The suprathermal particles and charge fluctuation effects on waves in complex plasma

Somayeh Mousavi[1]

Department of Physics, Faculty of physics and chemistry, Alzahra University, Tehran, Iran[1]

som.mosavi@gmail.com

Abstract

In the frame of kinetic theory, we investigated the effects of suprathermal particles and dust charge fluctuations due to the inelastic collision between the dust grains and plasma particles by calculating the longitudinal dielectric permittivity in an unmagnetized dusty plasma on the wave modes propagating in a complex plasma. The ion and electron distribution were assumed to be Maxwell and kappa distribution in the systems. It was shown that the wave frequency can be analyzed for various values of the spectral index K and the dust charge fluctuations. The Landau damping rate and Propagation rate in dust charge fluctuation presence increase.

Indexing terms/Keywords: Dusty Plasma, Ion acoustic, Acoustic and Langmuir waves, Dust charge variation, Kinetic theory

Introduction

Plasma is an ionized gas including photons, electrons, positive and negative ions, free radicals, excited and unexcited molecules which interact continuously. When the environment is low-ionized, dusty plasmas include ion, electron, dust particles and also neutral particles. In addition to electron, positive ion and dust, many of spatial dust plasmas, mesosphere and solar photosphere contain a component of negative ions. The type of dust particles is different in various environments. For example in mesosphere it is mostly composed of ice or space rocket exhausts is in the form of aluminum oxide dusts. Strong non-neutral plasmas are mostly happened in laboratories.

Suprathermal plasmas that contain a substantial component of high-energy particles are often found in nature. Such plasmas in space or laboratories can be effectively modeled by a Lorentzian (kappa) velocity distribution [1-3]. The physics of Lorentzian distribution has attracted much attention because of its interesting applications to space and laboratory plasmas that are far from thermal equilibrium. For instance, such distribution has been used to analyze the electrons in themagnetosphere [4], electromagnetic ion-cyclotron waves in the equatorial ring protons [5], Alfvén waves in the solar wind streams [6], and whistler emission of Jupiter [7]. Numerous theoretical studieson the ion-acousticmode [8], electron- acoustic mode [9], ion-cyclotron-sound mode [10], and ion-acoustic surface mode [11] in Lorentzian plasmas have also been reported. The suprathermal particles will modify the wave frequen- cies as well as the Landau damping of thewaves, which is one of the most well knownprocesses in plasmawave physics [18]. The Landau damping process for dust acoustic-type waves in a Maxwellian complex plasma has well been established [16].

The dispersion equations of longitude waves in Non-magnetized homogeneous plasma have been studied in the framework of kinetic theory. In investigation of ion fluctuation, impact of dust particles and plasma particles is considered as inelastic. For electrons and ions (positive and negative) Maxwell and kappa distributions and for dust particles and heavy negative ion Maxwell and static distributions were considered [13,15]. By calculation of dielectric with solving Valsof and Boltzmann equation, the principle relationship of dispersion in longitude propagation and the effects of particles on attenuation and development were studied. In all steps on the study, we assumed that kappa of negative and positive ions and electrons are equal, we assumed that plasma stuck by

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[1] E_mail:som.mosavi@gmail.com

dust particles are small and we used the average value but we considered the period of system investigation to be short [14]. The time needed for reaching to a balance of dust charge is much longer than the times used in this research. We considered the Γ, G small so that we were able to neglect them in equations. Effect of ion fluctuation on wave propagation were investigated. In studying the effect of charge fluctuation, distribution of ions and electrons distribution were assumed to be Maxwell and kappa distribution in the systems [13]. Furthermore the effect of the presence of suprathermal particles on attenuation of waves was studied.

Dispersion equations

In studying the ion fluctuation, the impact of dust particles and plasma particle consider to be inelastic.

$$\frac{\partial f_\alpha}{\partial t} + \frac{\vec{p}}{m_\alpha}.\vec{\nabla} f_\alpha + \vec{F}.\vec{\nabla}_P f_\alpha = \sum_\beta \left(\frac{\partial f_\alpha}{\partial t}\right)_{col}^{\alpha\beta} \tag{1}$$

$\vec{F}$ is the force on plasma particles. The impact statement is defined as below:[12]

$$\left(\frac{\partial f_\alpha}{\partial t}\right)_{col}^{\alpha d} = -\int dq_d \sigma_\alpha^d V\left(f_d f_\alpha - f_{do} f_{\alpha o}\right) \tag{2}$$

The angle of impact between the direction of fluctuation and heavy dust movement is considered 90 degree (dust particles due to their excess mass have no significant effect on equations) and by the defined equation the desirable longitudinal permeability coefficient in this study will be reached[12]

$$\varepsilon^{lo} = 1 + \frac{4\pi}{k^2}\sum_\alpha \frac{q_\alpha^2}{m_\alpha}\int d^3p \frac{1}{\omega - \vec{k}.\vec{V} + iv_{\alpha o}^d(V)}\vec{k}.\frac{\partial f_{\alpha o}}{\partial v}\left(1 + \frac{iv_{\alpha o}^d(V)}{\omega + iv_{ch}}\frac{1+\Gamma}{1+G}\right) \tag{3}$$

$$\varepsilon^{lo} = 1 + \sum_\alpha \chi_\alpha + \sum_\alpha \chi_\alpha^\sigma \tag{4}$$

χ_j is the coefficient of influence when there is no charge fluctuation in plasma, χ_j^σ is the coefficient of influence when there is charge fluctuation in plasma. The distribution function of electron and ion considered to be Maxwell and kappa and for dust particles and heavy negative ion considered as Maxwell and static:[13,15]

$$X_\alpha = \frac{4\pi}{k^2}\sum_\alpha \frac{q_\alpha^2}{m_\alpha}\int d^3p \frac{1}{\omega - \vec{k}.\vec{V}}\vec{k}.\frac{\partial f_{\alpha o}}{\partial v} \tag{5}$$

Using equations 6 and 7 the desired influence will be achieved:[13,17]

$$\begin{cases} Z(\zeta_\alpha) = \frac{1}{\zeta_\alpha} - \frac{1}{2\zeta_\alpha^3} - \frac{3}{4\zeta_\alpha^5}.....,\left|(\zeta_\alpha)\right| \to \infty \\ Z(\zeta_\alpha) = i\sqrt{\pi}e^{-\zeta_\alpha^2} - 2\zeta_\alpha + \frac{4}{3}\zeta_\alpha^3 + ...,\left|\zeta_\alpha\right| \to 0 \end{cases} \tag{6}$$

The first statement of equation 8 is related to the particles with kappa distribution and the second one is related to the particles with Maxwell distribution.

With equation 9 the rate of attenuation and development will be obtained.

$$
\begin{cases}
Z_k(\zeta_k) = \dfrac{ik!\,k^{k-\frac{1}{2}}\sqrt{\pi}}{(k-\frac{3}{2})!}\dfrac{1}{\zeta^2(k+1)}\left[1-\dfrac{k(k+1)}{\zeta_k^{\,2}}+.....\right]- \\[2mm]
-\dfrac{(2k-1)}{2k}\dfrac{1}{\zeta_k}\left[1+\dfrac{k}{2k-1}\dfrac{1}{\zeta_k^{\,2}}+\dfrac{3k^2}{(2k-1)(2k-3)}\dfrac{1}{\zeta_k^{\,4}}+....\right],,\left|(\zeta_K)\right|\to\infty \\[3mm]
Z_k(\zeta_k) = \dfrac{ik!\sqrt{\pi}}{k^{\frac{3}{2}}(k-\frac{3}{2})!}\left[1-\dfrac{k+1}{k}\zeta_k^{\,2}+.....\right]- \\[2mm]
-\dfrac{(2k-1)(2k+1)}{2k^2}\zeta_k\left[1-\dfrac{2k+3}{3k}\zeta_k^{\,2}+......\right],,\left|(\zeta_K)\right|\to 0
\end{cases}
\tag{7}
$$

$$
\lim\frac{1}{x\pm i\eta}=\frac{P}{x}\mp i\pi\delta(x)
\tag{8}
$$

$$
\chi_\alpha^\sigma = -2i\sqrt{\pi}\,\frac{\omega}{\omega_{p\alpha}}\frac{K!}{(K-\frac{3}{2})!}\sum_{\alpha=+i,-i,e,M}\frac{1}{(k\lambda_{D\alpha})^3}\frac{1}{K^{\frac{3}{2}}}\left(1+\frac{1}{K(k\lambda_{D\alpha})^2}\frac{\omega^2}{\omega_{p\alpha}^2}\right)^{-K-1}
$$

$$
-\sum_{\alpha=+i,-i,e,M}2i\sqrt{\pi}\,\frac{\omega}{\omega_{p\alpha}}\frac{1}{(k\lambda_{D\alpha})^3}
\tag{9}
$$

$$
\zeta_K=\frac{\omega}{kv_{K\alpha}},\;\zeta=\frac{\omega}{kv_\alpha}
\tag{10}
$$

The first term of the equation 9 is about particles with kappa distribution and the second term is about particles with Maxwell distribution.

By using equation 11, we obtain growth and attenuation rate.

$$
\gamma = -\frac{\varepsilon^{im}\left(\omega_r,k\right)}{\left.\dfrac{\partial\varepsilon^{re}}{\partial\omega}\right|_{\omega=\omega_r}}
\tag{11}
$$

sonic wave

The frequency of dusty sonic waves is in order of dust fluctuation frequency (HZ). Propagation of these waves happens longitudinally and sonic and from the layer to another layer and finally diffused by molecules impacts.

1- A plasma system with kappa distribution for electrons, kappa distribution for ions.

2- A plasma system was considered all the comprising particles with Maxwell distribution.

3- A plasma system with kappa distribution for electrons, Maxwell distribution for ions.

ion sonic wave

The propagation of dust ion-sonic waves like propagation of sonic or pressure wave will happen longitudinal and sonic. The sonic ion dust waves are similar to sonic ion in regular plasma and have a frequency in order of

ion frequencies (KHZ) with a difference that the dispersion equation has been changed due to the presence of dust particles.

4- A plasma system was considered all the comprising particles with Maxwell distribution.

5- A plasma system with kappa distribution for electrons, Maxwell distribution for ions.

6- A plasma system with kappa distribution for electrons, kappa distribution for ions.

Langmuir wave

One of the effects which cause the propagation of plasma fluctuation is the thermal effects or thermal movements. Electron which moves to the adjacent plasma layers with thermal velocities, transfer data of the fluctuating layer. Langmuir waves can be named as a type of plasma fluctuation.

7- A plasma system with kappa distribution for electrons, Maxwell distribution for ions.

8- A plasma system with kappa distribution for electrons, kappa distribution for ions we obtain:

