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Propagation and Dissipation of Slow Magneto-Acoustic Waves in Coronal Loops

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Abstract

We study the spatial damping of slow magnetoacoustic waves in homogeneous, isothermal, and unbounded coronal plasma permeated by a uniform magnetic field, with physical properties akin to those of coronal loops. Taking into account an energy equation with optically thin radiative losses, thermal conduction, and heating we obtain a fourth-order polynomial in the wavenumber k, which represents the dispersion relation for slow and thermal MHD waves. The fourth order dispersion relation has been solved numerically for different loop parameters. It is found that damping length of slow-mode waves exhibits varying behavior depending upon the physical parameters of the loop. We found that for solar coronal loops, the dominant wave damping mechanism is compressive viscosity and thermal conduction with less significant contribution by radiation. For any considered period, slow waves have much shorter damping length in hot coronal loops than that in cool loops and also slow waves damped very quickly in hot and long coronal loops.

Keywords: Sun: Corona, MHD slow waves, oscillations, coronal loops, heating.

Introduction

Recent observational evidences from various ground- and space based solar missions have confirmed that the Sun's outer atmosphere is highly dynamic. The observations of Yohkoh, SoHO, TRACE, Hinode/EIS, STEREO and SDO/AIA revel that there is lot of examples of small amplitude waves and oscillations in different coronal structures. These wave and oscillatory activities of the solar corona are mainly in the form of slow magneto-acoustic waves. Such wave modes are predominantly longitudinal and affect the coronal plasma by perturbing the density, temperature and the component of the velocity parallel to the magnetic field. Longitudinal oscillations may be in the form of either standing or propagating slow waves.

Propagating intensity oscillations were first observed in coronal holes high above the limb using the observations of Ultra Violet Coronal Spectrometer (UVCS) on board SoHO[1]. Similar propagating intensity oscillations (compressive waves) were also observed in solar polar plumes with Extreme Imaging Telescope (EIT) on board SoHO with periods of about 10–15 minutes[2]. These propagating oscillations were interpreted as the slow magnetoacoustic waves[3-4] due to their propagating speeds (~100 km s^{-1}) that are close to the sound speed in the corona. There have also been many observations of coronal loops that are consistent with wave-guiding of the slow mode along the loop structure. These are observed as low amplitude intensity and velocity oscillations located at the base of quiescent coronal loop systems[5-6]. The damping of slow magneto-acoustic waves in homogeneous medium has been investigated by taking into account thermal conduction and compressive viscosity[7]. They found that the inclusion of thermal conduction results in *'thermal mode'*, which is purely decaying in case of standing waves, but is oscillatory and decaying in the case of driven waves. The excitation and damping of standing slow-mode oscillations and waves has also been studied by several researchers[8-10]. They found that slow standing waves are attenuated within a few wave periods.

The main objective of this paper is to investigate the spatial damping of slow magneto-acoustic waves in coronal loops due to three possible damping mechanisms, namely compressive viscosity, thermal conduction and radiation. The paper is organized as follows. Theoretical considerations and the basic equations governing plasma motion are given in section 2, a general dispersion relation for the complex wavenumber as a function of frequency is also derived in this section. In Section 3, the dispersion relation is solved numerically and discussed to examine how wave damping depends upon compressive viscosity, thermal conduction and radiation. Finally, conclusions are drawn in section 4.

Methodology

Physical Model and Governing Equations: We consider the propagation of slow MHD waves in homogeneous, magnetically structured and compressible plasma. We restrict our attention to a motion along the uniform background magnetic field, which is directed along the z-axis. The basic one-dimensional MHD equations governing the plasma motion in coronal loops are the equation of continuity, equation of momentum, energy equation, and equation of state[11]. Considering small perturbations from the equilibrium in the form

$$B(r,t) = B_0 + B_1(r,t),\quad p(r,t) = p_0 + p_1(r,t),\quad \rho(r,t) = \rho_0 + \rho_1(r,t),\quad T(r,t) = T_0 + T_1(r,t),\quad v(r,t) = v_1(r,t) \qquad (1)$$

