Last lecture (4)

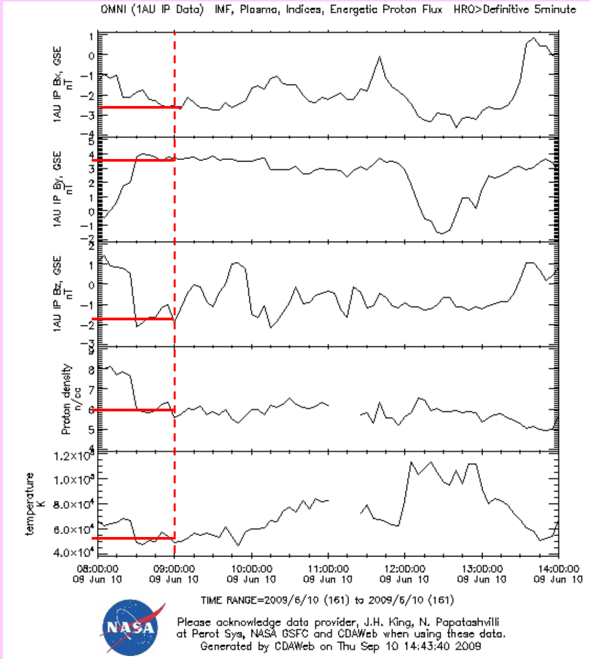
- Solar wind
  - magnetic structure
- Ionosphere
  - ionospheric layers

Today's lecture (5)

- Ionosphere
  - index of refraction
  - reflection of radio waves
  - particle drift motion in magnetized plasma
  - electrical conductivity in magnetized plasma
- Magnetosphere?

Today

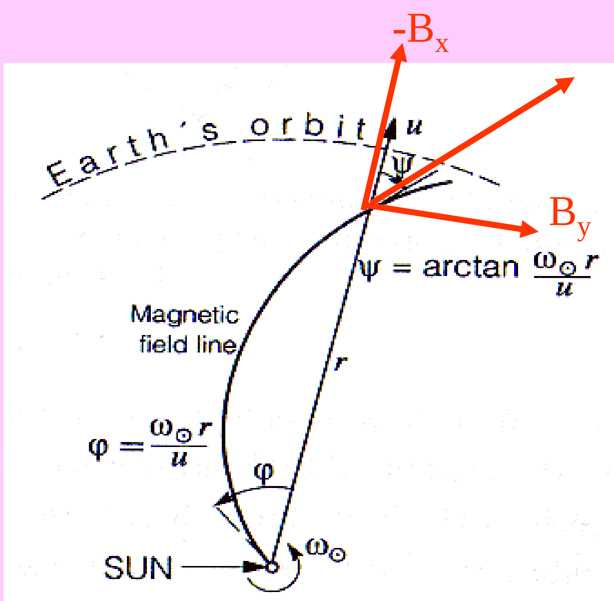
Activity	Date	Time	Room	Subject	Litterature
L1	31/8	13-15	V22	Course description, Introduction, The Sun 1, Plasma physics 1	CGF Ch 1, 5, (p 110-113)
L2	3/9	15-17	Q36	The Sun 2, Plasma physics 2	CGF Ch 5 (p 114-121), 6.3
L3	7/9	13-15	Q36	Solar wind, The ionosphere and atmosphere 1, Plasma physics 3	CGF Ch 6.1, 2.1-2.6, 3.1-3.2, 3.5, LL Ch III, Extra material
T1	10/9	15-17	Q36	Mini-group work 1	
L4	14/9	13-15	E2	The ionosphere 2, Plasma physics 4	CGF Ch 3.4, 3.7, 3.8
T2	17/9	8-10	Q31	Mini-group work 2	
L5	17/9	15-17	L52	The Earth's magnetosphere 1, Plasma physics 5	CGF 4.1-4.3, LL Ch I, II, IV.A
L6	21/9	13-15	L52	The Earth's magnetosphere 2, Other magnetospheres	CGF Ch 4.6-4.9, LL Ch V.
T3	24/9	16-18	Q36	Mini-group work 3	
L7	28/9	13-15	Q36	Aurora, Measurement methods in space plasmas and data analysis 1	CGF Ch 4.5, 10, LL Ch VI, Extra material
T4	1/10	15-17	V22	Mini-group work 4	
L8	5/10	13-15	M33	Space weather and geomagnetic storms	CGF Ch 4.4, LL Ch IV.B-C, VII.A-C
L9	6/10	8-10	Q36	Interstellar and intergalactic plasma, Cosmic radiation,	CGF Ch 7-9
T5	8/10	15-17	Q34	Mini-group work 5	
L10	12/10	13-15	Q36	Swedish and international space physics research.	
T6	15/10	15-17	Q33	Round-up.	
Written examination	28/10	8-13	Q21, Q26		



Mini-groupwork 2

a)

$$\psi = \arctan \frac{\omega_{sun} r}{u_{sw}} \quad \Rightarrow \quad u_{sw} = \frac{\omega_{sun} r}{\tan \psi}$$



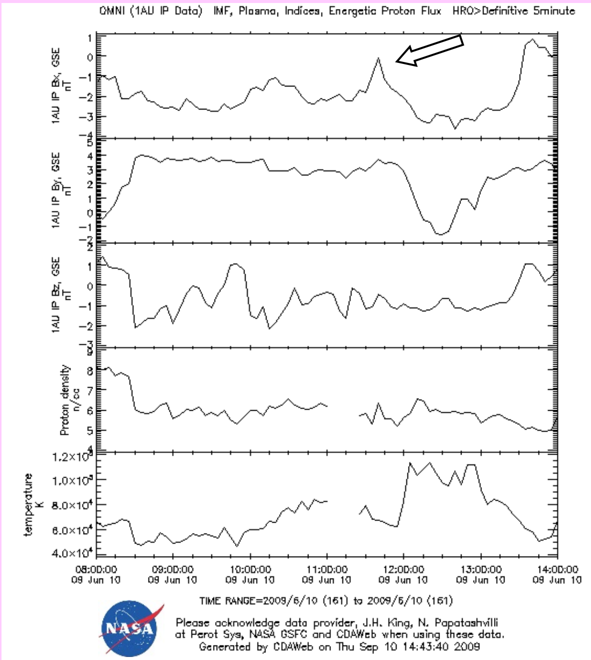
$\omega_{sun} = 2\pi/T = 2.9 \cdot 10^{-6}$ s^{-1} (T = 25 days at equator)

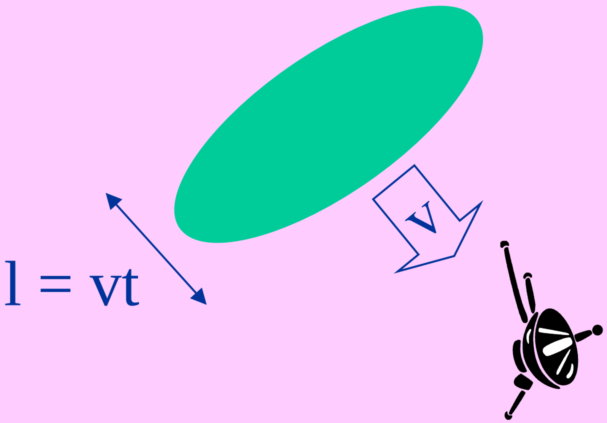
r = 1 A.U.

$\tan \psi = |B_y/B_x| \approx 3.6/2.6$ (from figure) ($\psi = 41°$)

With these figures I get $u_{sw} = 313$ km/s

Mini-groupwork 2





b)

The magnetic Reynolds number is calculated by using typical plasma flow velocities v_c and typical length scales of magnetic field variations l_c

Use solar wind velocity obtained in a) for typical flow velocity. To obtain l_c, multiply the time t it takes the magnetic field structure (indicated in the figure), to pass over the satellite and use l_c, = vt. I get $l_c = 2.8 \cdot 10^8$ m.

Using a temperature of $5 \cdot 10^4$ K, we can evaluate the conductivity, remembering that the temperature should be given in eV. We get the conversion from

$$W = \frac{3}{2} k_B T$$

which gives the result that 1 eV corresponds to a temperature of 7729 K. We then get T = 6.5 eV, and

$$\sigma = 3.1 \cdot 10^4 \text{ S/m}$$

Putting in the numbers I get

$$\mathrm{R_m} = \mu_0 \, \sigma \, v_c \, l_c \approx 9.8 \cdot 10^{14} >> 1$$

So the solar wind magnetic field is frozen into the plasma to a very good approximation.

Energy - temperature

Average energy of molecule/atom:

$$E = \frac{3}{2} k_B T \quad \Rightarrow$$

$$T = \frac{2E}{3k_B}$$

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J} \Rightarrow$$

$$T = \frac{2E}{3k_B} = \frac{2 \cdot 1.6 \cdot 10^{-19}\,\text{J}}{3 \cdot 1.38 \cdot 10^{-23}\,\dfrac{\text{J}}{\text{K}}} = 7729\,\text{K}$$

But beware!

In plasma physics, usually:

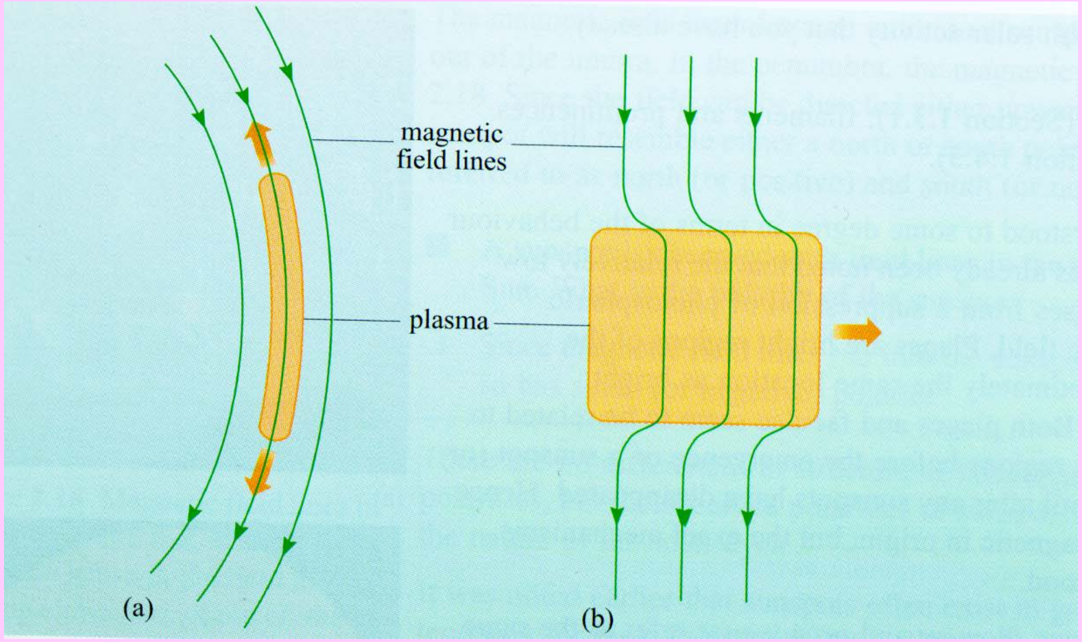
$$E = \cancel{\frac{3}{2}} k_B T \quad \Rightarrow$$

$$T = \frac{E}{k_B}$$

1 eV = 1.6·10^{-19} J $\Rightarrow$

$$E = k_B T = \frac{1.6 \cdot 10^{-19}\,\mathrm{J}}{1.38 \cdot 10^{-23}\,\dfrac{\mathrm{J}}{\mathrm{K}}} = 11594\,\mathrm{K}$$

Does the plasma follow the magnetic field (a) or the other way around (b)?



$\beta << 1$ $\beta >> 1$

Depends on relative energy density (pressure)

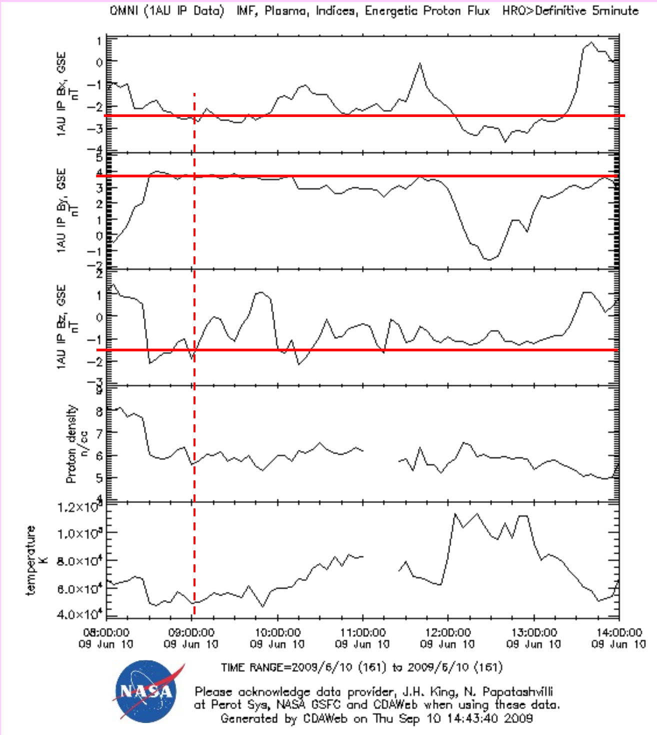
$$p_{pl} = nk_B T$$

$$p_B = \frac{B^2}{2\mu_0}$$

$$\beta = \frac{p_{pl}}{p_B}$$

Mini-groupwork 2

c)



$$\rho = n_e m_p = 6.1\cdot 10^{6}\cdot 1.67\cdot 10^{-27} = 1.02\cdot 10^{-20}$$

Then the kinetic energy density is (v = 313 km/s):

$$\rho v^2/2 = 5.0\cdot 10^{-10}\ \mathrm{Jm}^{-3}$$

The magnetic energy density is (using values of figure)

$$\frac{B^2}{2\mu_0} = \frac{\left(B_x^2 + B_y^2 + B_z^2\right)^2}{2\mu_0} = (2.6^2 + 3.6^2 + 1.7^2)\cdot(10^{-9})^2/2\mu_0 = 9\cdot 10^{-12}\ \mathrm{Jm}^{-3}$$

The ratio between the kinetic and magnetic energy densities is approximately **50,** thus the plasma motion determines the magnetic field configuration, and not the other way around.