In figures attenuation rate and propagation rate with wave number for Landau damping rate and propagation rate for K=5 (gray continuous line), K=2.5 (dashed line), K=∞ (dotted line), and without Landau damping rate and propagation rate (black continuous line) for K=5.
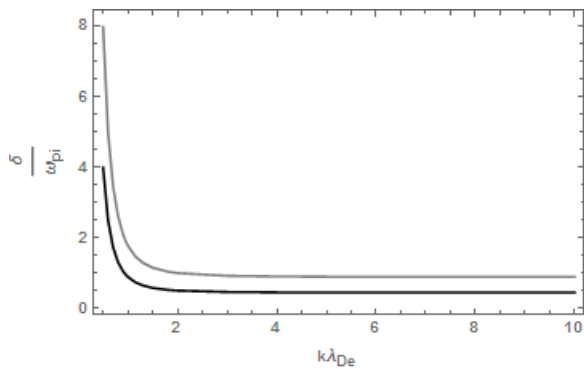
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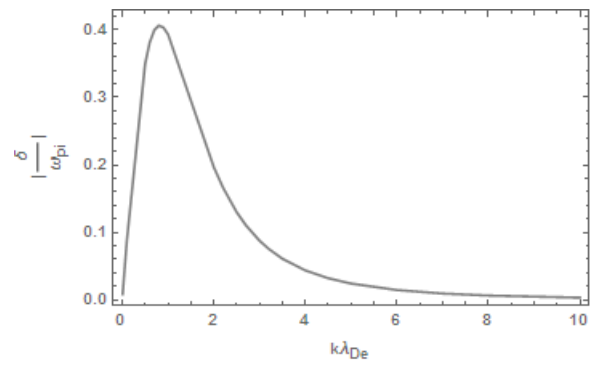
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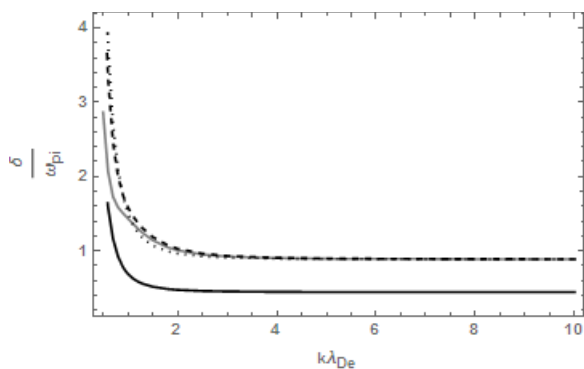
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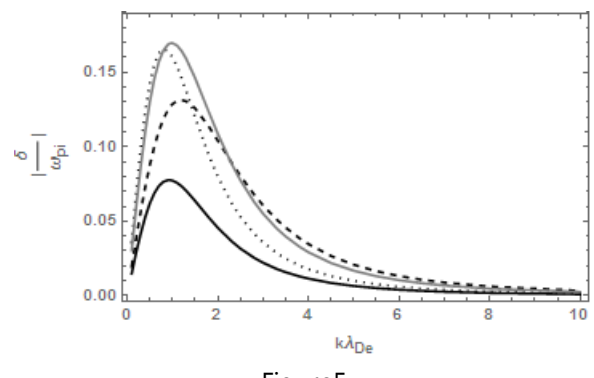
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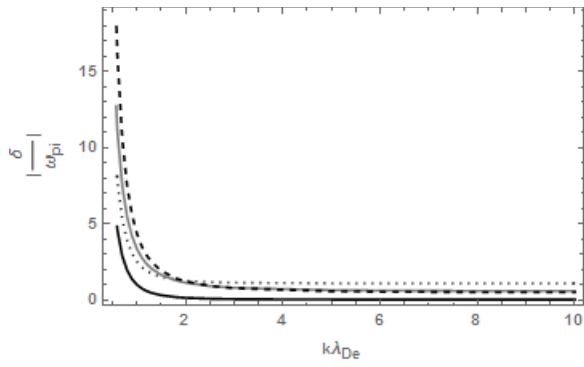
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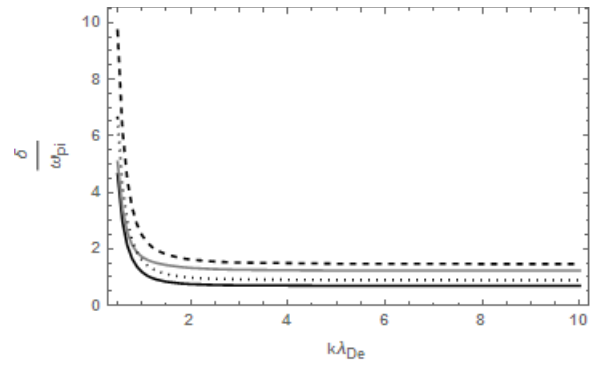
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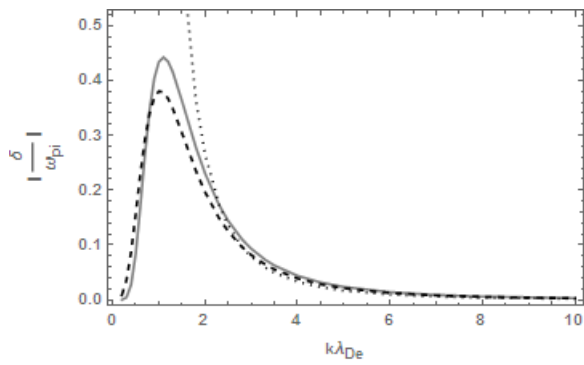
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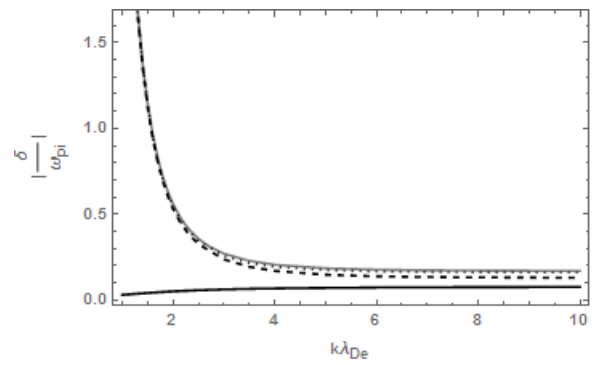
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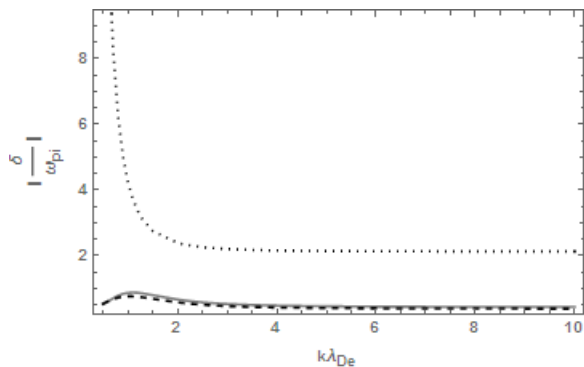
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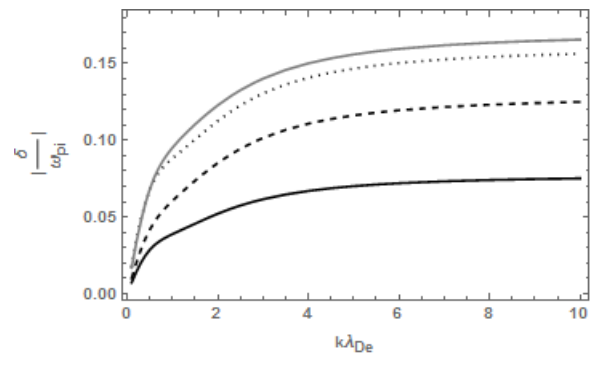
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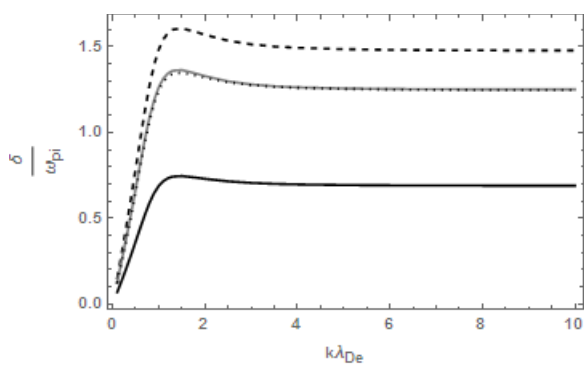
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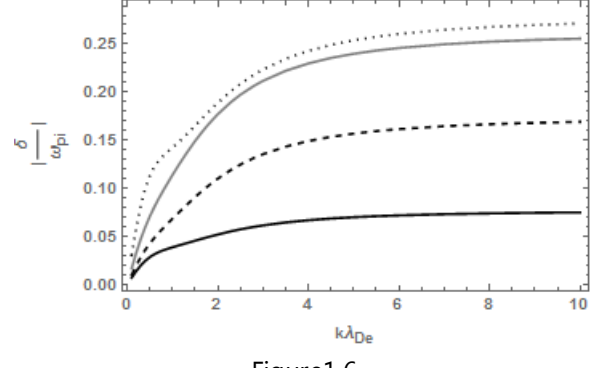
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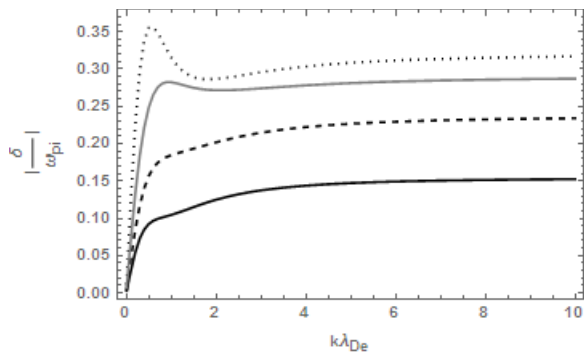
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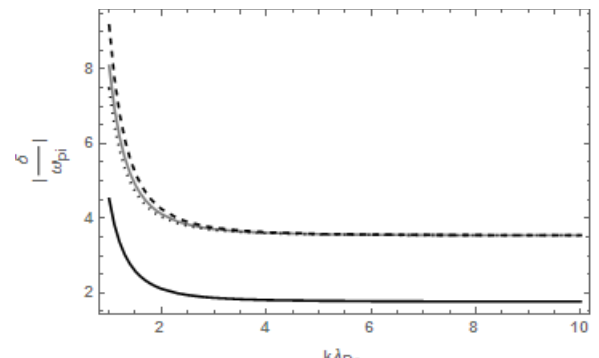
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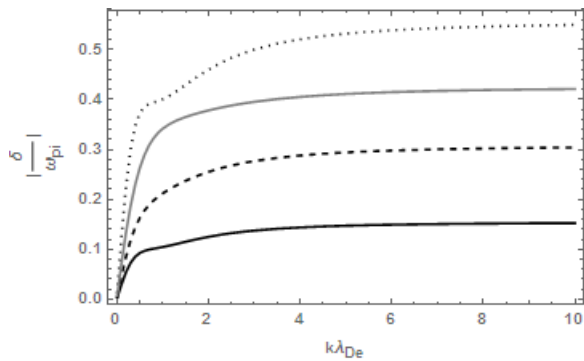
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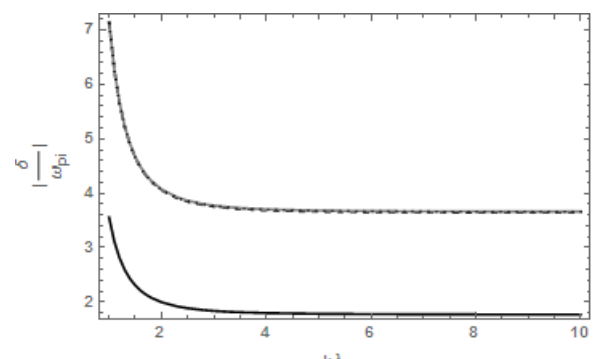
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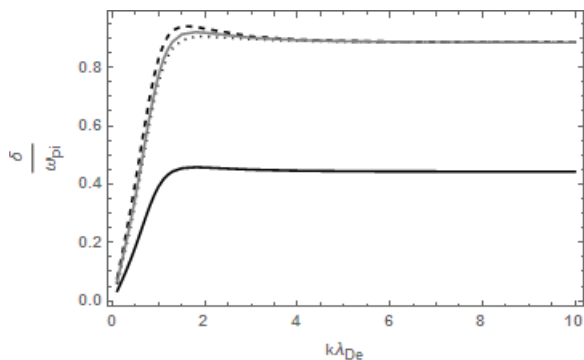
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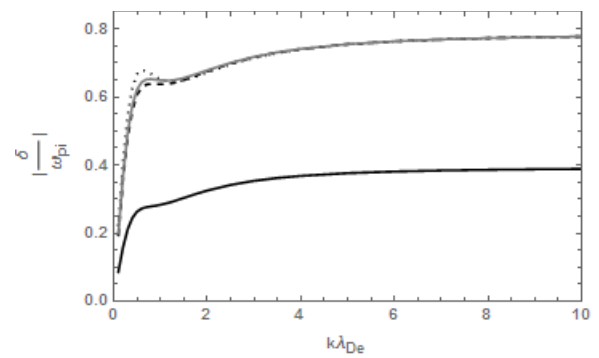
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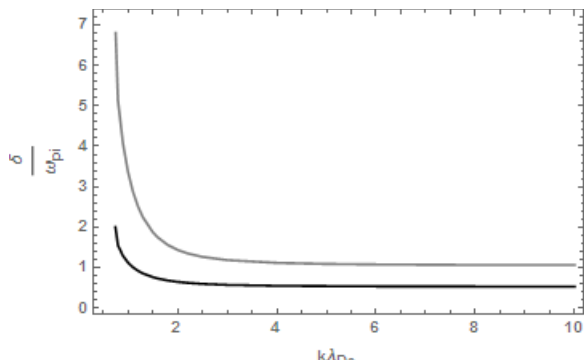
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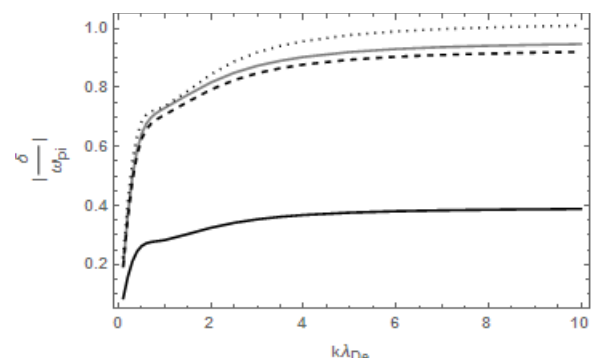
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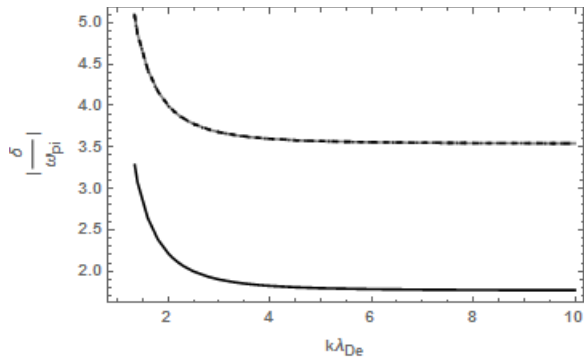
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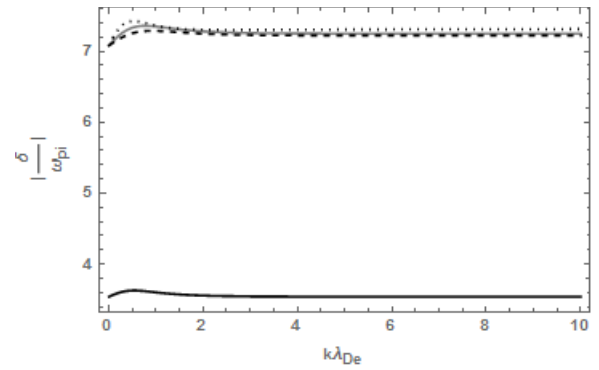
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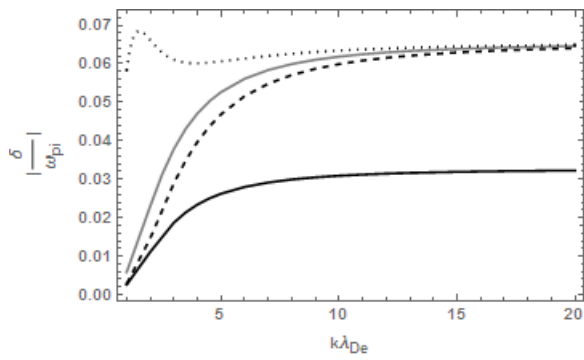
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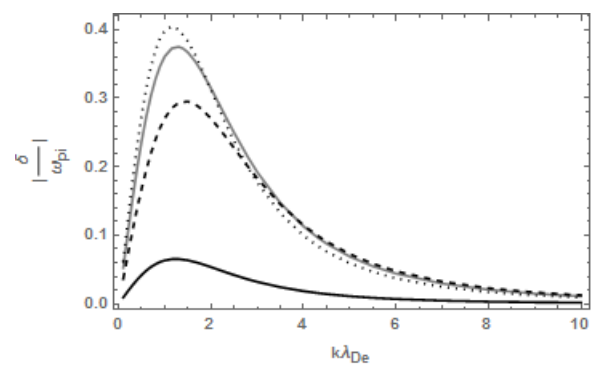
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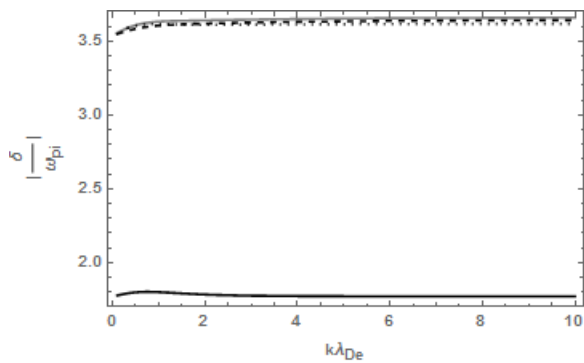
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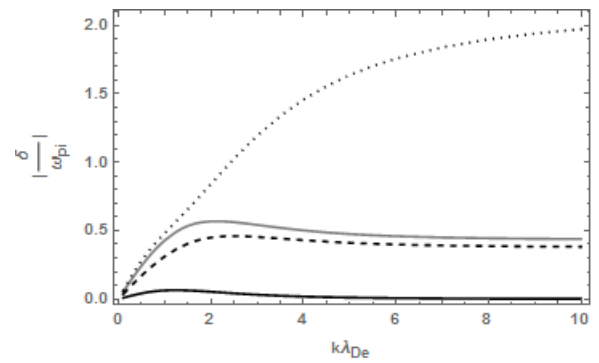
