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The Importance of Diffusivity and Viscosity in Increase the Temperature of Solar Plasma

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Abstract
The mechanical energy of Alfven waves can only be converted into thermal energy when the plasma has viscosity and resistivity. In the present paper, I would like to discuss about the importance of diffusivity and viscosity in order to increase of temperature of plasma in the North Polar Coronal Hole (1.05 RΘ < r < 1.35RΘ). These parameters are responsible for change the temperature of the solar plasma in given region.

Keywords: *Solar plasma, coronal heating, diffusivity and viscosity*

1. Introduction

Following the pioneering work of Parker [1], role of magnetohydrodynamics (MHD) waves has been discussed extensively in solar physics for understanding problems of solar coronal heating mechanism. The CDS and SUMER spectrometers on the SOHO spacecraft have provided invaluable information about the solar_-limb region around the Sun. In the present paper I have considered North Polar Coronal Hole (1.05 RΘ < r < 1.35RΘ). Where RΘ is the solar radius. According to Srivastava et al 2017 [2] high frequency torsional alfven waves acts as an source of energy for coronal heating .

For derivation of dispersion relation we have to consider following MHD equation

$$\rho\frac{\partial v}{\partial t}+\rho(v\cdot\nabla)v=\frac{1}{\mu}(\nabla\times B)\times B+\rho\upsilon\nabla^2 V \qquad (1)$$

$$\frac{\partial B}{\partial t}=\nabla\times(v\times B)+\eta\nabla^2 B \qquad (2)$$

$$\nabla\cdot B=0 \qquad (3)$$

The equations (1), (2) and (3) are known as momentum equation, Induction equation and Magnetic flux conservation equation respectively. Where v is the velocity, B the magnetic field and ρ, μ,η, V are, respectively, the mass density, Magnetic permeability, magnetic diffusivity and the coefficient of viscosity.

Taking the perturbations from the equilibrium (Priest [3]) and linearize the equations (1) through (3) by neglecting squares and products of the small quantities. After solving above equations we get a dispersion relation as follows

$$\omega^2=k^2\left[v_A^2-i\omega(\upsilon+\eta)\right]+\upsilon\eta k^4 \qquad (4)$$

Where V_A = $B_0/(sqrt\{\mu\rho_0\})$ is the Alfven velocity. The dispersion relation was obtained by Pekunu et al. [4]. This dispersion relation is applied for the plasma in the North Polar Coronal Hole where assumed the angular frequency ω to be a real quantity and the wave number *k* as a complex quantity.

2 Physical parameters:

2.1 Magnetic field

Let us consider the Alfven waves in the inner zone (1.05 RΘ < r < 1.35RΘ) of the North Polar Coronal Hole (NPCH). Here, RΘ is the solar radius. The spatial variation of the magnetic field in a coronal hole is (Hollweg [5], [6])

$$B=1.5(f_{\max}-1)R^{-3.5}+1.5R^{-2}\ \ \mathrm{G} \qquad (5)$$

where R is the distance measured from the centre of the sun in the units of solar radius, i.e., R = r/RΘ and the factor *fmax* is taken as 9.

2.2 Electron Density:

Electron density distribution in the coronal holes has been given by Banerjee et al. [7] which has been fitted through the following expression.

$$N_e(R)=\frac{3.74\times10^8}{R^8}+\frac{4.80\times10^8}{R^6}-\frac{1.37\times10^9}{R^4}+\frac{8.44\times10^8}{R^2}-1.50\times10^8\ \ \mathrm{cm}^{-3} \qquad (6)$$

2.3. Mass Density

The mass density ρ_0 in a coronal hole is given by $\rho_0 = \mu m_p N_e$, where μ= *0.6* is the atomic weight and *mp* the proton mass.

2.4 Temperature

The SOHO spectrometers CDS and SUMER have provided excellent data for variation of temperature with distance from the photosphere above the NPCH. For the radial distance ranging from 1.05 RΘ to 1.35 RΘ, David et al. [8] reported data in the form of a graphical representation. After reading these data, I have fitted them through the following expression.

$$T(R)=3.041\times10^7R^5-6.272\times10^7R^4-1.895\times10^7R^3+6.534\times10^7R^2+4.028\times10^7R-5.443\times10^7\quad \mathrm{K} \qquad (7)$$

2.5. Viscosity Coefficient:

The viscosity coefficient is given by (Spitzer [9])

$$\upsilon(R) = 1.0045 \times 10^{-16} T^{5/2} / \rho_0 \quad \mathrm{cm}^2 / s \qquad \textbf{(8)}$$

where ρ_0 is in c.g.s. units.

2.6 Magnetic Diffusivity

The magnetic diffusivity is given by

$$\eta = 1.144 \times 10^{13} T^{-3/2} \quad \mathrm{cm}^2 / s \qquad (9)$$

By using above equation, one can find out the values of above parameters. For finding these values, I have used a FORTRAN program and these values are given in the following Table.