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Space

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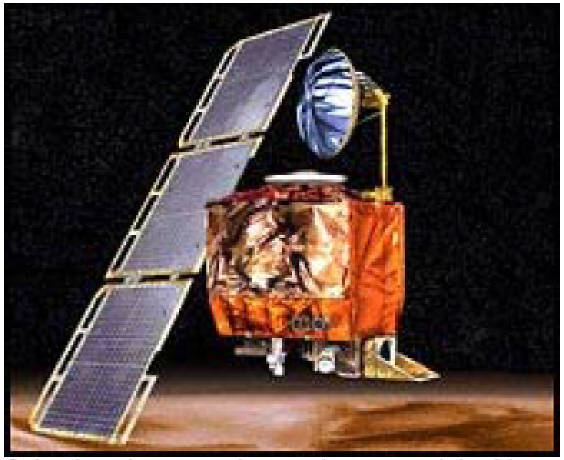
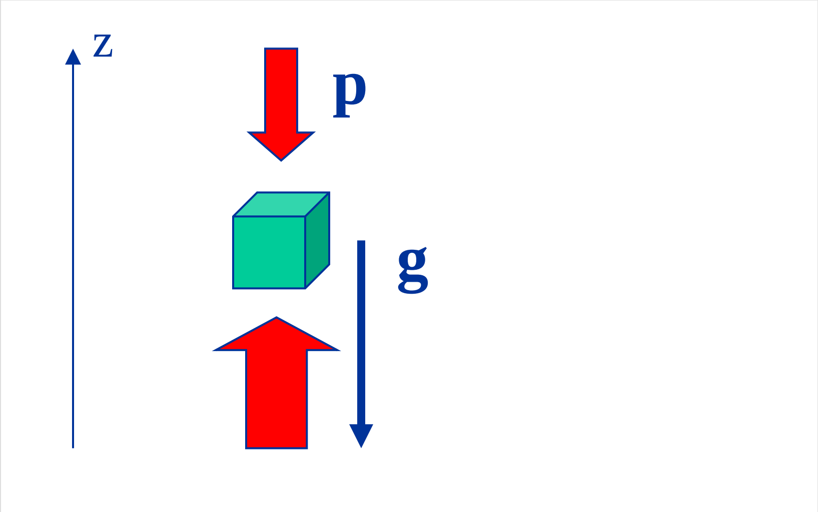
Mystery of Orbiter Crash Solved

By Kathy Sawyer
Washington Post Staff Writer
Friday, October 1, 1999; Page A1

NASA's Mars Climate Orbiter was lost in space last week because engineers failed to make a simple conversion from English units to metric, an embarrassing lapse that sent the $125 million craft fatally close to the Martian surface, investigators said yesterday.



Scientists do not yet know what caused the Mars Orbiter to crash. (AP)



Atmospheric scale height

$$-\frac{dp}{dz} = g\rho_m$$ hydrostatic equilibrium for a volume element

$$p = nk_BT = \frac{\rho k_B T}{m}$$ ideal gas law

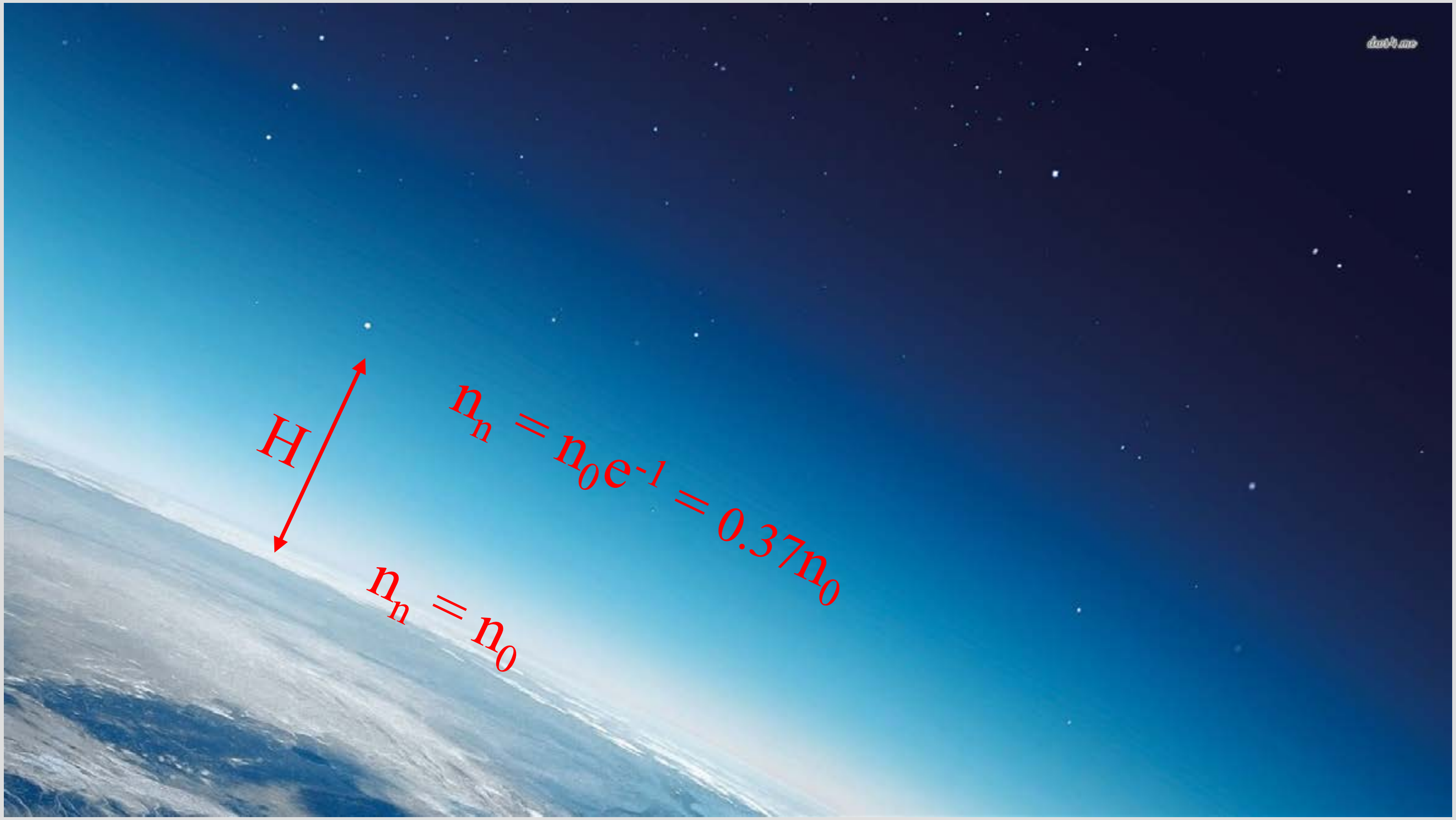
$$-\frac{k_BT}{m}\frac{d\rho_m}{dz} = g\rho_m$$ if T is constant

$$\rho_m = const \cdot e^{-z/(k_BT/gm)} = const \cdot e^{-z/H}$$

Scale height

$H = k_BT/gm$

Atmospheric scale height



$$\rho_m = const \cdot e^{-z/(k_B T/gm)} = const \cdot e^{-z/H}$$

Scale height

$H = k_B T/gm$

Ionization and recombination

Continuity equation

$$\frac{dn_e}{dt} = q - r$$

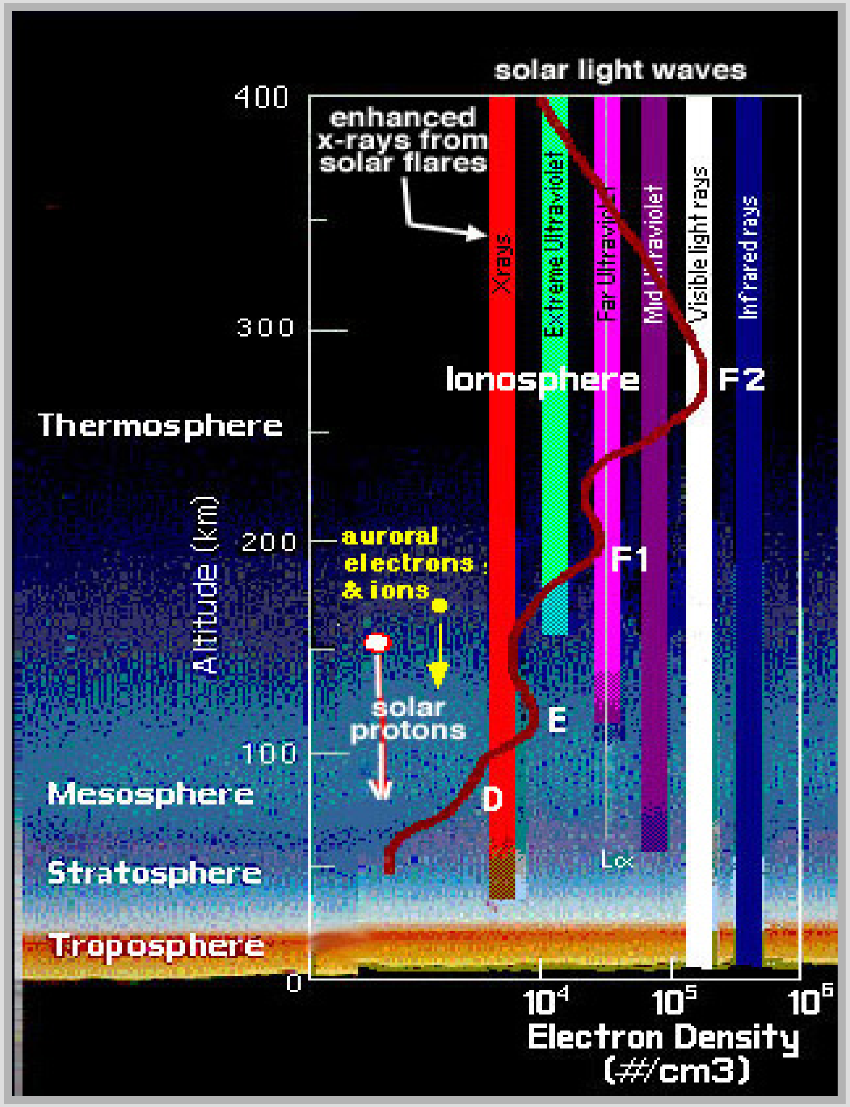
$$q = a_i I n_n$$

Ionization ($m^{-3}s^{-1}$)

Recombination ($m^{-3}s^{-1}$)

$$r = a_r n_e n_i = a_r n_e^2$$

Example: $e + O_2^+ \rightarrow O + O$ (dissociative recombination)



UV and X–ray radiation

$$\frac{dI}{dz} = I n_n a_a$$

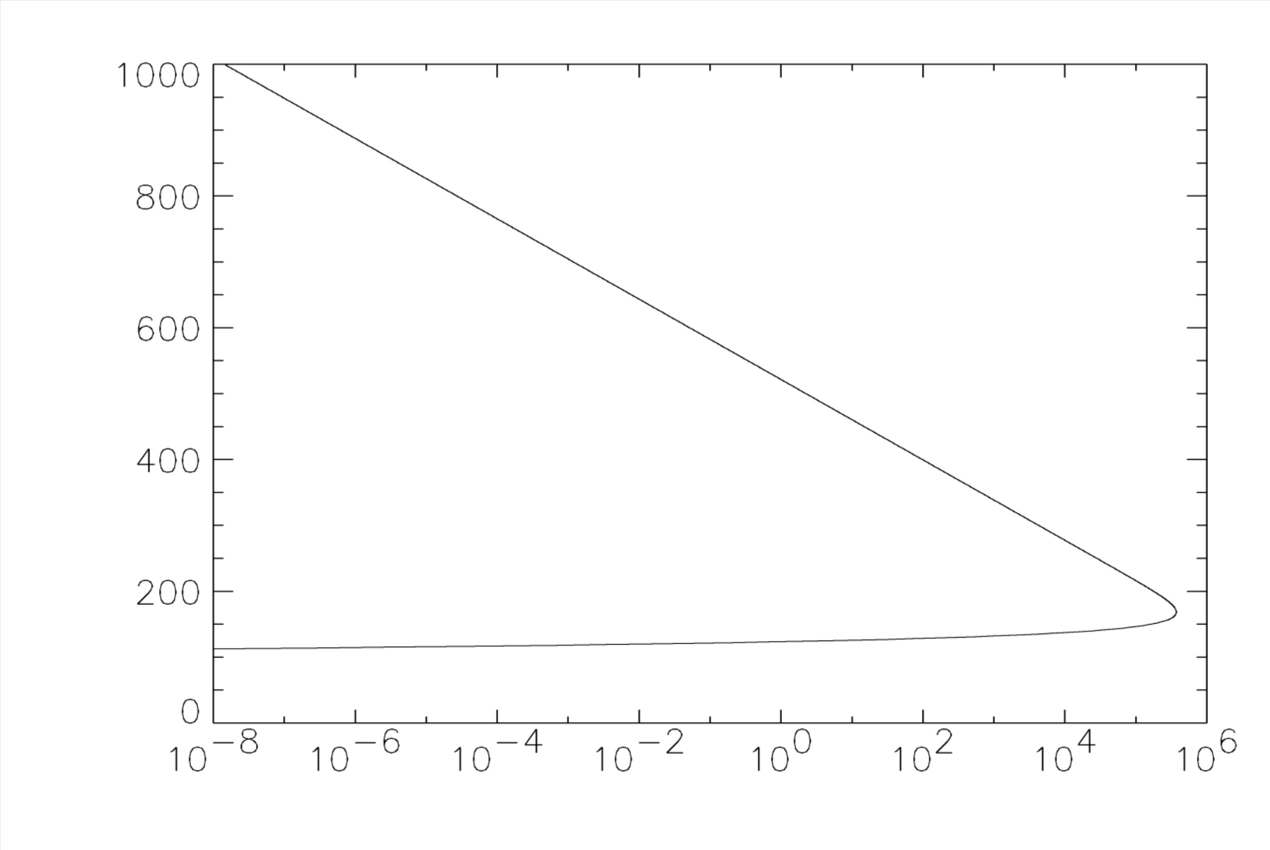
Electron density in Chapman layer

$$n_e = \left\{ \frac{a_i}{a_r} I_0 n_0 e^{-\left(H a_a n_0 e^{-z/H} + z/H\right)} \right\}^{1/2}$$

”F1-region” - simple model calculation

O_2 dominating species, 30 nm UV radiation

$a_a = 9.3\times10^{-23}$
$a_j = 9.3\times10^{-23}$
$a_r = 3.0\times10^{-14}$
$T = 500$
$m = 16*2*\text{amu}$
$n_0 = 2.7\times10^{25}\ \text{m}^{-3}$
$I_0 = 1.5\ \times10^{14}$ photons/m^2/s

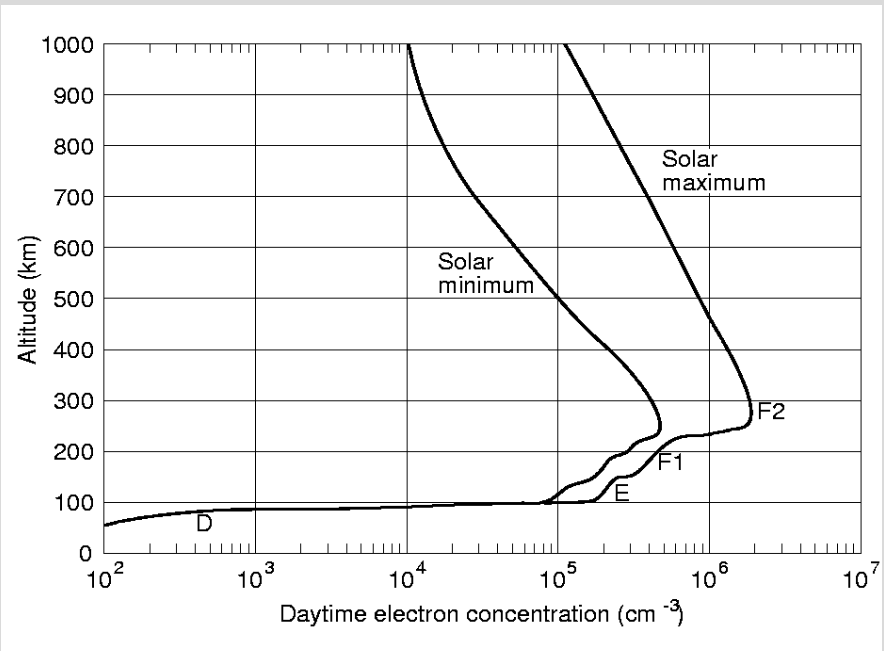


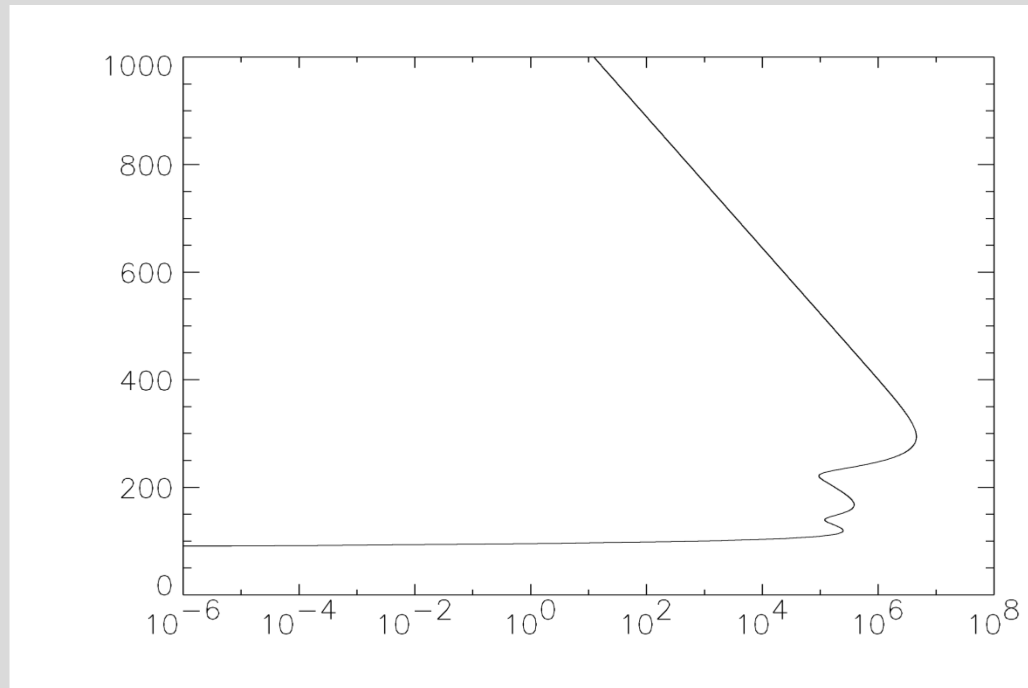
What does it look like in reality?