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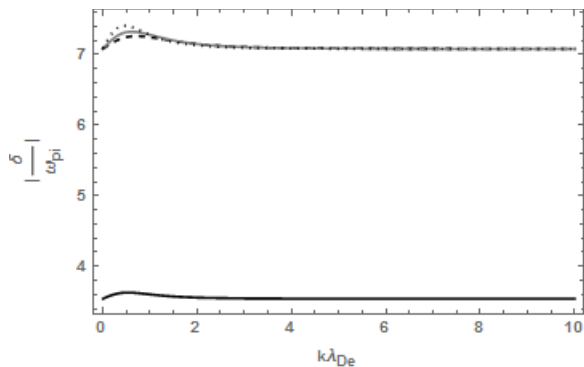
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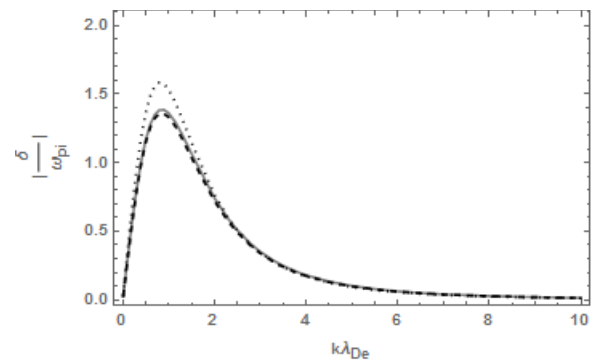
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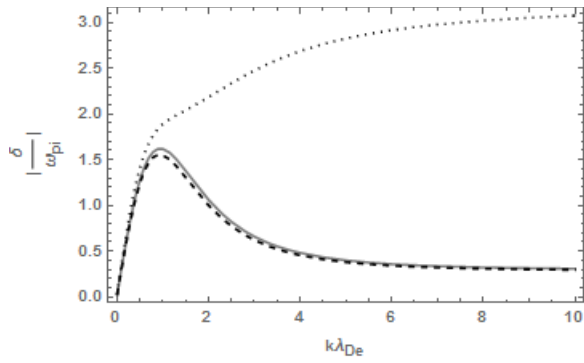
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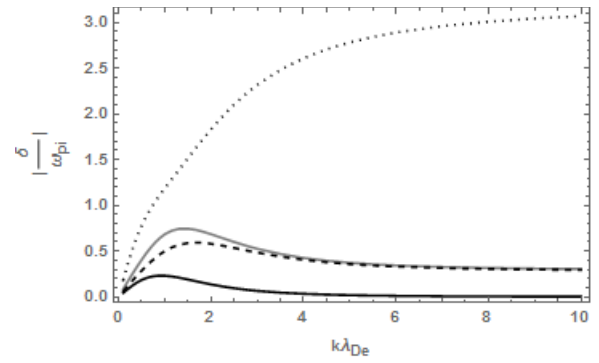
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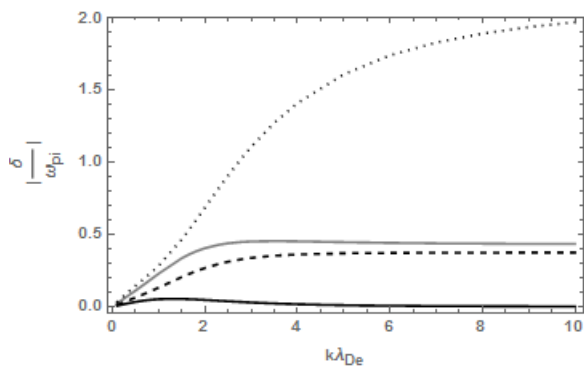
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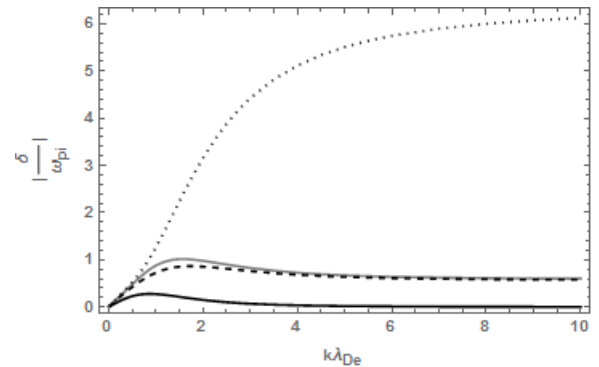
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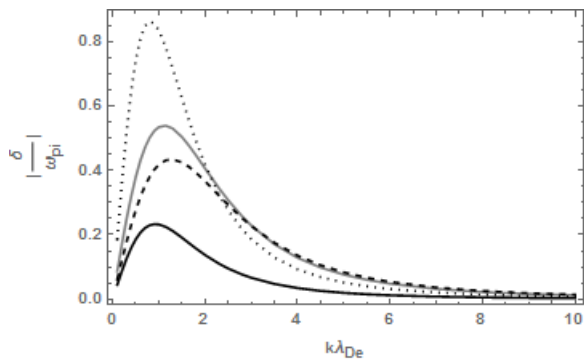
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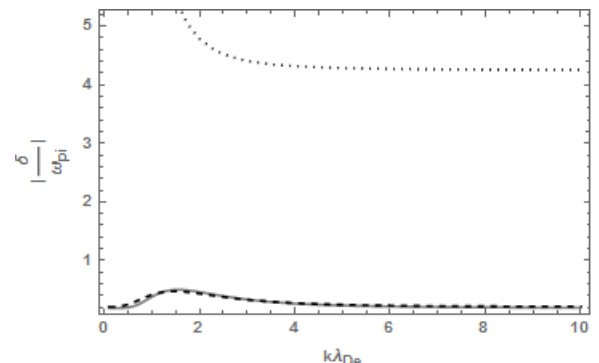
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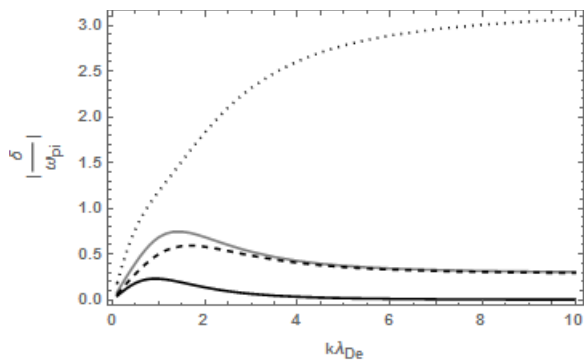
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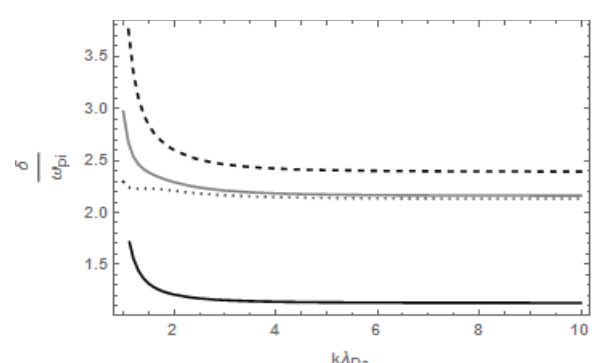
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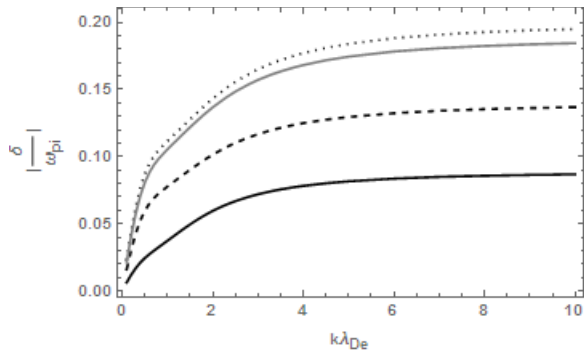
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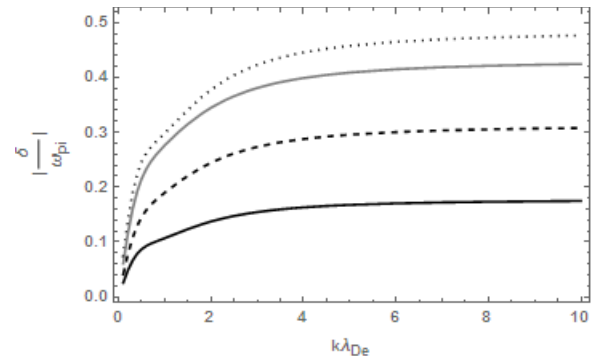
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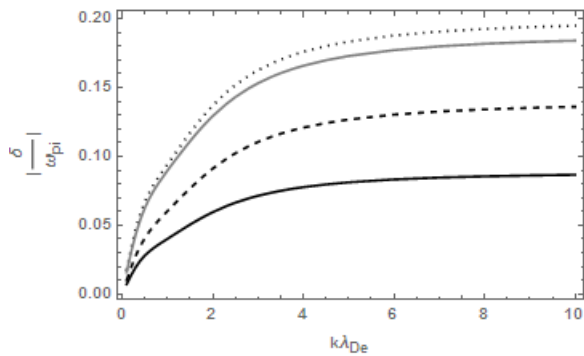
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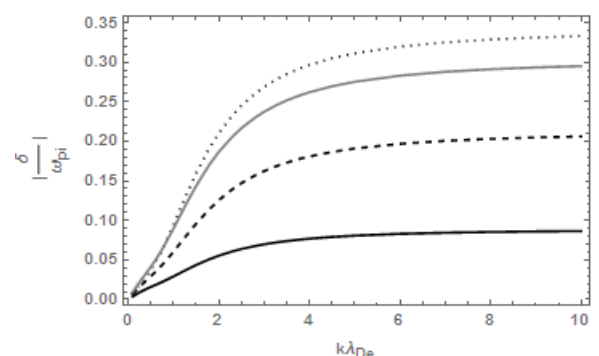
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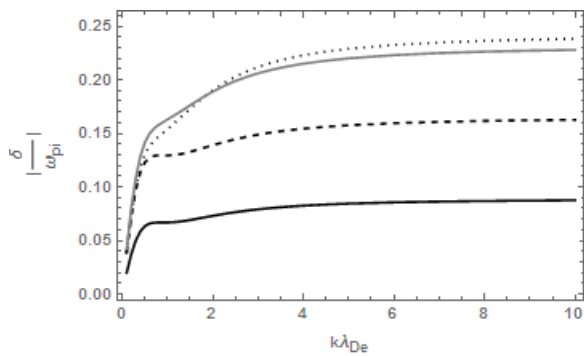
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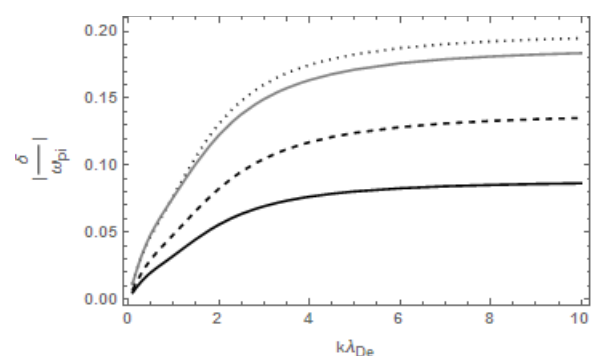
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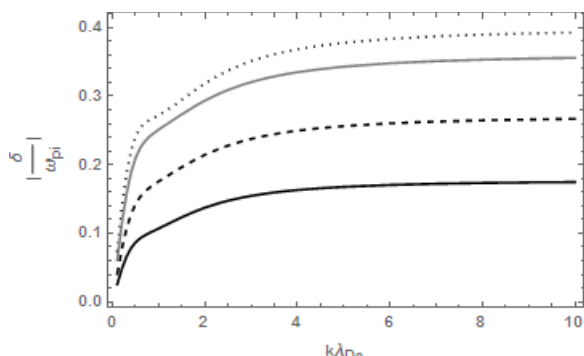
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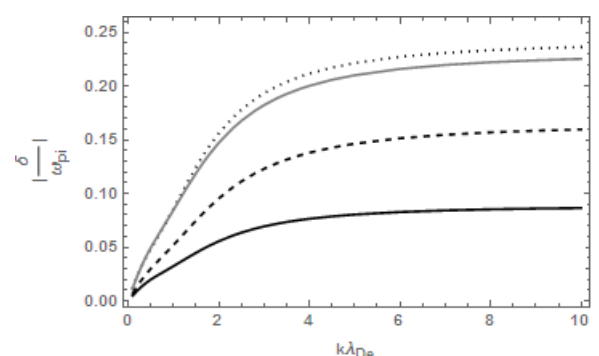
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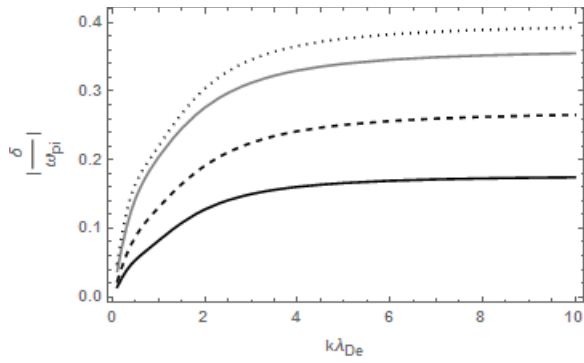
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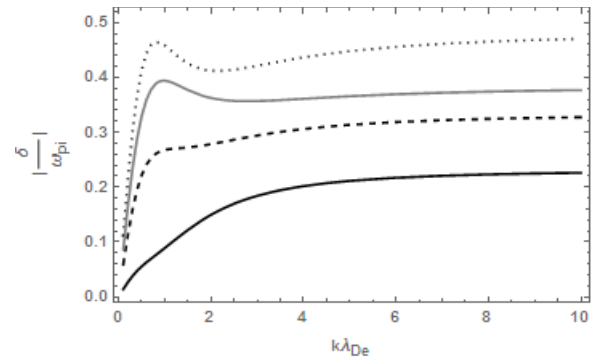
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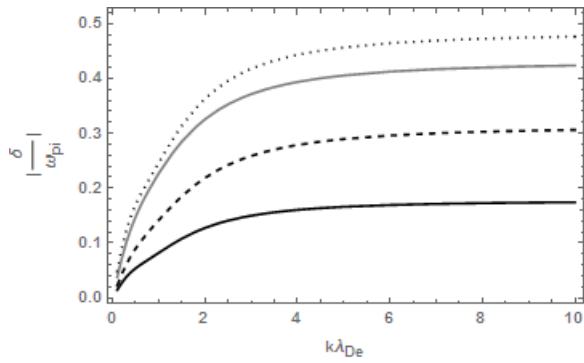
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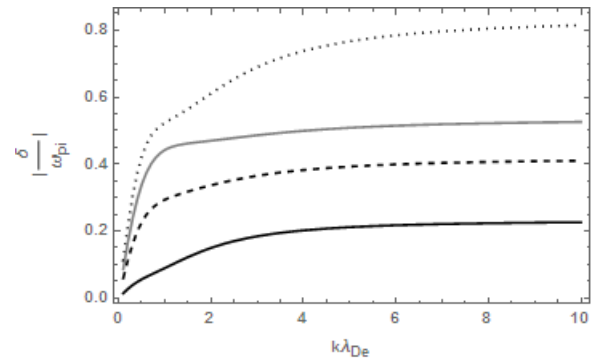
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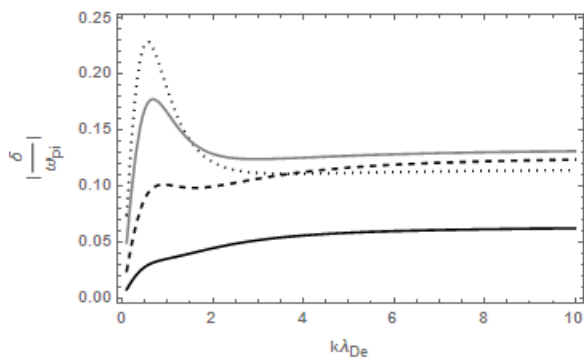
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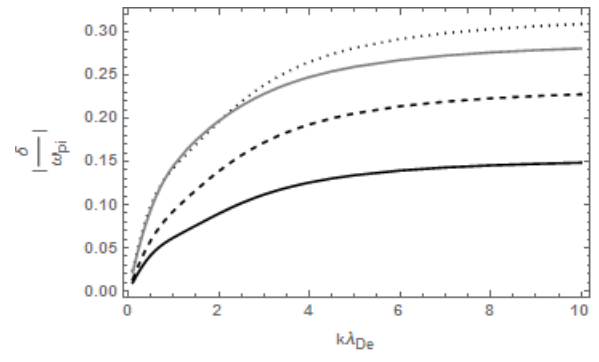
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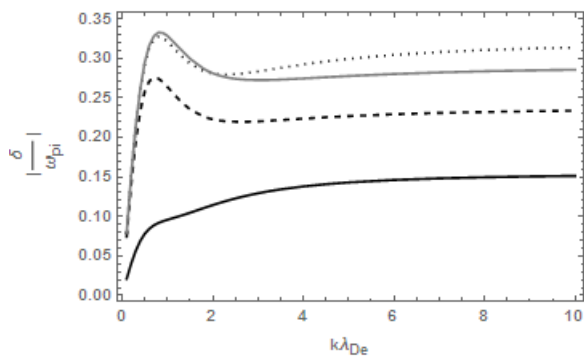
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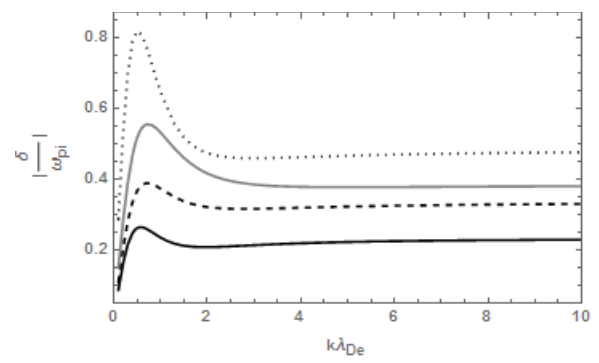
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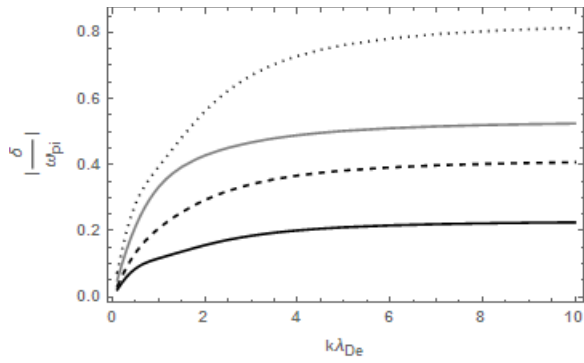
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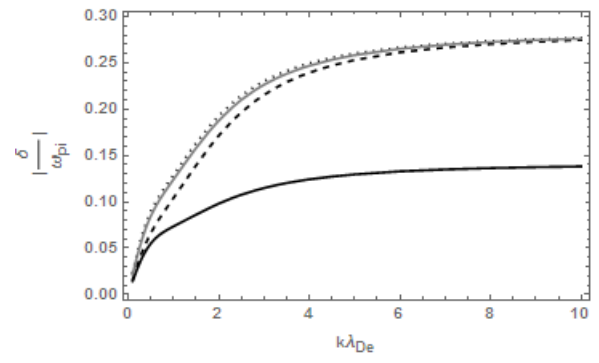
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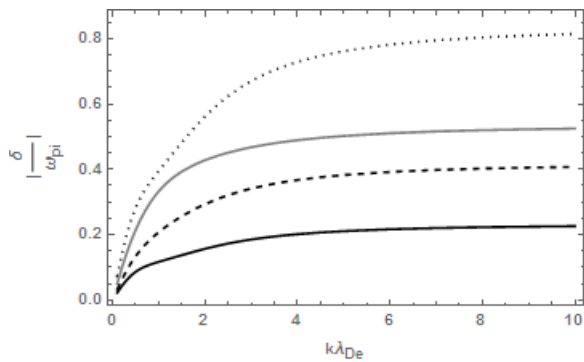


