Chapter One

The physics of geospace

Upper Atmospheric Layers

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Outlines of this chapter:

1. The purpose of this chapter is to summarize points of physics that will be needed in order to grasp the fundamentals of geospace science.
2. It is assumed that the student is already familiar with basic physical concepts such as energy, temperature, quanta, waves, molecules, heat, and electric and magnetic fields - topics, it will be noted, which come mainly within the domain of classical physics.
3. We have to deal with a gas, and in particular with an electrified gas.
4. We will be concerned with the propagation of waves-mainly electromagnetic waves, but some others too-in that gas.
5. We shall need to know how a steady magnetic field affects the behavior of gas and of waves.
6. Energetic particles and photons will enter the gas, and their interactions have to be included.

A. Properties of gases

Gas laws:

The kinetic theory of gases describes the bulk properties of a gas in terms of the microscopic behavior of its constituent molecules. Most basic are the gas laws of Boyle and Charles relating pressure (P), volume (V) and absolute temperature (T), which are generally combined into the *universal gas law*:

$$PV=NR^{*}T$$

Where N is the quantity of gas in the volume V measured in moles. The density of the gas is

$$\rho = \frac{NM}{V}$$

where

R^{*}=universal gas constant =8.314E03 J K^{-1} $(Kmole)^{-1}$

M = molecular weight of the gas.

And

$$R = \frac{R^*}{M}$$

where R is the gas constant (measured in J/kg.k), becomes

$$P=\rho RT \qquad \text{prove?}$$

The gas law can be written as

$$P=nKT \qquad \text{prove?}$$

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Where n is the number of molecules per unit volume, often called the number density. $R^* = N_A k$, where N_A is *Avogadro's number,* the number of molecules in one mole of gas.

Thermal equilibrium

1. The molecules within a body of gas exchange energy by collisions and come to a state of thermal equilibrium, when the velocities are distributed according to the Maxwell-Boltzmann law:

$$N(v)\,dv = 4\pi N_T \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 \exp\left(-\frac{mv^2}{2kT}\right) dv$$

   Where N(v) dv is the number of molecules with speeds between v and v + dv, N_T is the total number of molecules, m the molecular mass, T the absolute temperature and k Boltzmann's constant.
2. The distribution is illustrated in Fig 1. In a Maxwell-Boltzmann distribution, the root mean square speed (v_{rms}) and the most probable speed (v_{mp}) are given by

$$v_{m.p.} = (2kT/m)^{\frac{1}{2}},$$

$$v_{r.m.s.} = \left(\frac{3kT}{m}\right)^{\frac{1}{2}} = 1.225 v_{m.p.}.$$

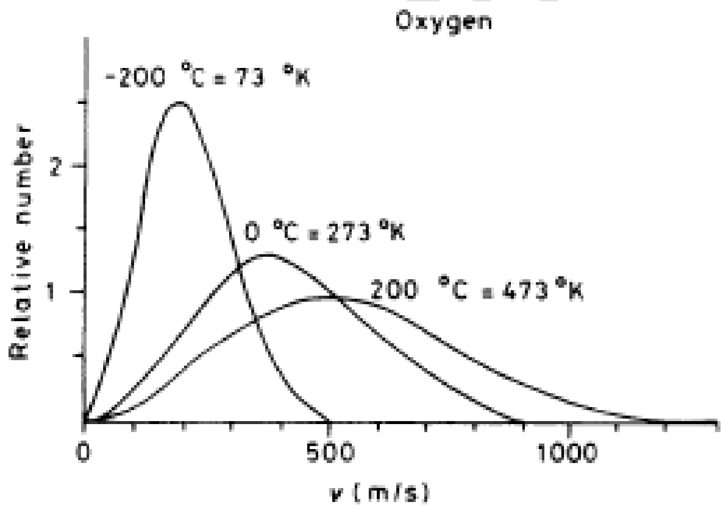

Figure (1) Maxwell-Boltzmann distribution of molecular speeds in oxygen at three temperatures.

3. Hence the mean kinetic energy of the gas particles and the temperature are related by

$$\tfrac{1}{2} m \overline{v^2_{r.m.s.}} = \tfrac{3}{2} kT.$$

4. In thermal equilibrium the energy is shared also between the various components of a mixture. If two species have molecular masses m_1 and m_2, the mean square speeds $\overline{V_1^2}$ and $\overline{V_2^2}$ are related by

$$m_1 \overline{v_1^2} = m_2 \overline{v_2^2}.$$

5. This is equivalent to saying that both components come to the same temperature. The lighter gas has the higher molecular speed:

