

Cherenkov Effect in ionospheric E layer plasma for Oxygen-ion

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Abstract

Cherenkov radiation is an electromagnetic Radiation that occurs in completely clear medium. The sufficient scientific condition for the phenomenon to be occurred is that the velocity of charged particles moving with should be greater than that of the electromagnetic radiation there (generally speaking this radiation is in the UV range of emission).

In this paper Cherenkov effect considered in the ionospheric E layer plasma and it showed that the velocity of charged particles in this plasma is greater than that of the phase velocity of electromagnetic radiation. Then the relation between Cherenkov frequency and the height and temperature of the this plasma studied .Also the Cherenkov angle for the oxygen ion that emits Cherenkov radiation is calculated. In this plasma as an important wave we considered only the oxygen-ion wave .

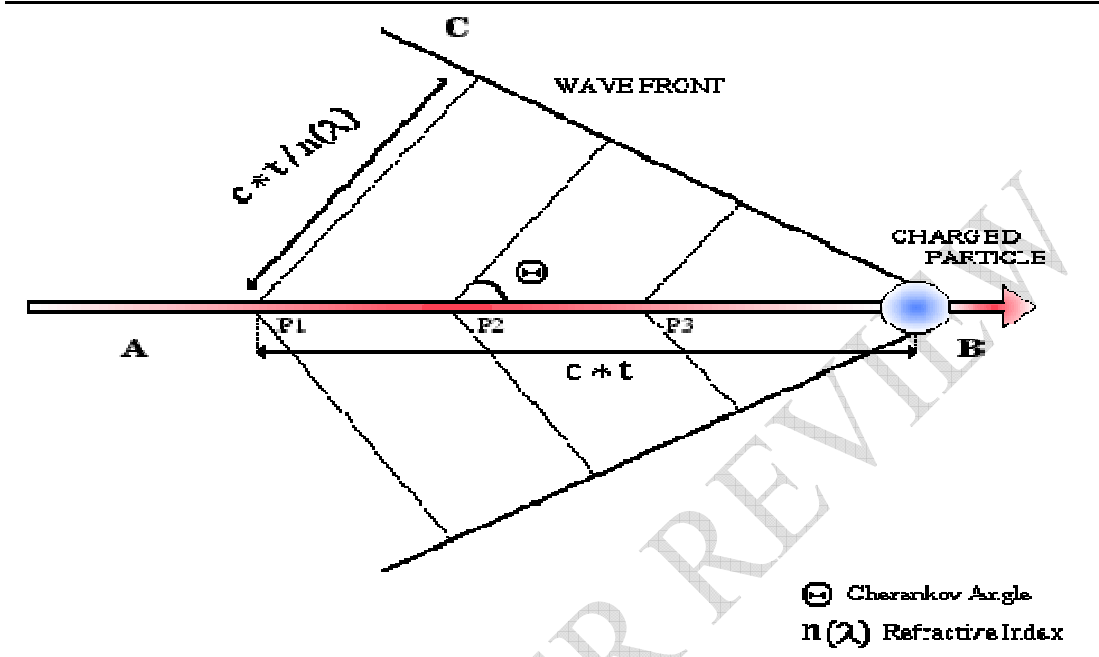
Key words: Cherenkov Radiation, Ionospheric E layer plasma, Oxygen-ion wave, UV frequency

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Introduction

Cherenkov radiation was first observed in the early 1900's by the experiments developed by Mary and Pierre Curie when studying radioactivity emission. The first attempt to understand the phenomenon was made by Mallet in 1926. He found that the light emitted from a wide variety of transparent bodies placed close to a radioactive source always had the same bluish- white quality, and the spectrum was continuous, that is not possessing the line or band structure characteristic of fluorescence. Mallet found that the nature of such emission is not be known yet . It was not until the experimental work carried out between years 1934-1937 by P. A. Cherenkov and the theoretical interpretation by I. E. Tamm and I. M. Frank (1937) that this radiation was described. Cherenkov light in the atmosphere is produced by charged particles traveling faster than the speed of the light in medium[1].

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Figure.1- Path of Cherenkov emission [2].