- Temperature not constant
- Many different wavelengths in solar radiation
- Several different molecules and atoms in neutral atmosphere. Composition also depends on altitude.

Measurements

"E" + "F1" + "F2"



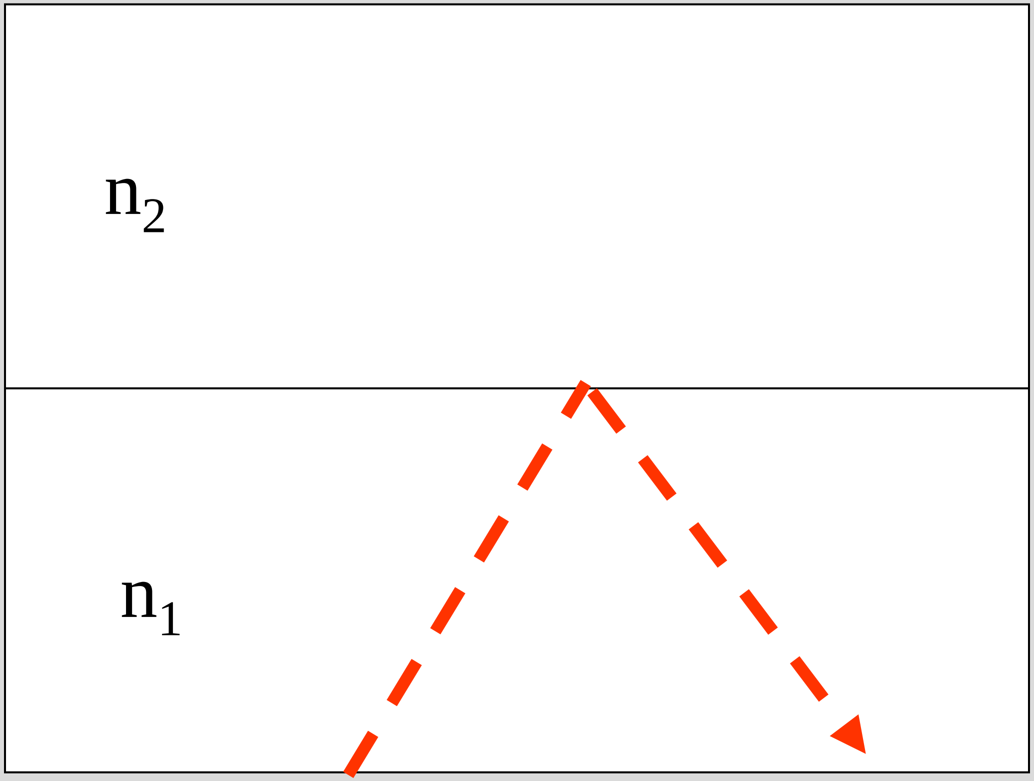


Ionospheric layers

Layer	D	E	F_1	F_2
Altitude (km)	60-85	85-140	140-200	200 - ca 1500
Nighttime electron density (cm^{-3})	$<10^2$	$2 \cdot 10^3$	—	$2 - 5 \cdot 10^5$
Daytime electron density (cm^{-3})	10^3	$1 - 2 \cdot 10^5$	$2 - 5 \cdot 10^5$	$0.5 - 2 \cdot 10^6$
Ion species	NO^+ O_2^+	NO^+ O_2^+	NO^+ O_2^+ O^+	O^+ He^+ H^+
Cause of ionization	Lyman α (1215 Å) + cosmic radiation	Lyman β (1025 Å) X-rays	UV	UV

NO^+ created by chemical reaction $N_2^+ + O \rightarrow NO^+ + N$

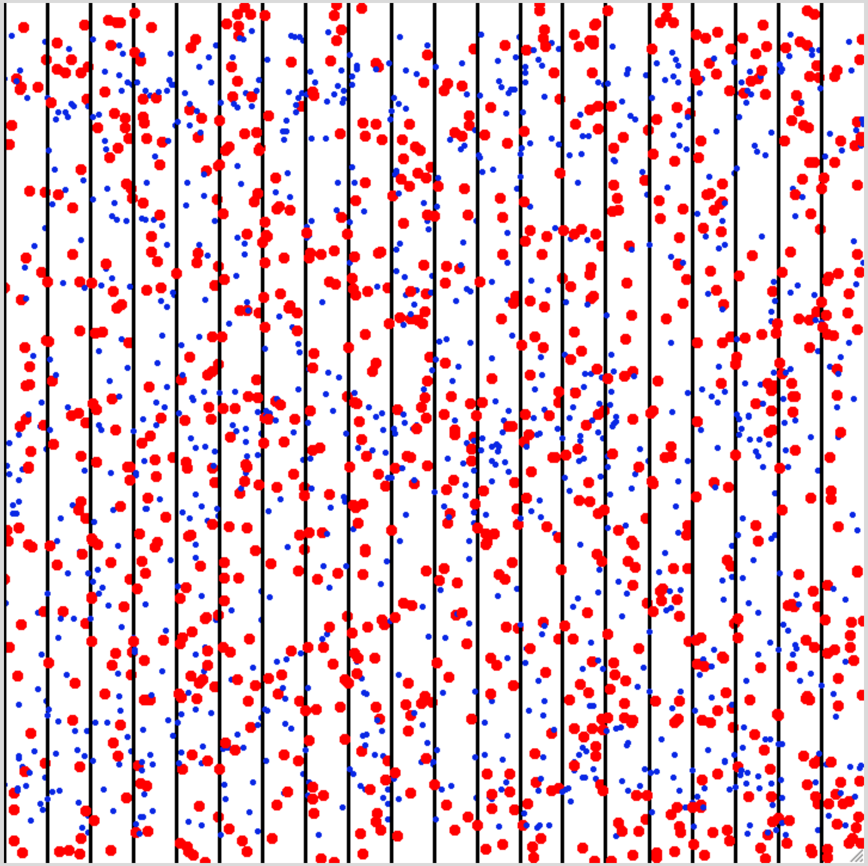
Reflection of radio waves

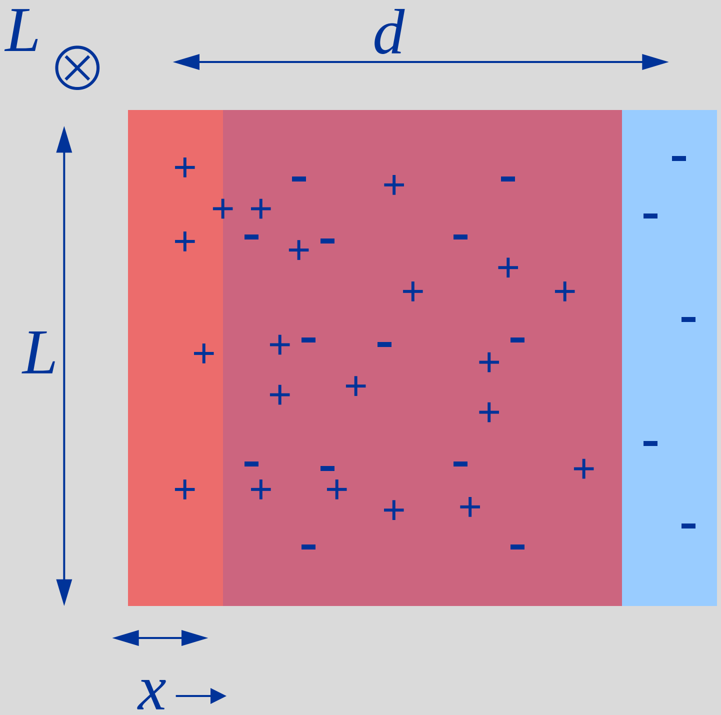


Total reflection at a sharp boundary (or large gradient) if

$$n_2 < n_1$$

Plasma oscillations parallel to B





$$-\frac{n_e e^2 x}{\varepsilon_0 m_e} = \frac{d^2 x}{dt^2}$$

$$x = \sin(\omega_{pe} t)$$

$$F = m_e a \qquad E = \frac{\sigma}{\varepsilon_0}$$

$$F = -eE \qquad \sigma = e n_e x$$

$$\boxed{\omega_{pe} \equiv \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}}$$

Index of refraction for electromagnetic waves in a plasma

(1) $$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

(2) $$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

(3) $$\mathbf{j} = -e n_e \mathbf{v}_e$$

(4) $$m_e \frac{\partial \mathbf{v}_e}{\partial t} = -e\mathbf{E}$$

Assume all quantities vary sinusoidally, with frequency ω, *e.g.*:

$$\mathbf{E} = \mathbf{E}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}$$

(1) $\Rightarrow$ $$\nabla \times (\nabla \times \mathbf{E}) = -\nabla \times \frac{\partial \mathbf{B}}{\partial t}$$

(2) $\Rightarrow$ $$\nabla \times \frac{\partial \mathbf{B}}{\partial t} = \mu_0 \frac{\partial \mathbf{j}}{\partial t} + \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\therefore \ \nabla \times (\nabla \times \mathbf{E}) = -\mu_0 \frac{\partial}{\partial t}(e n_e \mathbf{v}_e) + \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$\Rightarrow$

$$\nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E} = -\mu_0 e n_e \frac{\partial \mathbf{v}_e}{\partial t} + \frac{1}{c^2} \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$\Rightarrow$

Index of refraction for electromagnetic waves in a plasma

$$\mathbf{ik}\cancel{(i\mathbf{k}\cdot\mathbf{E})} - k^2\mathbf{E} = \mu_0(-i\omega)en_e\mathbf{v}_e + \frac{1}{c^2}(-i\omega)^2\mathbf{E}$$

Does not represent E.M. wave

(4) $\Rightarrow$

$$-k^2\mathbf{E} = \mu_0(-i\omega)en_e\frac{ie\mathbf{E}}{\omega m_e} + \frac{1}{c^2}(-i\omega)^2\mathbf{E}$$

$\Rightarrow$

$$c^2k^2 = -c^2\frac{\mu_0 n_e e^2}{m_e} + \omega^2 = \frac{-1}{\cancel{\mu_0}\varepsilon_0}\frac{\cancel{\mu_0}n_e e^2}{m_e} + \omega^2$$

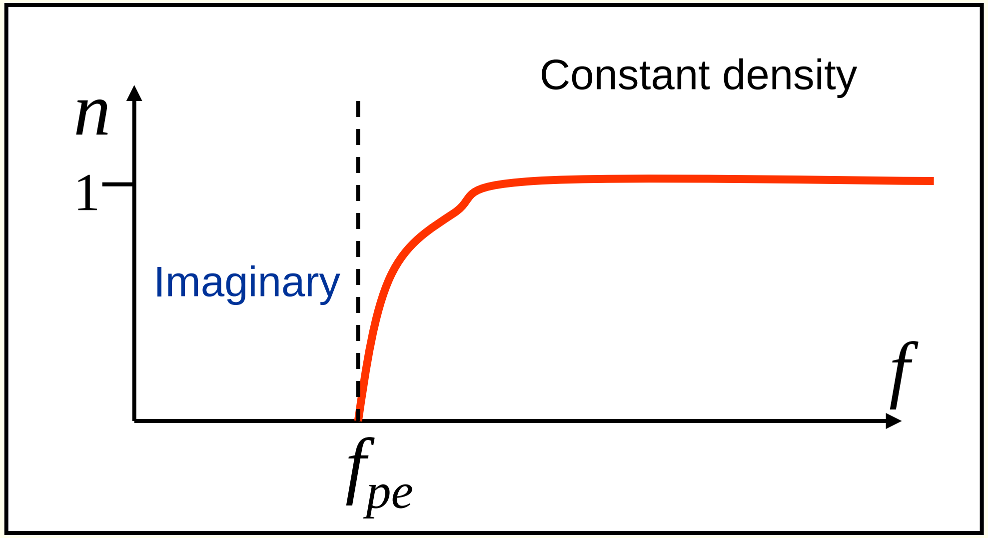
$$\therefore \quad \omega^2 = c^2k^2 + \omega_p^2$$

$$n^2 = \frac{c^2}{v_{ph}^2} = \frac{c^2k^2}{\omega^2} = \frac{\omega^2 - \omega_p^2}{\omega^2} = 1 - \frac{\omega_p^2}{\omega^2}$$

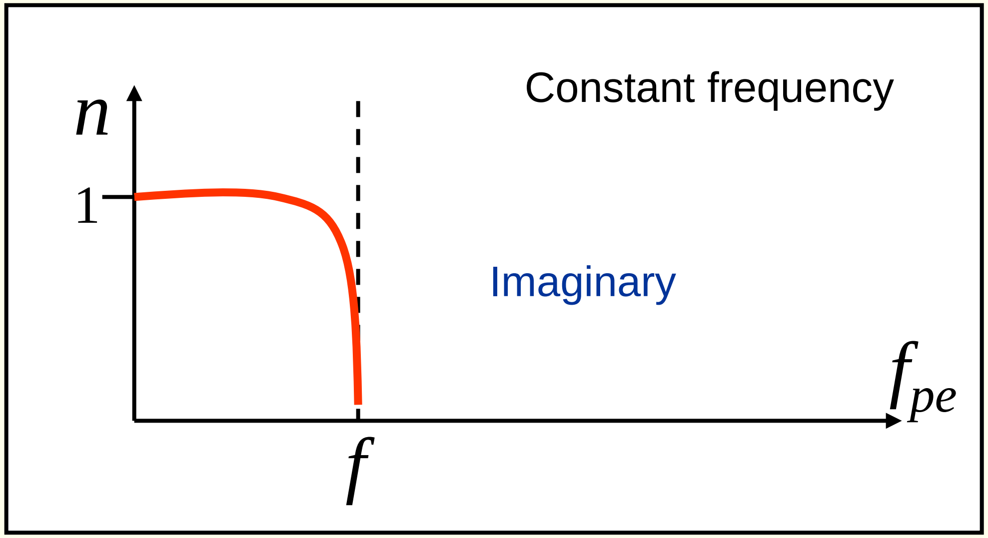
$\therefore$

$$\boxed{n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}} = \sqrt{1 - \frac{f_p^2}{f^2}}}$$

