortices alternate, the air flow meanders, and the air flow accelerated by the meandering air flow becomes the jet stream. The solar wind drives the atmosphere of the Earth, and the weather travels from west to east in a cycle of 3 to 5 days.

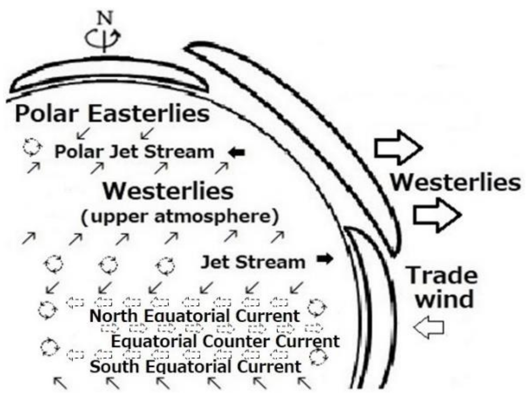


Fig.6 Distribution of east-west wind different by latitude

4.3 Polar easterlies and aurora belt

Since the flow of charged particles above the Earth's poles flows together with the polar easterlies, the place where the magnetic field line of geomagnetism enters the ground vertically becomes an annular region away from the pole of geomagnetism.

The solar wind shakes the vector potential and shakes the aurora. On the Earth, auroras occur in a ring-shaped region centered on the day side of the earth at magnetic latitudes of 75 degrees, and at night, around 65 degrees. On the daytime hemisphere side, many electrons generated by electromagnetic waves emitted from the sun become stronger geomagnetism, so the area where auroras occur moves to higher latitudes.

However, auroras generated in the magnetosphere of Jupiter and Saturn have many vortices of air flow containing charged particles in the polar region, and the geomagnetism is sputtered from the satellites and the emitted ions are taken in, so auroras are generated at the poles.

5 Geomagnetism and ionosphere of the Earth

5.1 Formation of the Van Allen Belt

The dissipation limit of Earth's air molecules is between 500 and 1,000 km. However, as shown in Fig.7, the Van

Allen belt has an inner belt with an altitude of 2,000 to 5,000 km and an outer belt of 10,000 to 20,000 km.

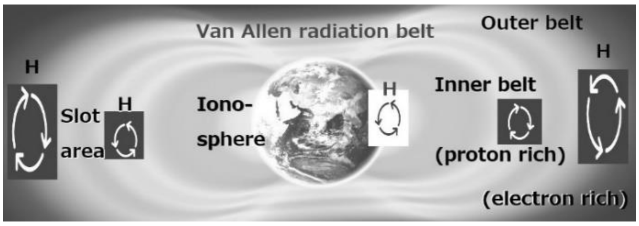


Fig.7 Structure of the Van Allen belt (Reproduced by S. Karasawa from https://swc.nict.go.jp/assets/img/knowledge/magnetosphere/mag6.png

The magnetic force lines shown in the arrow (H) in Fig.7 are generated by the charged particles those are flied to earth from the outside. There are a lot of electrons in the outer belt, and there are a lot of protons in the inner belt. Electrons are taken in areas of weak geomagnetism, forming the outer belt of the Van Allen belt. Protons, on the other hand, invade the interior of the magnetosphere to form an inner belt. The magnetic repulsion of the current in the opposite direction between the outer and inner bands results in a slot region without charged particles. In addition, there is also an area without charged particles between the inner band and ionosphere of the Earth.

There is the South Atlantic Anomaly (SAA) where geomagnetism is weakest in the latitudes where proton groups in the inner belt of the Van Allen Belt are closest to the surface.

5.2 Ionosphere and Geomagnetism of the Earth

On the Earth, the top of the sky is covered with oxygen and nitrogen, and those atoms will be ionized by X-rays and ultraviolet rays emitted from the Sun. Since velocity 450 km/sec of proton in the solar wind, that corresponds to 1.06 KeV, the collision between the protons in solar wind and atoms in the atmosphere also contributes to the formation of the ionosphere. The region where the total electron density is high throughout the season is over the Pacific Equator. Electron groups in the ionosphere also relates to thickness of atmosphere [6] pp887-890.

