Polar Gap Properties for Neutron Star Within Light Cylinder Limits

Sundus A. Abdullah*

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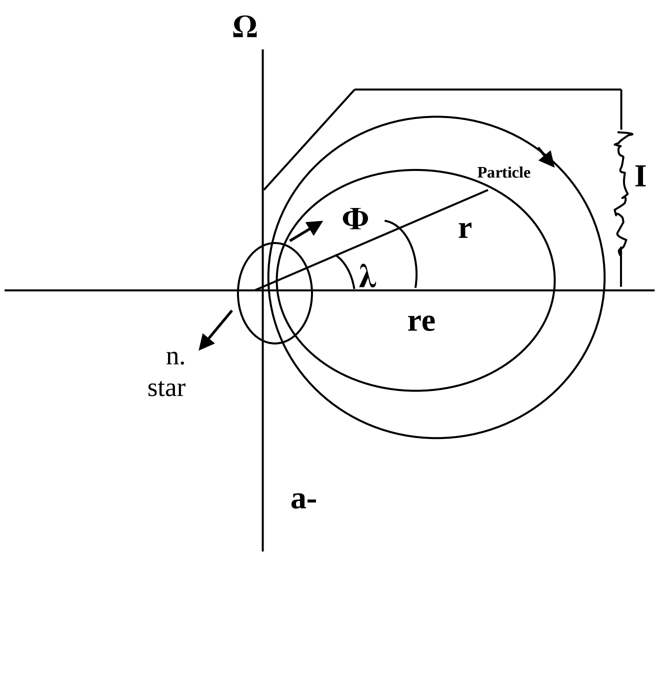
ABSTRACT:

The huge magnetic fields of neutron star cause the nuclei of the stellar surface to form a tightly bound condensed layer. In this research some characteristics of polar gap and magnetosphere enclosed the star according to Sturrock Model were illustrated, positrons move out along the open field lines, and electrons flow to the stellar surface as in the related to Sturrock model. The magnetic field within polar gap areas, which is defined by the Irvin Radius (R_L) decreases due to the expansion of the polar, resulting from the physical motion of the accreted material. The values of height gap at different distances from the star were estimated. The obtained results improve the most energetic positrons those with $E \approx E_{max}$ radiate away their energy in a distances re = 10^4m above the polar gap while less energetic positrons produced at much greater distances re =10^8m. The potential drop across the polar gap is obtained using a well defined adopted formula, it is found that the potential drop across the polar gap grows like (h^2), when $h \ll r_p$

1- Introduction

A spinning magnetized neutron star generates huge potential difference between different parts of its surface[1]. Charged particles flow out from the star to the neighborhood of light cylinder (where the co- rotation velocity is the velocity of light), the open magnetic field lines which penetrate the light cylinder play a role analogous to that of conducting wires in ordinary circuits as shown in fig.(1-a)[2] .



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* Department of Astronomy – College of Science – University of Baghdad.