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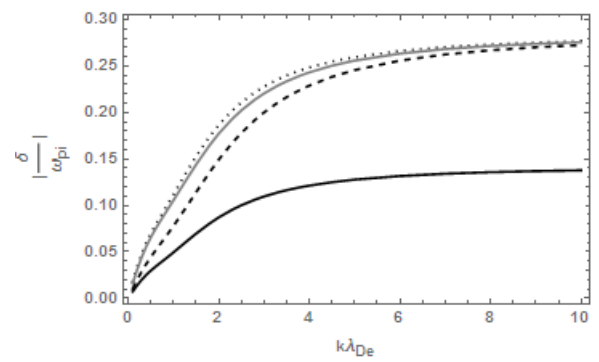
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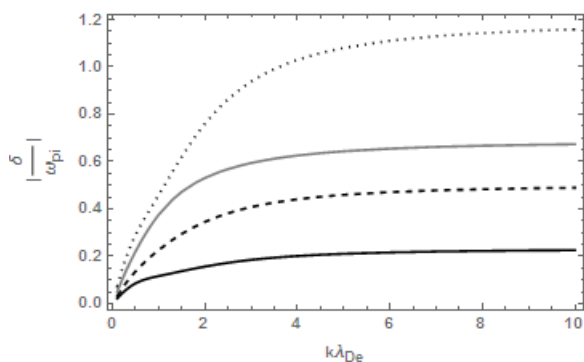
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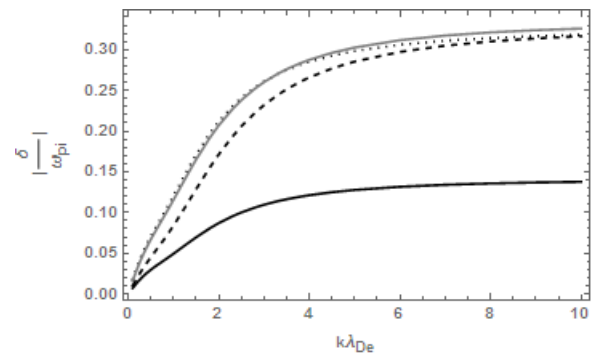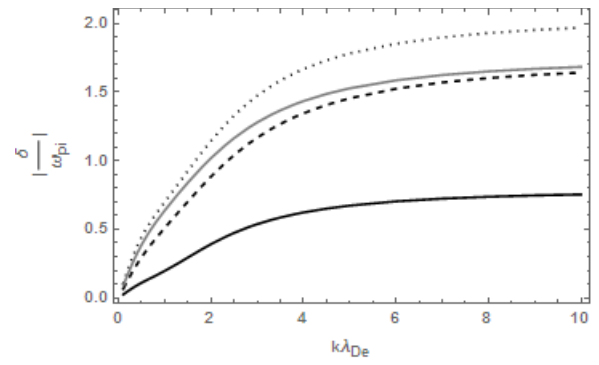

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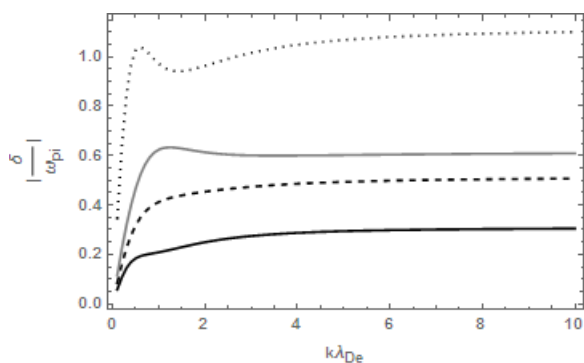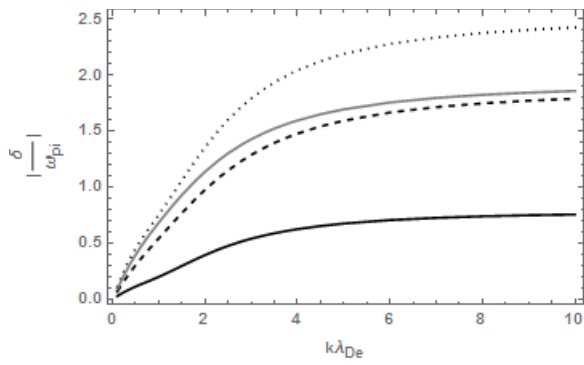