$$\overline{v_2^2}/\overline{v_1^2} = m_1/m_2.$$

Collisions

1. In a neutral gas the particles influence one another through collisions.
2. A gas without collisions would never come to thermal equilibrium.
3. In a gas with many collisions, both random and bulk motions are effectively communicated between the particles; the gas as a whole quickly comes to equilibrium.
4. The simplest definition of the collision frequency (v) is just the number of collisions that one particle makes with others in one second.
5. The average distance that the particle travels between collisions is the mean free path. If the r.m.s. velocity is $V = \sqrt{\frac{3KT}{m}}$, the mean free path is
$$l_f = (3kT/m)^{\frac{1}{2}}/\nu.$$
6. Consider a gas containing two species, masses m_1 and m_2, with velocities v_1 and v_2 which for simplicity we will assume to be in the same direction. If a particle of the first species collides head on with a particle of the second species, and the collision is elastic, conservation of momentum requires that the first particle gains momentum
$$2m_1m_2(v_2 - v_1)/(m_1 + m_2)$$
and the second particle loses the same amount.
7. If there are v_{12} such collisions per unit time, and n_1 particles of the first species per unit volume, the total force (total rate of change of momentum) on the first species due to collisions with the second is
$$F_{12} = n_1\nu_{12}\frac{2m_1m_2(v_2 - v_1)}{(m_1 + m_2)}.$$
Defined thus, v is the momentum- transfer collision frequency.
8. Since the forces on the two species (1 and 2) must be equal and opposite,
$$F_{12} = -F_{21}$$
$$\frac{\boldsymbol{v_{21}}}{\boldsymbol{v_{12}}} = \frac{\boldsymbol{n_1}}{\boldsymbol{n_2}}$$

Continuity

1. Continuity requires that drift velocity varies from place to place molecules will accumulate in some places and be depleted from others.
2. Consider an open box with sides x, y, and z, as in Figure (2) through which gas particles drift in the x direction only. If the particle density and velocity are n_1 and v_1 at face 1, and n_2 and v_2 at face 2, the number entering the box in unit time is n_xv_xyz and the number leaving is n_2v_2yz.
3. The rate of accumulation is therefore $(n_1v_1 — n_2v_2)yz$, and the rate of change of particle density within the box is $(n_1v_1 - n_2v_2)/x \rightarrow \partial(nv)/\partial x$ as the box is made infinitely small. Hence,

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$$\frac{\partial n}{\partial t} = -\frac{\partial (nv)}{\partial x}.$$

In the general case with movement in three dimensions

$$\frac{\partial n}{\partial t} = -\mathrm{div}\,(nv).$$

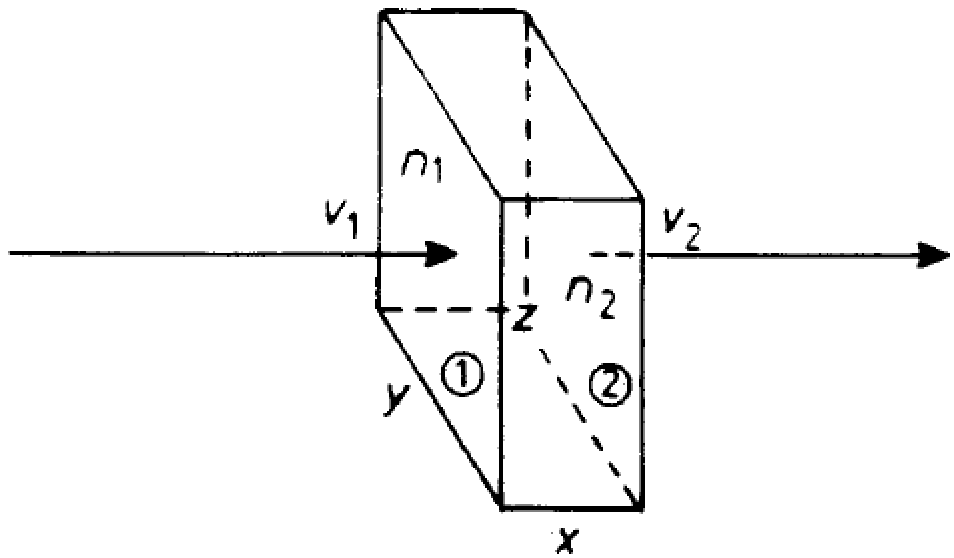

Figure (2) Continuity requires that the number density n is related to the drift speed, v, by ∂ (n)/∂t=-∂ (nv)/∂x

Diffusion

1. If there is a pressure gradient within a gas, molecules will move down the pressure gradient until the pressure is equalized.
2. At any moment the net velocity is proportional to the gradient. Then the drift speed may be written,

$$v = -\frac{D}{n}\frac{\partial n}{\partial x},$$

   where n is the particle density and D is the diffusion coefficient.
3. Diffusion in one direction only, as along a narrow column, has been assumed for simplicity. (In three dimensions, v = - (D/n) grad n).
4. The rate of change of particle density at a given point is obtained from Equation

$$\frac{\partial n}{\partial t} = \frac{\partial (vn)}{\partial x} = -\frac{\partial}{\partial x}\left(-D\frac{\partial n}{\partial x}\right) = +D\frac{\partial^2 n}{\partial x^2}.$$

In the three-dimensional case,

$$\frac{\partial n}{\partial t} = D \cdot \nabla^2 n.$$

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5. Note that the diffusion coefficient, D, has the dimensions (length)^2/time. We can derive an expression for the diffusion coefficient of a gas at constant temperature by equating the pressure gradient,

$$\frac{\partial p}{\partial x}\left(=kT\frac{\partial n}{\partial x}\right)$$

to the drag force due to collisions, nνmv, to obtain

$$kT\frac{\partial n}{\partial x} = -n\nu mv.$$

Then, comparing with drift velocity

$$D = kT/m\nu,$$

6. If $\nu \propto n\sqrt{T}$, so $D \propto \frac{\sqrt{T}}{n}$, Molecular diffusion in a gas proceeds more rapidly at higher temperature and at lower pressure.