we linearize the basic equations (1) – (4) of[11], to obtain the wave equation

$$\left(\frac{\partial}{\partial t}\frac{(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\frac{\partial^2}{\partial z^2}-(2-\alpha)(\gamma-1)\frac{\rho_0^2\chi T_0^\alpha}{\gamma p_0}-\frac{4\eta_0}{3\gamma p_0}\frac{\gamma(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\frac{\partial^3}{\partial t\partial z^2} + \frac{4\eta_0}{3\gamma p_0}\frac{\partial^2}{\partial t^2}+\frac{4\eta_0}{3\gamma p_0}\alpha(\gamma-1)\rho_0^2\chi\frac{T_0^\alpha}{p_0}\frac{\partial}{\partial t}\right)c_s^2\frac{\partial^2 v_z}{\partial z^2}$$
$$=\left(\frac{\partial}{\partial t}-\frac{\gamma(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\frac{\partial^2}{\partial z^2}+(\gamma-1)\frac{\rho_0^2\chi T_0^\alpha}{p_0}\right)\frac{\partial^2 v_z}{\partial t^2} \qquad (2)$$

Now, since the medium is unbounded and uniform we perform a Fourier analysis assuming

$$v(z,t) = v_0\, exp\left(i\left(\omega t - kz\right)\right) \qquad (3)$$

and obtain the following dispersion relation for slow mode in terms of wavenumber as function of frequency under the combined effects of compressive viscosity, thermal conduction and radiation as

$$\left[\frac{i(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}c_s^2-\frac{4}{3}\frac{\eta_0}{\gamma p_0}c_s^2\frac{\gamma(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\omega\right]k^4$$
$$-\left[c_s^2\omega+i\frac{4}{3}\frac{\eta_0}{\gamma p_0}c_s^2\omega^2+i\frac{\gamma(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\omega^2+\frac{4}{3}\frac{\eta_0}{\gamma p_0}c_s^2\frac{\alpha(\gamma-1)\rho_0^2\chi T_0^\alpha}{p_0}\omega+i(2-\alpha)(\gamma-1)\frac{\rho_0^2\chi T_0^\alpha}{\gamma p_0}c_s^2\right]k^2$$
$$-i(\gamma-1)\frac{\rho_0^2\chi\alpha T_0^\alpha}{p_0}\omega^2+\omega^3=0 \qquad (4)$$

Equation (4) can be made dimensionless by using the non-dimensional dissipative ratios ϵ, d and r defined by[11-12]

$$\varepsilon = \frac{4}{3}\frac{\eta_0}{\gamma p_0 L}c_s = \frac{4}{3}\times 10^{-17}T_0^3\frac{\sqrt{\frac{\gamma R}{\tilde{\mu}}}}{\gamma p_0 L} \qquad (5)$$

$$d = \frac{1}{\gamma}\frac{\tau_s}{\tau_{cond}} = \frac{(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0 L c_s} = \frac{(\gamma-1)\times 10^{-11}T_0^3}{\gamma p_0 L\sqrt{\frac{\gamma R}{\tilde{\mu}}}} \qquad (6)$$

$$r = \frac{\tau_s}{\tau_{rad}} = \frac{(\gamma-1)\rho_0^2\chi T_0^\alpha}{\gamma p_0 c_s}L. \qquad (7)$$

Here $p_0, T_0, R,$ *and* $\tilde{\mu}$ are the equilibrium pressure, temperature, gas constant and mean molecular weight respectively; $\eta_0 = 10^{-17}T^{5/2}\ kg\ m^{-1}s^{-1}$ is the compressive viscosity; $\kappa_{\parallel} = 10^{-11}T_0^{5/2}\mathrm{W\ m^{-1}deg^{-1}}$ is the coefficient of thermal conduction parallel to ambient magnetic field; $\tau_{cond} = \frac{L^2 p_0}{(\gamma-1)\kappa_0 T_0}$ is the thermal conduction time and $\tau_{rad} = \frac{\gamma p_0}{(\gamma-1)\rho_0^2\chi T_0^\alpha}$ is the radiative time, where χ *and* α are the piecewise continuous functions depends on the temperature[13]. We have given the values of these parameters and times for various loop temperatures and loop lengths in table 1[14]. For the considered loop temperatures and loop lengths, the radiative time is much larger than other dissipative times except for the cooler loops, where it is shorter than the other times, implying that at low temperatures radiation may be the dominant dissipative mechanism. In terms of dimensionless quantities, equation (4) can be rewritten as

$$\left(id-\gamma\varepsilon d\omega\right)k^4-\left(\omega+i\varepsilon\omega^2+i\gamma d\omega^2+\alpha\gamma\varepsilon r\omega+i(2-\alpha)r\right)k^2-i\alpha\gamma r\omega^2+\omega^3=0 \qquad (8)$$