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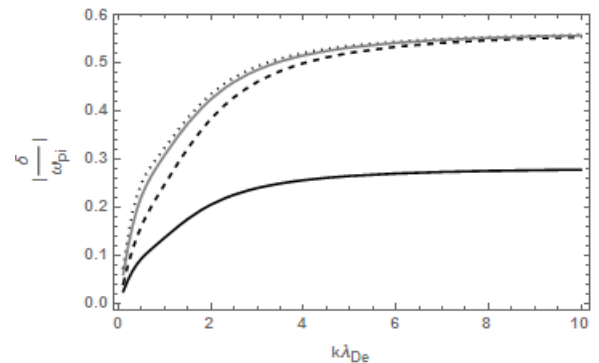
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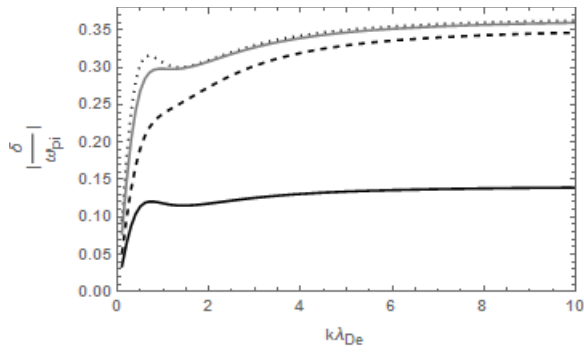
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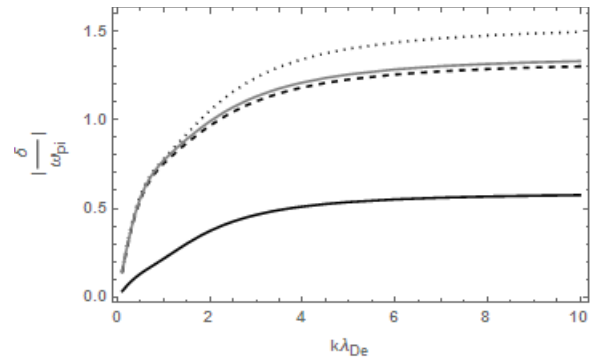
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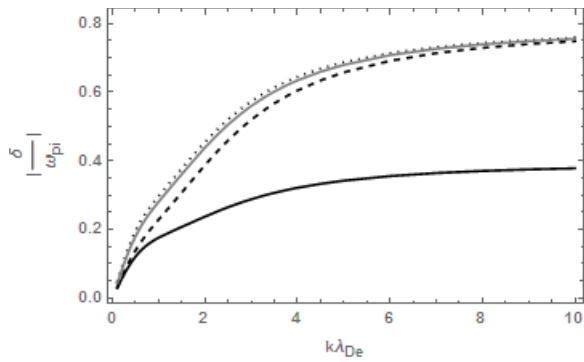
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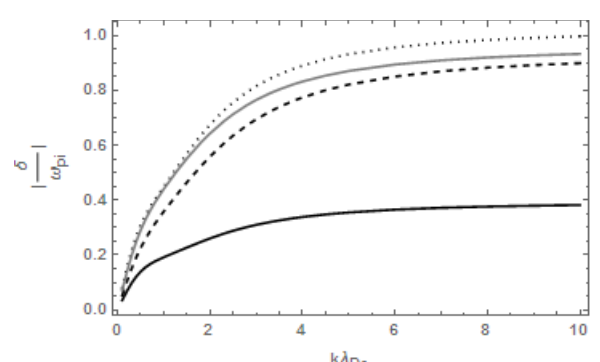
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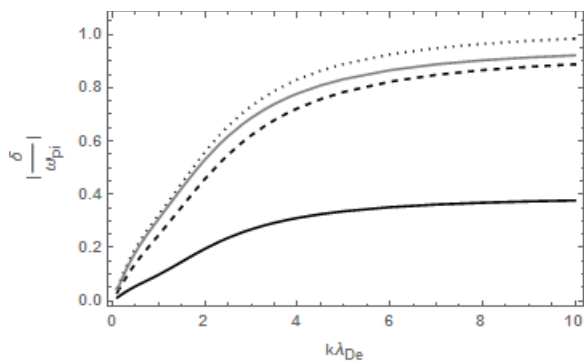
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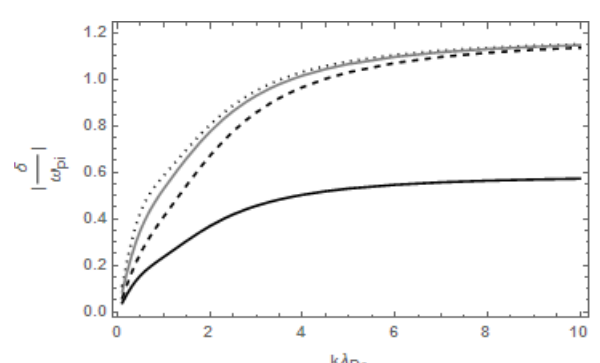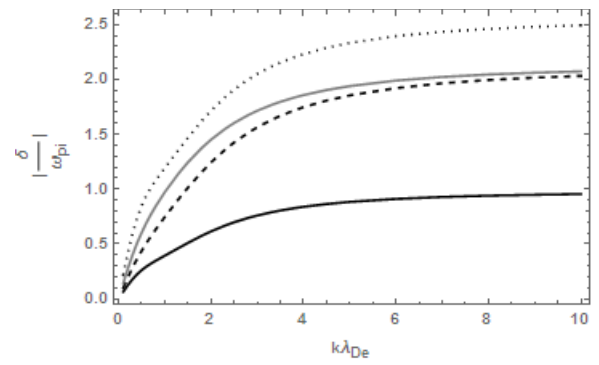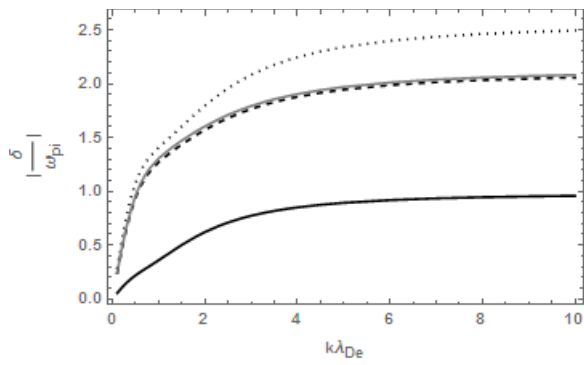
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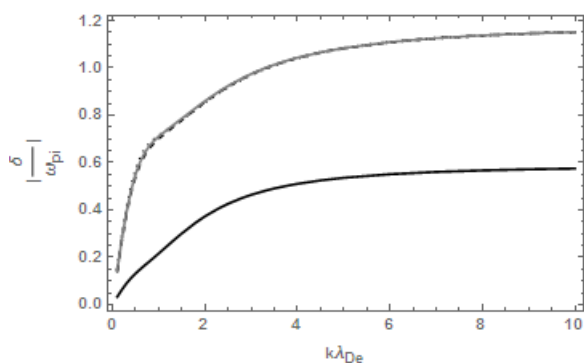
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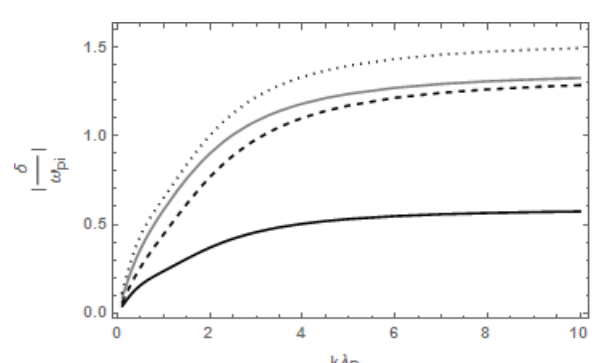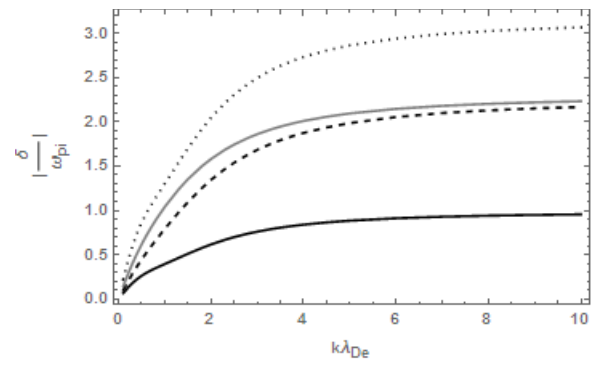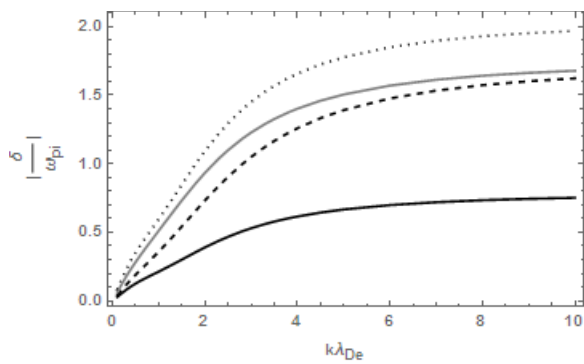
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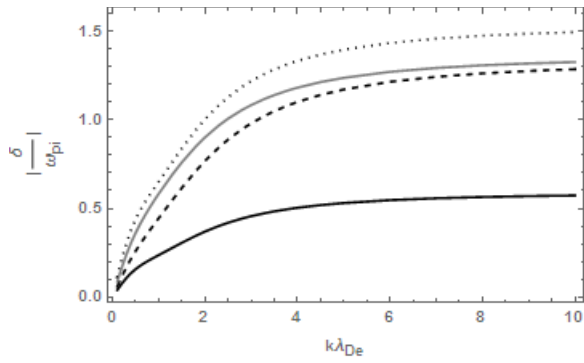
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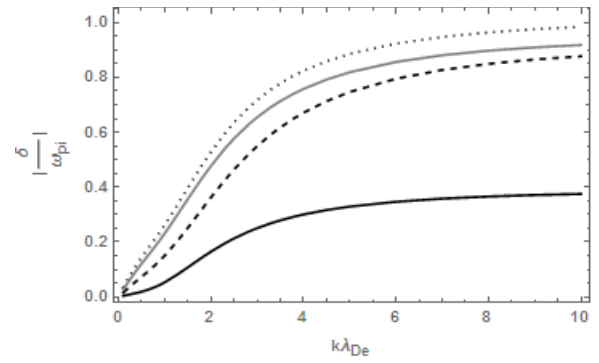
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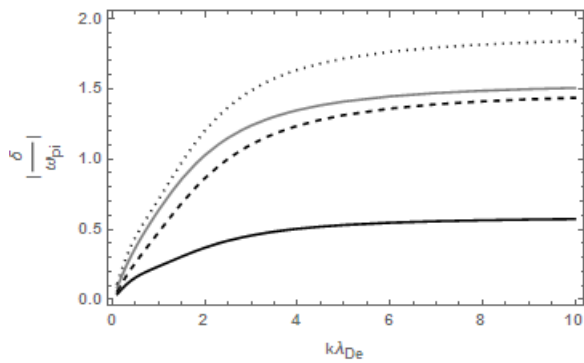
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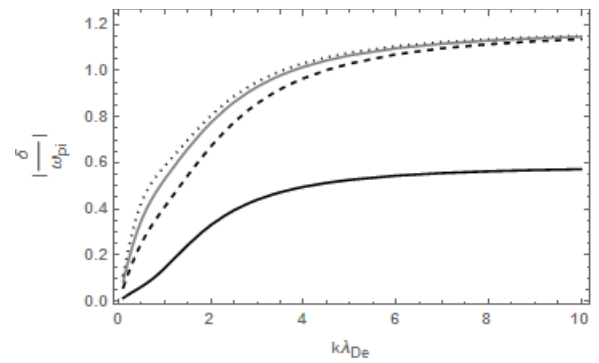
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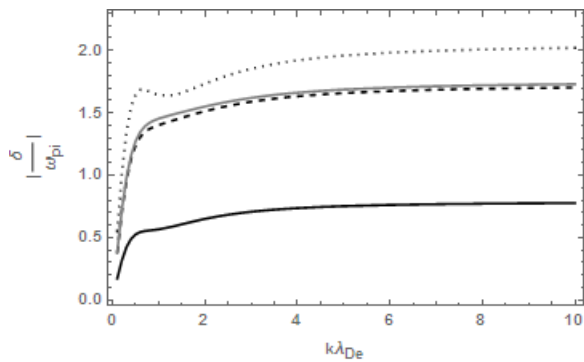
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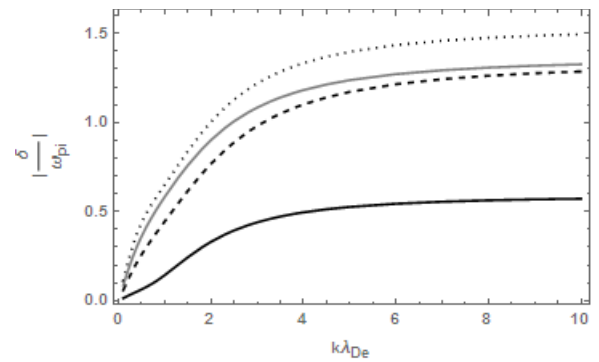
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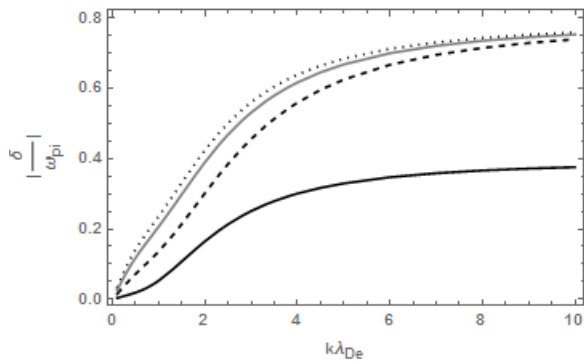
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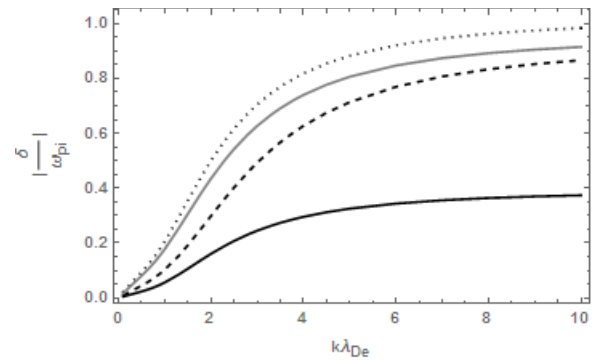
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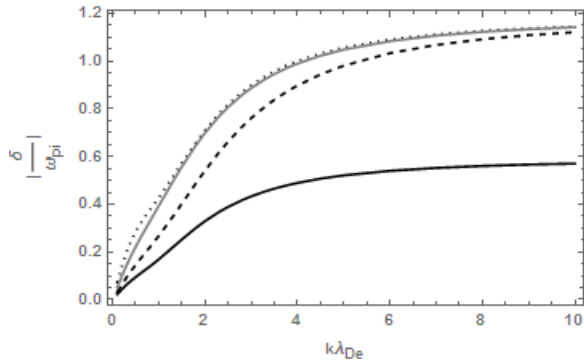
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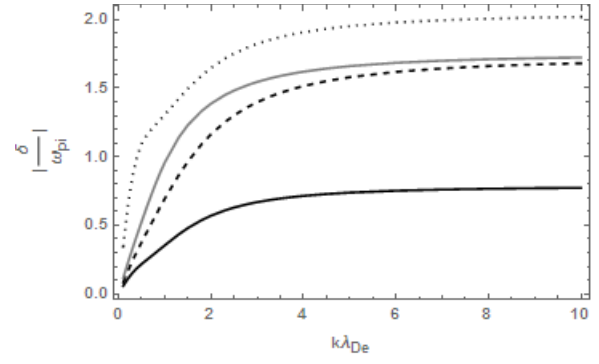
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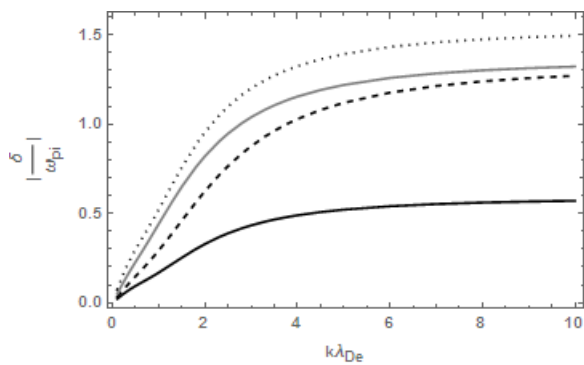
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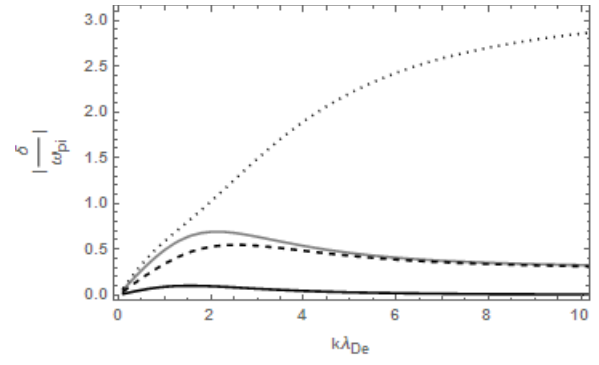
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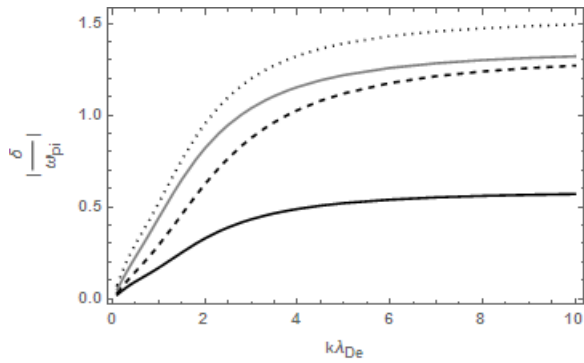
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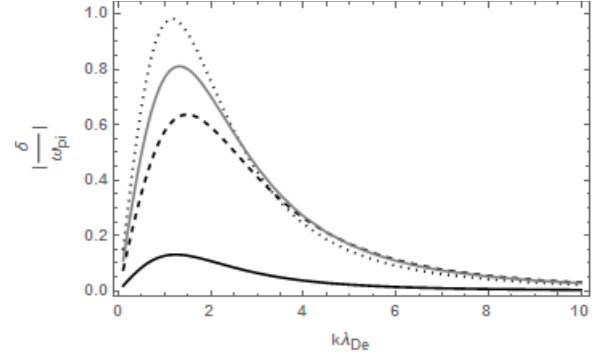
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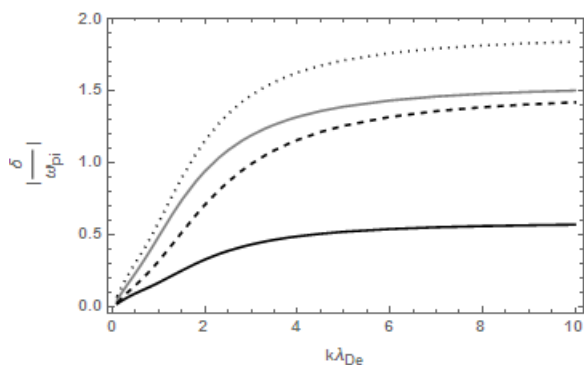
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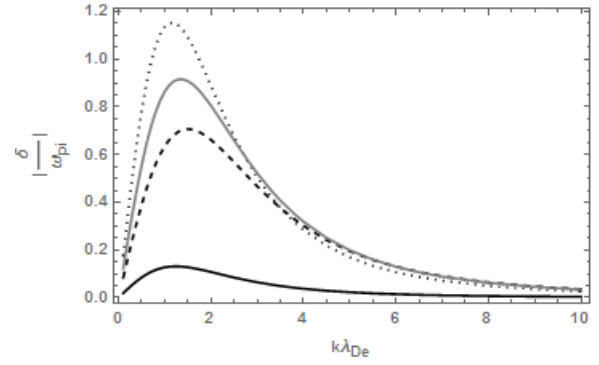
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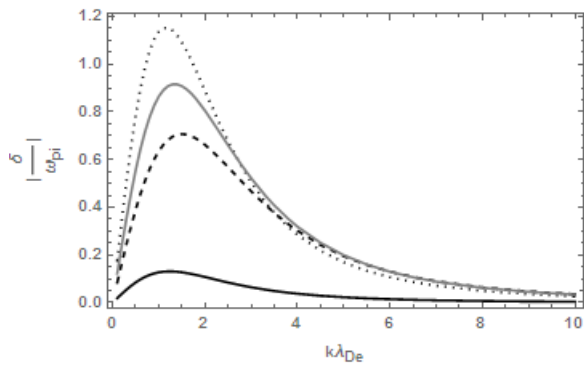
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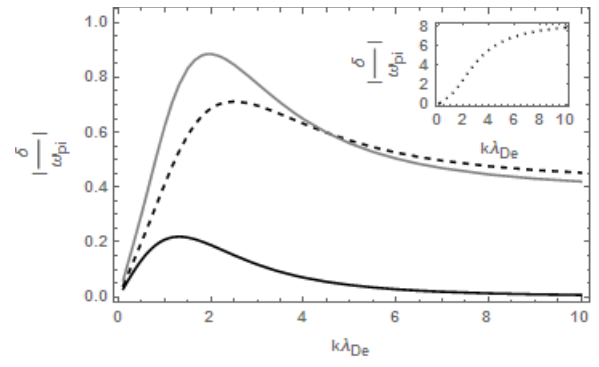
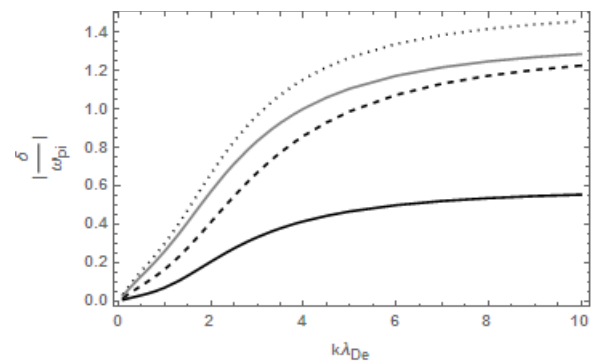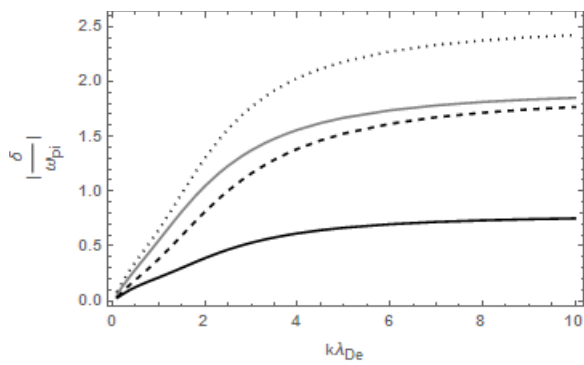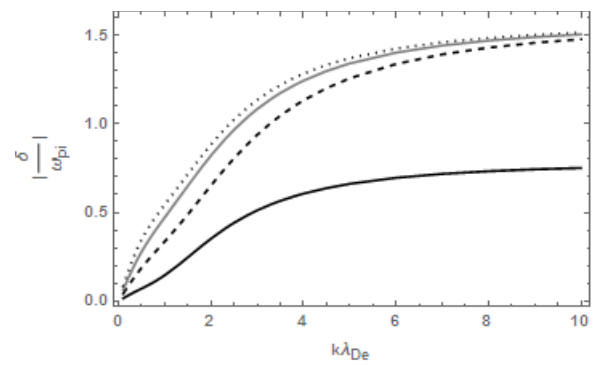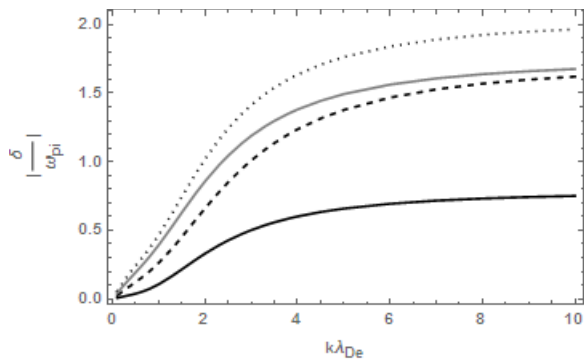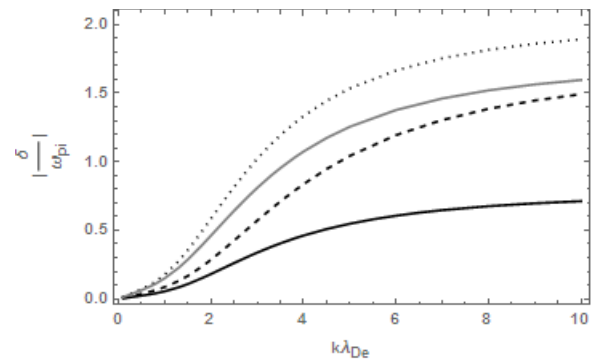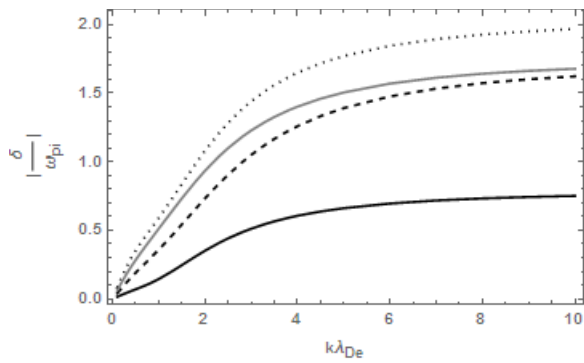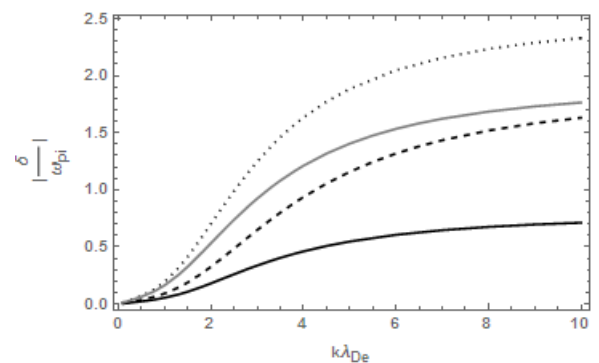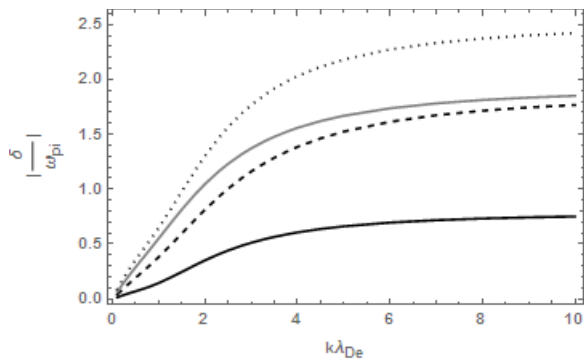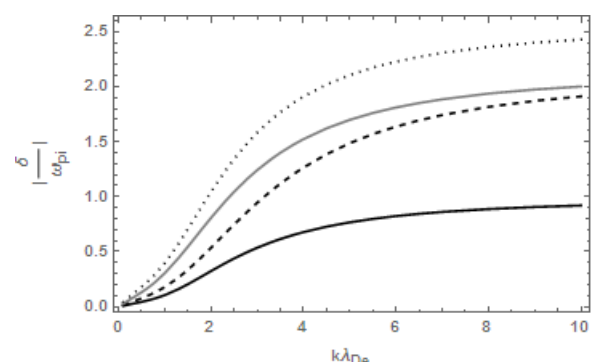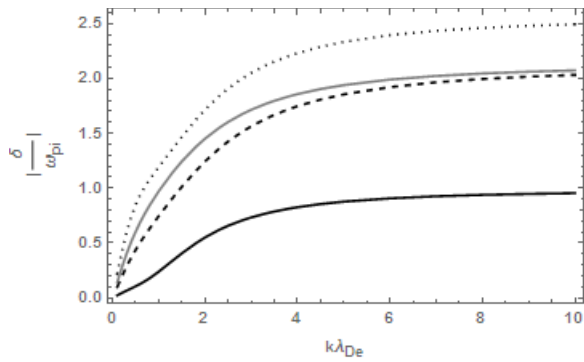Figure5,6,8
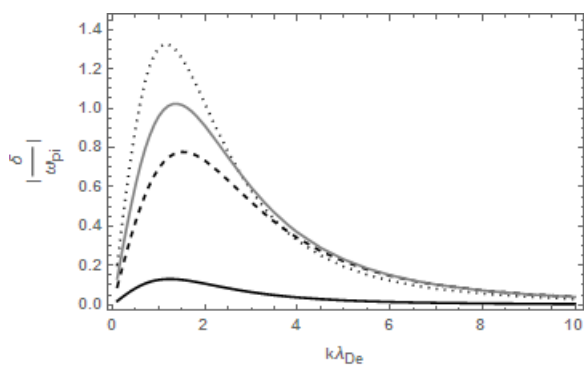
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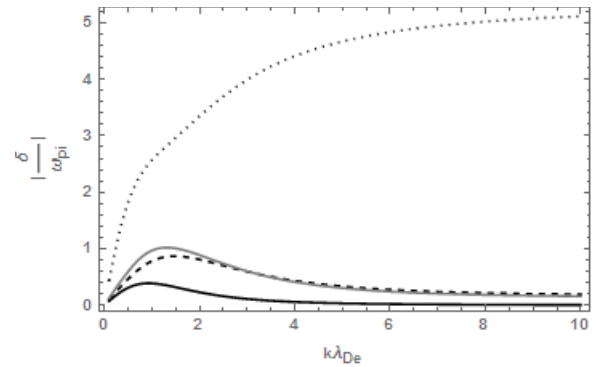
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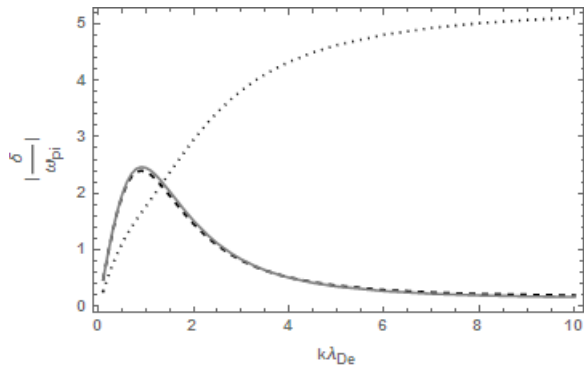
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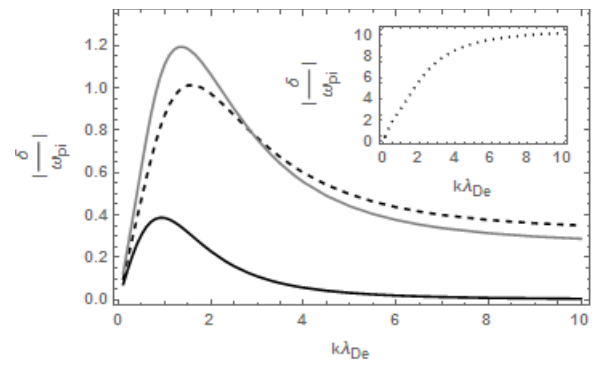
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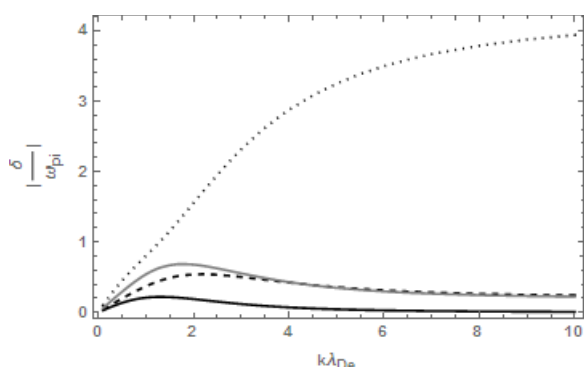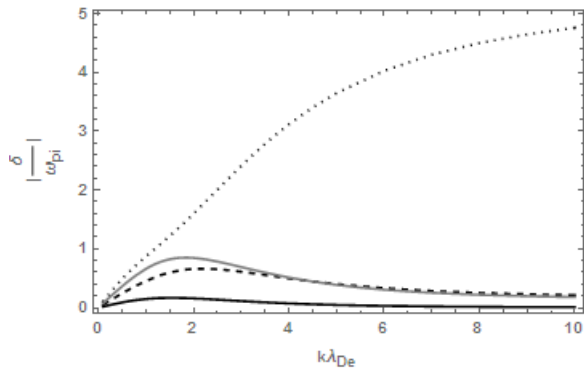