Drag Force

1. The density of the air can be determined from its effect in retarding a moving object. The air drag force on a sphere is

$$D = 0.5C_DA\rho v^2 \qquad \text{……….1}$$

Where ρ is the air density, v is the speed of the sphere relative to the air, A the cross sectional area, and C_D is the drag coefficient.

2. The form of this equation may be proved as follows. If there are n molecules per unit volume, the sphere encounters Anv molecules per unit time.
3. If the change of momentum at each collision is mv, the retarding force (= rate of change of momentum) is $Anmv2 = A\rho v^2$, where ρ is the air density. A 'drag coefficient' is needed because the sphere's effective cross section is not the geometrical cross-section but is altered by the pattern of air flow around it.
4. In the *falling object*, it is retarded by an air drag force (Equation 1) opposing the gravitational force m_sg, m_s being the mass of the object, and hence it accelerates towards the ground more slowly than it would in a vacuum.
5. The same principle underlies the well-known *satellite drag* method. Satellite tracking by optical and radio means is quite accurate enough to detect the effects of the atmosphere on the orbit of a satellite, and tracking data have been applied to the determination of air density ever since the first satellites were launched in the late 1950s.
6. If a satellite is subject to a drag force D, given by Equation 1, the rate of loss of energy is (force x distance/time)

$$Dv = C_DA\rho v^3 = -\frac{d(TE)}{dt} = -\frac{d(TE)}{dr}\cdot\frac{dr}{dt},$$

where TE is the total energy (potential plus kinetic), r is the distance of the satellite from the center of the Earth, and v is its velocity. Fter some simplification and substitutions we have

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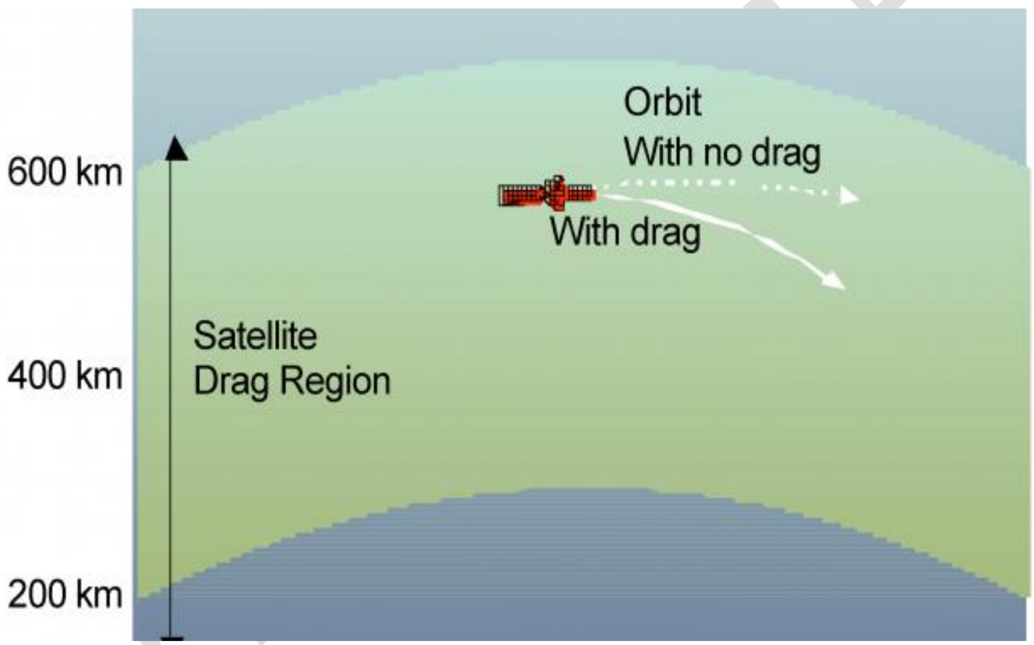
$$\frac{dr}{dt} = -\frac{C_D A \rho v}{m_s}.$$

This gives the rate of decrease of satellite altitude due to air density ρ. However, the orbital period (P) is more accurately measured than the height. Using $P = 2\pi r/v$,

$$\frac{dP}{dt} = -\frac{3\pi C_D A r \rho}{m_s}.$$

7. Atmospheric drag is the main non gravitational force that acts on a satellite in LEO. Drag is part of the total aerodynamic force that acts on a body moving through a fluid such as air. It acts in the direction opposite of the velocity and takes away energy from the orbit. The decrease in energy causes the orbit to decay until the satellite reenters the atmosphere.
8. Atmospheric drag is weak at altitudes above 600 km and thus a satellite's orbital lifetime is longer than its operational life.