Results and Discussion

As we are interested in the spatial damping of slow waves in coronal loops, we consider **ω** to be real and seek complex solutions of the wavenumber k expressed as $k = k_r + ik_i$. A number of theoretical and numerical studies show that thermal conduction can play an important role in the quick damping of slow magneto-acoustic waves in coronal loops[15, 7, 11]. However, it has been pointed out that the observed damping of coronal loop oscillations observed by trace can be explained via viscous or resistive dissipation of wave energy if the viscosity or resistivity of the medium is enhanced compared with classical values[16]. Therefore, it becomes utmost important to study the effects of different dissipative mechanisms on the damping of slow waves in coronal loops and to identify the dominant dissipative mechanism.

Effect of Compressive Viscosity: According to[16] the observed damping of coronal loop oscillations indicates the presence of strong dissipation of the wave energy. Thus dissipation via viscosity or resistivity leads to the heating of coronal loops. Therefore, in this section we investigate the effect of compressive viscosity on the damping of slow waves in coronal loops. So, in the absence of thermal conduction and radiation $(\kappa_{\parallel} = 0,\ \chi = 0)$, equation 2 becomes

$$\frac{4}{3}\frac{\eta_0}{\gamma p_0}c_s^2\frac{\partial}{\partial t}\left(\frac{\partial^2 v_z}{\partial z^2}\right) = \left(\frac{\partial^2}{\partial t^2} - c_s^2\frac{\partial^2}{\partial z^2}\right)v_z \qquad (9)$$

Using equation 3 in equation 9, we obtain

$$k = \omega\left[\frac{1}{1+i\varepsilon\omega}\right]^{1/2} \approx \omega\left(1-i\frac{\varepsilon\omega}{2}\right), \qquad (10)$$

or, $v \sim \exp\left(i\omega t - ikz\right) = \exp i\omega(t-z)\exp\left(-\varepsilon\omega^2 z/2\right)$. Thus, compressive viscosity will cause the amplitude of the velocity perturbation to decrease as $\exp\left(-\varepsilon\omega^2 z/2\right)$ i.e. in the absence of thermal conduction and radiation the motion is purely damped which is also clear from figure 1a, where the dimensionless damping length of slow waves is plotted against dimensionaless viscous coefficient parameter 'ε'.