Refraction index for plasma

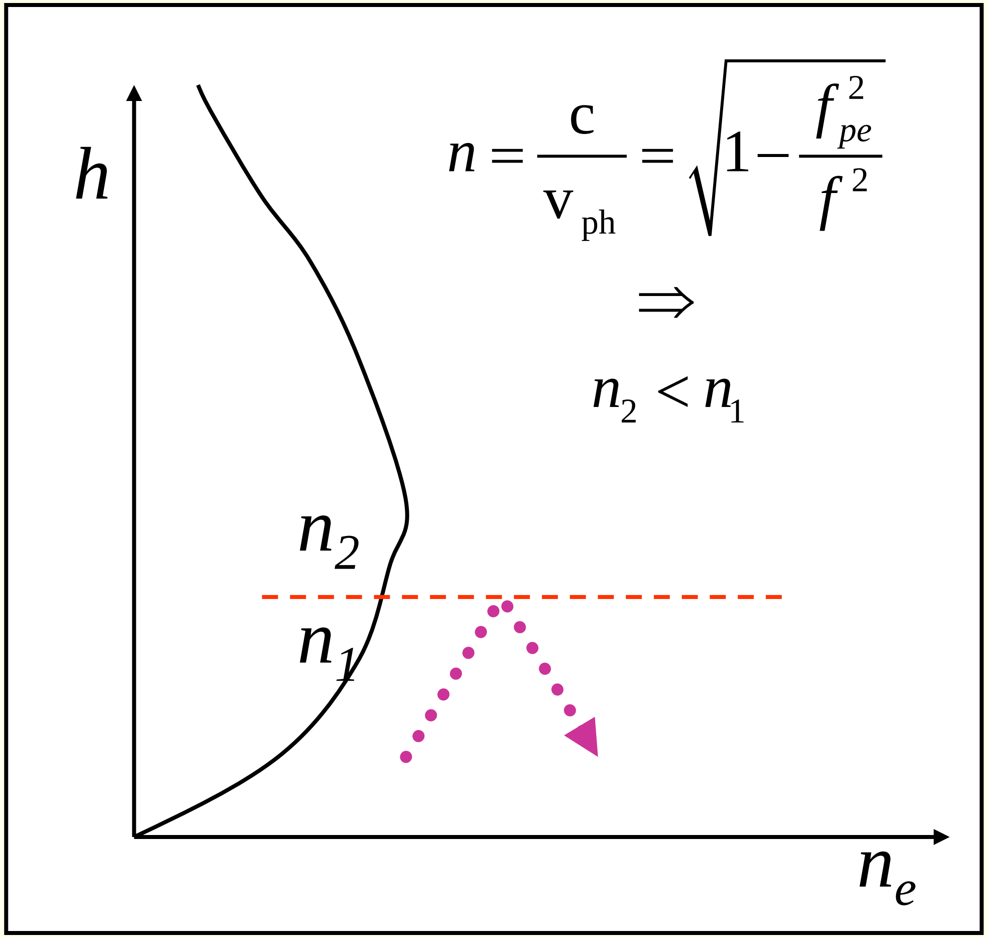


$$n = \frac{c}{v_{ph}} = \sqrt{1 - \frac{f_{pe}^2}{f^2}}$$



$$\omega_{pe} \equiv \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

Where does the total reflection take place?

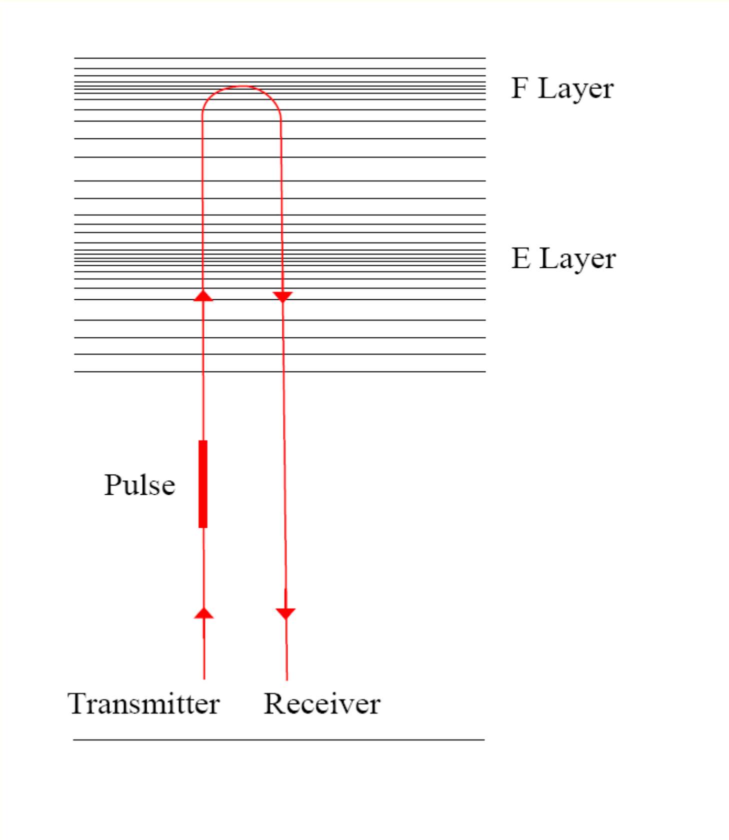


Large gradient when

$$\boxed{f \approx f_{pe}}$$

Higher frequencies $\rightarrow$ higher $f_{pe}\,(n_e)$

Ionosonde



The pulse will be reflected where

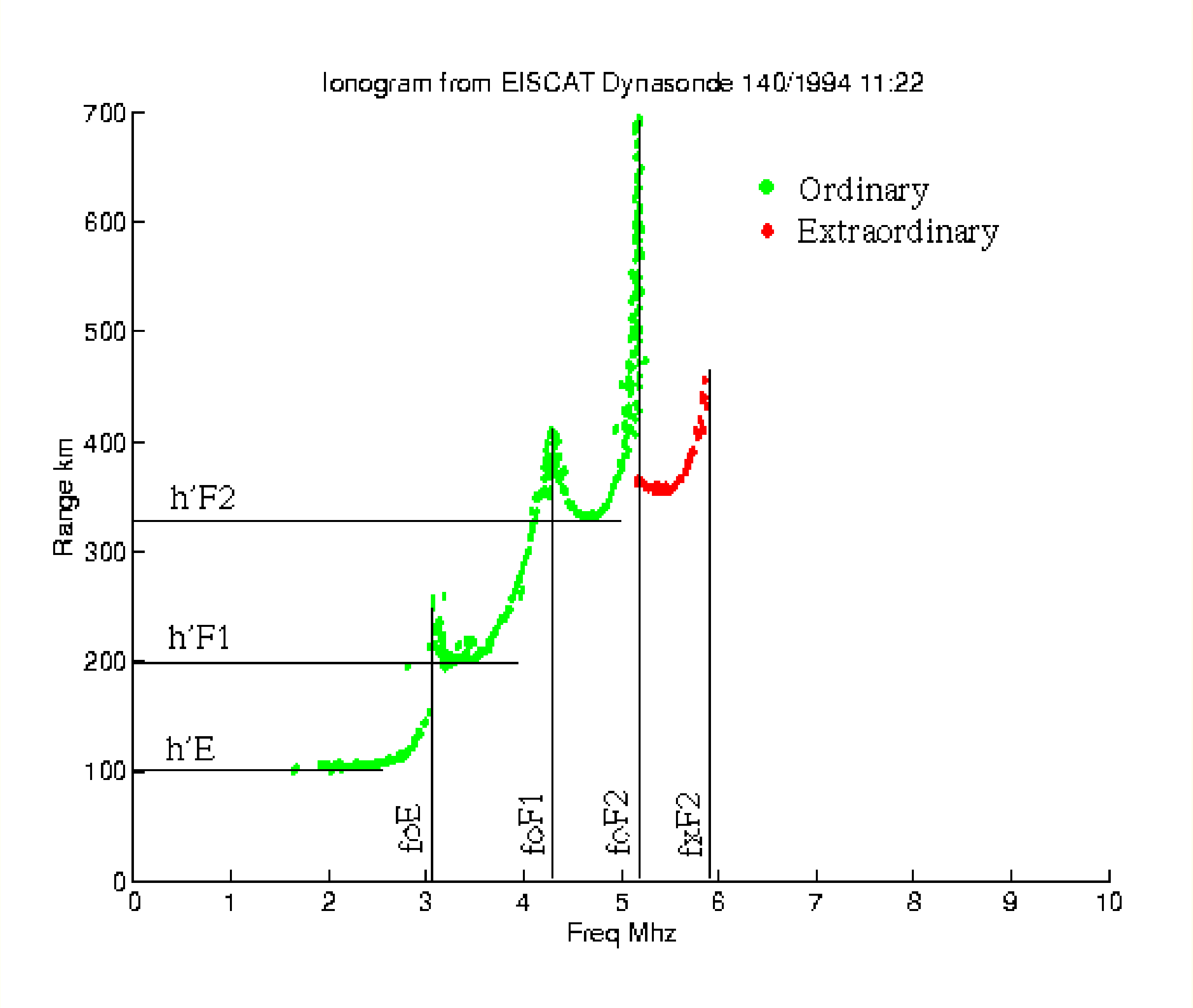
$$f = f_{pe}$$

The altitude will be determined by

$$2h = ct$$

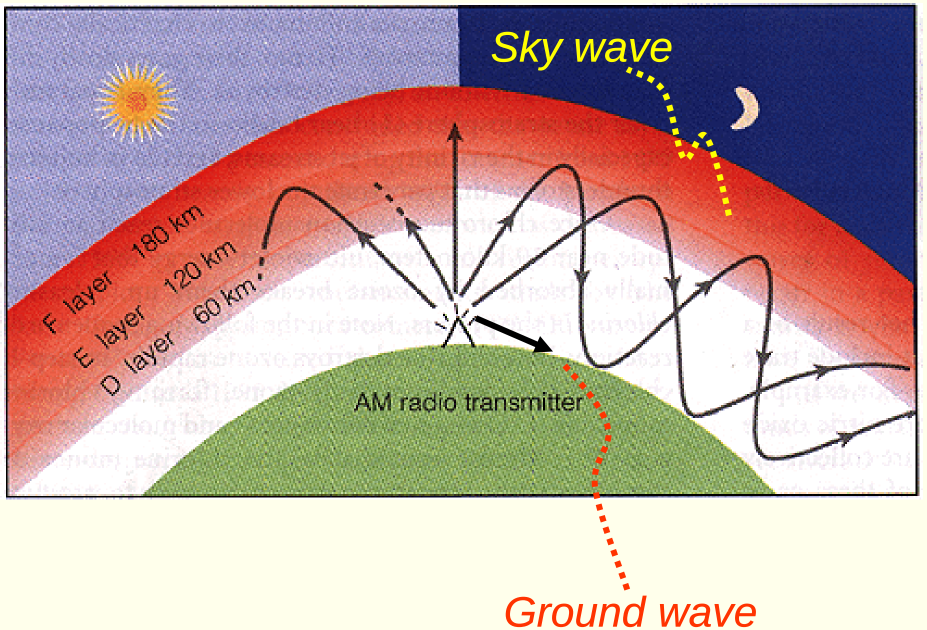
Where t is the time between when the pulse is sent out and the registered again.

Ionogram



Ionogram from EISCAT Dynasonde 140/1994 11:22
Ordinary
Extraordinary
Range km
Freq Mhz
h'F2
h'F1
h'E
foE
foF1
foF2
fxF2
0
100
200
300
400
500
600
700
1
2
3
4
5
6
7
8
9
10

Reflection of radio waves



F2-layer during night:

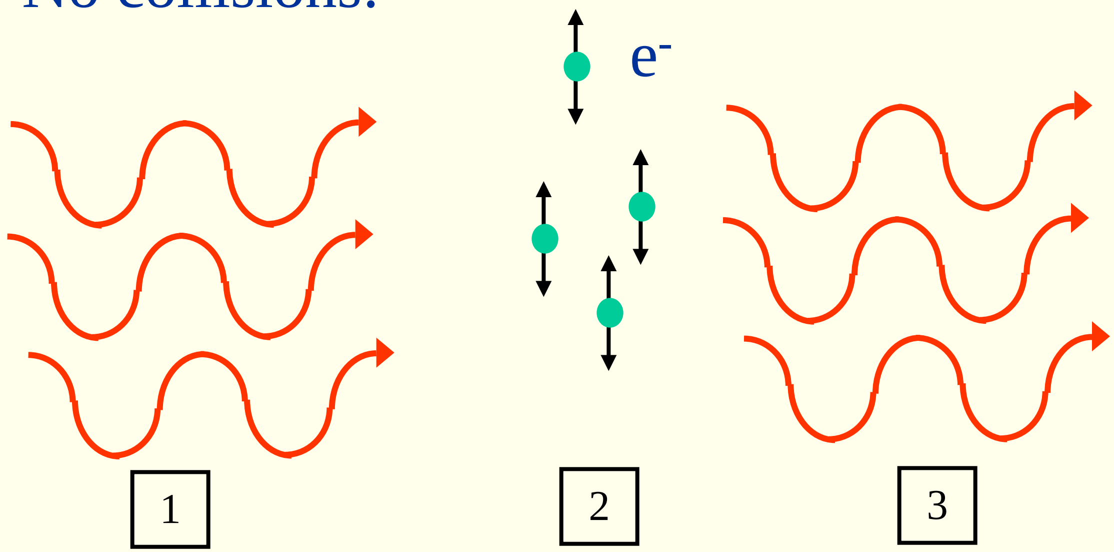
$$n_e = 5 \cdot 10^{11}\ \mathrm{m}^{-3} \quad \Rightarrow$$

$$f_{pe} = 10^7\ \mathrm{Hz} = 10\ \mathrm{MHz}$$

= HF/short wave

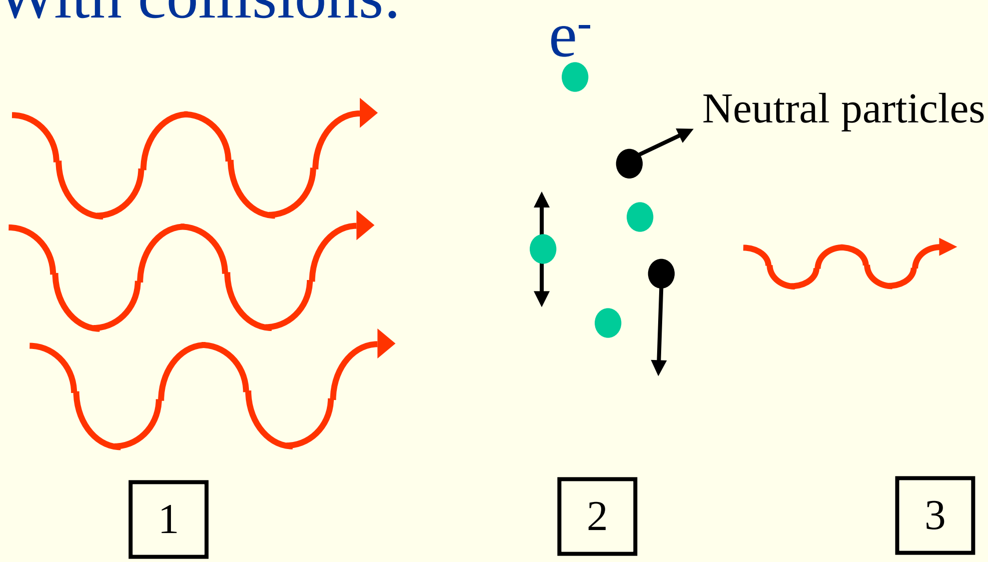
Absorption of radio waves

No collisions:



Absorption of radio waves

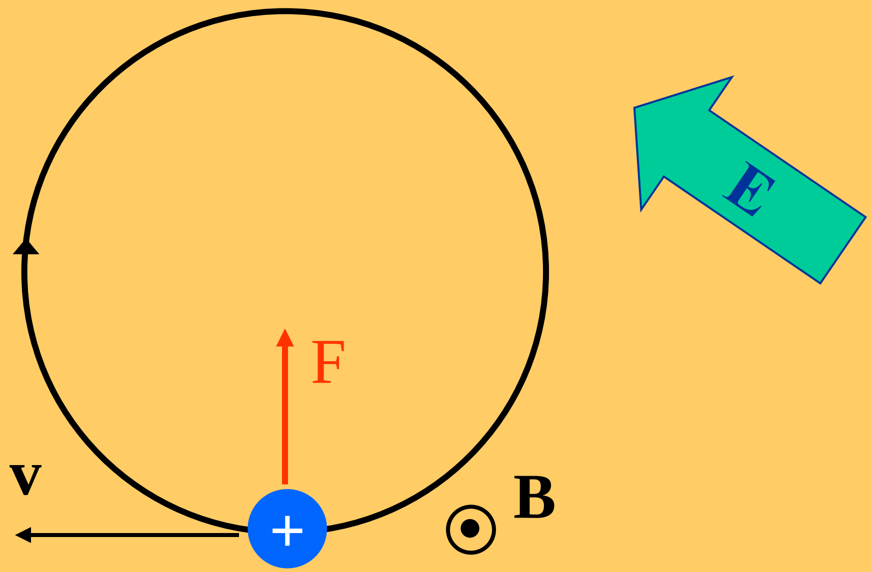
With collisions:



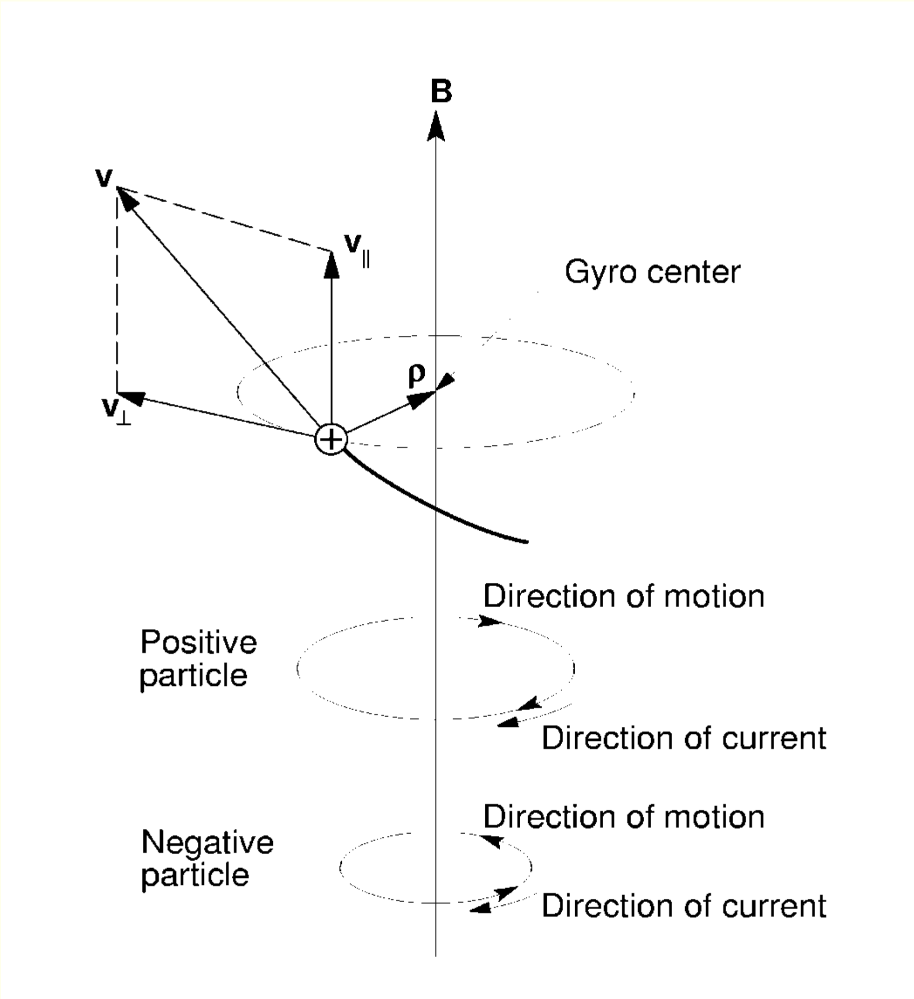
Think about this:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

What happens if you add an electric field $\mathbf{E}$?



Particle motion in magnetic field



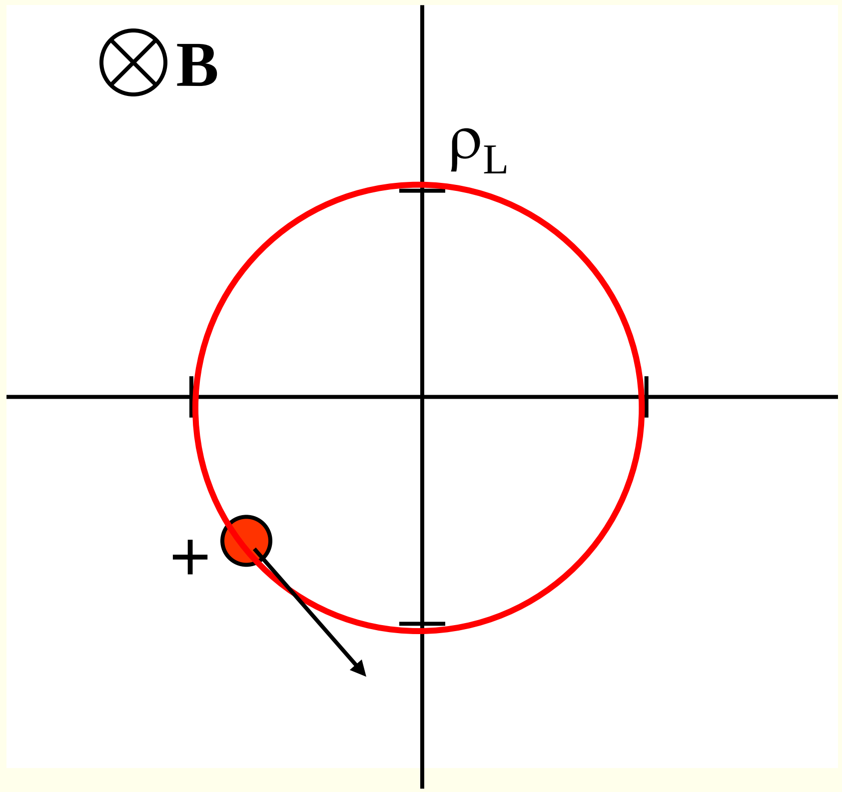
gyro radius

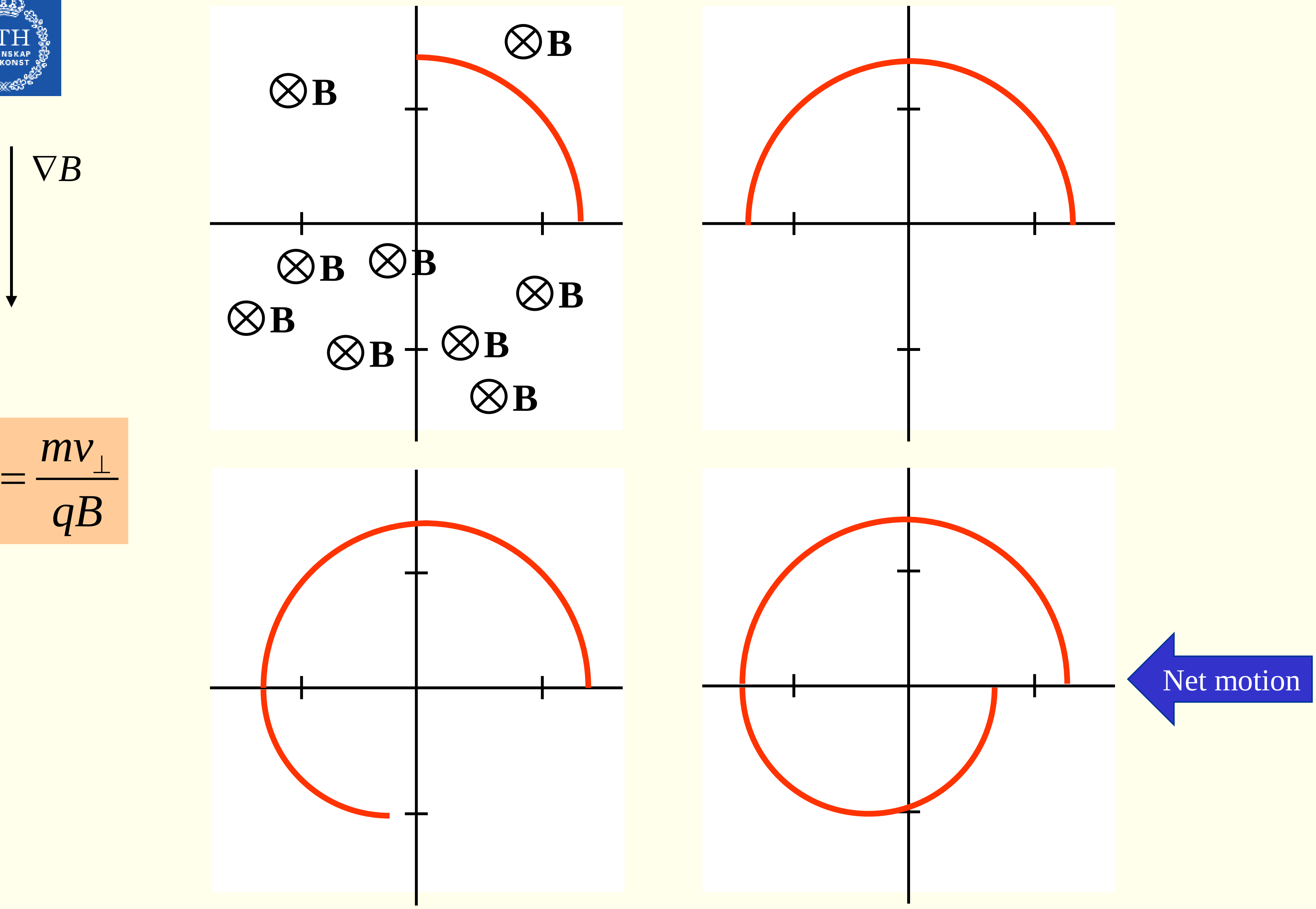
$$\rho = \frac{mv_\perp}{qB}$$

gyro frequency

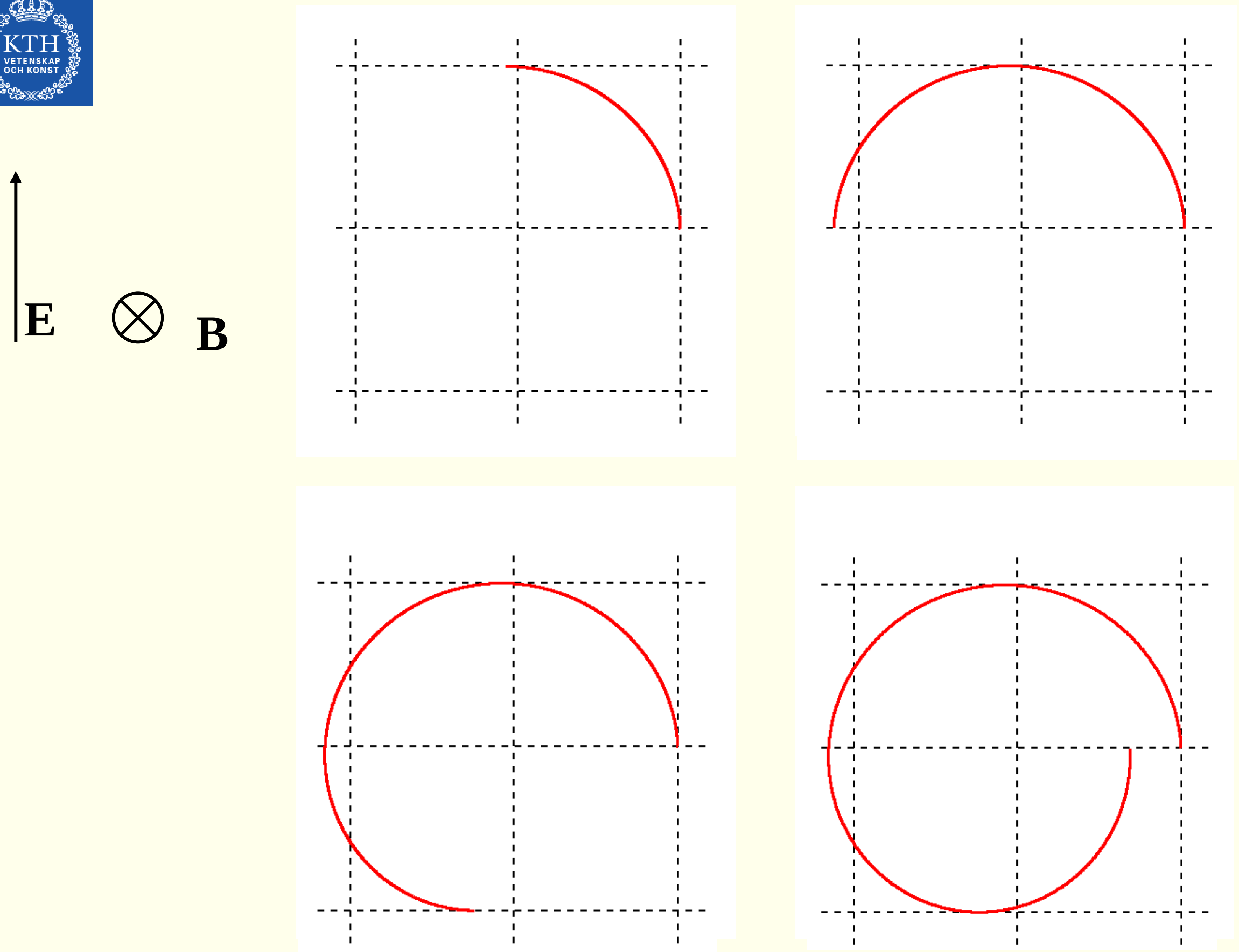
$$\omega_g = \frac{qB}{m}$$

Drift motion



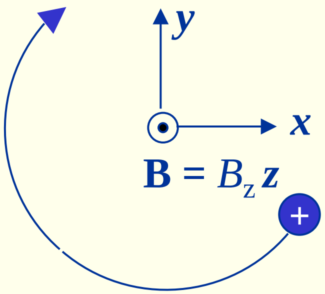


$$\rho = \frac{mv_\perp}{qB}$$


E
B

Drift motion

Consider a charged particle in a magnetic field.