Table: Physical Parameters

R^a	N_e^b	T^c	V^d	η^e	B^f	V_A^g
1.050	9.98	0.54	0.21	2.89	11.48	3.24
1.066	8.32	0.67	0.45	2.07	10.91	3.37
1.082	6.96	0.78	0.77	1.67	10.39	3.51
1.098	5.85	0.86	1.16	1.44	9.90	3.64
1.110	5.15	0.90	1.49	1.34	9.55	3.75
1.126	4.37	0.94	1.94	1.26	9.10	3.88
1.142	3.74	0.95	2.36	1.23	8.69	4.00
1.158	3.22	0.95	2.71	1.24	8.30	4.12
1.170	2.91	0.93	2.89	1.27	8.02	4.19
1.186	2.56	0.90	3.02	1.34	7.67	4.27
1.202	2.28	0.86	2.98	1.44	7.34	4.32
1.218	2.07	0.80	2.81	1.59	7.03	4.35
1.230	1.93	0.76	2.60	1.73	6.81	4.36
1.246	1.79	0.70	2.27	1.97	6.52	4.34
1.262	1.68	0.63	1.91	2.27	6.26	4.30
1.278	1.59	0.57	1.56	2.64	6.00	4.24
1.290	1.54	0.53	1.34	2.95	5.82	4.18
1.306	1.48	0.48	1.11	3.39	5.59	4.09
1.322	1.44	0.45	0.96	3.76	5.38	3.99
1.338	1.41	0.44	0.90	3.96	5.17	3.88
1.350	1.38	0.44	0.93	3.91	5.02	3.80

a Distance from the centre of sun in RΘ;
b Electron density in 10^{13} m^{-3};
c Temperature in 10^6 K;
d Coefficient of viscosity in 10^{11} m^2 s^{-1};
e Magnetic diffusivity in m^2 s^{-1}
f Magnetic field in 10^{-4} T;
g Alfven velocity in 10^6 m s^{-1}

3 Result and Discussion:

Fig 1 is the graph plotted between radial distance from the centre of Sun and Temperature, Coefficient of Viscosity and Magnetic diffusivity. From this fig , it is clear that as the distance increases means we move away from photosphere *i.e.* in the corona temperature increases up to the 1.20RΘ. Further temperature is decreasing. For the same range Coefficient of Viscosity is increasing and after 1.20RΘ its values goes on decreasing. But for Magnetic diffusivity it decreases first then after 1.20RΘ its values goes on increasing.

In the Fig2. Graph plotted between Coefficient of Viscosity and Temperature. This graph shows the large variation for the first values temperature is goes on increasing and reaches to maximum 3.02 values then it goes on decreasing. It gives us temperature is depends upon number of factors.

In the Fig3. graph plotted between Magnetic diffusivity and Temperature. This graph shows as the values of Magnetic diffusivity increases the value of temperature decreases.

From these graph one can conclude the diffusivity and viscosity are responsible for changes the temperature of the solar plasma in given region. We have to consider their importance in the solar plasma.

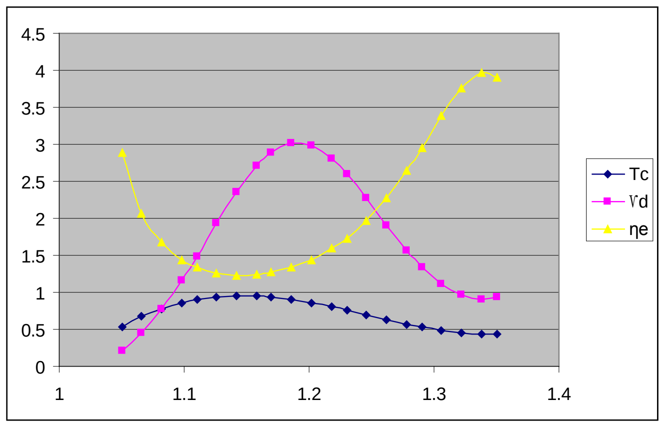

Fig1: Graph plotted between Distance from the centre of sun and Temperature, Coefficient of Viscosity and Magnetic diffusivity.

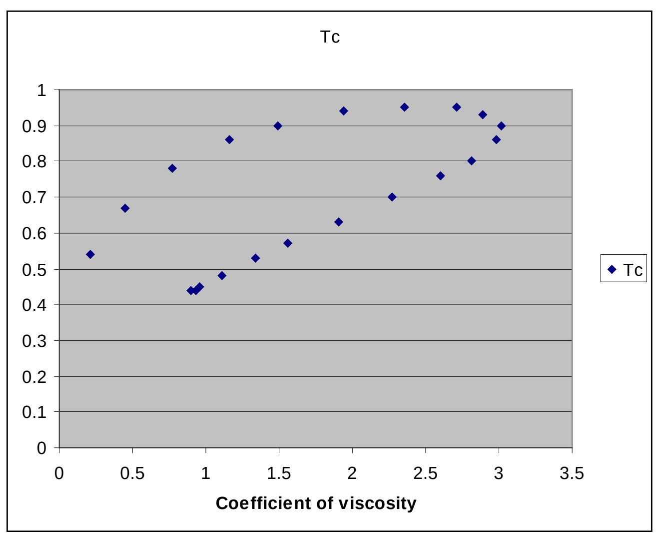

Fig2: Graph plotted between Coefficient of Viscosity and Temperature.

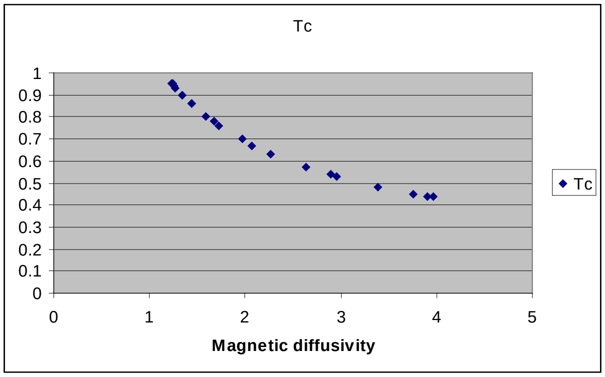

Fig3: Graph plotted between Magnetic diffusivity and Temperature.

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