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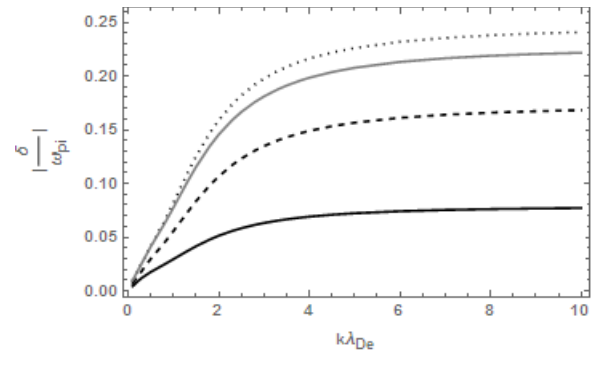
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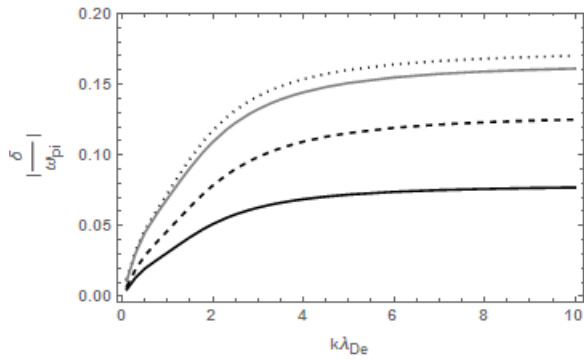
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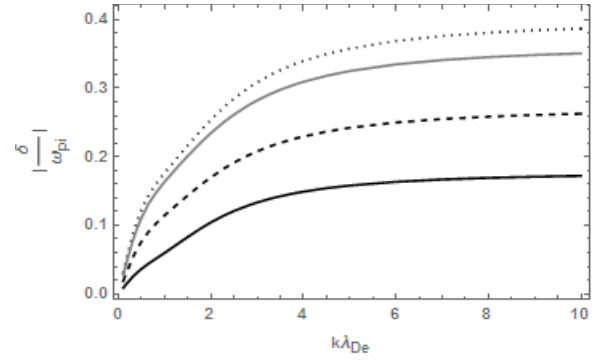
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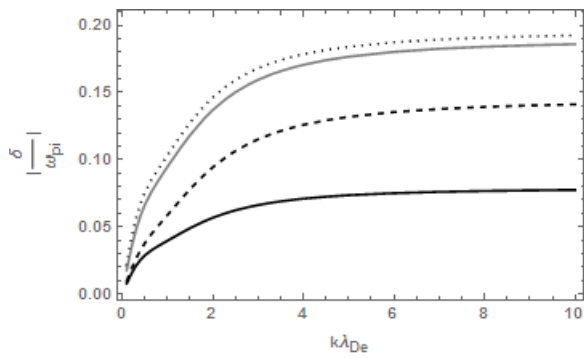
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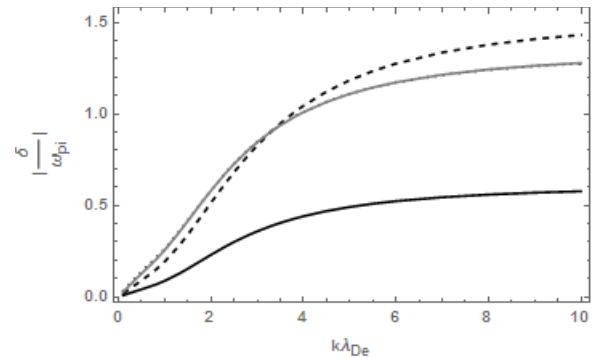
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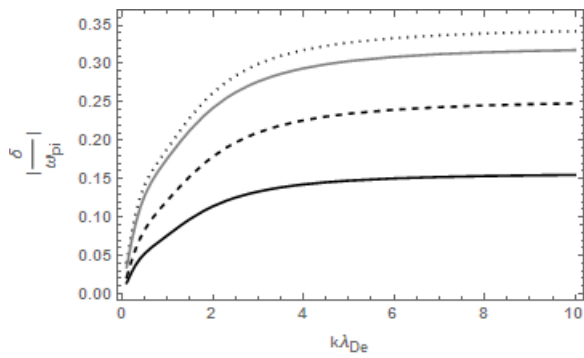
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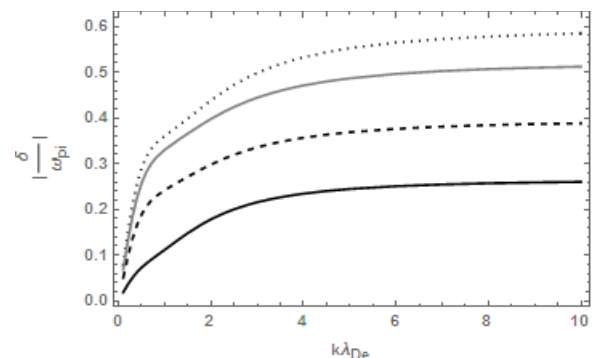
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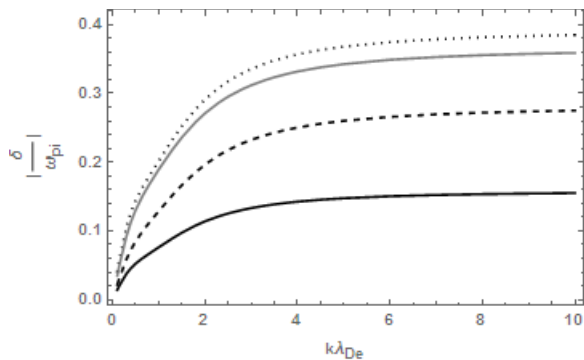
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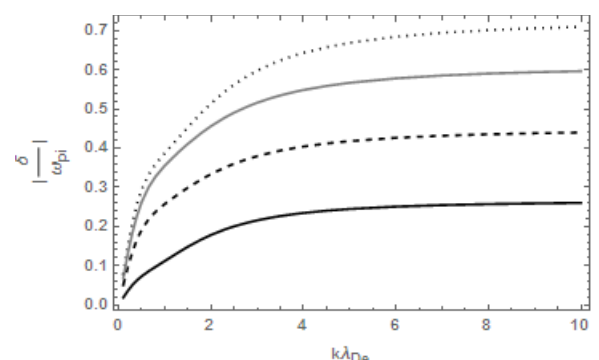
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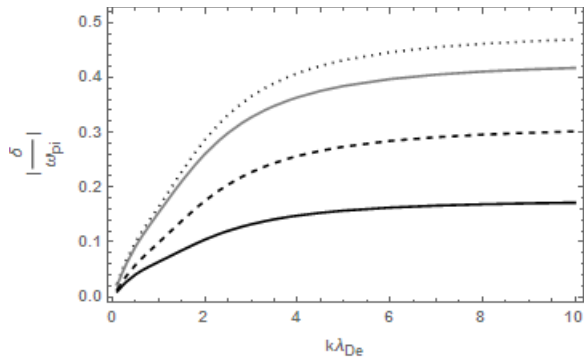
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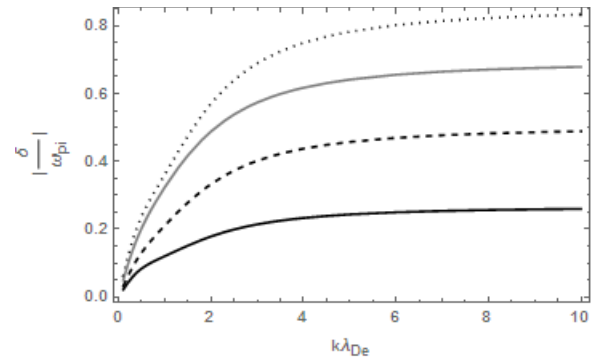
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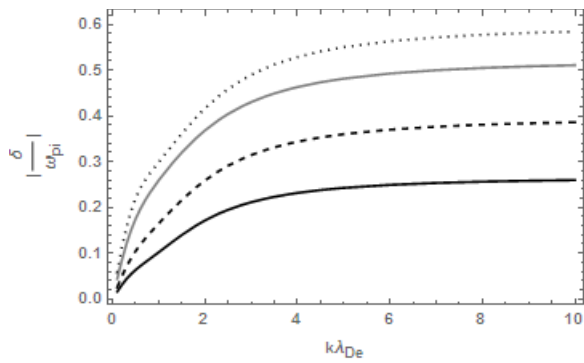
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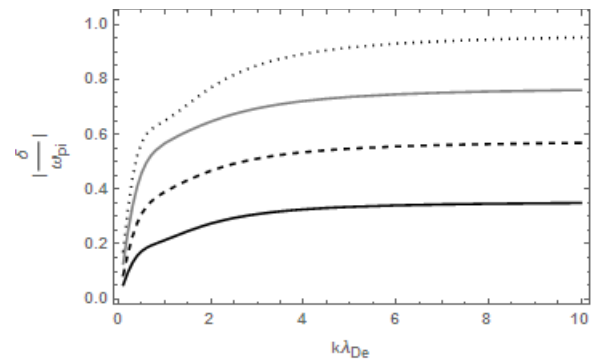
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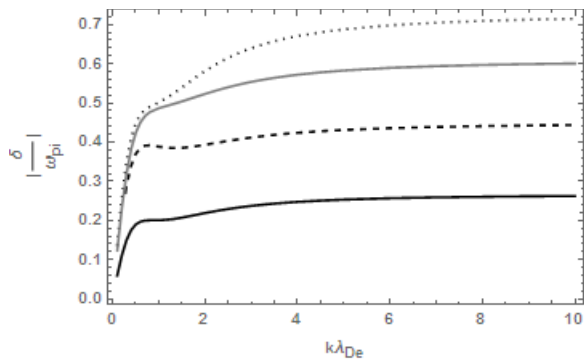
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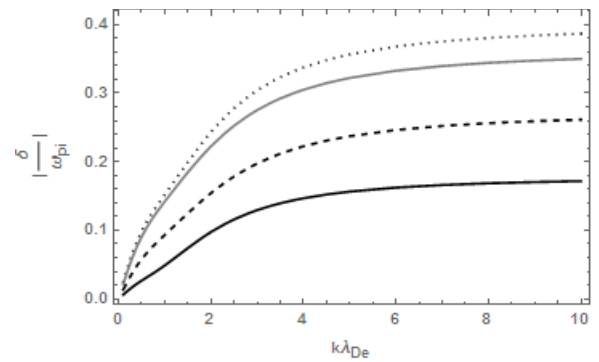
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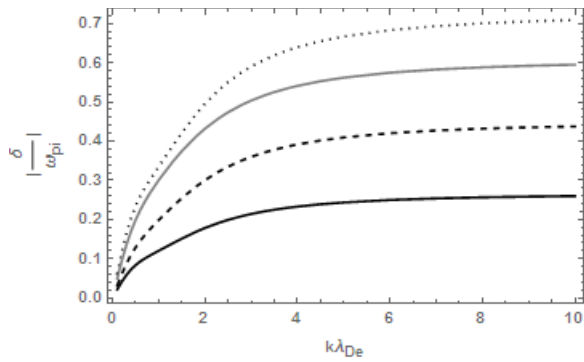
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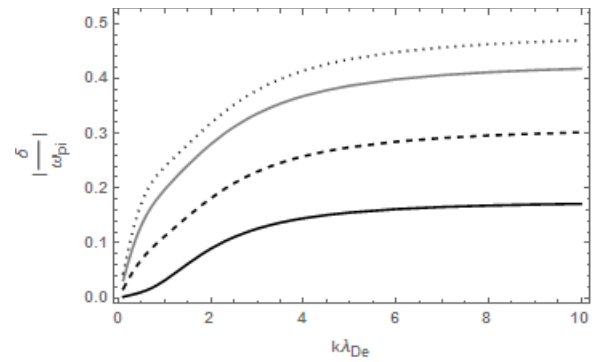
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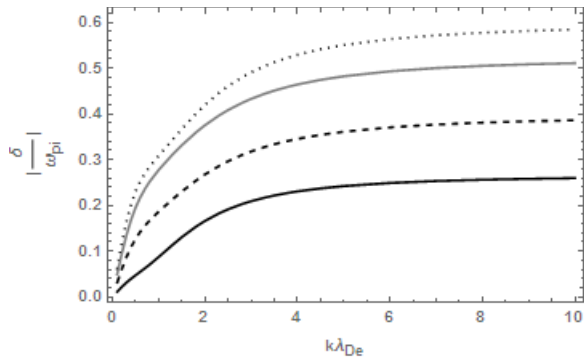
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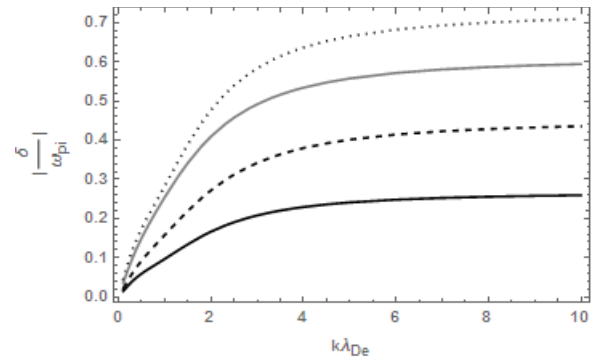
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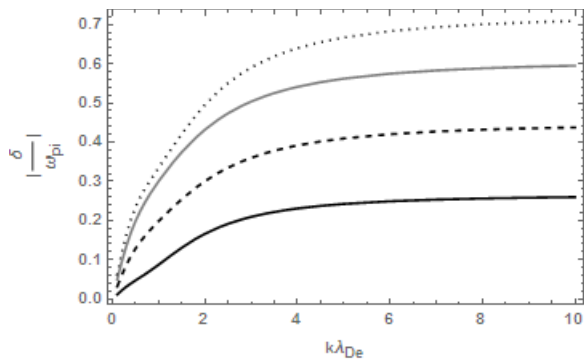
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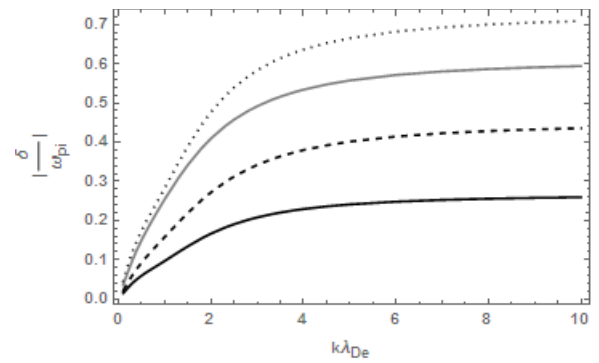
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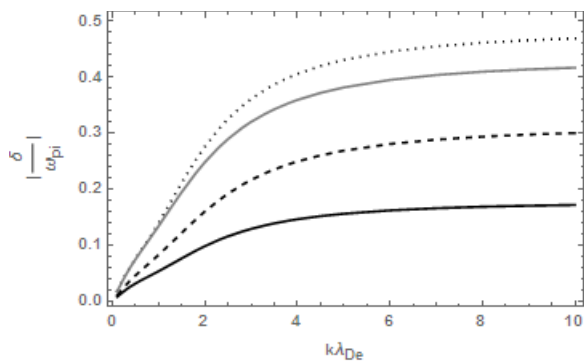
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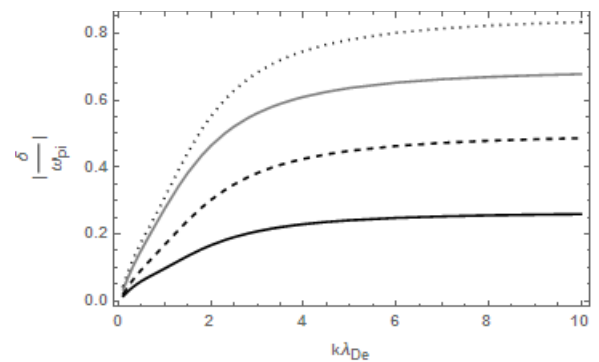
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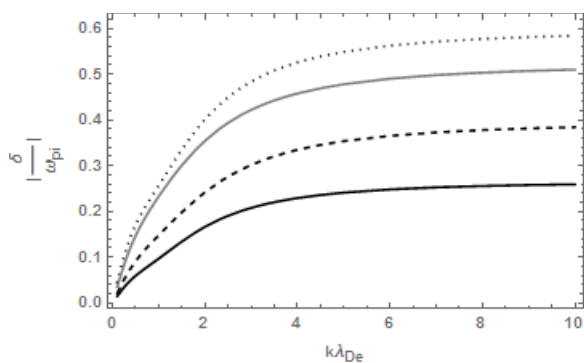
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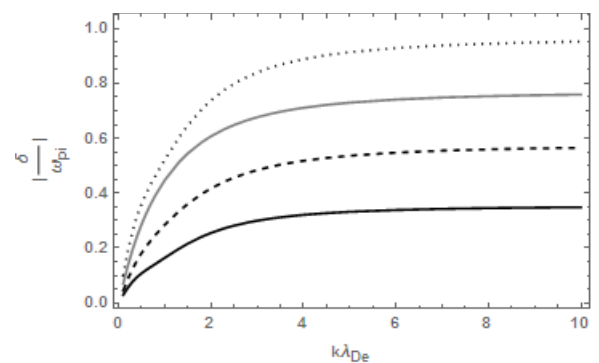
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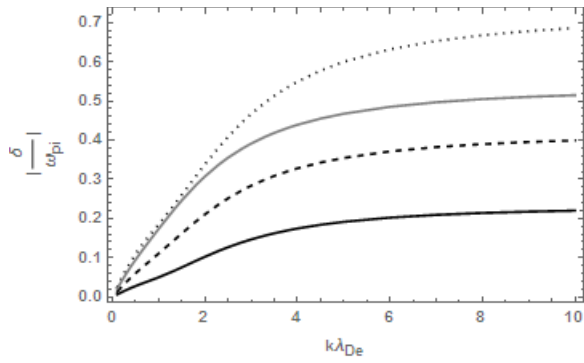
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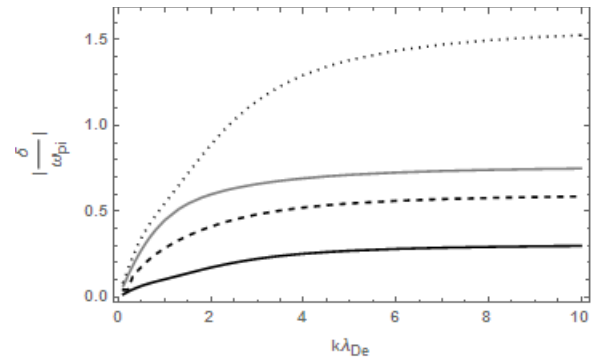
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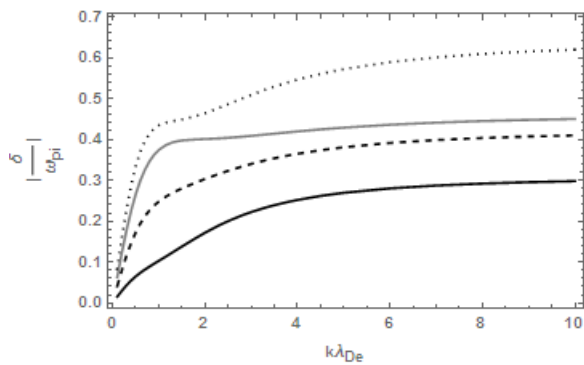
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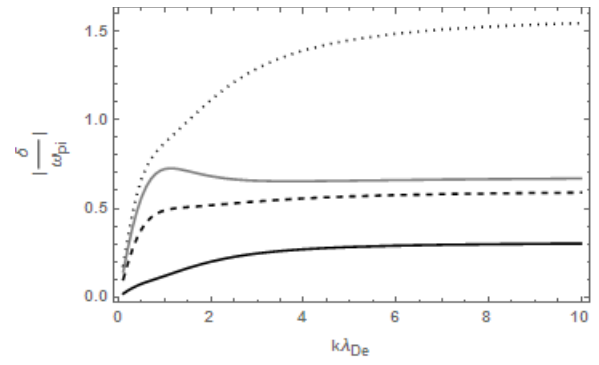
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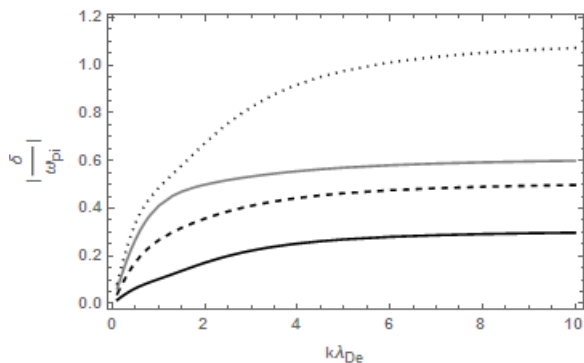
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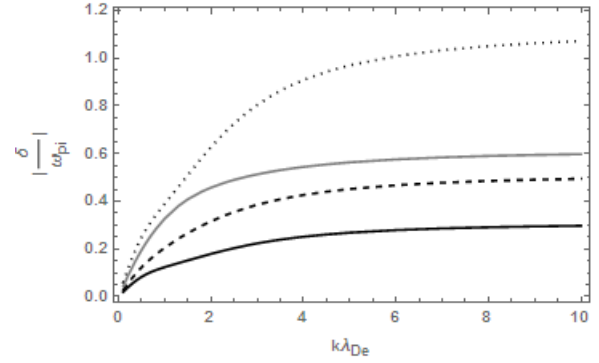
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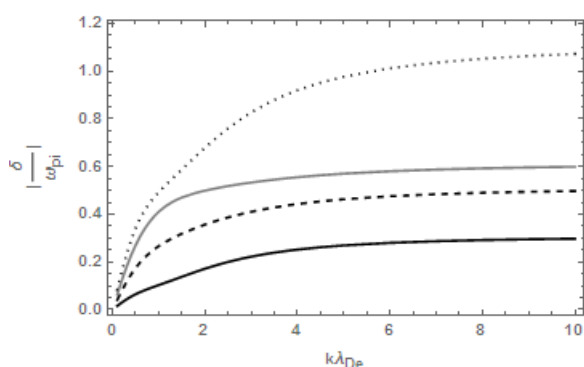
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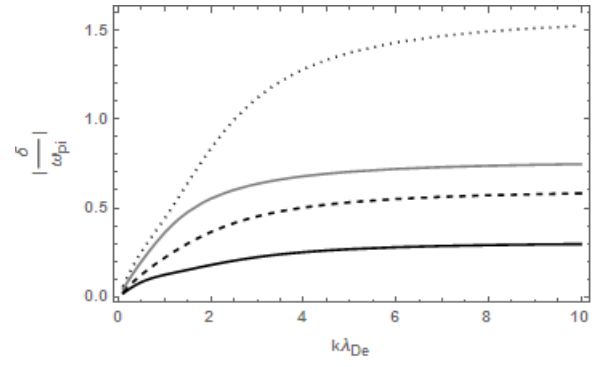
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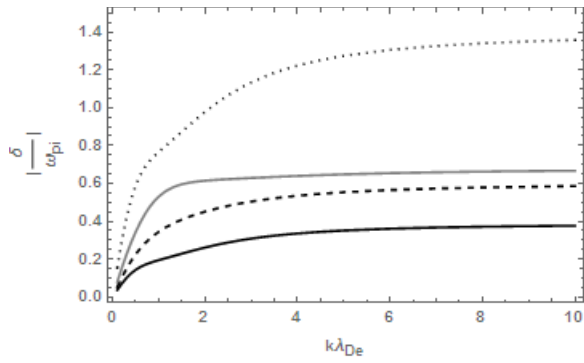
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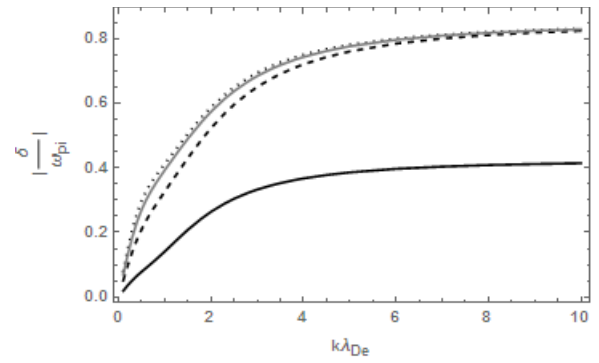
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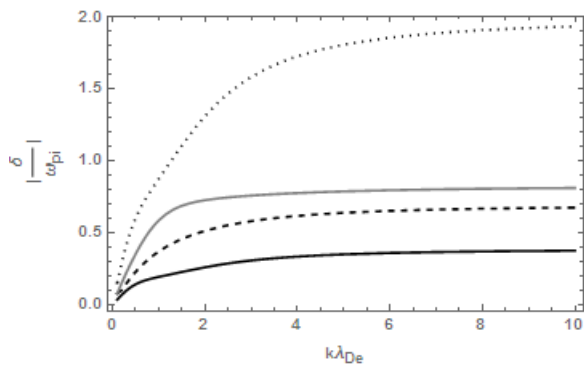
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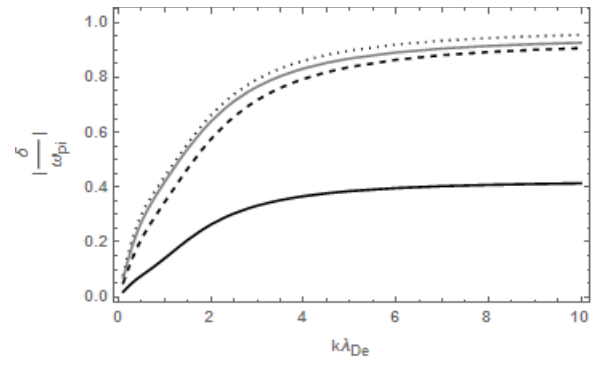
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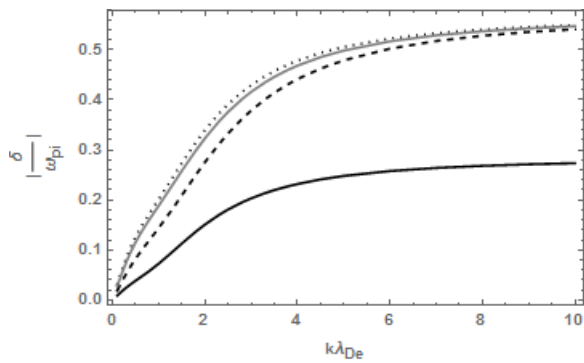
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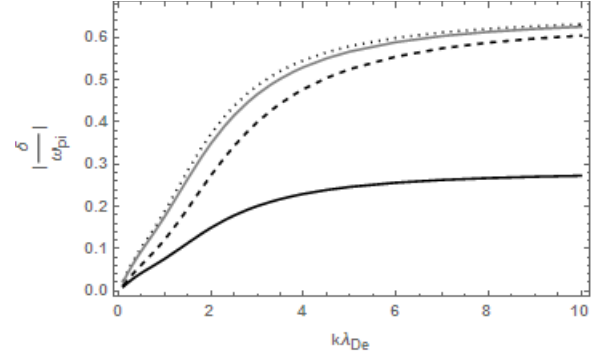
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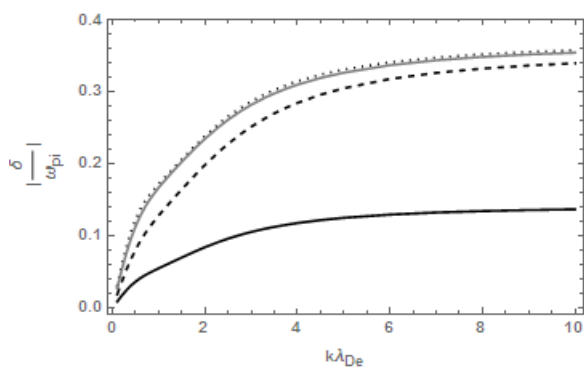
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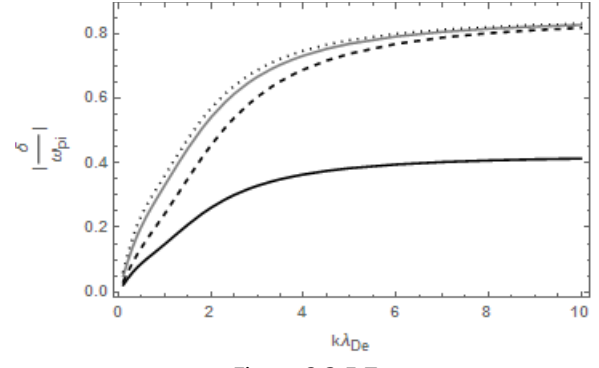
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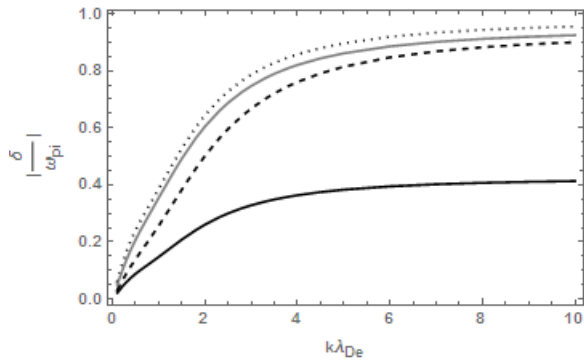
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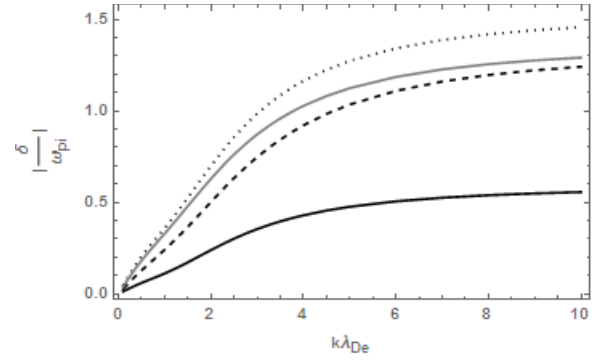
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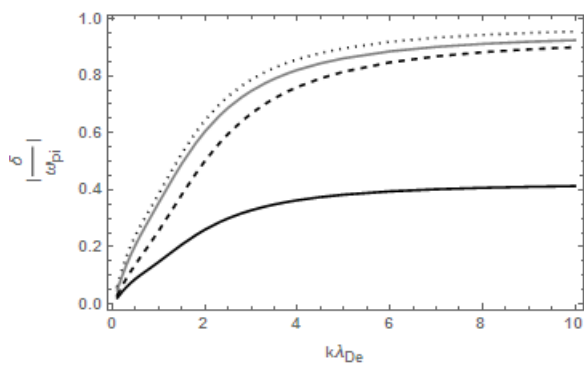
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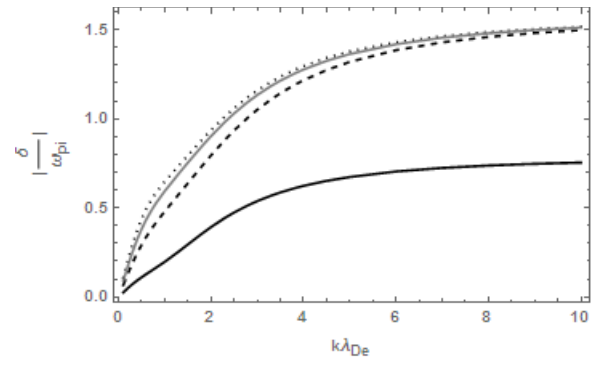
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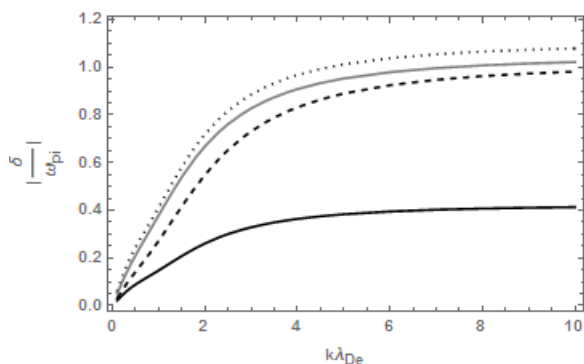
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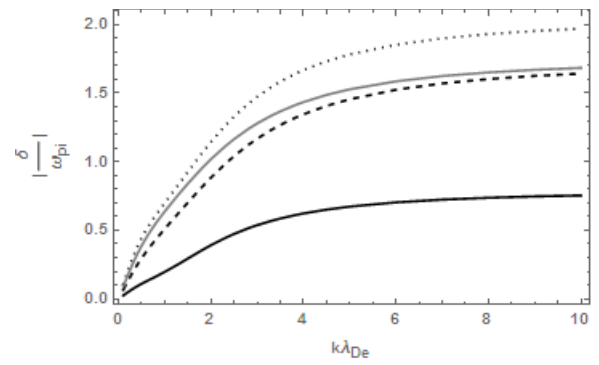
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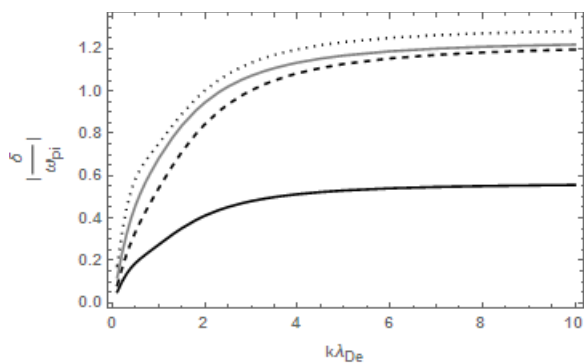
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Figure3,4,5,6