60 From this figure it is understood that this radiation is only observed at a particular angle θ
61 called Cherenkov angle, with respect to the track of the particle. This angle represents the
62 position in which waves from arbitrary point such as P1, P2 and P3 over the track AB are
63 coherent and combine to form a plane wave front BC. This coherence takes place when the
64 particle travels from A to B in the same time that the light travels from A to C. If the
65 velocity of the particle is v or $\beta.c$ where c is the velocity of light in vacuum, and c/n is the
66 velocity of the Cherenkov light in the medium, then we can write the Cherenkov angle in
67 the following way with only taking into account the geometrical considerations:[3]
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$$\cos\theta = \frac{\frac{c}{n(\lambda)}\Delta T}{\beta.c\Delta T} \quad (3-1)$$

$$\cos\theta = \frac{1}{\beta.n(\lambda)} \quad (3-2)$$

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where n is the refractive index of the medium and ΔT is the time in which the particle moves from A to B.

73 The number of photons emitted by a charged particle of charge ze per unit path length ,per
74 unit energy interval, in term of λ , of the photons is equal to :[4]

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$$\frac{d^2N}{dx d\lambda} = \frac{2\pi\alpha z^2}{\lambda^2} \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) \quad (3-3)$$

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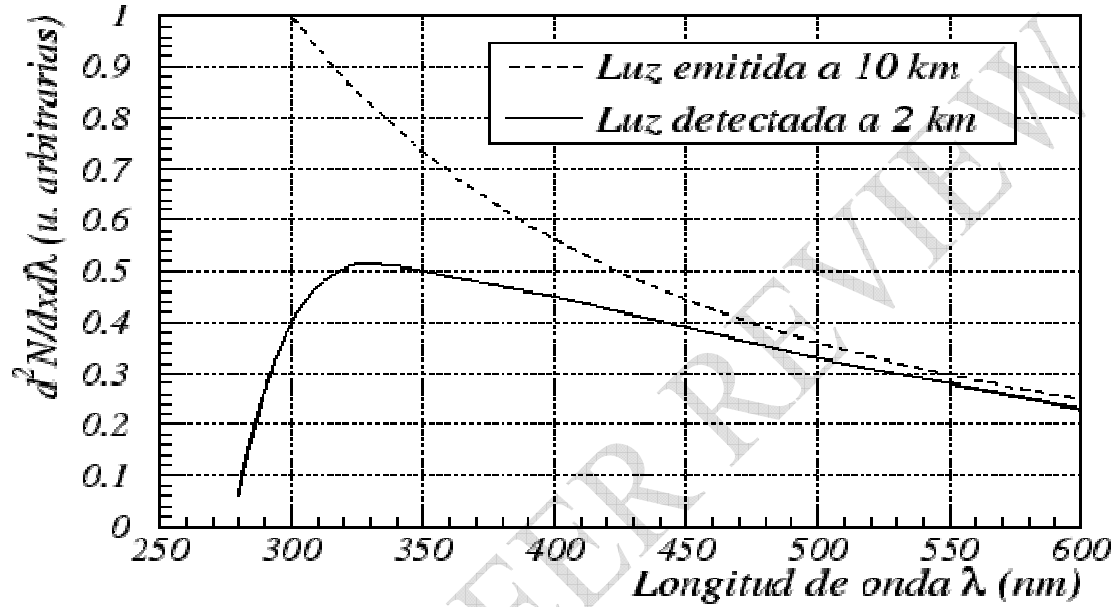


Figure.2-Differential Cherenkov photon spectrum. Continuous line includes absorption by ozone and Rayleigh and Mie scattering [5].

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79 where α is the micro structure constant $\alpha = \frac{e^2}{hc} = \frac{1}{137}$ and n is the refraction index of the
 80 medium that is a function of the photon energy, straight forward to λ . This means that
 81 most part of Cherenkov photons are emitted in the ultraviolet range, because :

$$\frac{d^2N}{dx d\lambda} \propto \frac{1}{\lambda^2}$$

82 and the spectrum has a peak at around 330 nm[6].

83 In ionosphere from 90 kilometer of earth surface up to 120 kilometer of earth surface the E
 84 layer occurred that in this medium the oxygen ionization take place with solar x ray and uv
 85 radiation respectively.