Assume an electric field in the x-z plane:

$$\mathbf{E} = \left(E_x, 0, E_z\right)$$

$$m\frac{d\mathbf{v}}{dt} = q\left(\mathbf{v}\times\mathbf{B}+\mathbf{E}\right) \Rightarrow$$

$$\begin{cases} m\dfrac{dv_x}{dt} = qv_yB + qE_x \\ m\dfrac{dv_y}{dt} = -qv_xB \\ m\dfrac{dv_z}{dt} = qE_z \end{cases}$$

Constant acceleration along z

$$\Rightarrow$$

$$\begin{cases} \dfrac{d^2v_x}{dt^2} = \dfrac{qB}{m}\dfrac{dv_y}{dt} = \omega_g\dfrac{dv_y}{dt} = -\omega_g^2 v_x \\ \dfrac{d^2v_y}{dt^2} = -\dfrac{qB}{m}\dfrac{dv_x}{dt} = -\omega_g\dfrac{dv_x}{dt} = -\omega_g^2 v_y - \dfrac{q^2B}{m^2}E_x \end{cases}$$

$$\Rightarrow$$

Drift motion

$$\begin{cases} \dfrac{d^2 v_x}{dt^2} = \dfrac{qB}{m}\dfrac{dv_y}{dt} = \omega_g \dfrac{dv_y}{dt} = -\omega_g^2 v_x \\ \dfrac{d^2 v_y}{dt^2} = -\dfrac{qB}{m}\dfrac{dv_x}{dt} = -\omega_g \dfrac{dv_x}{dt} = -\omega_g^2 v_y - \dfrac{q^2 B}{m^2} E_x \end{cases}$$

$\therefore$

$$\begin{cases} \dfrac{d^2 v_x}{dt^2} - \omega_g^2 v_x \\ \dfrac{d^2\left(v_y + \dfrac{E_x}{B}\right)}{dt^2} = -\omega_g^2\left(v_y + \dfrac{E_x}{B}\right) \end{cases}$$

$\Rightarrow$

$$\begin{cases} v_x = v_\perp e^{i\omega_g t + \delta_x} \\ v_y = -\dfrac{E_x}{B} + v_\perp e^{i\omega_g t + \delta_y} \end{cases}$$

Average over a gyro period:

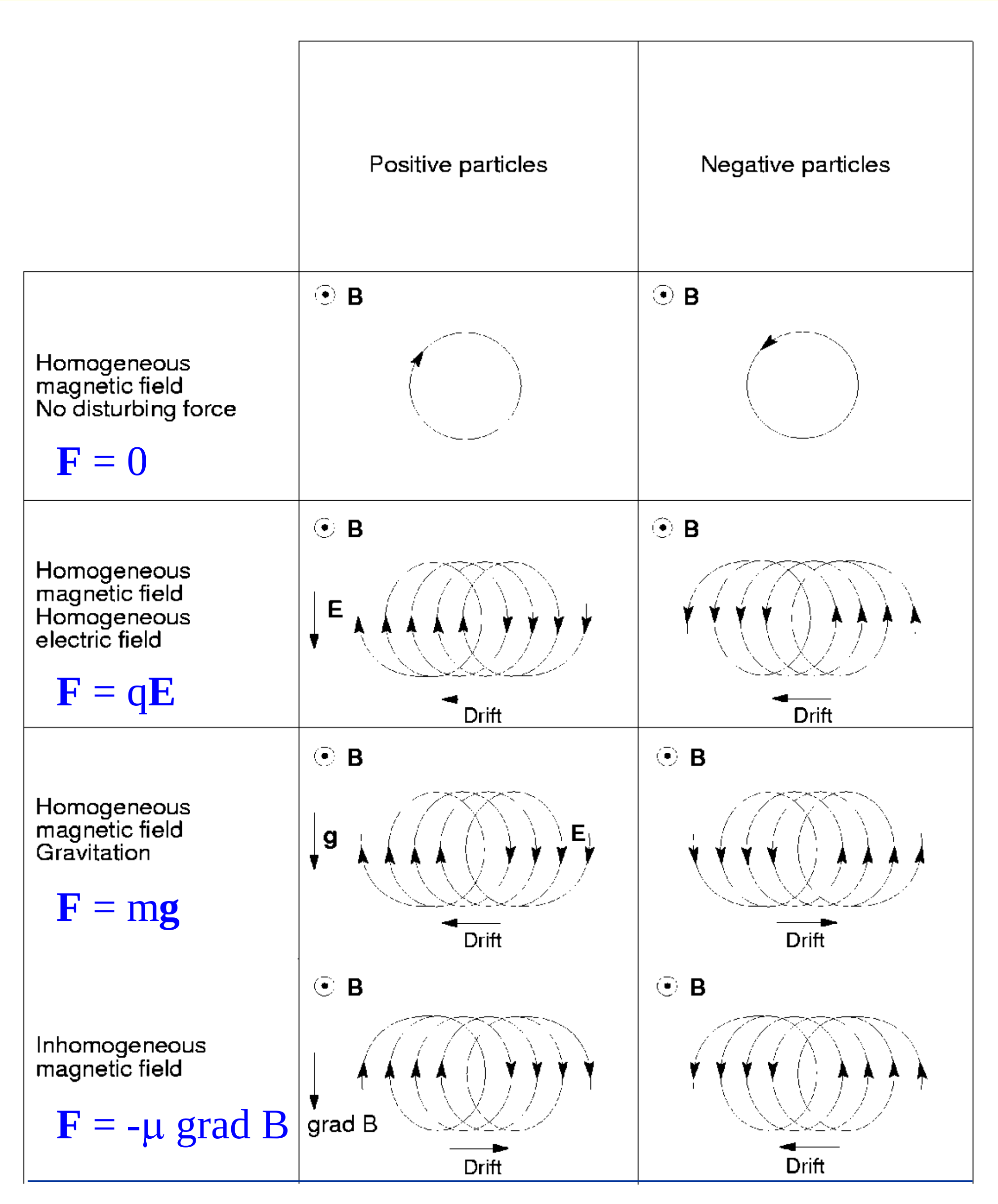
$$v_{drift,y} = -\frac{E_x}{B} = -\frac{E_x B_z}{B^2} = \frac{(\mathbf{E}\times\mathbf{B})_y}{B^2}$$

In general:

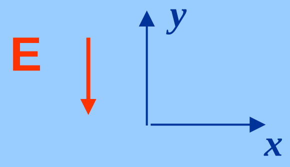
$$\boxed{\mathbf{v}_{drift} = \frac{\mathbf{E}\times\mathbf{B}}{B^2} = \frac{q\mathbf{E}\times\mathbf{B}}{qB^2} = \frac{\mathbf{F}\times\mathbf{B}}{qB^2}}$$

Drift motion

$$\mathbf{u}_{drift} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2}$$



Suppose you apply an electric field **E** in the direction showed in the figure, and that one electron and one ion (charge –*e* and *e*) is present. What will the resulting current be?



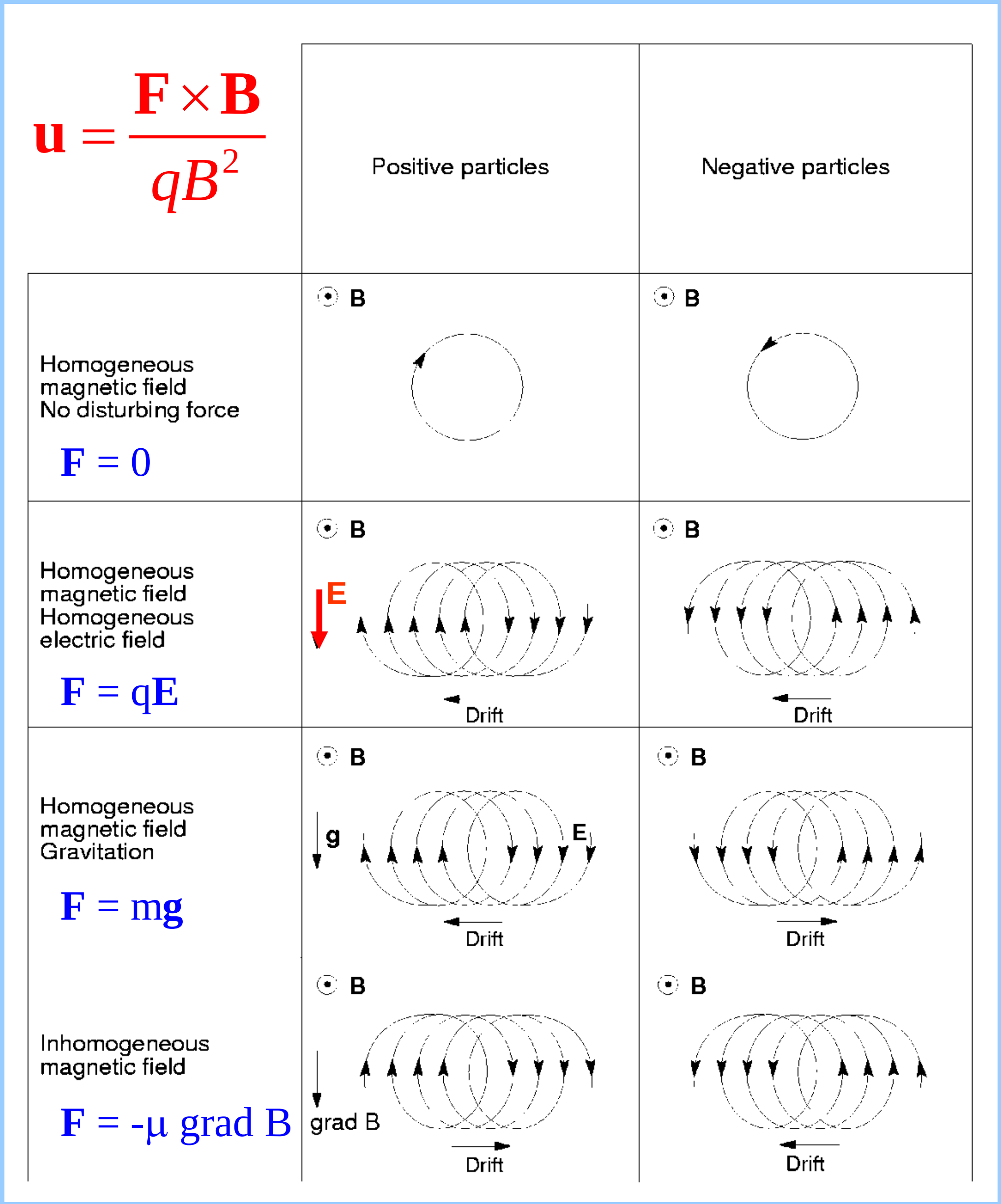
$$\mathbf{I} \equiv e\mathbf{u}_{\mathrm{i}} - e\mathbf{u}_{\mathrm{e}}$$

Yellow $\quad \mathbf{I} = -e\frac{E}{B}\hat{\mathbf{x}}$

Blue $\quad \mathbf{I} = 0$

Red $\quad \mathbf{I} = \frac{1}{2}e\frac{E}{B}\hat{\mathbf{x}} - \frac{1}{2}e\frac{E}{B}\hat{\mathbf{y}}$

Green $\quad \mathbf{I} = e\frac{E}{B}\hat{\mathbf{y}}$



$$\mathbf{I} \equiv e\mathbf{u_i} - e\mathbf{u_e}$$

$$\mathbf{u_i} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2} = \frac{e\mathbf{E} \times \mathbf{B}}{eB^2} = -\hat{\mathbf{x}}\frac{EB}{B^2} = -\hat{\mathbf{x}}\frac{E}{B}$$

$$\mathbf{u_e} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2} = \frac{-e\mathbf{E} \times \mathbf{B}}{-eB^2} = -\hat{\mathbf{x}}\frac{EB}{B^2} = -\hat{\mathbf{x}}\frac{E}{B}$$

$$\mathbf{I} \equiv e\mathbf{u_i} - e\mathbf{u_e} = e\left(\mathbf{u_i} - \mathbf{u_e}\right) = 0$$

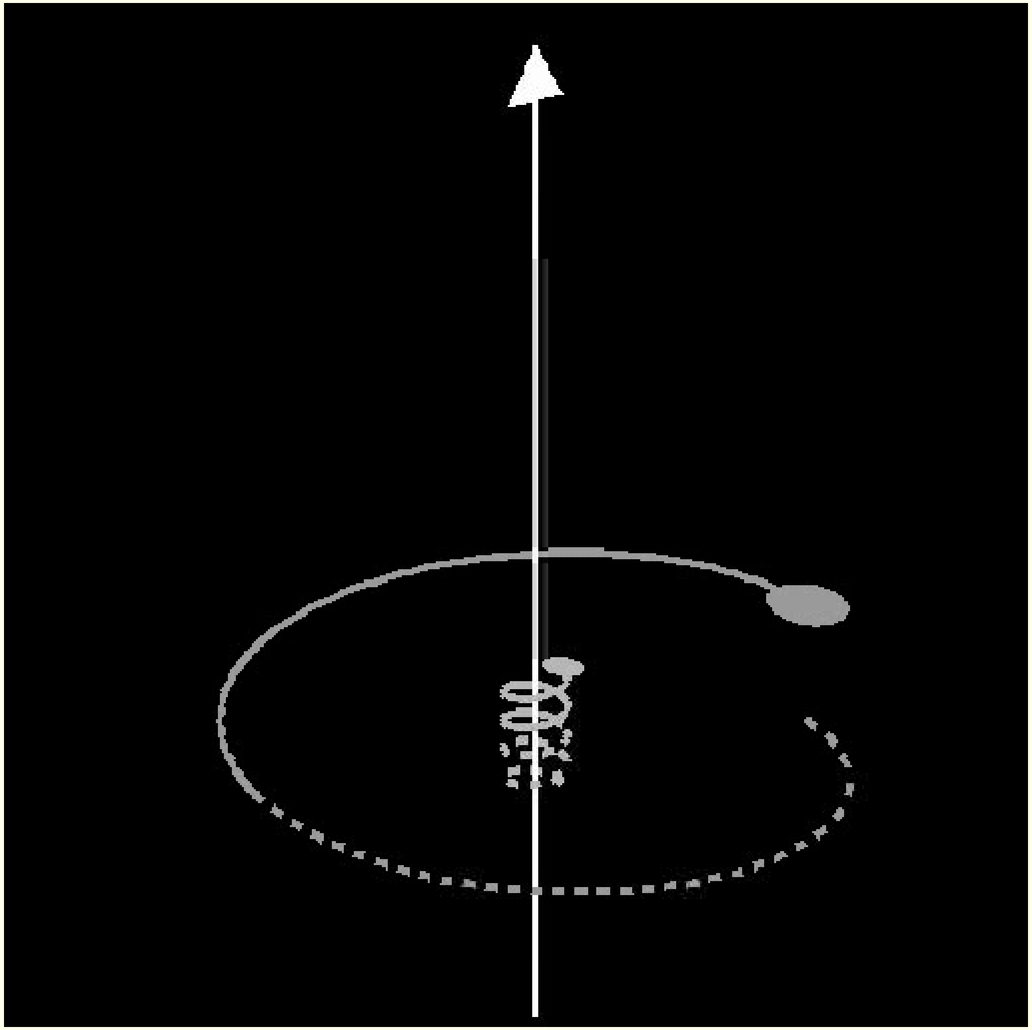
Blue

So, if there is no current when you apply an electric field, is the conductivity of the ionospheric plasma zero ?