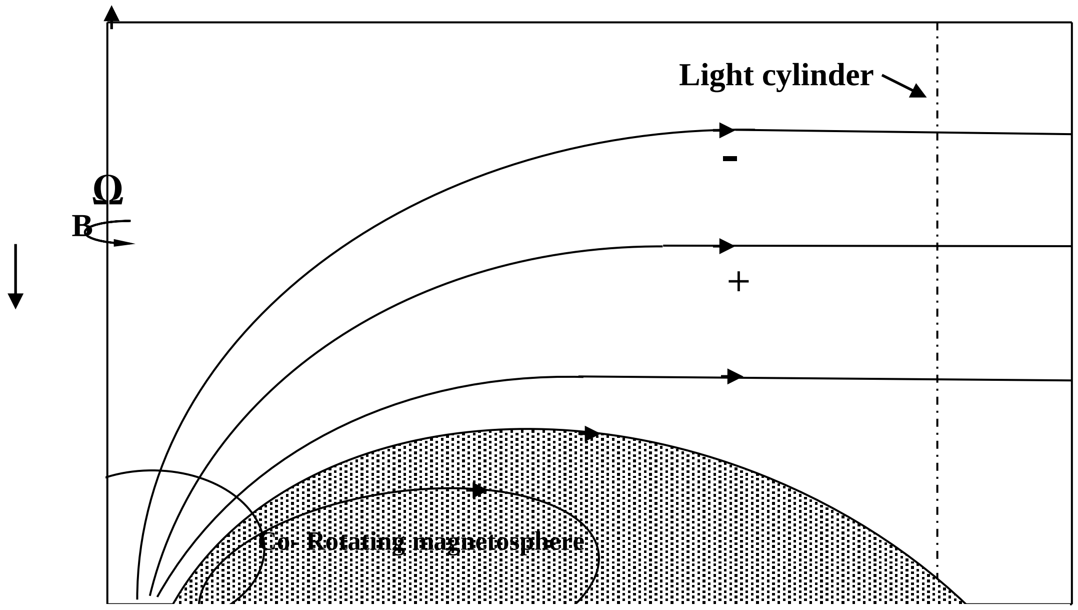

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Fig.(1,a-b) :a – A rotating conducting magnetized sphere as a homopolar generator. The charged particle moving along field lines flow out from the star with potential difference (ΔΦ), r: the curvature radius, re: the distance from the center of star, λ: the position angle of particle
b- The positive and negative charges will be pulled out of the surface and accelerated along the open field lines, [2].

The typical voltages that will be generated by an iron magnet and a neutron star are given in the table (1) [3].
Table (1): presents the values of voltages, radius(R),periods(P) and magnetic field for an iron magnet comparison with the neutron stars:

	Iron	Neutron star (n.s)
R(m)	10	10^4
P(sec)	.015	1
B(Gauss)	10^4	10^{15}
ΔΦ (Volts)	5	3×10^{16}

Where R: The radius of neutron star (m)

B: The surface magnetic field of star
ΔΦ: Potential drop

The out flow of charged particles along field lines from the outer regions of the magnetosphere cause a magnetospheric gap to build upon the (open) field lines which connect it to the stellar surface, as shown in fig .(1-b). There (E.B) value does not vanish it essentially does every where else in the near magnetosphere[1,4]. The inability of the stellar surface to supply a flow of positive ions ultimately causes the near magnetosphere above the polar gap to pull away from the surface and leave a gap, [5].

In this research some characteristic of polar gap are illustrated, the height of polar gap with different values of magnetic field are determined within light cylinder limits. The potential difference across the polar gap within light cylinder limits are illustrated with angular frequency Ω=2π.

The maximum energy of particles is calculated at different distances (re) from the surface of neutron star. Notational energy of the star becomes available to the outside of the star when the potential difference across the polar gap, sustained by rotation, drives the current across the stellar surface.

2- The Residual Fields of Neutron Stars

The majority of neutron star in globular clusters must be very old and hence whether their fields have decayed or nor, the presently observed fields is direct evidence that magnetic field of neutron star do not decay indefinitely, there is of course, a possibility that some of these neutron stars (n.s) could have been formed more recently due to accretion induced collapse of white dwarfs. There are two possible origins of neutron stars in a low mass x-ray binary[6]:
a- From an accretion induced collapse of a massive white dwarf.
b- The standard supernova scenario.

3- The Standard Model

In 1971 Sturrock considered an electron – positrons production from the curvature of radiation flowing out of the stellar surface, [7]. The accelerating electric fields were essentially taken as those which would obtain if there were no co rotating magnetosphere at all on open field lines. The associated accelerating voltages are then much greater than those from space change effects in the co rotating magnetosphere associated with bringing the emitted electrons to relativistic speeds, these give for (P=1s) less than a 10^{10} V potential drop above the surface [7,8].

4- The Polar Gap

We shall deduce consequences for the near magnetosphere from two circumstances:
1- We accept the conventional wisdom that electrons, flow out through the light cylinder along swept – pack magnetic field lines, do not easily flow back through the light cylinder into the co rotating magnetosphere.
2- The neutron star surface is a copious supplier of electrons, but not of positive ions.
The positively charged magnetosphere at the surface of the neutron star begins to pull away from the surface and produces a growing gap. Wherever the near magnetosphere charge density is non zero, E.B=0 as shown in figures.(2, 3)[2].The rotating magnetosphere is derived for a rotating neutron star with an aligned pure dipole magnetic field.