86 Because the plasma is a quasi-neutral gas with equal electrons and ions particles together
 87 with neutral species, then the E layer also is a plasma medium so as we can use the
 88 plasma equations for the parameters inside .

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90 Equations

91 We use the MHD approximation specially when the orientation of motion for ion is
 92 parallel to magnetic field , then this would be :

$$93 \quad Mn \left[\frac{\partial v_i}{\partial t} + (v_i \cdot \nabla) v_i \right] = enE - \nabla p \quad (4.1)$$

94

95 With consideration of:

$$96 \quad E = -\nabla \varphi, \quad ik\hat{x} = \nabla, \quad -i\omega = \frac{\partial}{\partial t}$$

$$n_e = n_0 + n_1, \quad v_e = v_0 + v_1, \quad E = E_0 + E_1$$

97 That in these equations ,index 1 shows the turbulence state.

98 So we have:

$$99 \quad -i\omega Mn_0 v_{1i} = -en_0 ik\varphi - \gamma_i k T_i i n_1 \quad (4.2)$$

100

101 Also from Boltzmann equation it is true that :

$$102 \quad n_e = n_0 e^{\frac{e\varphi}{kT_e}} \rightarrow n_e = n_0 \left(1 + \frac{e\varphi_1}{kT_e} \right) \rightarrow n_1 = n_0 \frac{e\varphi}{kT_e} \quad (4.3)$$

103 The continuity equation also is:

$$104 \quad \frac{\partial n_e}{\partial t} + \nabla \cdot (n_e v_e) = 0 \quad (4.4)$$

105 But we knew:

$$\nabla n_0 = v_0 = E_0 = 0$$

$$\frac{\partial n_0}{\partial t} = \frac{\partial v_0}{\partial t} = \frac{\partial E_0}{\partial t} = 0$$

106 In the continuity equation we can write:

$$107 \quad \frac{\partial n_1}{\partial t} + \nabla \cdot (n_0 v_1 + n_1 v_1) = 0 \quad (4.5)$$

108 With replacing approximation of $\nabla \cdot (n_1 v_1)$ we can write:

$$109 \quad \frac{\partial n_1}{\partial t} + \nabla \cdot (n_0 v_1) = 0$$

$$110 \quad \text{and because } \nabla = ik\hat{x} \text{ and } \frac{\partial}{\partial t} = -i\omega$$

111 we reach to:

$$112 \quad -i\omega n_1 = -n_0 ik v_1 \quad (4.6)$$

113 Now refer to the Equations (4.6) and (4.3) ,we can write MHD approximation as:

$$114 \quad -i\omega M n_0 v_{1i} = \frac{(en_0 ik \frac{KT_e}{M} + \gamma_i KT_i ik) n_0 ik v_{i1}}{i\omega} \quad (4.7)$$

115 so we reach to:

$$116 \quad \omega^2 = k^2 \left(\frac{KT_e}{M} + \frac{\gamma_i KT_i}{M} \right) \quad (4.8)$$

117 with the limitation of $T_i \rightarrow 0$

118 we can write:

$$119 \quad \omega^2 = k^2 \left(\frac{KT_e}{M} \right)^{1/2} \quad (4.9)$$

120 Now for the bottom side and up side of the ionosphere values with taking on account the Fig.3 we have :

$$121 \quad T(90 \text{ km}) = 300 \text{ K}^\circ \text{ and } T(120 \text{ km}) = 600 \text{ K}^\circ \text{ and}$$

$$122 \quad K = 1.37 \times 10^{-23} \text{ and } M(o) = 2.65 \times 10^{-26} \text{ kg}$$