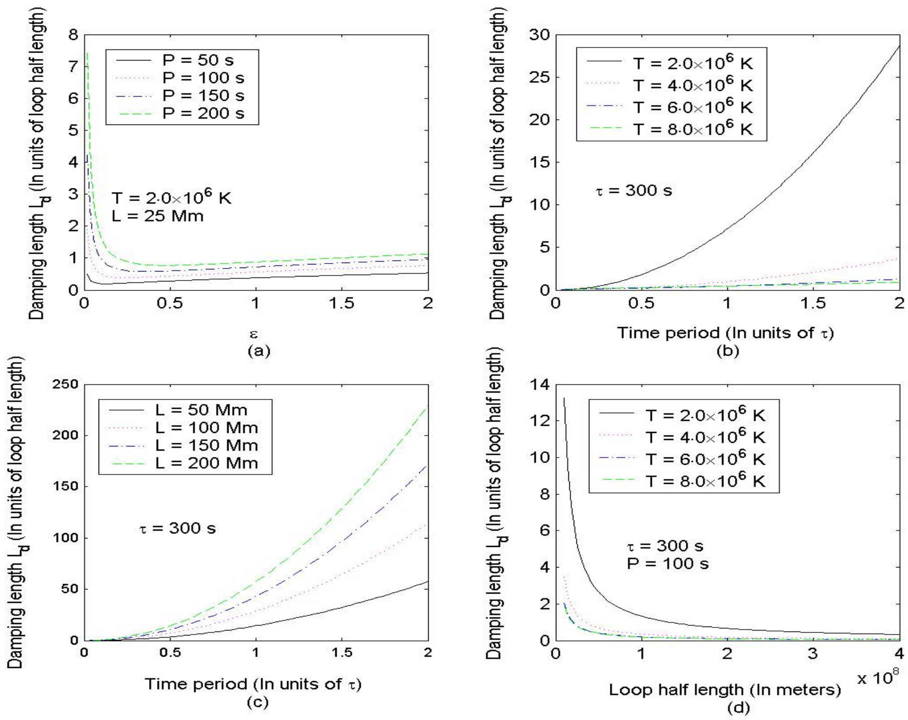

Figure-1

Variation of normalized damping length L_d as function of (a) compressive viscosity parameter ε (b) time period for constant temperature (c) time period for constant loop half length and (d) loop half length

Figure 1 shows the behaviour of damping length of slow mode waves as a function of viscous parameter, time period (for constant temperature and constant loop half length) and loop half length. Damping length is the distnace over which the amplitude of the wave drops to 1/e times of its original amplitude. Figure 1a shows the variation of normalized damping length of slow waves with viscous coefficient (ϵ) for different considered periods. The damping length of slow waves is maximum for $\varepsilon = 0$ and decreases from its maximum value to a minimum value for certain values of ε. Numerically, the minimum value of the damping length is found to be 0.193L for $\varepsilon = 0.12$, 0.386L for $\varepsilon = 0.24$, 0.58L for $\varepsilon = 0.36$ and 0.773L for $\varepsilon = 0.48$ for waves of period 50s, 100s, 150s and 200s respectively. The damping length then increases slowely for suffeciently large viscous coefficient. As the wave period increases, minima of the curves shifts towards the right corresponding to the long period waves. This shifting of minima implies that long period waves would travel a longer distance as compared to short period waves before damping. Table 1 shows that for different coronal loop parameters observed by TRACE and SUMER the viscous coefficient in majority of cases remains very small hence slow waves have maximum damping length. We therefore, conclude that in such coronal loops the damping effect of viscosity is very small. However, for hot and short coronal loops observed by SUMER compressive viscosity have a significant effect on the damping of slow magnetoacoustic waves.

Figure 1b depicts the behaviour of damping length with time period for different loop temperatures *i.e.,* for cool and hot coronal loops at constant loop half length. In cool coronal loops $(T \leq 2\times10^6 K)$ irrespective of viscous parameter it is found that short period waves $(P < 0.5\tau)$ damp very quickly whereas long period waves $(P > 0.5\tau)$ travel undamped along the length of loop. However, in the case of hot coronal loop $(T \geq 4\times10^6 K)$, damping length of slow waves shows a appericiable decrease as we go from long to short period waves. This behaviour of damping length of slow waves in hot coronal loops can be easily understood with the help of equation 5 as the viscous coefficient parameter ϵ varies with the cube of the loop temperature T and inversely with the loop half-length *L* for fixed loop pressure p_0. Thus, it is clear that wave damping will slow down at low temperatures and large loop half lengths whereas in short and hot coronal loops compressive viscosity will cause strong damping of slow waves due to $\varepsilon \approx T^{3/2}/L$. These results are in agreement with the simulation results of[14]. They found that the amplitudes of oscillations of coronal loops increase with decreasing loop temperature and increasing loop length and the waves are dissipated by the combined effects of viscosity and thermal conduction at higher temperatures, whereas wave dissipation is governed by radiation at lower temperatures.

For different loop half lentghs, we have studied the behaviour of damping length as function of wave period (figure 1c). The damping length of short period waves is much shorter than that of long period waves that leads to the wave energy of these short period waves will be dissipated due to viscous dissipation. It means that the dissipation of mechanical energy of slow waves via compressive viscosity can balance the energy losses in coronal loops. Figure 1d further gives the information about the dependence of damping length of slow waves on the loop half length and temperature. On increasing the loop temperature viscous coefficient increases, leading to the decrement in damping length whereas the increment in loop half length acts to balance out the effect of increasing temperature (equation 5). Accordingly, in hot and long coronal loops, damping length of slow waves becomes almost constant which is evident from figure 1d. However, for short and hot coronal loops observed by SUMER, slow waves damp quickly as the damping length decreases from maxima and ultimately attains a low constant value. Thus the overall behaviour of damping length of slow waves is that it decreases from its maximum value and after showing a dip, attains a constant value.