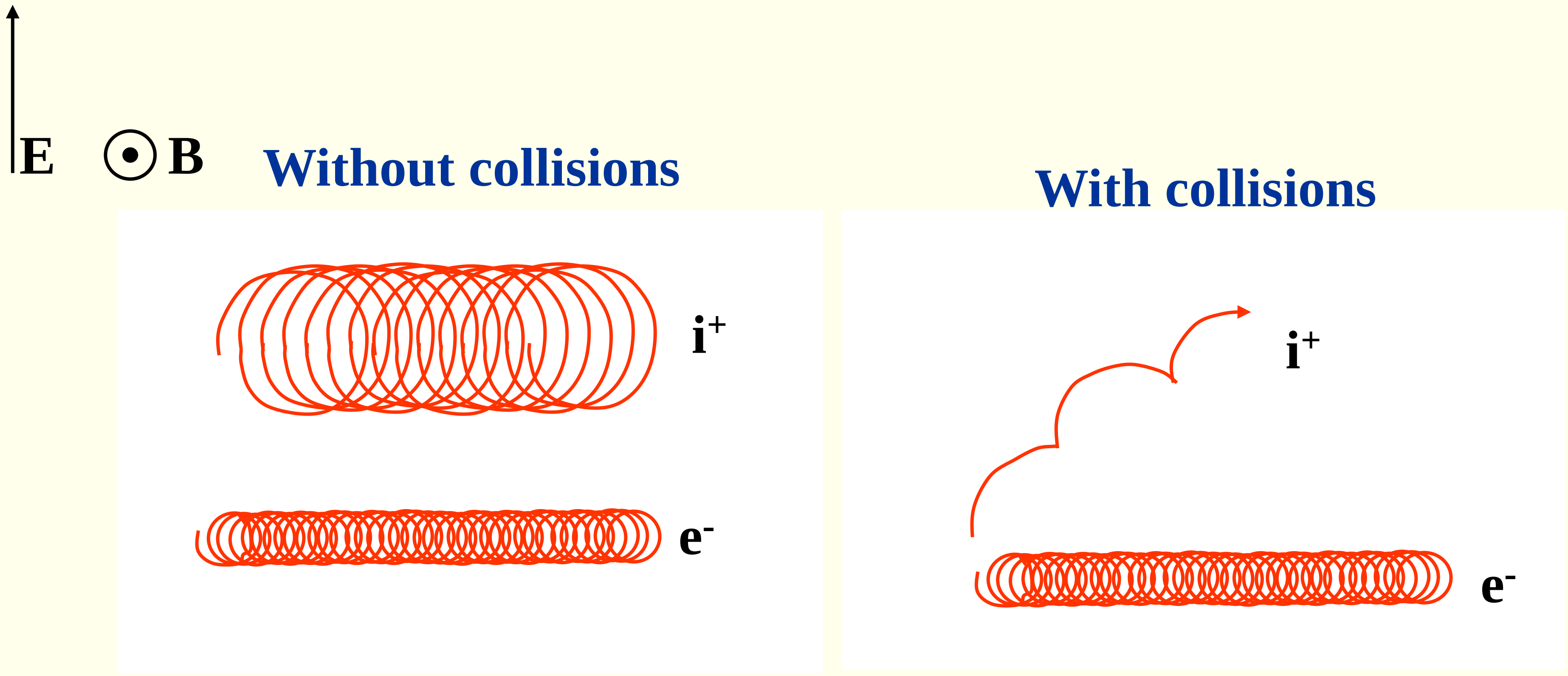
What is the electron density at 100 km?

What is the neutral density at 100 km?

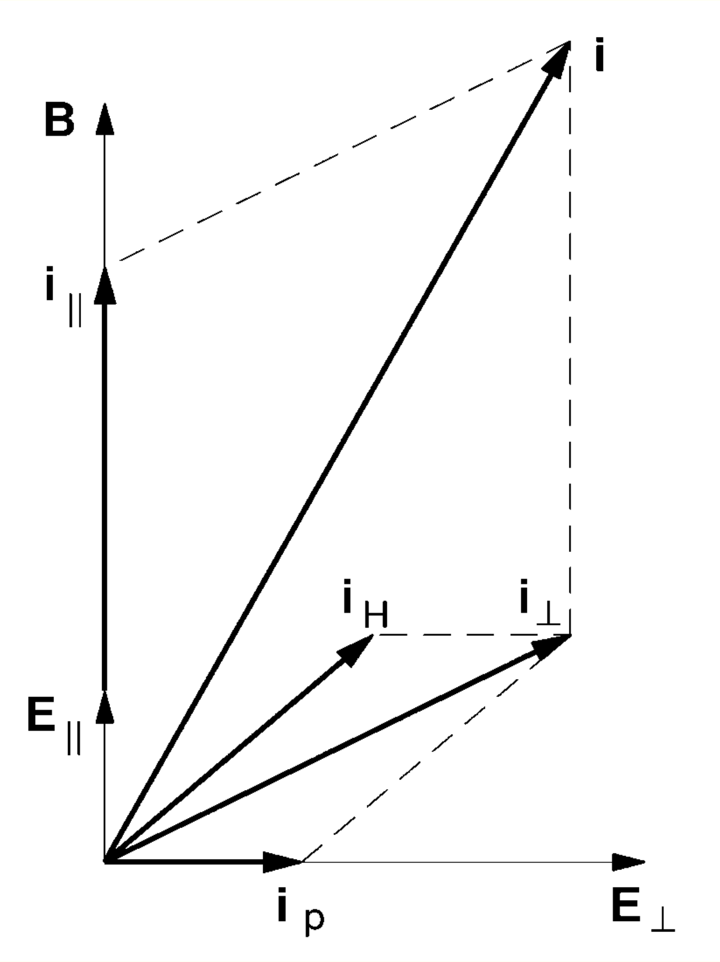
Gyro motion



ExB-drift

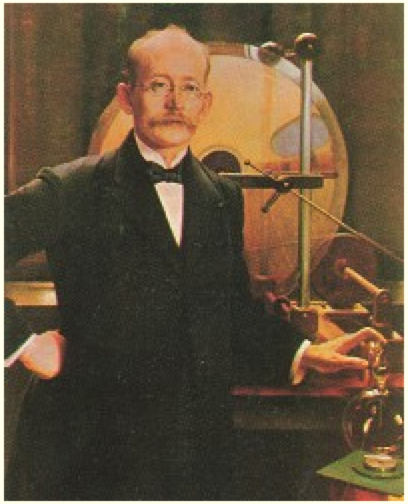


Electric conductivity in a magnetized plasma



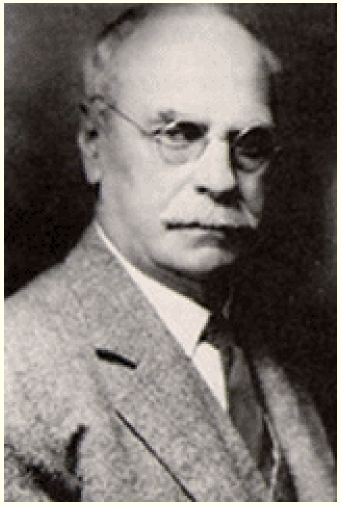
- $i_{//}$ = parallel current
- i_P = Pedersen current
- i_H = Hall current

Birkeland, Hall, Pedersen



Kristian Birkeland
1867-1917

Norwegian
scientist



Edwin Hall
1855-1938

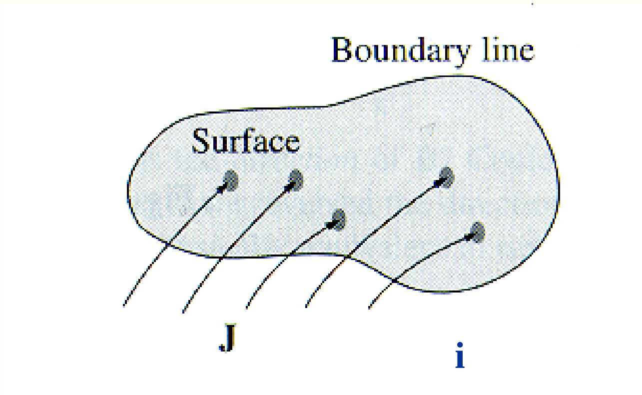
American
physicist

Peder Oluf Pedersen
1874-1941

Danish engineer
and physicist

Current density

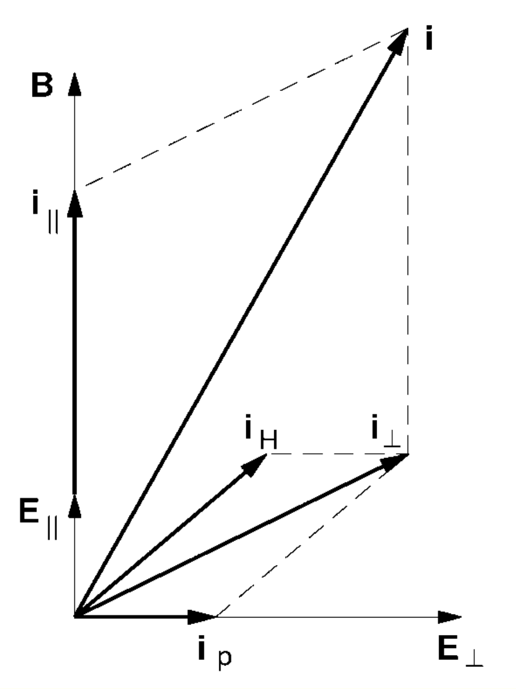
The current density $\mathbf{j}$ is a vector field with dimension $[\mathbf{i}] = \mathrm{Am}^{-2}$.



The total current I through the surface S is

$$I = \int_S \mathbf{j} \cdot d\mathbf{S}$$

Electric conductivity in a magnetized plasma II



$$\sigma_P = \sigma_e \frac{1}{1+\omega_{ge}^2\tau_e^2} + \sigma_i \frac{1}{1+\omega_{gi}^2\tau_i^2}$$

$$\sigma_H = \sigma_e \frac{\omega_{ge}\tau_e}{1+\omega_{ge}^2\tau_e^2} - \sigma_i \frac{\omega_{gi}\tau_i}{1+\omega_{gi}^2\tau_i^2}$$

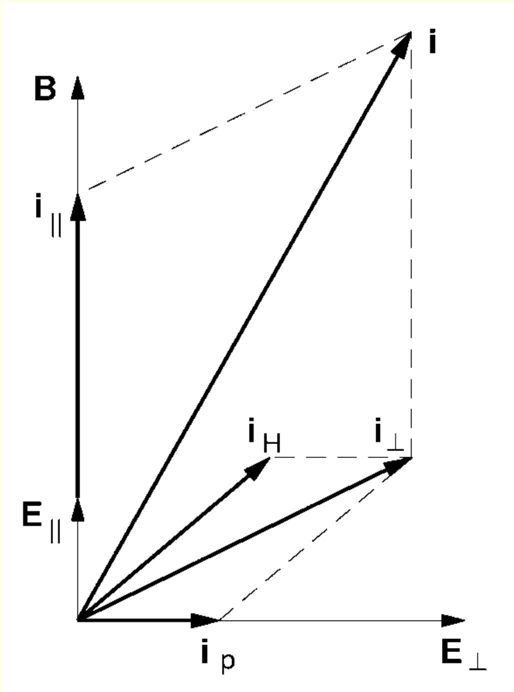
$$\sigma_{//} = \sigma_e + \sigma_i$$

$$\sigma_e = e^2 n \tau_e / m_e \qquad \sigma_i = e^2 n \tau_i / m_i$$

$$i_{//} = \sigma_{//} E_{//}$$

$$\left.\begin{aligned} i_P &= \sigma_P E_\perp \\ i_H &= \sigma_H E_\perp \end{aligned}\right\} \quad \text{or} \quad \mathbf{i}_\perp = \sigma_P \mathbf{E}_\perp + \sigma_H \frac{\mathbf{B}\times\mathbf{E}_\perp}{B}$$

Electric conductivity in a magnetized plasma II

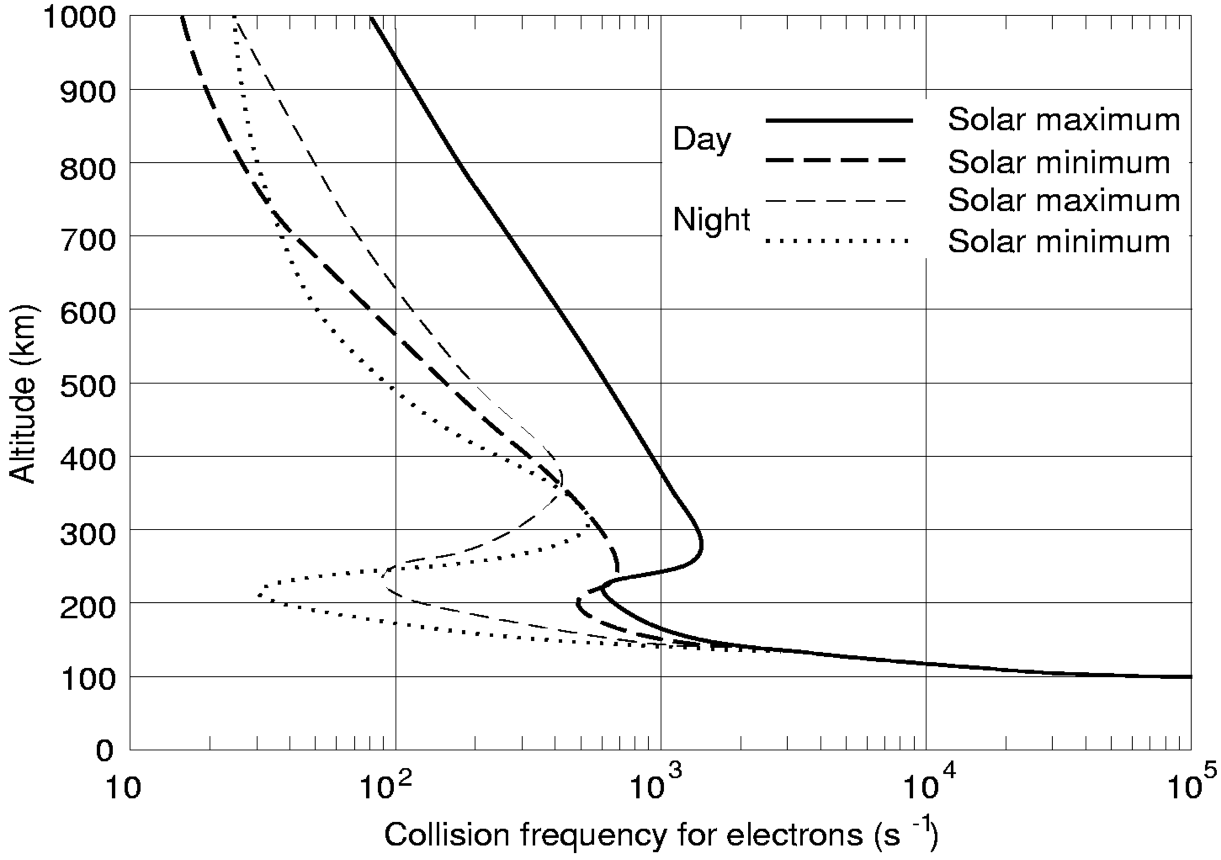


$$\mathbf{i} = \boldsymbol{\sigma} \cdot \mathbf{E}$$

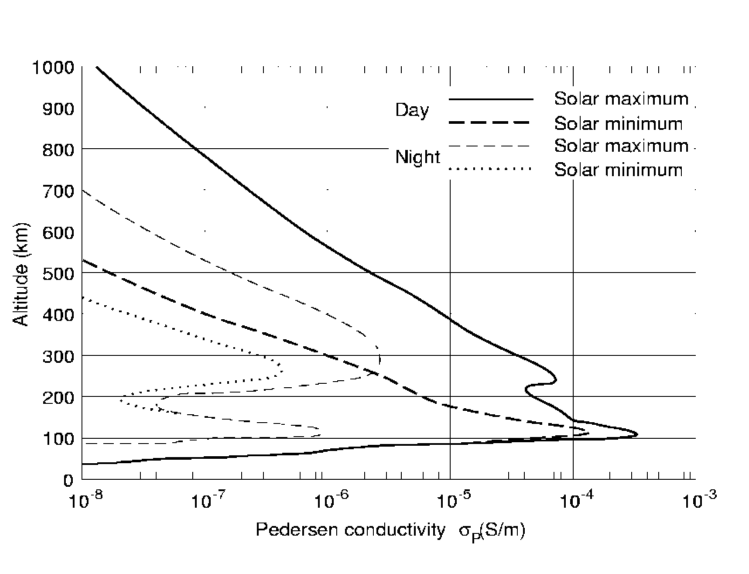
$$\boldsymbol{\sigma} = \underbrace{\begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_{//} \end{pmatrix}}_{\textit{conductivity tensor}}$$