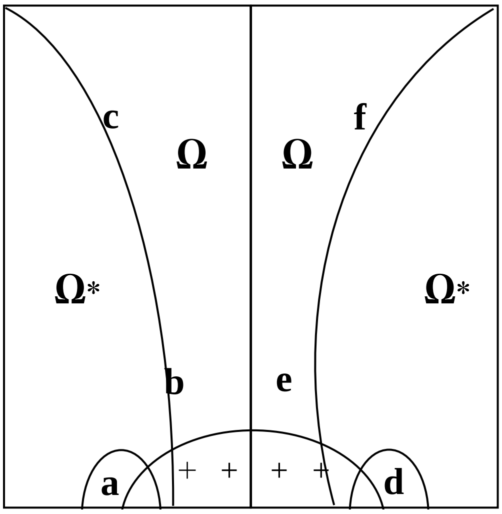


Fig.(2) magnetosphere of a rotating neutron star (angular velocity Ω^*).the magnetosphere within the cone(cbef) rotates with angular velocity Ω .significant departures of E.B from zero occur only within the polar gap (abed).

5- Considerations and Basic Idea

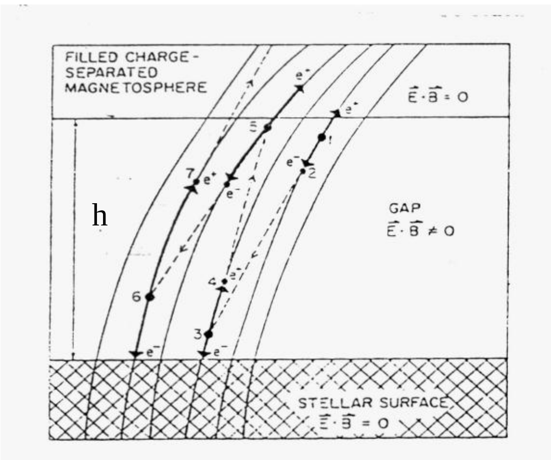
5-1 Spherical Gap

We consider a rotating (angular frequency) neutron star with an axisymmetric dipolar magnetic field aligned with the rotation axis as shown in fig.(1-b).The magnetosphere is separated from the star by a spherical gap of height h as shown in fig.(3), and two rotation speeds are related by +[2,3]:

$$\Omega^*/\Omega = (1+3h^2/R^2) \quad (h \ll R) \text{ ----------- } (1)$$

Where Ω^*: is angular frequency of neutron star (s^{-1})

Ω: is the angular frequency of magnetosphere (s^{-1})
R: is the radius of star ($R= 10^4$m)



h: the height of the polar gap (m)

Fig. (3)The magnetosphere is separated from the star by spherical gap of height h, also this cascade pair production acceleration of electrons and positrons along field lines [3].

At the pole, the gap electric field at neutron star is normal to the stellar surface and is given by [10]:

$E_p= 2\Omega\mathbf{B}h /c$ (h«R) ------------ (2)
Where c: the light speed
B: the magnetic field of neutron star which is given by, [9]

$\mathbf{B} = (a/r^3)\,[1+3 \sin^2\lambda]^{1/2}$ -------------- (3)

Where r: the magnetic line of force has the form:
$r= r_e \cos^2\lambda$ -------------------- (4)
Where re: the distance from the center of star as shown in fig.(1-a).
a : the dipole magnetic moment was estimated to be (2×10^{20} Tm^3)[9].
λ :the position angle of particle as shown in fig.(1-a).
The relation between the height of gap (h) and the potential drop (ΔΦ) along field line traversing the gap is given by:

$\Delta\Phi =2 \pi \rho_e h^2$ -------------------- (5)

Within the neutron star the matter is assumed to be a conductor, because of the interior uniform ax magnetization.
The charges density is given by:

$\rho_e = \mathbf{B}\, \Omega^* / 2\pi c$ ---------------------(6)
Equation (5) with equation (6) gives:

$\Delta\Phi= \Omega\, \mathbf{B}h^2/ c$ ---------------------- (7)
* Equation (7) represents the potential drop across the polar gap [7].
For an aligned dipolar magnetic field, the magnetosphere charge density is purely quadrupolar [2].
The potential drop across the gap for different values of magnetic field is determined by the equation (7). The important physical case will be occur in the gap formed when positive charge flows out along the open field lines emanating from the polar gap of radius ($r_p= 10^2$m) , and the surface binding of ions does not permit its replacement from the star, when the height of the gap h« rp .