Figure2,5,6,8

Figure3,4,5,7

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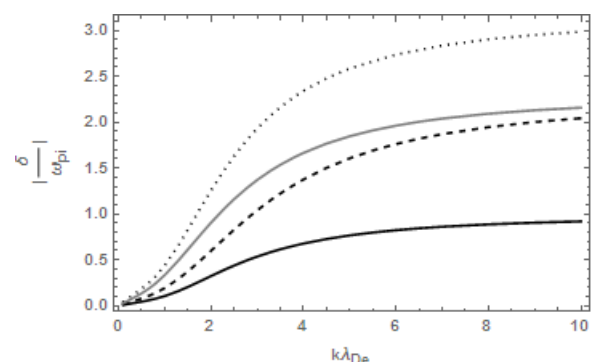
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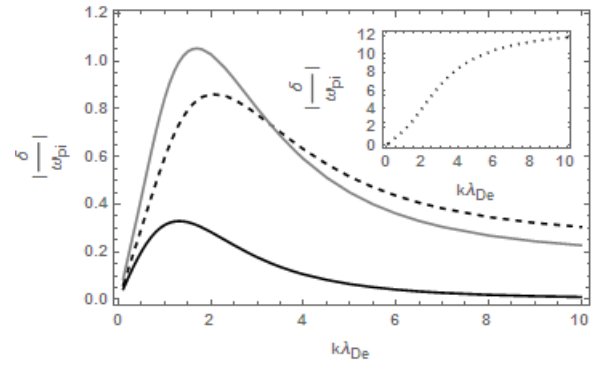
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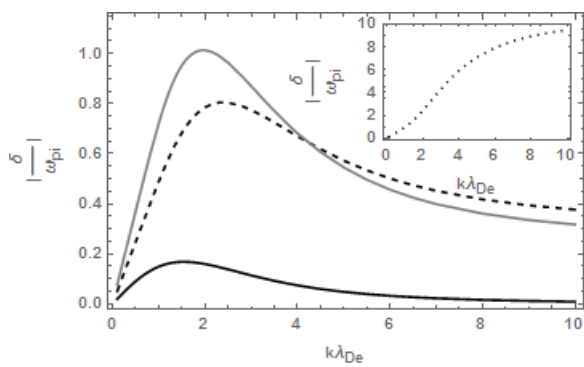
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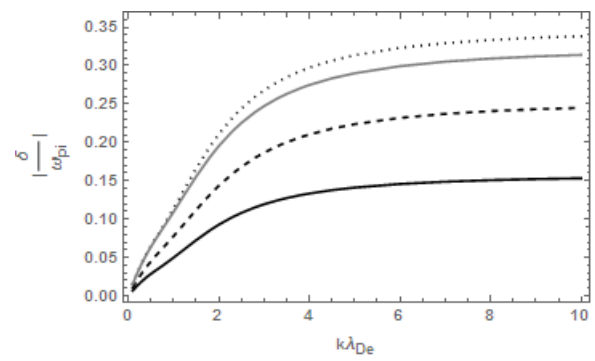
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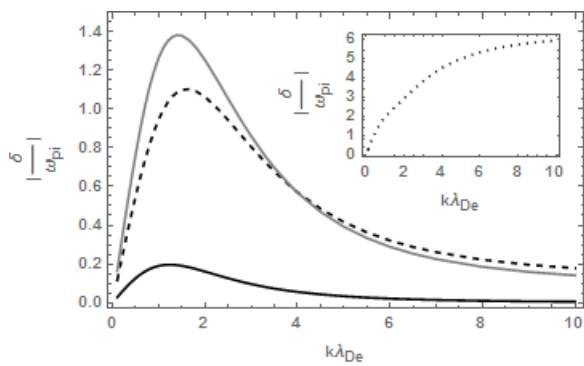
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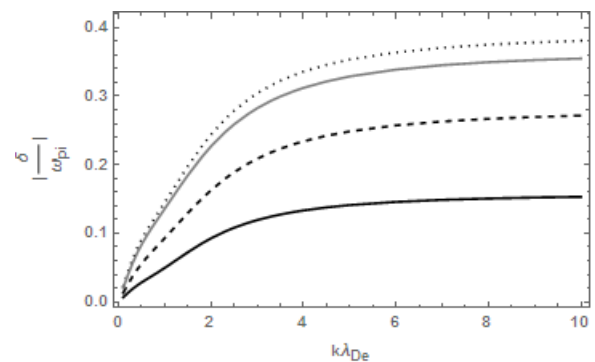
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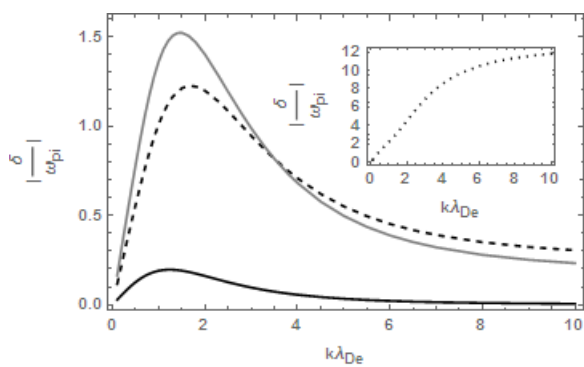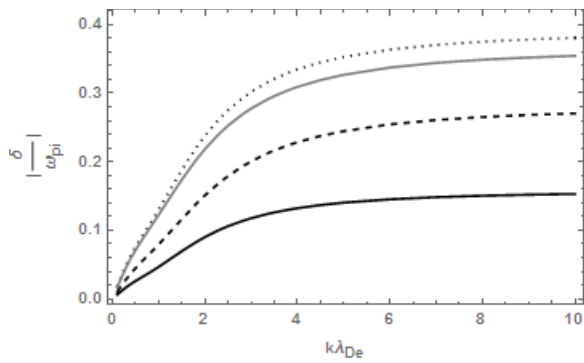

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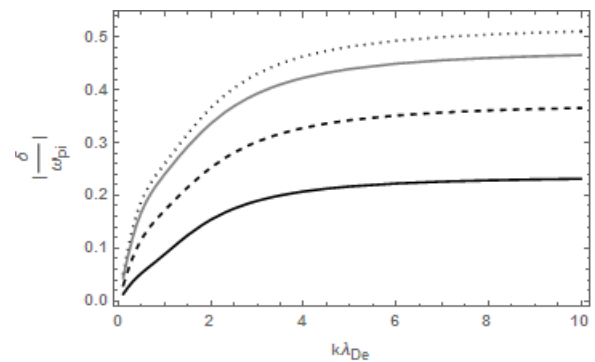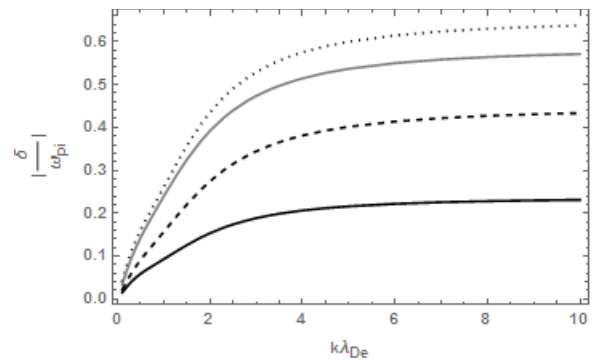

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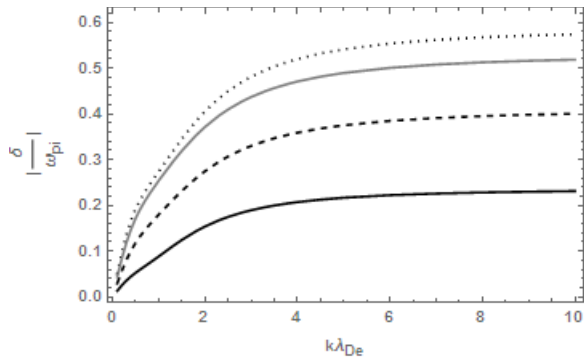
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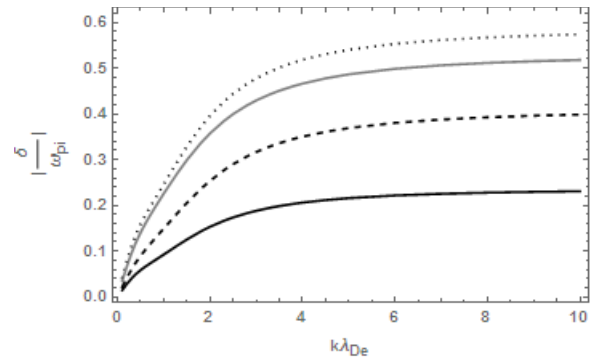
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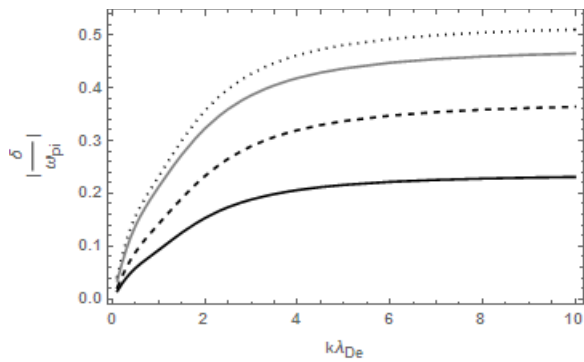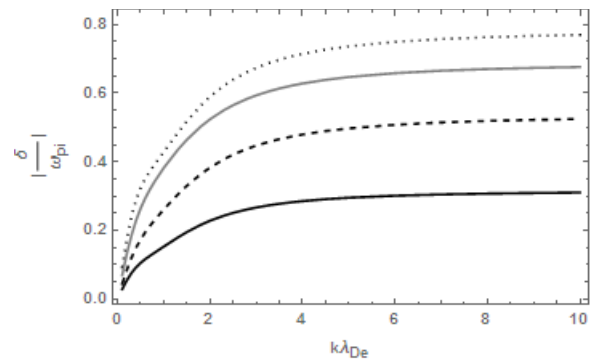

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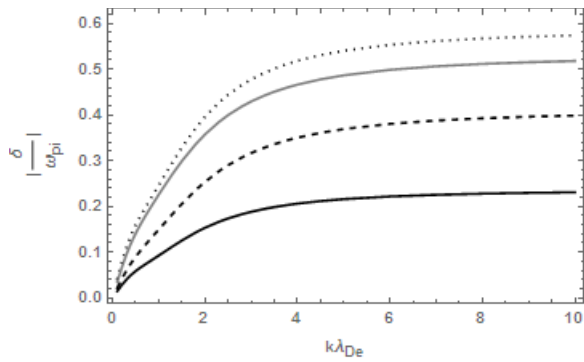

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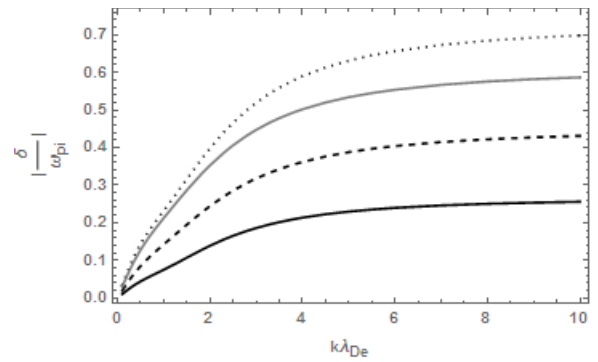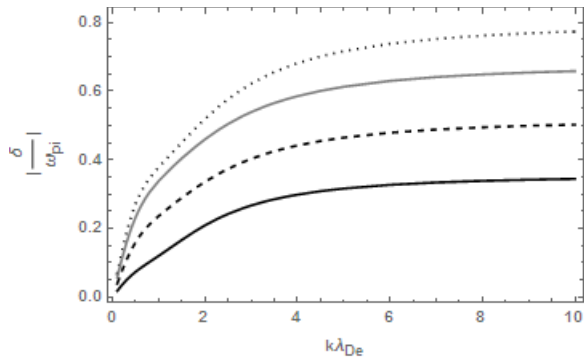Figure1,2,3,5,7

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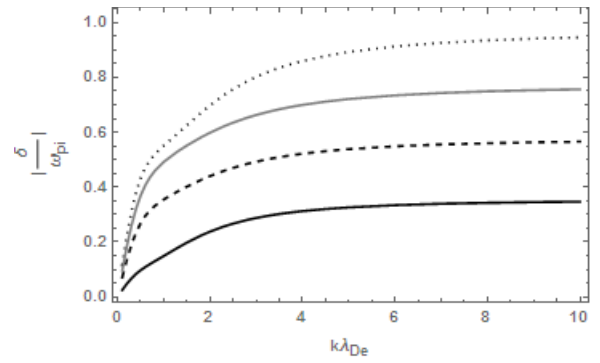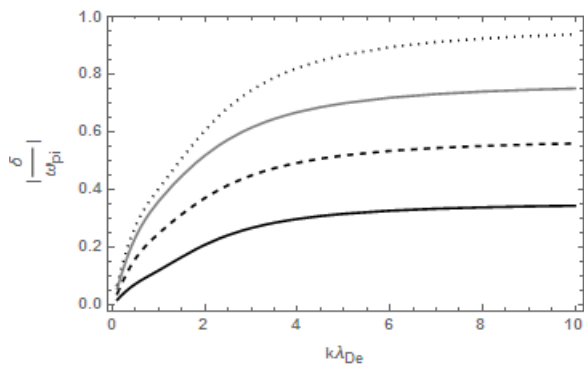Figure1,2,3,5,8

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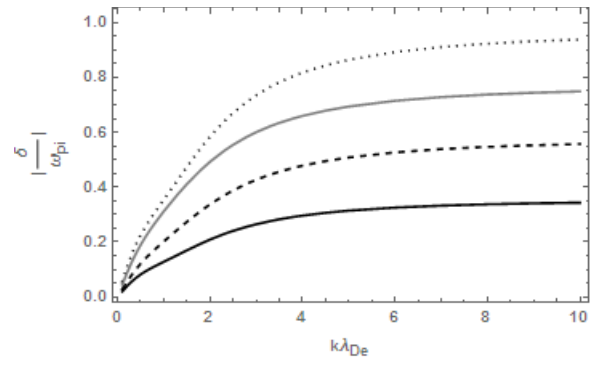
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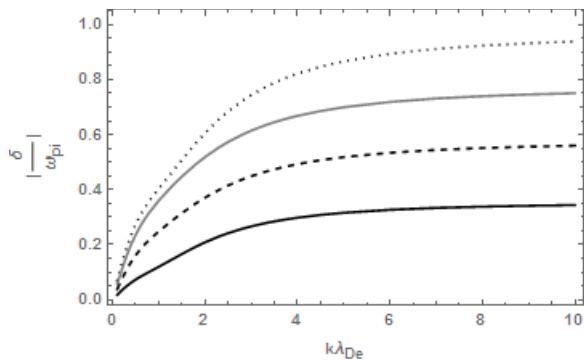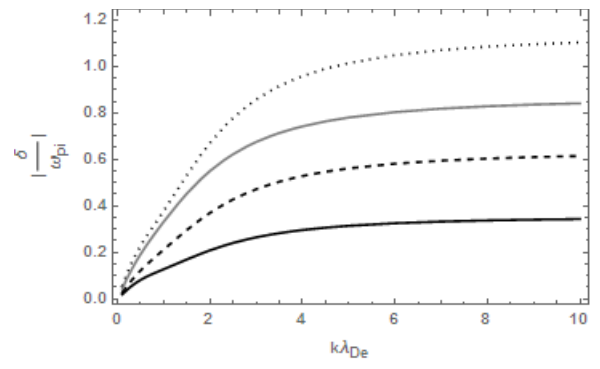Figure1,2,4,7,8

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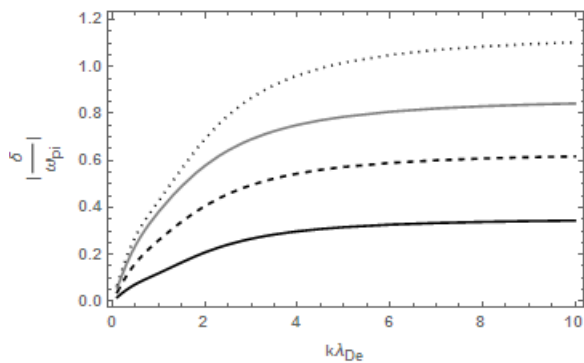

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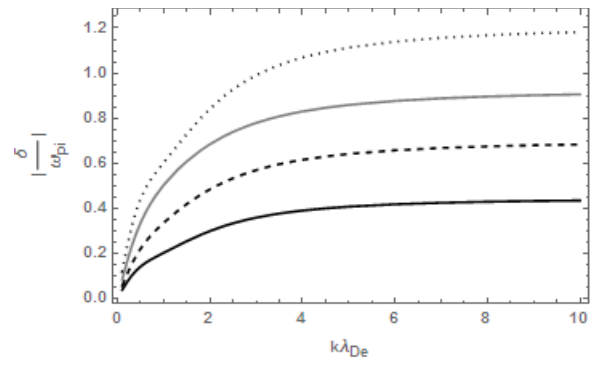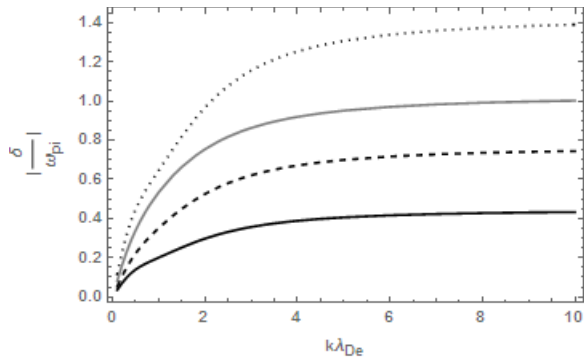

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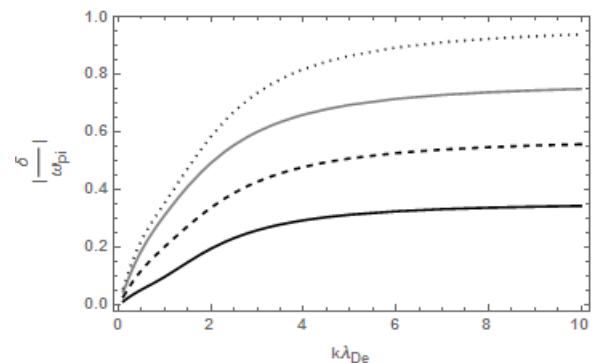

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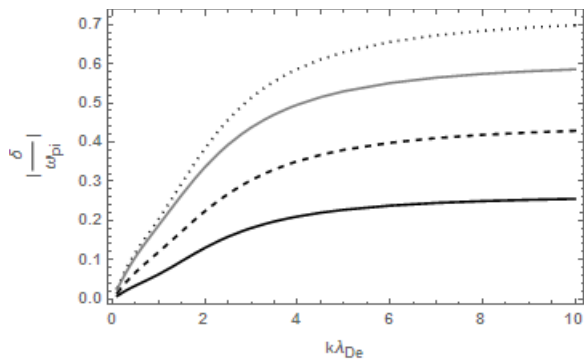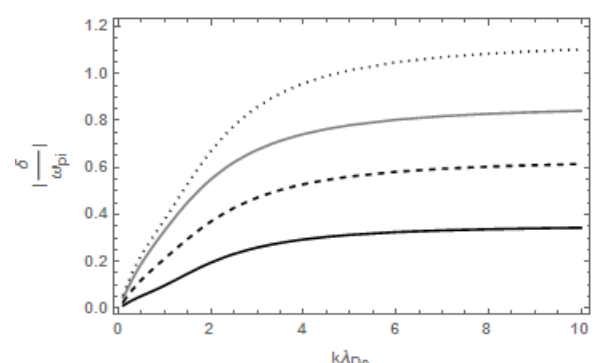
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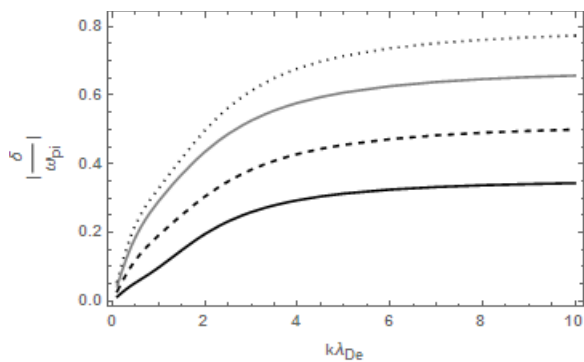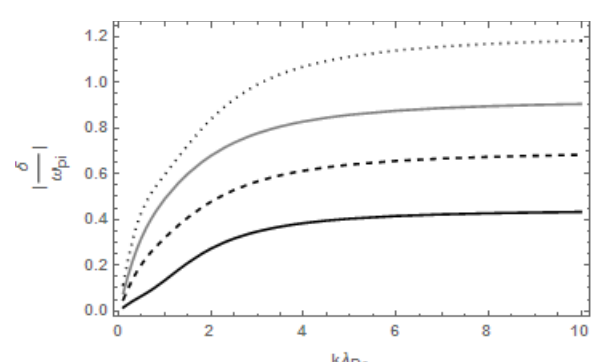Figure1,3,4,6,7

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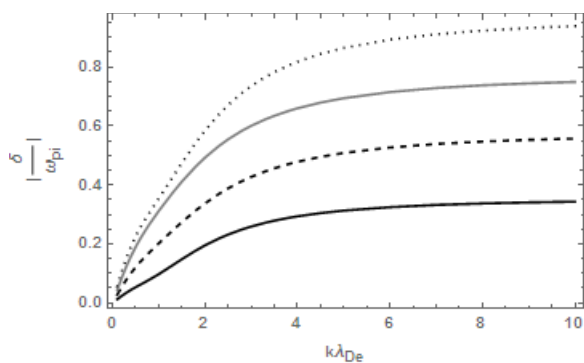

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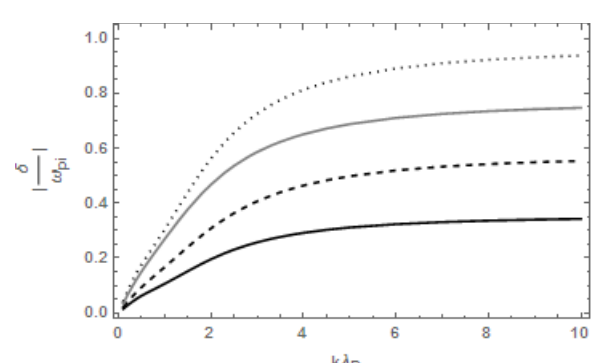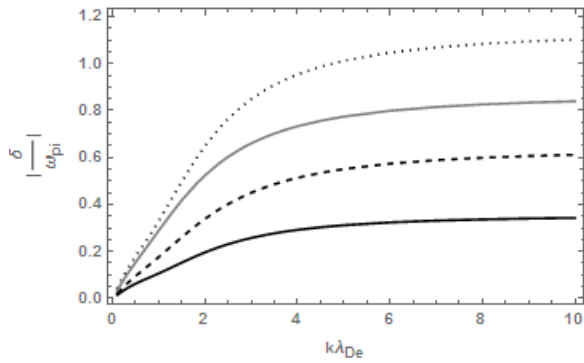Figure1,3,4,5,7