Definition of a Plasma

1. A plasma is a gas of charged particles, which consists of equal numbers of free positive and negative charge carriers.
2. Having roughly the same number of charges with different signs in the same volume element guarantees that the plasma behaves quasi neutral in the stationary state.
3. While only a few natural plasmas, such as flames or lightning strokes, can be found near the Earth's surface, plasmas are abundant in the universe. More than 99% of all known matter is in the plasma state

Debye Shielding

1. For the plasma to behave quasi neutral in the stationary state, it is necessary to have about equal numbers of positive and negative charges per volume element.
2. To let the plasma appear electrically neutral, the electric Coulomb potential field of every charge, q

$$\phi_c(r) = \frac{q}{4\pi\varepsilon_o}\frac{1}{r} \qquad \text{.........(1)}$$

is shielded by other charges (cloud of other charge sign) in the plasma and assumes the Debye potential form

$$\phi_c(r) = \frac{q}{4\pi\varepsilon_o}\frac{1}{r}\exp(-\frac{r}{\lambda_D}) \qquad \text{.........(2)}$$

in which the exponential function cuts off the potential at distances r >λ_D.

3. The characteristic length scale, λ_D, is called Debye length. Figure 3 A&B show the shielding effect.
4. The Debye length is a function of the electron and ion temperatures, T_e, and T_i,, and the plasma density, $n_e \cong n_i = n$; (assuming singly charged ions)

$$\boldsymbol{\lambda_D = \sqrt{\frac{\varepsilon_o\, k_b\, T_{e,i}}{n_{e,i} e^2}}}$$

Where we have assumed $T_e = T_i$

5. In order for a plasma to be quasi neutral, the physical dimension of the system, L, must be large compared to λ_D

$$\lambda_D << L$$

Otherwise there is not enough space for the collective shielding effect to occur, and we have a simple ionized gas. This requirement is often called the first plasma criterion.

6. Numerically

MKS $\quad \lambda_D = 69\sqrt{\frac{T}{N}}\, m \quad$ T in K^o, N in m^{-3} .... (3)

cgs $\quad \lambda_D = 6.9\sqrt{\frac{T}{N}}\, cm \quad$ T in K^o, N in cm^{-3}

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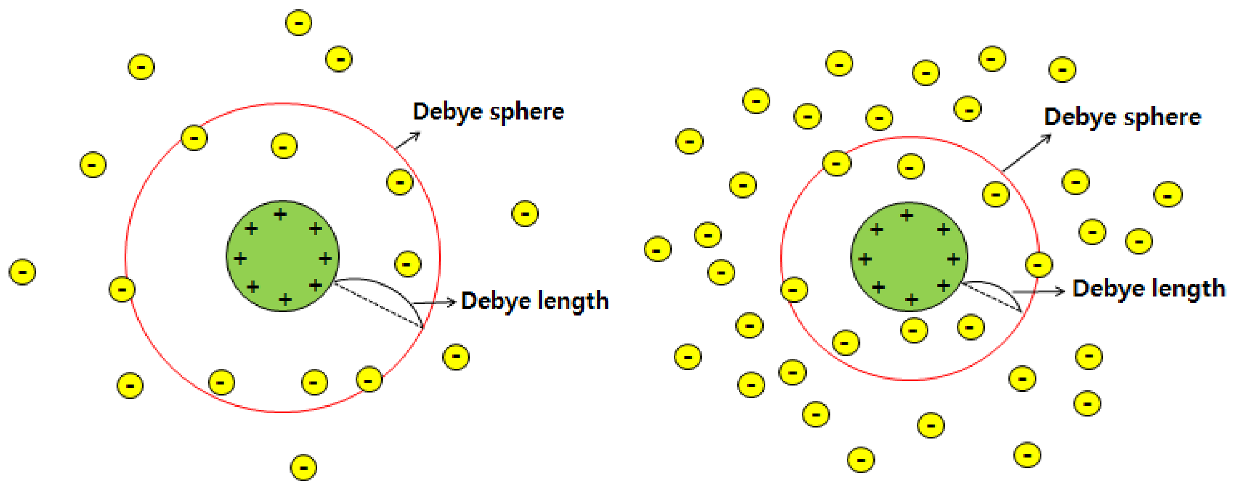