Due to the momentum of proton ($\mathbf{p}=m_p\mathbf{v}$) in the solar wind, the atmosphere in the sky, including the ionosphere, orbits in the counterclockwise direction faster than the earth's rotation. Therefore, the current due to the movement of the electron-dense ionosphere becomes the current that orbits in the clockwise direction, forming a geomagnetism that moves south to north on the outside of the earth.

The electric current due to charged particles orbiting the sky around low latitudes is parallel to the orbital plane. The current flowing parallel to that current is generated in the surface layer and inside of the earth by the magnetic coupling. In addition, the current of the metal electrons and seawater in the earth's interior will be driven in the same direction as the charged particles in the sky [10].

The fact that the geomagnetism of the earth today is generating magnetic lines from the South Pole to the North Pole in outer of the Earth indicates that the transfer of electrons in the ionosphere mainly forms geomagnetism.

It is reported that the geomagnetic reversal of the Earth occurred many times in the past. The reversal of geomagnetism occurs when changes in the relative relationship between antagonistic elements those contribute to geomagnetism accumulate.

5.3 Ionosphere of the Earth

The electron density of the ionosphere is denser in the daytime hemisphere than in the night hemisphere, and the presence of the **F layer** in the night hemisphere depends on the charged particles captured in the magnetosphere. That is, **F2 layer** exists in upper sky between 800km and 200km in the daytime hemisphere. But in the night hemisphere, there is one **F** layer (800km - 150km).

The **E-layer layer** is between 150km and 100km in the upper sky, and its electron density is high in the daytime hemisphere and low in the night hemisphere. In the E layer, there are many molecules of the air, and there are many electrons generated by ionization. So, the day-night difference in the electron density of the E layer is larger than the F layer [6]. The **Sporadic E layer** is a phenomenon in which an area reflecting radio waves is generated and moved about 100 km above the sky [11]. It can be understood as phenomenon of plasma region caused by protons those came from the Sun.

The **D layer** is formed by the Sun's electromagnetic waves in the daytime hemisphere. The propagation distance of medium-wave radio broadcasts is attenuated in the D layer, so you can hear the surface waves in the daytime. It is reflected in the E layer at night, so it can reach hundreds to more than 1000 km.

Shortwaves pass through the low electron density D layer and are reflected in the F layer with high electron density. Radio waves with higher frequencies than VHF or UHF pass through the ionosphere.

5.4 Phenomenon of unusual radio wave propagations

Sudden ionosphere disturbance, known as the **Dillinger Effect**, occurs in low latitudes during the day and does not occur at night[12]. When flares are emitted from the Sun's surface, the electromagnetic waves are reached Earth eight minutes after the explosion, and molecules in the atmosphere in the region (60 km to 90 km) of the lowest ionosphere are ionized, the electron density increase abnormally. Therefore, radio waves in the high frequency band are also reflected, causing a sudden failure to propagate the shortwave band with frequencies of 3 MHz to 30 MHz used for long-distance communication.

Ionosphere negative phase storm causes protons to decrease the electron density of the upper ionosphere because the main component of charged particles in magnetic storms is protons [13]. Large proton masses emitted by the sun are released so fast that they absorb slow little flare protons. The solar wind is wavy due to a bunching action caused by the high-speed proton group, which occurs less frequently. Therefore, plasma bubbles that move from west to east one after another, where the electron density of the ionosphere decreases around sunset in the equatorial region, cause delay of **GPS** satellite radio waves, etc. [14].

6. Conclusions

This report described the phenomenon that charged particles interact with other charged particles via vector potential. The magnetic force line is a closed loop, it cannot handle local effects due to moving charged particles.