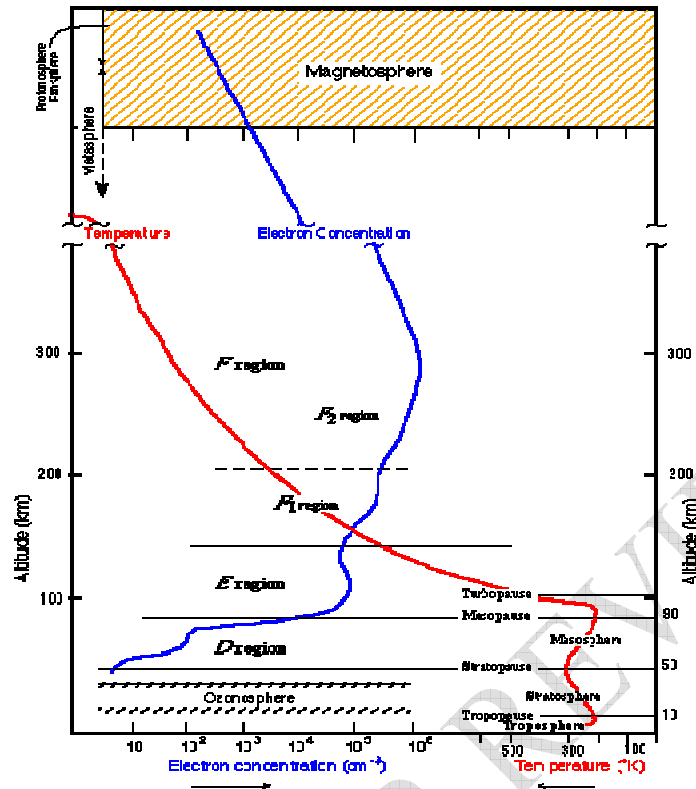


Figure.3- Temperature and electron density in ionospher[7].

so:

At 90 kilometer from the earth surface:

$$\frac{\omega}{K}(O) = \left(\frac{KT_e(90 \text{ km})}{M} \right)^{1/2} = \left(\frac{1.37 \times 10^{-23} \times 300}{2.65 \times 10^{-26}} \right)^{1/2} = 3.93 \times 10^2 \quad \left(\frac{j}{kg} \right)^{1/2} \quad (4.10)$$

And at the 120 kilometer from the earth surface:

$$\frac{\omega}{K}(O) = \left(\frac{KT_e(120 \text{ km})}{M} \right)^{1/2} = \left(\frac{1.37 \times 10^{-23} \times 600}{2.65 \times 10^{-26}} \right)^{1/2} = 5.56 \times 10^2 \quad \left(\frac{j}{kg} \right)^{1/2} \quad (4.11)$$

With Maxwell equation in the following :

$$\nabla \times B = \mu_0(j_f + j_p + \epsilon_0 \dot{E}) \quad (4.12)$$

And rewriting this equation in the following form :

$$\nabla \times B = \mu_0(j_r + \epsilon \dot{E}) \quad (4.13)$$

139 And putting :

$$140 \quad \varepsilon = \varepsilon_0 + \frac{j_P}{\dot{E}} \quad (4.14)$$

141 and the following values:

$$142 \quad j_P = ne(V_{ip} - V_{ep}) \quad (4.15)$$

$$143 \quad v_p = \mp \frac{1}{\omega_{CB}} \frac{dE}{dt} \quad [8] \quad (4.16)$$

144 So:

$$145 \quad j_P = ne(V_{ip} - V_{ep}) = \frac{ne}{eB^2} (M + m) \frac{dE}{dt} = \frac{\rho}{B^2} \frac{dE}{dt} \quad (4.17)$$

146 Which from equation(4.14) it is obvious that :

$$147 \quad \frac{\varepsilon}{\varepsilon_0} = 1 + \frac{\mu_0 \rho C^2}{B^2} \quad (4.18)$$

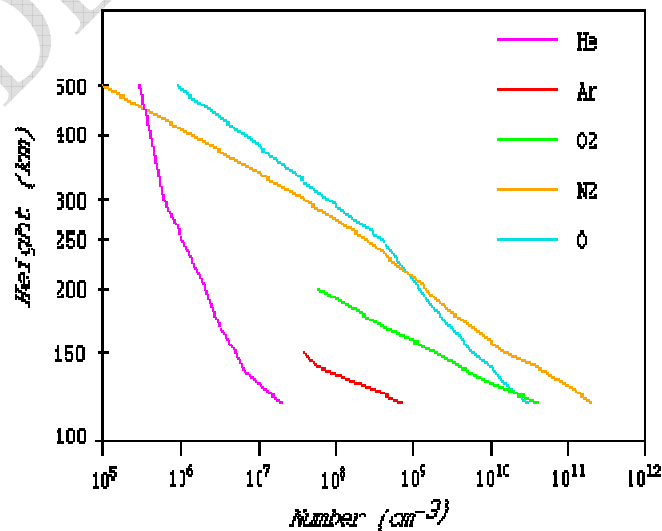
148 With the approximate values about $2^{nd} \gg 1$ we reach :