5-2 Limitation the Height of Gap for Neutron Star

The gap height (h) will grow at speed near the light velocity (c) if the out ward flow of positive charge through the light cylinder limits that of equation[6]:
$N_{max}= \varphi\Omega / 2 \pi$ ------------ (8)
Where N_{max}: maximum net charged particle flux from the polar gap
φ : total open field line flux from polar gap
Ω : angular frequency (Ω=2 π)
Figures (4, 5) represent the relationship between height (h) and the potential drop a long a field line traversing the gap within light cylinder limits, ($r_e = 10^4$ m ,10^6 m,10^8 m)
In the huge gap magnetic field any γ-ray whose energy greatly exceeds ($2m_ec^2$) may generate an ($e^- e^+$) pair, for $\mathbf{B} = 10^{14}$Gauss, $\Omega = 2\pi\ s^{-1}$, and $h= 10^3$cm,

$e\Delta\Phi \approx 10^{11}$ eV. The electron moving along the curved magnetic field lines emits "curvature radiation ", the height of the polar gap is given by the equation:

$h = m^2c^{3\,/}\,\mathbf{B}e$ ------------------- (9)

It remains to be shown that the curvature radiation from the particles produced the end accelerated in the gap can lead to a quasi- steady discharge of the gap on each grows. Fig. (6) shows the relation between the height of polar gap, and the potential drop at different values of magnetic field for neutron stars. We approximate the magnetic field within the polar gap as constant in magnitude and normal to the stellar surface.

5-3 Determination the Energy of Particle

According to Sturrock model that the poloidal field is stretched out by the out flowing matter beyond the radius R_L which seems to require that the kinetic energy density must exceed the magnetic energy density. The acceleration of the charge is so rapid that the radiated power exceeds the power supplied to the charges by the stellar rotation. It means the rate of energy loss through curvature radiation by an electron or positron of energy γmc^2. The maximum energy of such an particle is given by [8]:

$e\,\Delta\Phi_{max} = \Omega\,\mathbf{B}rp\,/2c$ ----- (10)

Where rp: the radius of the polar gap region out of which flow of positive charges [8].

As the gap height (h) approaches and exceeds rp , the electric field begins to drop exponentially with height[6,8]:

$E = \exp(-h\,/\,rp)$ ------------- (11)

Calculations and Results:

Fig. (7) represent the values of maximum energy at different distances from the surface of neutron stars where $r_{max} = 2\times10^8$ m .The frequency of coherent radiation at this distance is:

$$\upsilon_{min} = 1.5\times10^7 \text{ Hz}$$

Whether this estimate of υ_{min} is depends on quantitative details of the time history of a gap. However, the existence of a υ_{min} in this region predict that neutron star radiation emission should reach a maximum at frequency:

$$10^7 \text{Hz} < \upsilon < 2\times 10^9 \text{ Hz}$$

The results indicated that all of the radiation of typical neutron star is predicated to occur at distances of order 10^2 stellar radii above the polar gaps. At such distances, magnetic field irregularities which may be important within the polar gap or within 10^4m of the stellar surface are expected to be absent, and a pure dipole field approximation may be reasonable.

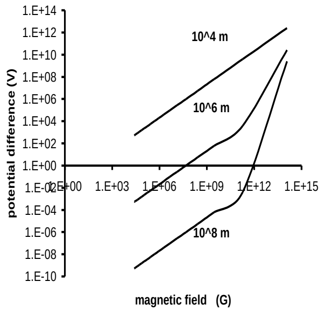


Fig.(4) The relation between the potential drop and magnetic field at different distance within light cylinder limits

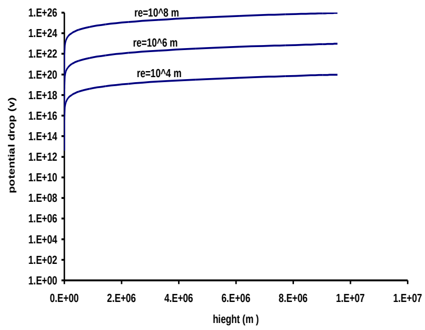


Fig.(5) The relation between potential drop($\Delta\Phi$) and height of polar gap (h) within light cylinder limits.