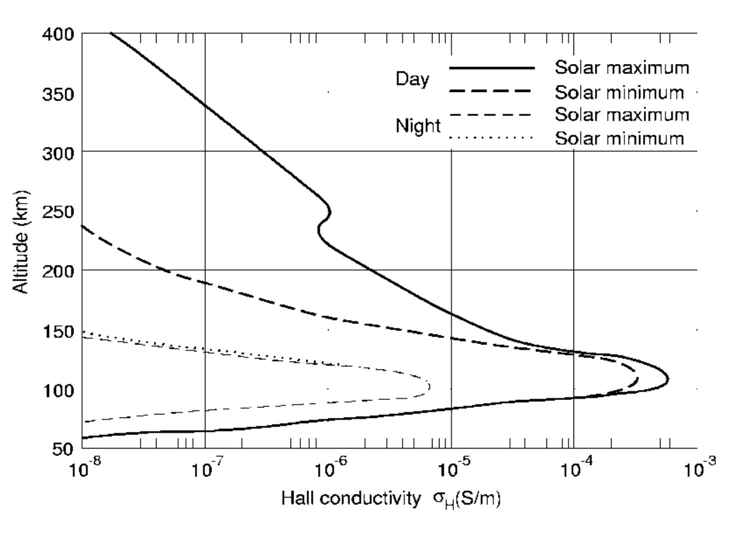
May be formulated as a tensor equation

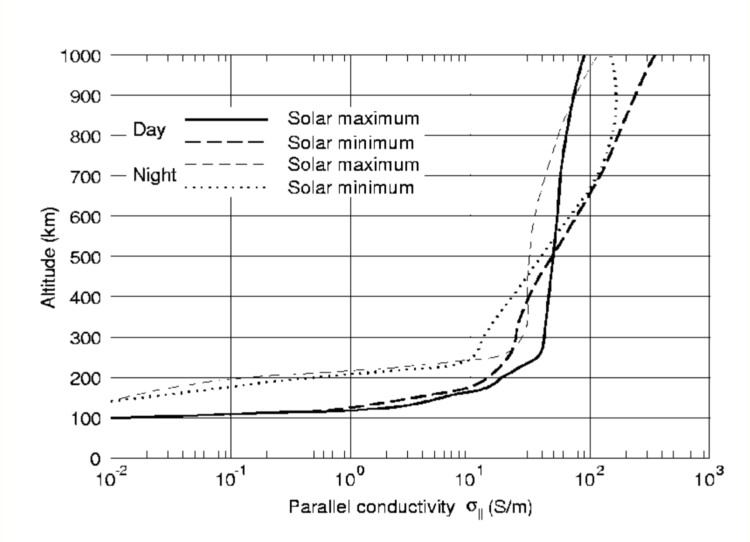
Collisional frequency



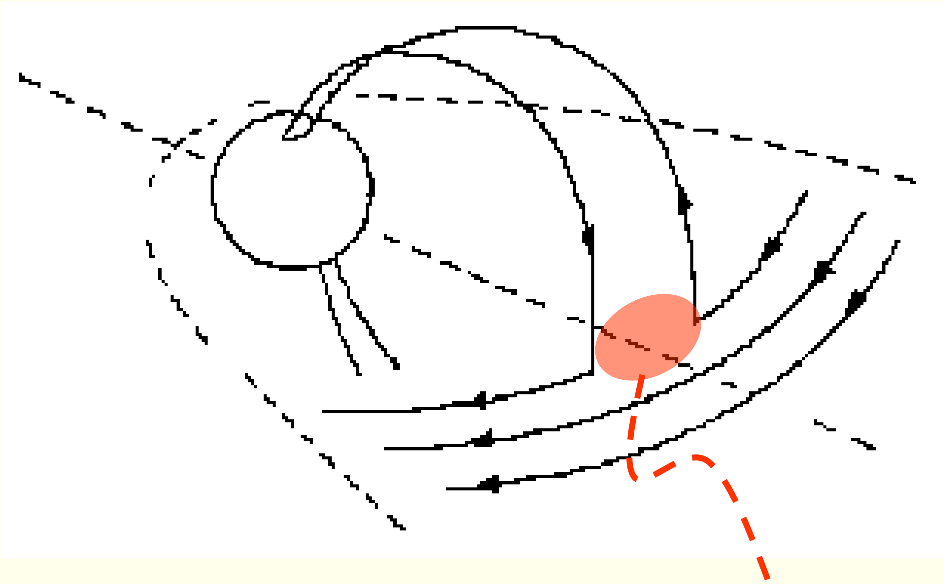
Ionospheric conductivities







Consequence: Birkeland currents



When the conductivity out in the magnetosphere is low, it is easier for the current to close through the ionosphere via currents parallel to the geomagnetic field. Such currents are called *Birkeland* currents.

Exemple: Electric field 700 km above the aurora.

$$\mathbf{E} = E_x \hat{\mathbf{x}} + E_y \hat{\mathbf{y}}$$

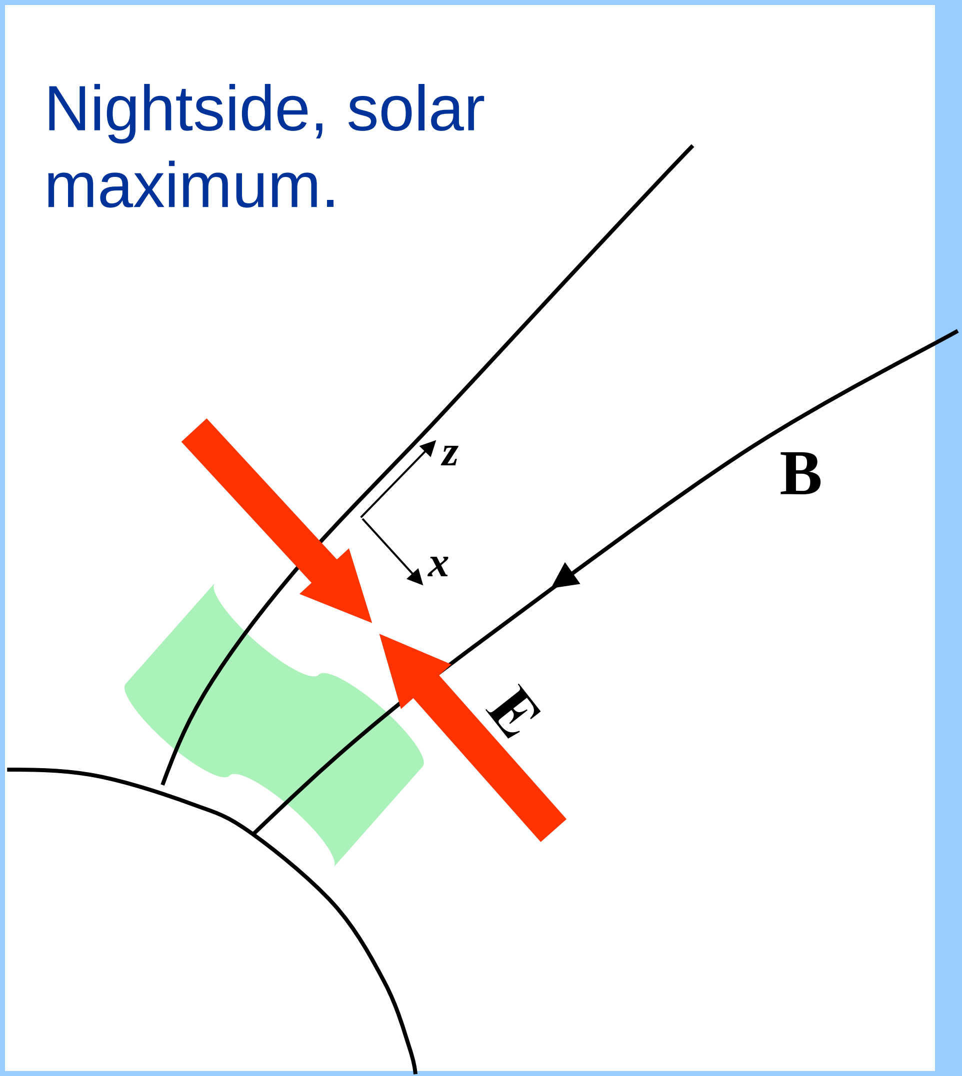
$$E_x = 1\,\mathrm{Vm}^{-1}$$

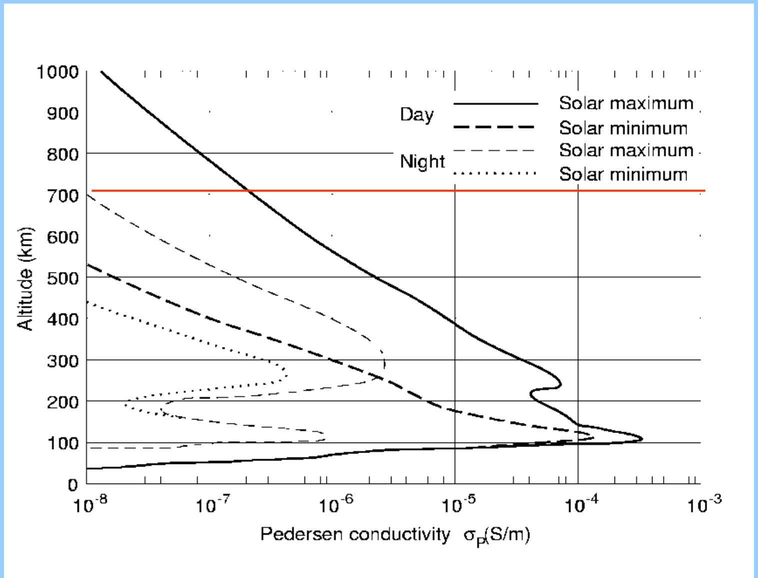
$$E_z = 1\,\mu\mathrm{Vm}^{-1}$$

$$\left.\begin{array}{l} j_P = j_x = 0.01\ \mu\mathrm{Am}^{-2} \\ j_{//} = j_z = 40\ \mu\mathrm{Am}^{-2} \end{array}\right\}$$ Yellow

$$\left.\begin{array}{l} j_P = j_x = 10.0\ \mu\mathrm{Am}^{-2} \\ j_{//} = j_z = 4.0\ \mu\mathrm{Am}^{-2} \end{array}\right\}$$ Red

$$\left.\begin{array}{l} j_P = j_x = 1.0\ \mu\mathrm{Am}^{-2} \\ j_{//} = j_z = 40\ \mathrm{mAm}^{-2} \end{array}\right\}$$ Blue



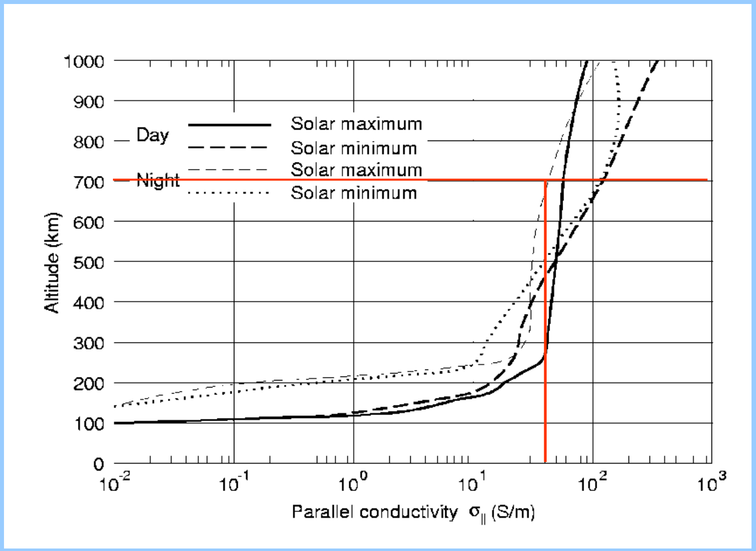


$$\sigma_P \approx 1\cdot 10^{-8}\ \mathrm{Sm}^{-1}$$

$$\sigma_{//} \approx 40\ \mathrm{Sm}^{-1}$$

$$j_P = j_x = \sigma_P E_x = 1\cdot 10^{-8}\ \mathrm{Am}^{-2} = 0.01\,\mu\mathrm{Am}^{-2}$$

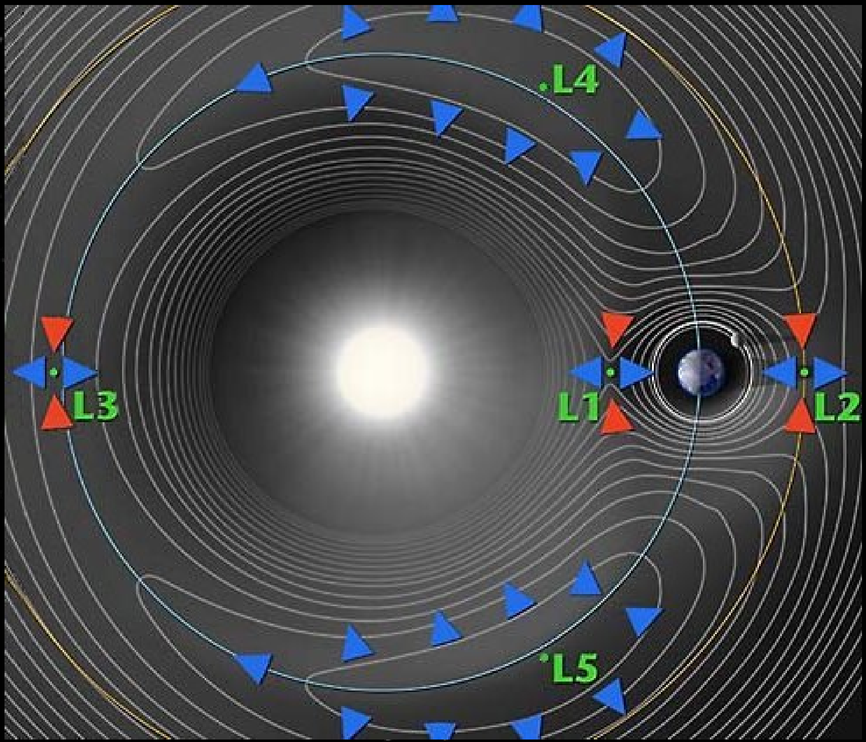
$$j_{//} = j_z = \sigma_{//} E_z = 40\cdot 10^{-6}\ \mathrm{Am}^{-2} = 40\,\mu\mathrm{Am}^{-2}$$



Yellow

Last Minute!

SOHO
(Solar and Heliospheric Observatory)



SOHO orbits the first Lagrange point

ESA - NASA collaboration