Table-1

Values of non-dimensional dissipative parameters and characteristic times as function of loop half length and loop temperature. The dimensionless parameters ε, d and r respectively, the viscous ratio, the thermal ratio and radiation ratio; τ_s is the sound travel time, τ_{visc} is the viscous time, τ_{cond} is the heat-conduction time and τ_{rad} is the heat-radiation time

L (Mm)	ε	d	r	τ_s (min)	τ_{visc} (min)	τ_{cond} (min)	τ_{rad} (min)
T = 1 MK							
25	0.883e-3	0.0192	0.619e-3	2.74	3102.43	85.93	73.76
50	0.442e-3	0.0096	0.123e-2	5.48	12409.74	343.75	73.76
100	0.221e-3	0.0048	0.248e-2	10.97	49638.98	1375.00	73.76
150	0.147e-3	0.0032	0.371e-2	16.45	1.116e5	3093.75	73.76
200	0.110e-3	0.0024	0.495e-2	21.93	1.985e5	5500.00	73.76
T = 2 MK							
25	0.707e-2	0.153	0.547e-4	1.94	274.22	7.596	590.13
50	0.353e-2	0.0765	0.109e-3	3.88	1096.87	30.383	590.13
100	0.177e-2	0.0383	0.219e-3	7.75	4387.50	121.53	590.13
150	0.118e-2	0.0255	0.328e-3	11.63	9871.89	273.45	590.13
200	0.883e-3	0.0191	0.438e-3	15.51	17550.03	486.13	590.13
T = 4 MK							
25	0.565e-1	1.225	0.484e-5	1.37	24.23	0.671	4721.05
50	0.282e-1	0.613	0.968e-5	2.74	96.95	2.68	4721.05
100	0.141e-1	0.306	0.193e-4	5.48	387.80	10.74	4721.05
150	0.942e-2	0.204	0.290e-4	8.22	872.56	24.17	4721.05
200	0.707e-2	0.153	0.387e-4	10.97	1551.21	42.97	4721.05
T = 6 MK							
25	0.19093	4.136	0.117e-5	1.12	5.86	0.162	15933.57
50	0.954e-1	2.068	0.234e-5	2.24	23.45	0.657	15933.57
100	0.477e-1	1.034	0.468e-5	4.48	93.82	2.598	15933.57
150	0.318e-1	0.689	0.703e-5	6.71	211.09	5.85	15933.57
200	0.238e-1	0.517	0.937e-5	8.95	375.27	10.39	15933.57
T = 8 MK							
25	0.452	9.803	4.28e-7	0.969	2.14	0.0593	37768.46
50	0.226	4.902	8.55e-7	1.94	8.57	0.237	37768.46
100	0.113	2.450	1.71e-6	3.88	34.27	0.954	37768.46
150	0.754e-1	1.634	2.56e-6	5.81	77.12	2.136	37768.46
200	0.565e-1	1.225	3.42e-6	7.75	137.10	3.798	37768.46
T = 10 MK							
25	0.884	19.15	1.96e-7	0.867	0.981	0.0271	73766.53
50	0.442	9.57	3.91e-7	1.73	3.92	0.108	73766.53
100	0.221	4.787	7.83e-7	3.47	15.69	0.435	73766.53
150	0.147	3.191	1.17e-6	5.20	35.31	0.978	73766.53
200	0.110	2.393	1.56e-6	6.93	62.78	1.74	73766.53

Effect of Thermal Conduction: In the absence of viscosity and radiation $(\eta_0 = 0,\ \chi = 0)$, equation 2 reduces to

$$\left(\frac{\partial}{\partial t} - \frac{(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\frac{\partial^2}{\partial z^2}\right)c_s^2\frac{\partial^2 v}{\partial z^2} = \left(\frac{\partial}{\partial t} - \frac{\gamma(\gamma-1)\kappa_{\parallel}T_0}{\gamma p_0}\frac{\partial^2}{\partial z^2}\right)\frac{\partial^2 v}{\partial t^2} \quad (11)$$

Using equation 3 in equation 11, we obtain

$$dk^4 + (i\omega - \gamma d\omega^2)k^2 - i\omega^3 = 0 \quad (12)$$

where all quantities are dimensionless.