$$149 \quad \frac{\varepsilon}{\varepsilon_0} \cong \frac{\mu_0 \rho C^2}{B^2} \quad (4.19)$$

150 And

$$151 \quad n = \sqrt{k} = \frac{\sqrt{\varepsilon}}{\sqrt{\varepsilon_0}} = \left(\frac{\mu_0 \rho C^2}{B^2} \right)^{1/2} \quad (4.20)$$

152 From the following we know the density of oxygen :



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Figure.4-density of elements in ionosphere [9].

At 90 kilometer from the earth surface:

$$\rho(O) \propto 10^{13} (cm^{-3})$$

And at the 120 kilometer altitude:

$$\rho(O) \propto 10^{12} (cm^{-3})$$

Also we knew that the magnetic field intensity in E layer plasma about 1(Oe)[10]. We reach to:

$$B = \mu_0 H = 4\pi \times 10^{-7} \times \frac{1}{4\pi} \times 10^3 = 10^{-4} (T) \quad (4.21)$$

Then:

At 90 kilometer altitude:

$$n(O) = \left(\frac{4\pi \times 10^{-7} \times 9 \times 10^{16} \times 5.3 \times 10^{-26} \times 10^{19}}{10^{-8}} \right)^{1/2} = 1.73 \times 10^6 \quad (4.22)$$

And about the 120 kilometer altitude:

$$n(O) = \left(\frac{4\pi \times 10^{-7} \times 9 \times 10^{16} \times 5.3 \times 10^{-26} \times 10^{18}}{10^{-8}} \right)^{1/2} = 5.47 \times 10^5 \quad (4.23)$$

With regards to the speed of light c/n

At 90 kilometer from the earth surface:

$$c/n = 1.73 \times 10^2 \quad m/s \quad (4.24)$$

And at 120 kilometer from the earth surface:

$$c/n = 0.54 \times 10^2 \quad m/s \quad (4.25)$$

refer to the following figure and considering a volume of polarized plasma we reach to the electric field as:

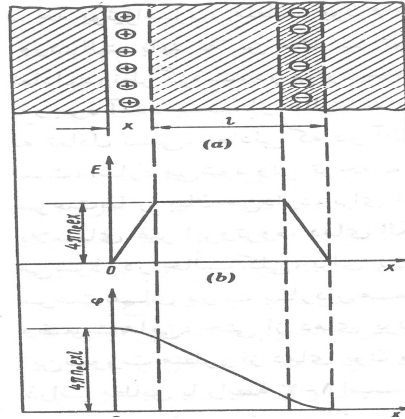


Figure.5- Diagram of plasma state in the E layer[11].

$$E = 4\pi\sigma = 4\pi n_e e x \quad (4-26)$$

The electric potential is as :

$$\phi = lE = 4\pi n_e e x l \quad (4-27)$$

That in this equation l is the width of E layer or 3×10^4 m.

If we put $x \approx l$:

$$E = e\phi = 4\pi n_e e^2 l^2 \quad (4-28)$$

from figure.3 we know:

$$n_e(90 \text{ km}) = 10^4 \text{ (cm}^{-3}\text{)}$$

$$n_e(120 \text{ km}) = 10^5 \text{ (cm}^{-3}\text{)}$$

The energy will be :

$$E(90 \text{ km}) = 4\pi \times 10^{10} \times (1.6 \times 10^{-19})^2 \times (3 \times 10^4)^2 = 2.89 \times 10^{-18} \text{ j} \quad (4-29)$$

$$E(120 \text{ km}) = 4\pi \times 10^{11} \times (1.6 \times 10^{-19})^2 \times (3 \times 10^4)^2 = 2.89 \times 10^{-17} \text{ j} \quad (4-30)$$