Figure (3-A) The Deby shielding

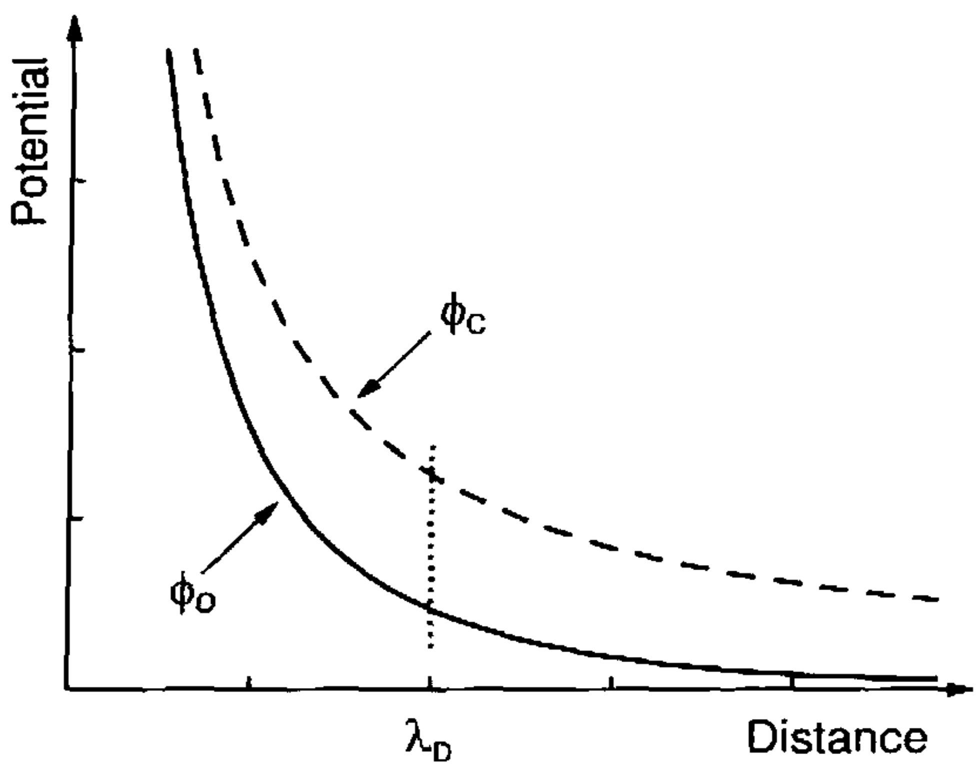

Figure (3-B) Comparison of Debye and Coulomb potential.

Plasma Parameter

1. Since the shielding effect is the result of the collective behavior inside a Debye sphere of radius λ_D, it is necessary that this sphere contains enough particles.
2. The number of particles inside a Debye sphere is $\frac{4\pi}{3} n_e \lambda_D^3$. The term $n_e \lambda_D^3$ is called plasma parameter Λ, and the second criterion for a plasma reads

$$\Lambda = n_e \lambda_D^3 \gg 1$$

Plasma Frequency

1. If the quasi neutrality of the plasma is disturbed by some external, force, *the plasma oscillations* set up in response to a charge imbalance.
2. The strong electrostatic fields which drive the electrons to re-establish neutrality cause oscillations about the equilibrium position (the electrons, being more mobile than the much heavier ions) at a characteristic frequency, the *plasma frequency* ω_p.
3. Due to their inertia they will move back and forth around the equilibrium position, resulting in fast collective oscillations around the more massive ions.

$$\omega_N = \left(\frac{Ne^2}{\varepsilon_0 m}\right)^{\frac{1}{2}} \quad \text{in SI,}$$

$$\omega_N = \left(\frac{4\pi Ne^2}{m}\right)^{\frac{1}{2}} \quad \text{in c.g.s.}$$

4. A convenient approximate formula for the electron plasma frequency

$$f_N = 9 * \sqrt{N_e\ (m^{-3})}\ \text{Hz}$$

Where N_e is the electron density of the plasma.

5. Some plasmas, like the Earth's ionosphere, are not fully ionized. Here we have a substantial number of neutral particles and there are more collisions between electrons and ions with neutral particles. There are two types of collisions, these are:

When a charged particle hits a neutral it can simply

1. Scatter with no change in the internal energy of the neutral; this is called *elastic scattering.*
2. It can also transfer energy to the structure of the neutral and so cause an internal change in the neutral; this is called *inelastic scattering*. Inelastic scattering includes ionization and excitation of atomic level transitions (with accompanying optical radiation).

When ions collide with neutrals

1. The incident ion can capture an electron from the neutral and become neutralized while simultaneously ionizing the original neutral. This process, called *charge exchange.*
2. Because ions have approximately the same mass as neutrals, ions rapidly exchange energy with neutrals and tend to be in thermal equilibrium with the neutrals if the plasma is weakly ionized.

6. For the electrons to remain unaffected by collisions with neutrals, the average time between two electron- neutral collisions, τ_n must be larger than the reciprocal of the plasma frequency

$$\omega_{pe}\tau_n \gg 1$$

This is the third criterion for an ionized medium to behave as a plasma.

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Magneto plasma

Much of the upper atmosphere is ionized, and the ionized gas is permeated by the geomagnetic field. The combination of magnetic field and ionized gas is a magneto plasma. In this section we outline some basic properties of a magneto plasma.