According to Aharonov–Bohm effect, vector potential exists even in spaces without magnetic fields, affecting the motion of charged particles. The vector potential affects a distortion of the attributes of space that propagates at the speed of light, and it causes a magnetic coupling effect. The vector potential is generated in the vicinity of moving charged particle, and the vector potential affects the movement of the other charged particle. When the motion of the point charge is parallel to the motion of the other point charge, the energy due to the vector potential is lower.

The structure of the Sun's plasma can be understood by the magnetic energy of vector potential caused by the protons running side by side. The solar wind drives air currents that collide with planets and orbit the atmosphere. The ionosphere of the Earth is caused by electrons ionized by the Sun's electromagnetic waves, and the geomagnetism is formed by the flow of charged particles of upper sky.

The author hopes that this report will be helpful in examining the prerequisites for simulation.

[References]

[1] T. Tanaka, "How Far Simulation Reproduces Magnetosphere Variation?", JAXA-SP-12-017, The 9th Space Environment Symposium 2012.

[2] S. Karasawa, "Effects of high-speed protons of solar wind on the ionosphere of the Earth ", IEICE Technical Report, Vol.119, no.203, A-P 2019-70, pp.1-6, JAXA Sagamihara campus,

[3] S. Karasawa, "Effects of solar wind on Magnetic storm, Ozone hole, Westerlies, Trade winds, Typhoons, Lightning and Superrotation ", IEICE Technical Report SANE2018-110 pp.1-6, JAXA Tanegashhima Space Center, Feb 13, 2019

[4] Y. Aharonov, D. Bohm., Significance of Electromagnetic Potentials in the Quantum Theory". *Phys. Rev.* **115**: 485-491, 1959.

[5] A. Tonomura, N. Osakabe, T. Matsuda, T. Kawasaki, and J. Endo, "Evidence for Aharonov-Bohm Effect with Magnetic Field Completely Shielded from Electron wave", *Phys. Rev. Lett.* vol. 56, pp. 792–795 (1986).

[6] Chronological Scientific Tables, 2020(National Astronomical Observatory of Japan, Chronological scientific Tables 2020, "Ionosphere", p.872-892, Marzen Publishing, 2019

[7] T. Hirayama, "Theoretical model of flares and prominences. I: Evaporating flare model， " Solar Phys.34,323, 1974.

[8] I. Shibata, "Challenging the Mystery of Solar Explosions (Flares)- Where Did "Yoko" Unravel?" -,"Astronomical Monthly Report Vol.89 No.2pp.6069, 1996.

[9] M. Maeno, "Well-Understood Electromagnetism" pp.305, pp.232, Tokyo Books, 2010.

[10] H. Kurokawa, "Distribution of Electron Temperature and Electron Density from Photosphere to Corona", Series Modern Astronomy Vol.10, Sun 5.1, Fig. 5.1 (Nihon Hyoronsha).

[11] H. Jin, "Ionospheric Dynamo Process" Journal of the National Institute of Information and Communications Technology, Vol.56 Nos.1-4, 2009

[12] Y. Sakamoto, T. Abe, W. Miyake, "Detailed structure of electron temperature and density inside the sporadic E layer， " JAXA Research and Development Report, October 2018.

[13] M. Nakagoe, K. Miya, K. Shimizu," Frequency characteristics of shortwave anomaly attenuation at the time of the appearance of the Dillinger Phenomenon," Journal of the Denki Society, Vol.57 No.585 P333, 1937

[14] Y. Zhang, L. J. Paxton, D. Morrison, B. Wolven, H. Kil, C. I. Meng, S. B. Mende, T.J. Immel, "O/N_2, changes during 14 October 2002 storms: IMAGE SI-13 and TIMED/GUVI observations" J. Geophys. Res., Vol.109, A10308. DOI:10.1029/2004JA010441.2004

[15] K. Matsunaga, T. Sakai, K. Hoshino, A. Saito, Y. Otsuka, "Observation of Ionospheric Plasma Bubbles using GPS", Electronic Navigation Research Institute Research Presentation (5th), 2005.