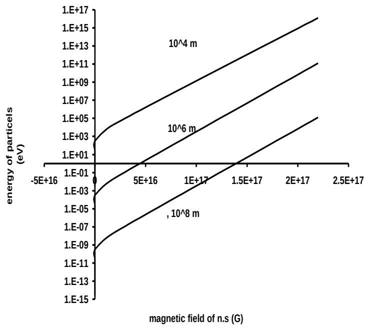


Fig.(6) The relation between energy of particles with the magnetic field of neutron star within light cylinder limits

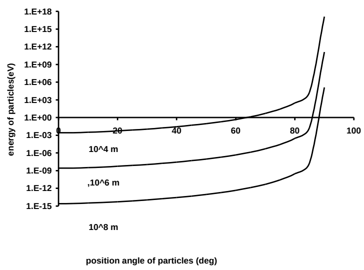


Fig.(7) The relation between energy of particles with the position angle along field line

Conclusions:

1. A potential drop proportional to height gap develops along the magnetic field line In gap. So the potential drop across the polar grows like h^2, when h « rp.
2. The formation of an electron-positron discharge in the gap occurs when the Potential difference reaches about 10^{12} V. The expansion of the polar gap leads to decreases in the magnetic field within the gap.
3. The positrons with E ≈ Emax will radiate away their energy at distances ($re=10^4$m), while less energetic positrons at much distances far away from gap ($re=10^8$ m) .So as (re) increase enough to allow the positrons to leave the near magnetosphere without much more radiation loss.
4. At angle $\lambda=90^\circ$ the particles have strong that is leads to get strong energy. Also the results indicated that the kinetic energy density at critical R_L is smaller by ($\Omega R_L /c^2$) than the magnetic energy density.
5. The results shows that the ultra relativistic positrons and the pair produced by curvature radiation from positrons leads to coherent microwave radiation in frequency rang 10^7Hz < υ< 10^9Hz

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خواص الفتحة القطبية للنجم النيوتروني ضمن حدود الاسطوانة لضوئية

سندس عبدالعباس عبد اللة البكري*

* جامعة بغداد– كلية العلوم – قسم الفلك

الخلاصة

المجالات المغناطيسية االضخمة للنجم النيوتروني تسبب في جعل نويات السطح المغناطيسي على تكوين طبقة ممتدة ومضغوطة. في هذا البحث وضحنا بعض خواص الفتحة القطبية وطبقة المغنوسفير المحيطة بالنجم وفقا لموديل (Sturrock model), البوزترونات تتحرك خارجا على طول خطوط المجال المغناطيسي والالكترونات تتحرك باتجاه السطح النجمي وفقا لموديل(Sturrock model). المجال المغناطيسي داخل الفتحة القطبية يقل نسبة التوسع مساحة الفتحة القطبية وهذا ناتج عن الحركة الفيزيائية للمادة المضغوطة داخل النجم. ارتفاع الفتحة القطبية حسب عند مسافات مختلفة من السطح النجمي وضمن حدود الاسطوانة الضوئية .

اوضحت النتائج ان اغلب طاقات البوزترونات والتي تصل $E \approx E_{max}$ تشع بعيدا عن النجم عند مسافة $r_e=10^4 m$ فوق الفتحة القطبية, بينما اقل طاقة للبوزترونات تكون عند مسافات بعيدة $r_e=10^8 m$، اي عند حدود الاسطوانة الضوئية. انخفاض الحهد عبر الفتحة القطبية حصلنا عليه باستعمال صيغة رياضية معتمدة.وجدنا من خلال هذا البحث ان انخفاض الحهد يتنامى بنسبة h^2 عندما $h \ll r_p$.