Electric and magnetic energy

The energy of a magneto plasma comes principally from

1. the energy of the particles and
2. the energy of the magnetic field
3. Contributions from any electric field and wave motions that may be present.
4. The behavior of the medium may well depend on which of these components are the greatest.
5. Consider a parallel-plate capacitor C, with charge Q and potential V. The work done in charging the capacitor is

$$W = \int V\,dq = \int_0^Q (q/C)\,dq = Q^2/2C.$$

If the area is A and the separation d, the electric energy density is

$$w = \frac{W}{Ad} = \frac{Q^2}{2CAd} = \frac{\varepsilon V^2}{2d^2} = \frac{\varepsilon E^2}{2},$$

In MKS units

$$C = \varepsilon A/d$$

$$V = Ed$$

In vacume (or air) $\varepsilon \quad = \varepsilon_o$ and

$$w = \varepsilon_0 E^2/2.$$

In c.g.s. (e.s.u.)

$$C = \frac{\epsilon A}{4\pi d}$$

so

$$w = \varepsilon E^2/8\pi$$

In air ε=1

$$w = \frac{E^2}{8\pi}$$

The formula for magnetic energy density is derived similarly, but now in terms of a solenoid. If a solenoid of length 1 and area A carries a current i, the total magnetic energy is $Li^2/2$ where the inductance, $L = \mu N^2 A/1$. Then the energy density within the solenoid is (in MKS):

$$w = \frac{W}{Al} = \frac{Li^2}{2Al} = \frac{\mu N^2 i^2}{2l^2} = \frac{\mu H^2}{2} = \frac{B^2}{2\mu},$$

since the magnetic field strength in the solenoid is H = Ni/1, and the magnetic flux density B = μH. In a non-magnetic material $\mu=\mu_o$ (permeability of free space). In c.g.s. (e.m.u)

$$\mathbf{w} = \mu \mathbf{H}^2/8\pi$$

and μ = 1 in a non-magnetic material.

$$w = \frac{H^2}{8\pi}$$

Gyrofrequency

1. In a magnetic field charged particles tend to go round in circles, and the gyrofrequency is just the rate of this gyration. If the magnetic flux density is B, the charge on the particle is e and its velocity is v, then the Lorentz force on the particle is

   F = e. v x B

   Acting normal to both v and B.

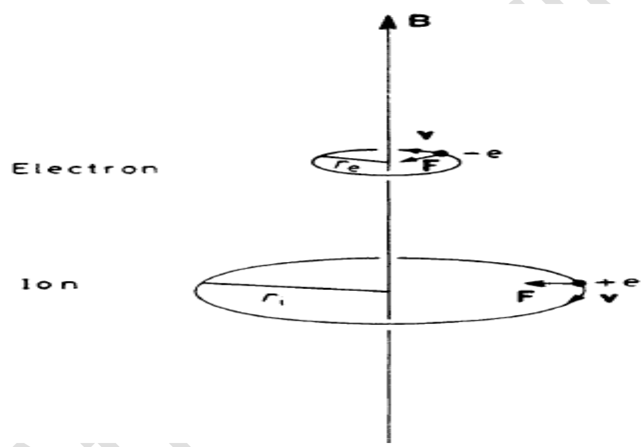

Figure (4) Gyration of an electron and positive ions in a magnetic field

2. The Lorentz force provides the centripetal acceleration v^2/r_B where r_B is the radius of the circle. If m is the mass of the particle, the gyroradius is

   $\mathbf{r_B = mv/Be.}$ **Prove?**

   The period of revolution is

   $$\mathbf{P = 2\pi r_B/v = 2\pi m/Be}$$

   The angular frequency is

   $$w_B = \frac{2\pi}{p} = \frac{Be}{m} \ \left(\frac{rad}{sec}\right)$$

   And

   $$f_B = \frac{Be}{2\pi m}$$

   Note that r_B and w_B depend on both

   1. the magnetic field and
   2. the mass of the particle,

   but the gyro frequency is independent of the velocity.

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For kinetic energy, E,

$$v = (2E/m)^{1/2}$$

and

$$r_B = (2mE)^{1/2}/Be.$$

Using subscripts i and e for ions and electrons, the energy being the same, we see that

$$\omega_i/\omega_e = m_e/m_i$$

and

$$r_i/r_e = (m_i/m_e)^{\frac{1}{2}}.$$

Ex.1 / take the magnetic field as 0.5 G (= 0.5 x 10^{-4} Wb/m^2), e = 1.6 x 10^{-19} C and m_e =9.1x 10^{-31} kg. Find the gyro frequency for both the electron and oxygen Ion.?

Sol./

$\omega_e = 8.8 \times 10^6$ rad/s = 1.4 MHz

For an oxygen ion (O+), ω_i is smaller by a factor of 29380, $\frac{m_i}{m_e} = 29380$, using

$\omega_i/\omega_e = m_e/m_i$

ω_i = 48 Hz.

Ex.2/ For electrons with E=10 Kev. Find the gyroradius for both electrons and O^+ permeated in earth magnetic?