The dispersion relation (12) has been solved numerically for different loop parameters and the results are presented in figure 2. Figure 2a shows the behaviour of damping length of slow waves as a function of thermal conduction ratio for the exact solution given by equation 12. This figure clearly points out that all slow waves have maximum damping length for small value of *d* and decreases sharply with *d* until wave attains a minimum damping length. Similar results for slow waves in coronal loops are also obtained by[7]. Numerically the minimum value of damping length is found to be 0.33L, 0.66L, 0.98L and 1.31L for 50s, 100s, 150s and 200s period waves respectively at low thermal conduction ratio and thereafter damping length increases for sufficiently large *d.* It is also evident from figures 1a and 2a that the effect of compressive viscosity on wave damping is more pronounced than that of thermal conduction.

Figures 2b and 2c show the variation of damping length with time period for different loop temperatures (*i.e.,* for cool and hot coronal loops) and loop half lengths. For hot and cool coronal loops observed by SUMER and TRACE respectively, the damping length of slow waves irrespective of thermal ratio parameter shows the same pattern of variation with time period as in the case of viscous damping. For fixed loop temperature, figures 1b and 2b clearly indicate that slow waves in loops dissipate energy strongly via compressive viscosity as compared to thermal conduction. However, for fixed loop half length, it can be seen clear form figures 1c and 2c that the damping length of slow waves due to compressive viscosity is larger than that due to thermal conduction. This simply implies that thermal conduction is the dominant wave damping mechanism as compared to compressive viscosity. This contradictory behaviour of slow waves for fixed loop half length and loop temperature can be easily understood from the data given in table 1 and equations (5) - (6).