Refer to $v = \sqrt{\frac{2E}{m}}$:

So:

1-At the bottom side of the E layer(90Km) :

$$v(0) = \sqrt{\frac{2E}{m}} = 1.47 \times 10^4 \text{ m/s} \quad (4-31)$$

2-At the upper side of the E layer(120Km):

$$192 \quad v(o) = \sqrt{\frac{2E}{m}} = 4.67 \times 10^4 \frac{m}{s} \quad (4-32)$$

$$193 \quad \text{We know } v = \frac{E}{h}$$

194 1-At:

$$195 \quad V = \frac{2.89 \times 10^{-18}}{6.62 \times 10^{-34}} = 4.36 \times 10^{15} \text{ Hz} \quad (4-33)$$

196 2- At:

$$197 \quad v = 4.36 \times 10^{16} \text{ Hz} \quad (4-34)$$

198 From equation (3.2) it showed that:

$$\cos\theta = \frac{1}{\beta \cdot n(\lambda)}$$

199 And because:

$$200 \quad V = \beta \cdot c$$

201 We can write:

$$202 \quad \cos(\theta) = \frac{c}{V \cdot n(\lambda)} \quad (4-35)$$

203 It is resulted that the velocity of oxygen ion is greater than that of the of electromagnetic
204 waves in E layer, obviously this is because the Cherenkov effect is possible

205 So oxygen ion emits Cherenkov radiation in the following angles:

206 At 90 kilometer altitude:

$$207 \quad \theta(0) = 83.22^\circ \quad (4-36)$$

208 And at 120 kilometer altitude:

$$209 \quad \theta(0) = 89.327^\circ \quad (4-37)$$

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211 Conclusion Remarks

212 1-It is shown that in two limit of height at E layer the thermal velocity of Oxygen ion is
213 greater than the phase velocity of ionic wave of Oxygen and so Cherenkov radiation is
214 possible.

215 2- At 90 kilometer altitude Cherenkov radiation emitted in 83.22° from oxygen ions.

216 3- At 120 kilometer from earth surface Cherenkov radiation emitted in 89.327° from the
217 same oxygen atoms.

218 4-the frequency of Cherenkov radiation is in UV range.

219 5- With increasing the height and temperature in E layer Cherenkov frequency increased.

220 6-In other hand increasing the height and temperature in E layer Cherenkov angle also increased.

221 8- Then with increasing the height and temperature in E layer the phase velocity of ionic waves
222 increased.

223 9- With increasing the height and temperature in the E layer plasma would lead to increasing the
224 thermal velocity of ions.

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226 Experimental Achievements

227 1-Cherenkov radiation is received by a magnetic satellite that circles around ionosphere
228 and it is showed that Cherenkov frequency is in UV range [12].

229 2-In presence of electrical field in E layer refractive index is greater than 1, and Cherenkov
230 radiation is observed [13].

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232 References

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234 [1],[2],[3],[4],[5],[6]-Wilhelmi,E, , "Cherenkov radiation" Departamento de Física Atómica,
235 Molecular y Nuclear Facultad de Ciencias Físicas Universidad Complutense de Madrid
236 ,(2001)

237 [7]-RSPP(radio and space plasma physics group," ionospheric physics", university of
238 Leicester,(2005)

239 [8]-Chen,F"introduction to plasma physics and controlled fusion" vol1.
240 2nd.plenum press(1994),p83

241 [9]-RSPP(radio and space plasma physics group," ionospheric physics", university of
242 Leicester,(2005)

243 [10],[11]-Golant,V.E,Zhilinskaya A.P,Sakharov,I.E,"Fundamentals of plasma physics
244 ,published in Russian by Atomizdat,(1998).

245 [12]-Biancalani,A. Pegoraro,F. "Cherenkov emission of electron cyclotron waves by a
246 magnetized satellite orbiting the ionosphere"(2008)

247 [13]-Pokhotelov,D," "Effects of the active auroral ionosphere on magnetosphere-
248 ionosphere coupling"(2005),p32

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