Sol./

$$r_e = \frac{\sqrt{2 * 9.1 * 10^{-31} * 10 * 10^3 * 1.6 * 10^{-19}}}{0.5 * 10^{-4} * 1.6 * 10^{-19}} = 6.7\ m$$

From the masses ratio $\frac{m_i}{m_e} = 29380$, and

$r_i/r_e = (m_i/m_e)^{\frac{1}{2}}.$

$r(O^+)$=1.2 Km.

Betatron acceleration

1. If the magnetic flux density is gradually increased, the gyro frequency is increased in proportion.
2. However, the angular momentum, $mvr_B = mv^2/w_B$, is conserved,
3. and therefore the kinetic energy increases:

$$E = mv^2/2 \propto \omega_B \propto B.$$

4. This mechanism energizes particles in proportion to the magnetic field variation and is an acceleration mechanism for particles in the magnetosphere

Fermi acceleration

1. The Betatron process can accelerate charged particles moving at right angles to a magnetic field.

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2. For charged particles moving along a magnetic field the main acceleration process is Fermi acceleration.
3. Consider a particle travelling back and forth between two ' mirrors' which are moving closer together.
4. If the speed of the particle is v and the path has length l, there is one reflection every 1/v.
5. If the path shortens at dl/dt, the particle speed increases by dl/dt at each reflection, therefore at a rate

$$\frac{\frac{dV}{dt}}{V} = \frac{\frac{dl}{dt}}{l}$$

Hence,

$$\frac{dV}{V} = \frac{dl}{l}$$

6. And if the particle mass is m the rate of increase of its energy is

$$\frac{dE}{dt} = \frac{d}{dt}\left(\frac{mv^2}{2}\right) = mv \cdot \frac{dv}{dt} = \frac{mv^2}{l} \cdot \frac{dl}{dt}.$$

7. Also, for an increment of 1,

$$\frac{dE}{dl} = \frac{d}{dl}\left(\frac{mv^2}{2}\right) = mv \cdot \frac{dv}{dl} = \frac{mv^2}{l} = \frac{2E}{l}.$$

8. Hence, the relative increment of energy *(δE/E)* due to a relative increment of path shortening *(δl/l)* is simply

$$\frac{\delta E}{E} = \frac{2\delta l}{l}.$$

9. That is, if the path shortens by 5 % the energy increases by 10 %. This mechanism can energize geomagnetically trapped particles if the field-lines contract.

Frozen in Field

1. This simple model illustrates an important property of magneto plasma which applies throughout most of geospace: when the electrical conductivity of the plasma is very large, relative motion between the plasma and the magnetic field becomes virtually impossible. The field is then said to be frozen in.
2. Similarly, a magnetic field cannot enter a region already occupied by a highly conducting plasma, and it is then frozen out.
3. The freezing of magnetic field may be proved rigorously from Maxwell's equations and is treated in texts on electromagnetic theory. We give a simplified version here. For current density J, electric field E and magnetic induction B, two of Maxwell's equations, neglecting displacement current, give (SI form).

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$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t},$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J}.$$

Ohm's law states

$$\mathbf{J} = \sigma(\mathbf{E} + \mathbf{v} \times \mathbf{B}).$$

Putting $\mathbf{v} = 0$, and eliminating $\mathbf{J}$ and $\mathbf{E}$, we obtain

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{\nabla^2 \mathbf{B}}{\mu_0 \sigma} = \varepsilon_0 c^2 \frac{\nabla^2 \mathbf{B}}{\sigma},$$

c being the speed of light.

This is a diffusion equation with diffusion coefficient

$$\frac{1}{\mu_o \sigma}$$

Having the dimensions of $(\text{length})^2/(\text{time})$.

4. If the conductor occupies a space characterized by length L, the time taken for a magnetic field to enter or leave it is approximately