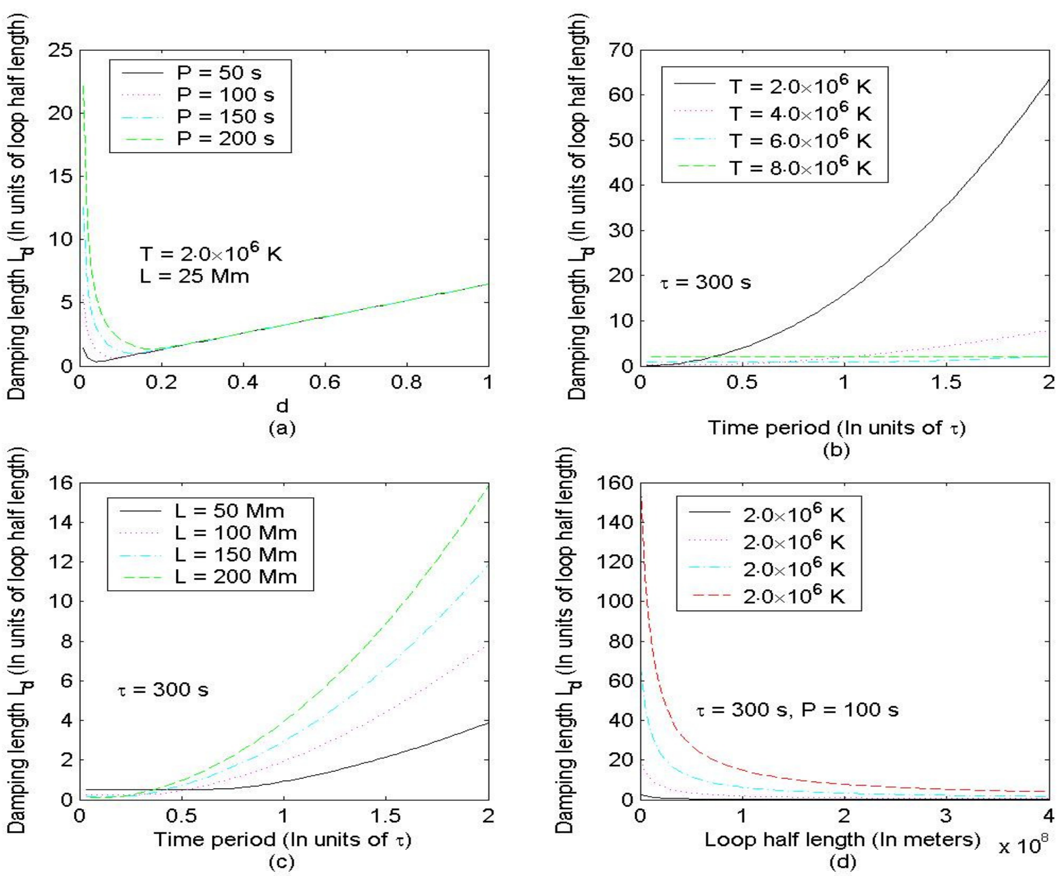

Figure-2
Variation of normalized damping length L_d as function of (a) thermal conduction parameter *d* (b) time period for constant temperature (c) time period for constant loop half length and (d) loop half length

The information about the damping length of slow waves in relation to the loop half length and temperature is presented in figure 2d. On increasing the loop temperature thermal ratio increases that leads to an increase in damping length whereas the increment in loop half length acts to balance out the effect of increasing temperature (equation 6). Accordingly, in cool and long coronal loops, damping length of slow waves becomes almost constant which is evident from figure 2d. However, for short and hot coronal loops such as observed by SUMER, slow waves are undamped because they have larger damping hength in comparision with loop length. Thus, the slow waves in cool coronal loops will dissipate energy via thermal conduction however, compressive viscosity can dissipate wave energy in both cool and hot coronal loops.

Effect of Heat Radiation: In this section we investigate the damping of slow waves due to heat radiation and compare it with the wave damping due to compressive viscosity and thermal radiation. When α is negligible and dissipative mechanisms such as compressive viscosity and thermal conduction are absent, from equation 2, we get

$$\left(\frac{\partial}{\partial t} - 2(\gamma-1)\frac{\rho_0^2 \chi T_0^{\alpha}}{\gamma p_0}\right) c_s^2 \frac{\partial^2 v}{\partial z^2} = \frac{\partial^3 v}{\partial t^3} \qquad (13)$$

On using equation 3 in equation 13, we obtain

$$k \approx \omega\left(1-\frac{ir}{\omega}\right) so,\; v \sim \exp i\omega(t-z)\exp(-rz) \qquad (14)$$