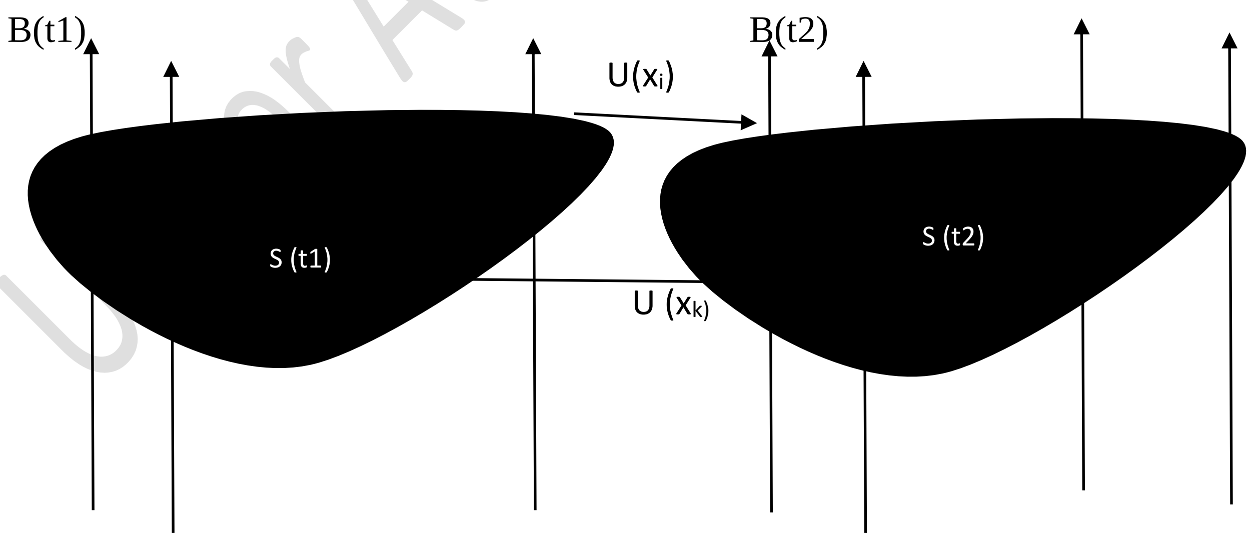
$$\tau = \mu_o \sigma L^2$$

5. To explain this property of a very high conductivity plasma, we need to consider a surface (S) in the plasma not parallel to lines of magnetic force. The fluid that lies on surface s(t1) threaded by a a magnetic field with a component B(t1) normal to the surface at time t1 flows through the system and lies on the surface s(t2) threaded by a field with normal component B(t2) at time t2. The frozen in flux condition requires that

$$B_{n2}\, S\,(t2) = B_{n1}\, S\,(t1)$$

$$\Phi_{t1} = \Phi_{t2}$$

Where Φ is the magnetic flux $= \int \mathrm{B.\,ds}$



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Ex B drift

1. If an electric field (E) is applied at right angles to the magnetic field (flux density B) the plasma particles drift at velocity v given by

$$\mathbf{v} = \frac{\mathbf{E} \times \mathbf{B}}{|\mathbf{B}|^2}.$$

2. The vector v is normal to both E and B, and its magnitude is E/B.
3. The total force on a particle with charge e moving at velocity v in electric and magnetic fields, as

$$\mathbf{F} = e(\mathbf{E} + \mathbf{v} \times \mathbf{B}).$$

4. E x B drift is one of the fundamentals of the physics of the magnetosphere and the ionosphere,

Home works

1. What is the condition of the frozen in magnetic field in plasma?
2. Prove the concept of frozen in field mathematically using Maxwell's equation?
3. Define 1. Fermi acceleration 2. Collision frequency. 6. Mean free path. ?
4. Prove that P=ρRT?
5. Derive the equation of the plasma frequency f_N in MKS units?
6. Prove that the Debye length is given by

$$\lambda_D = 69(T/N)^{\frac{1}{2}}\,m,$$

7. Derive the relation of the diffusion coefficient?
8. Find the relation between the root mean square speed $V_{r.m.s.}$ and the most probable speed $V_{m.p.}$ according to Maxwellian-Boltzmann distribution for a gas in thermal equilibrium?
9. Explain mathematically the following statement (Molecular diffusion in a gas proceeds more rapidly at a higher temperature and at lower pressure)?
10. Find the ratio of root mean square speeds for oxygen atom with mass m for temperatures 73 k^o and 473 k^o?
11. The Debye length of a plasma is given

$$\lambda_D = \left(\frac{\varepsilon_0 kT}{Ne^2}\right)^{\frac{1}{2}}.$$

Find the number of particles are contained in the Debye sphere?

12. In a mixture of a gas with thermal equilibrium, two species with molecular masses $m_2=4m_1$. Find the ratio of their mean speeds?
13. Find (in MKS)

    a/ Plasma frequency,

    b/ Angular plasma frequency,

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c/ Debye length.

d/ Number of particles in Debye sphere, for plasma with

1. N=10 $m^{-3,}$ T=100 k^o
2. N=10^{24} m^{-3}, T=10^6 k^o?

14. Derive the following relation?

$$w = \varepsilon_0 E^2/2.$$

15. Explain with derivation the acceleration mechanism in the magnetosphere for particles moving at right angles to the geomagnetic field?
16. If the geomagnetic field lines contract by a percent 20 %, find the relative increment of energy of trapped particles?
17. Define 1. Debye and Coloumb potential. 2. ExB drift. 3. quasi neutral
18. Fill in the blanks

- When the ……………….of the plasma is very large, …………………… between the plasma and the magnetic field becomes virtually impossible. The field is then said to be ……….. Similarly, a magnetic field cannot enter a region already occupied by a ……………………..and it is then frozen out.
- In a magnetic field charged particles tend to go round in …....... and the ……………… is just the rate of this gyration.
- The energy of a magneto plasma comes principally from 1…..………. 2…………..3……………
- Atmospheric drag is ……… at altitudes above 600 km and thus a ……………………………is longer than its operational life.
- If there is a pressure …………….. Within a gas, molecules will ……………. the pressure gradient until the pressure is ……………. At any moment the net velocity is proportional to the …………….
- Continuity requires that .... varies from place to place molecules will .... in some places and be .... from others.
- In a gas with many collisions, both .... motions are effectively communicated between the particles; the gas as a whole quickly comes to........................

Upper Atmospheric Layers