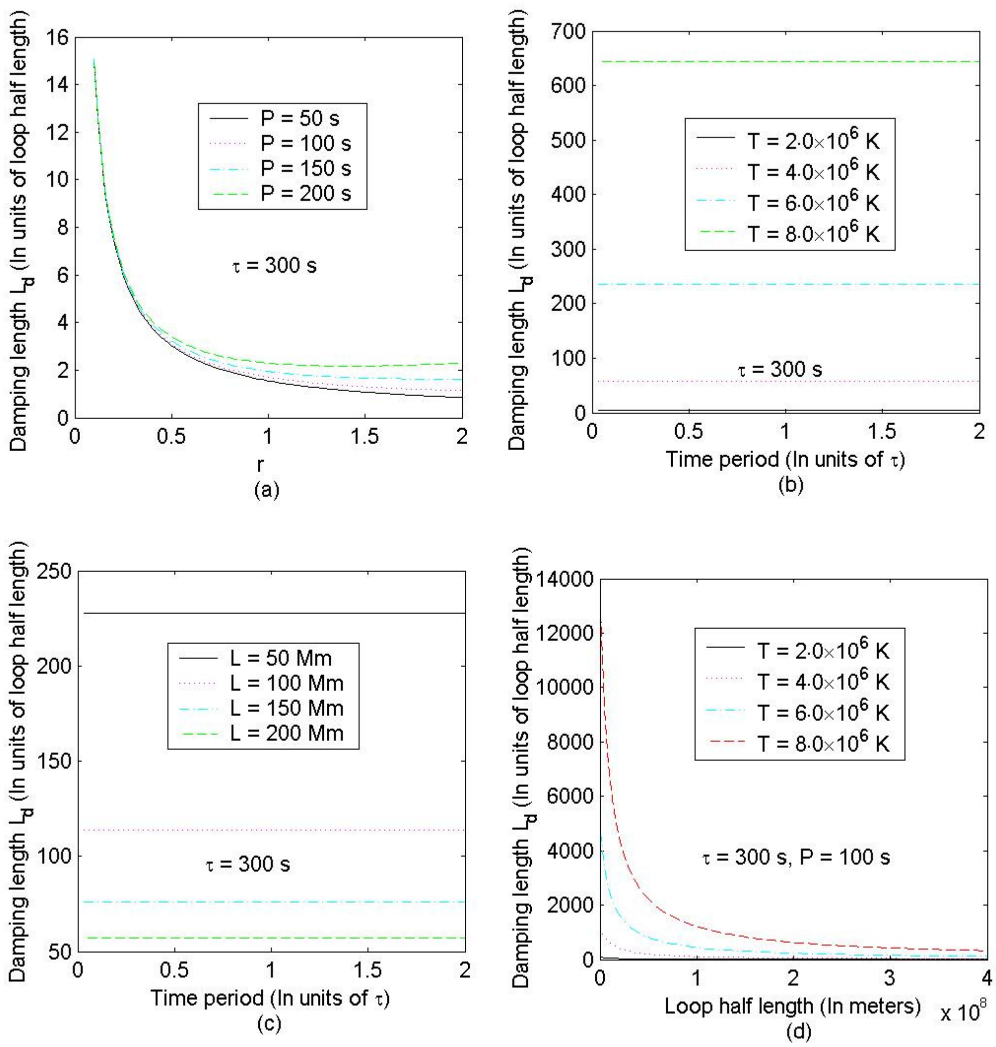

Figure-3
Variation of normalized damping length L_d as function of (a) thermal conduction parameter *d* (b) time period for constant temperature (c) time period for constant loop half length and (d) loop half length

Thus, similar to viscosity and thermal conduction effects radiation will also cause the amplitude of velocity perturbation to decrease as *exp*(*-rz*). The behaviour of damping length of slow waves with radiation coefficient for the exact numerical solution given by equation 13 has been shown in figure 3. In figure 3a, we have shown the variation of damping length with radiation coefficient for slow waves of different periods. This figure shows that the pattern of variation of damping length with radiation coefficient is same for slow waves of different periods. Damping length of slow waves decreases with radiation coefficient, as expected from the analytical expression equation 14. From equation 7 we can see that the value of dimensionless radiation parameter *r* is very small for different coronal loops. For such a small value of *r*, the effect of radiation on wave damping would be hardly noticeable and therefore, in the present investigation we are using some large values of radaition parameter. Form figure 3 it can be seen that initially for small values of radiation coefficient *r*, slow waves of any considered period have large damping length. Thus, the wave damping due to optically thin radiation is not very effective for very small value of radiation coefficient. For large value of radiation coefficient only short period waves $(P \leq 50\,s)$ show meaningful damping whereas long period waves travel undamped in the loop.

Conclusion

In this paper, we have investigated the individual effects of compressive viscosity, thermal conduction and heat radiation on the spatial damping of slow magneto-acoustic waves in coronal loops observed by SUMER and TRACE. For it, we have numerically solved the dispersion relations to study the damping length of slow waves in a medium having physical properties akin to those of solar coronal loops. The main conclusions that can be extracted from our study are: i) We find that for the typical observational solar parameters of coronal loops, the dominant wave damping mechanism is compressive viscosity and thermal conduction, with less significant contribution by radiation. ii) Slow waves have minimum damping length due to compressive viscosity and if the observed damping length of slow waves in coronal loops is shorter than the minimum damping length predicted by compressive viscosity, then the slow MHD waves must be damped by other damping mechanisms. iii) For any considered period, slow waves have much shorter damping length in hot coronal loops than that in cool loops and also slow waves damp very quickly in hot and long coronal loops. iv) Since the dissipative ratios ε and d depend on the temperature and loop half length as $\mathrm{T}^{3/2}/\mathrm{L}$, so in short and hot coronal loops dissipation is enhanced due to viscosity and thermal conduction. However, according to Hildner's (1974), the cooling exponent $\alpha = -1$ is for temperature range $0.8 \leq T \leq 10\,MK$, so it follows from Eq. (11) that radiative ratio *r* depends on temperature and loop half length as $L/T^{5/2}$. This simply implies that radiative damping becomes the dominent damping mechanism in cool and long coronal loops. Our results clearly show that at lower temperatures, wave damping is almost goverend by radiative cooling whereas at higher temperatures the wave damping is dominent due to viscosity and thermal conduction.

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