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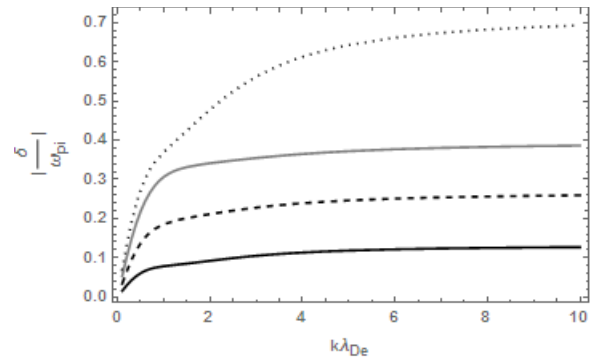

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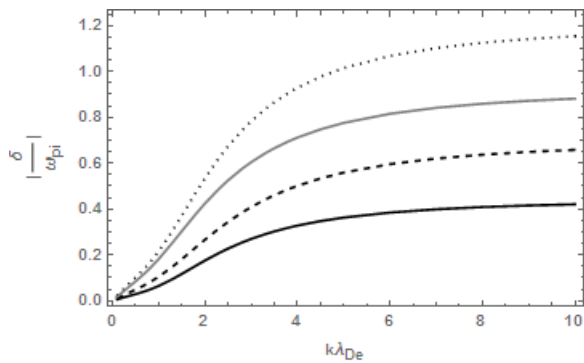
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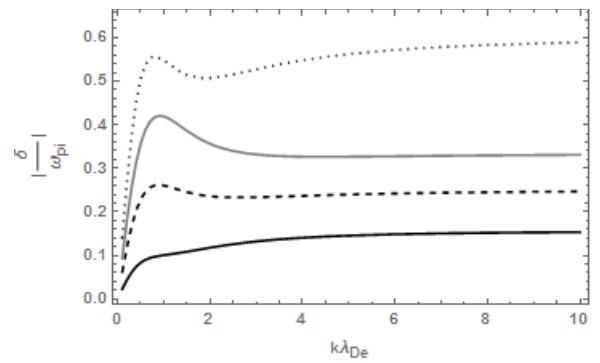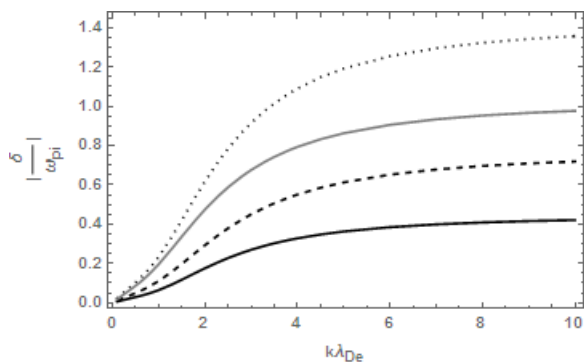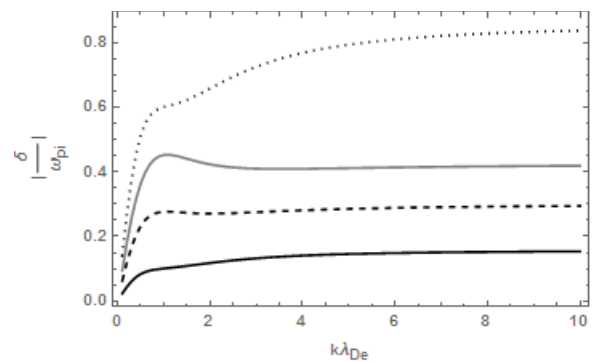

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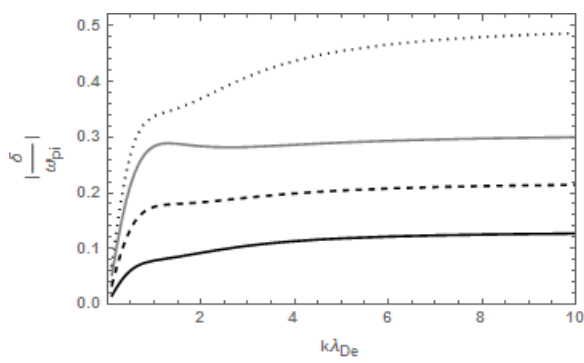
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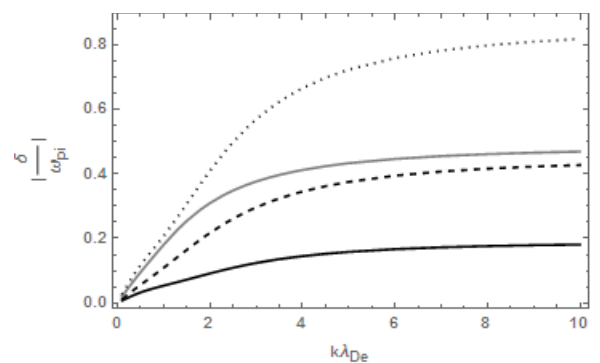

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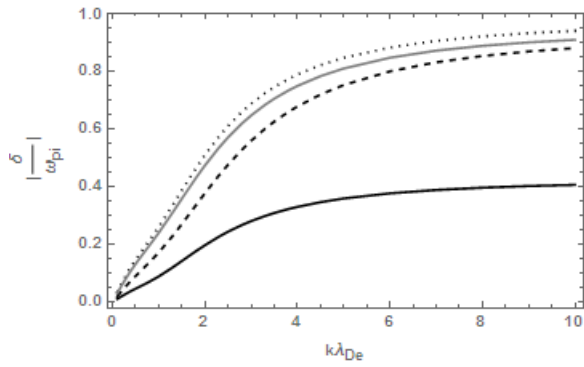
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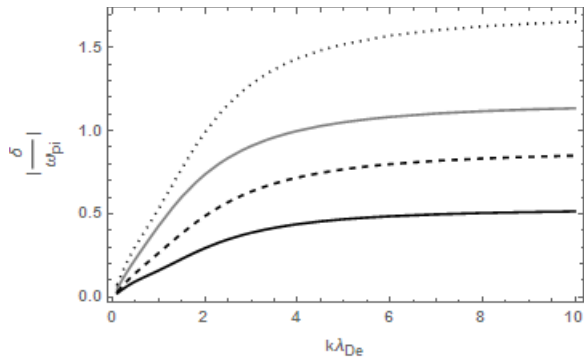
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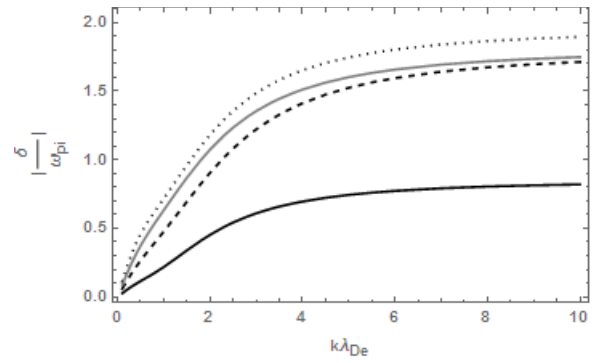
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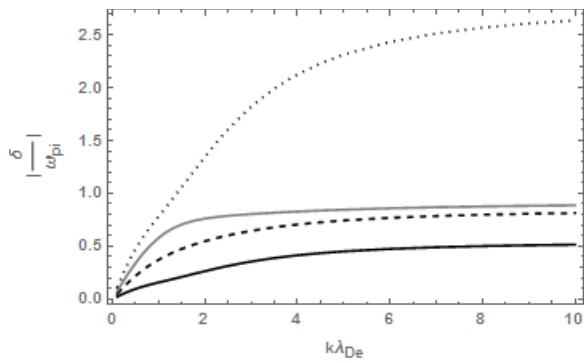
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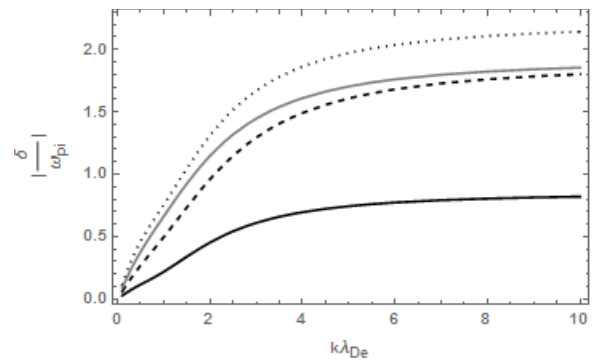
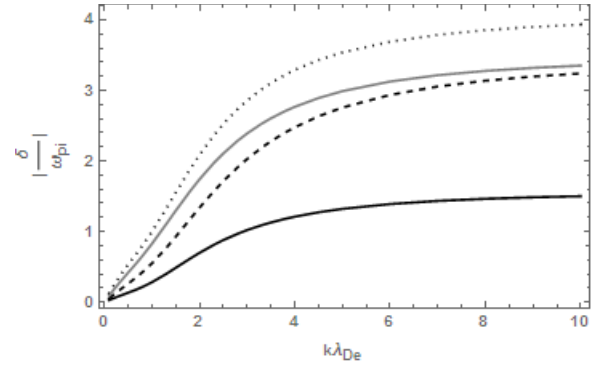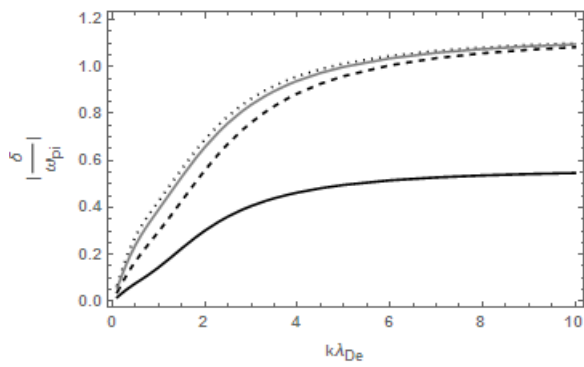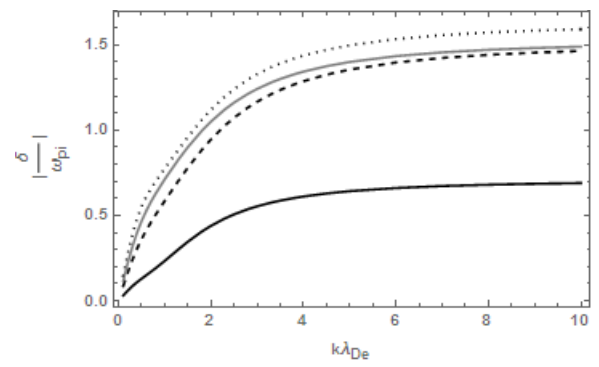Figure2,3,4,6,7,8
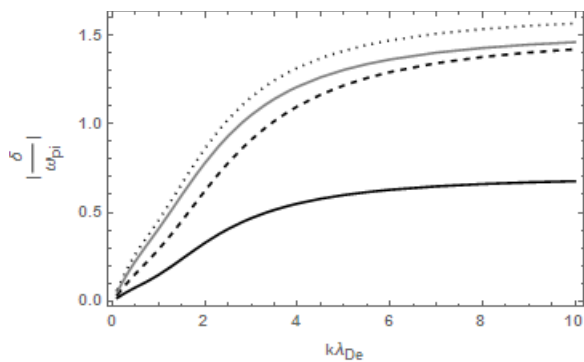
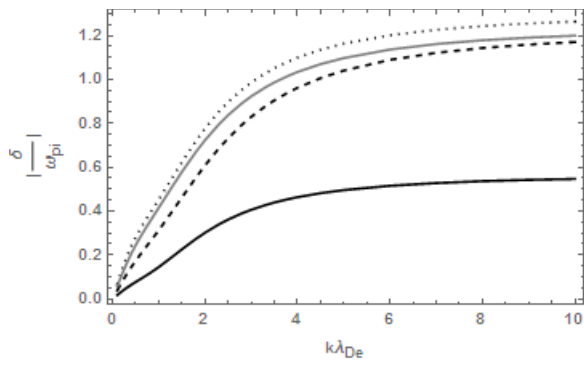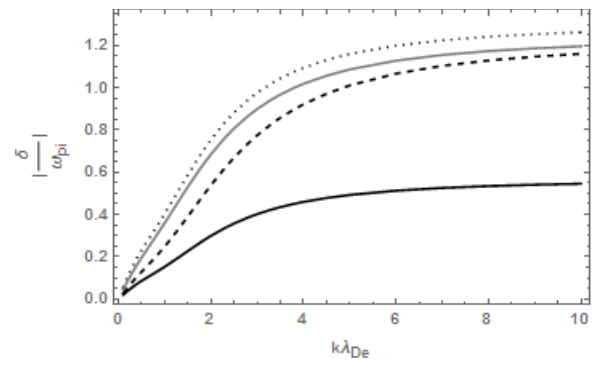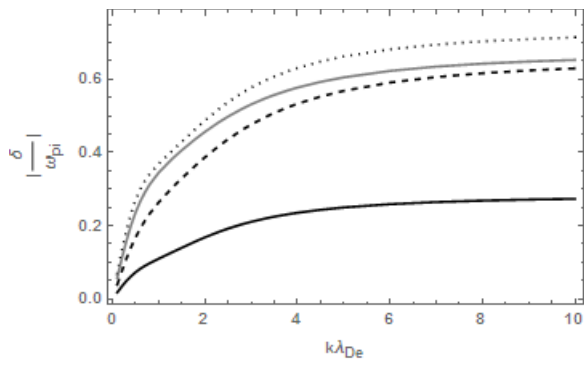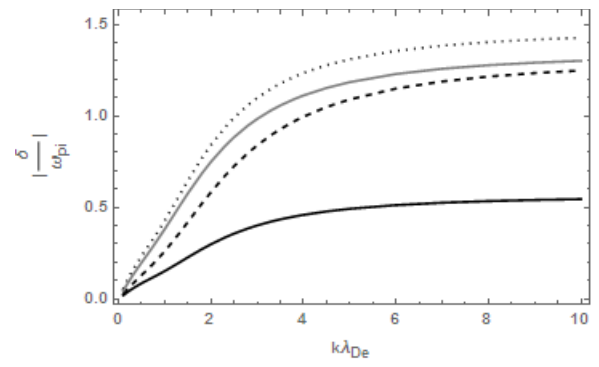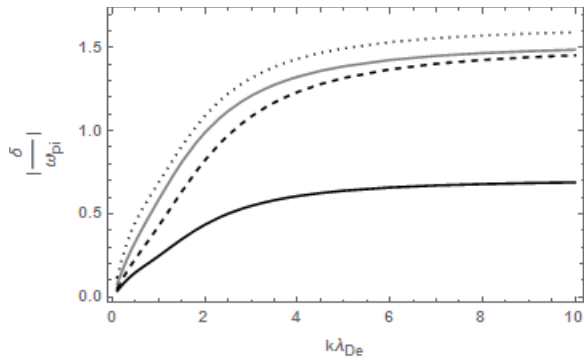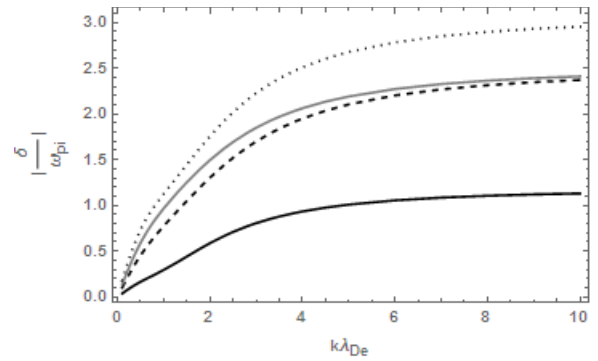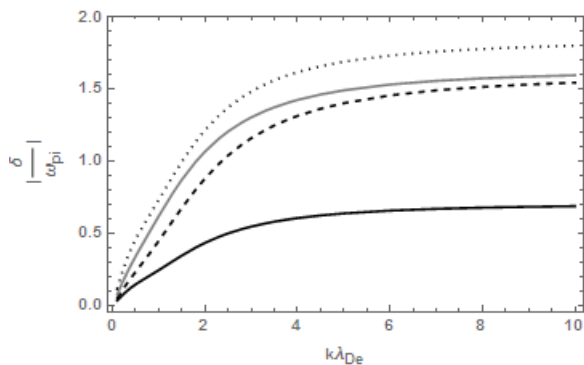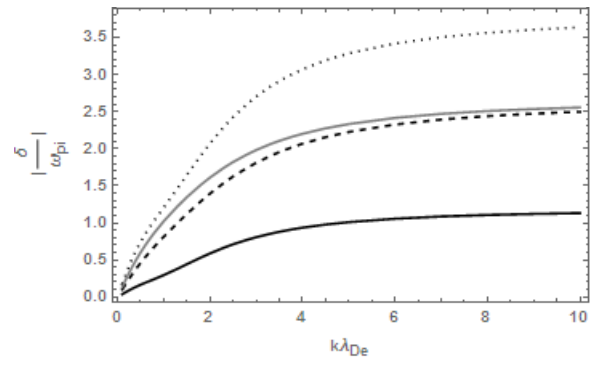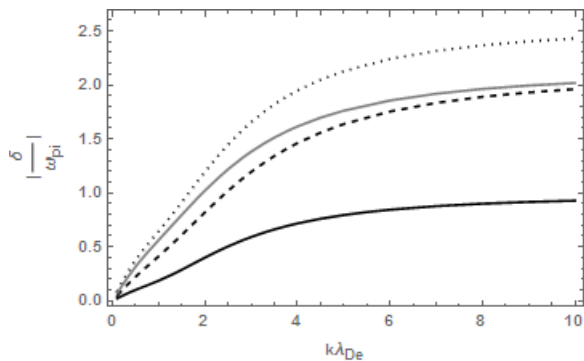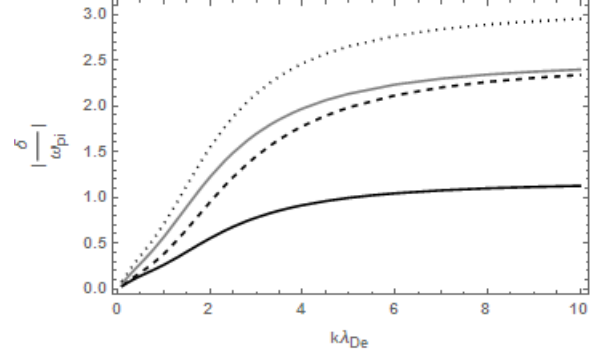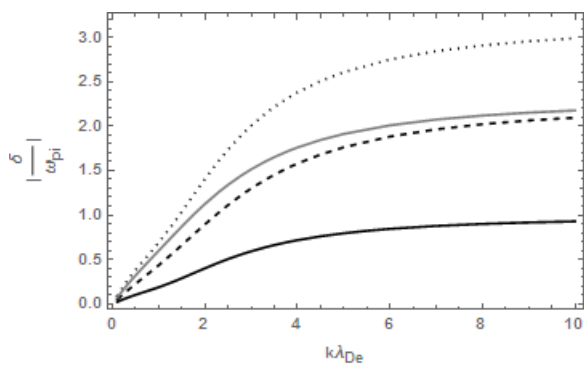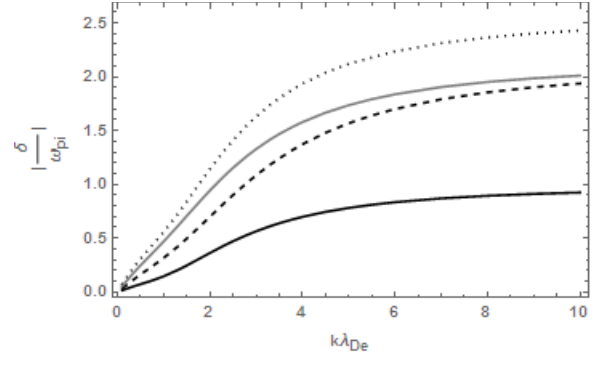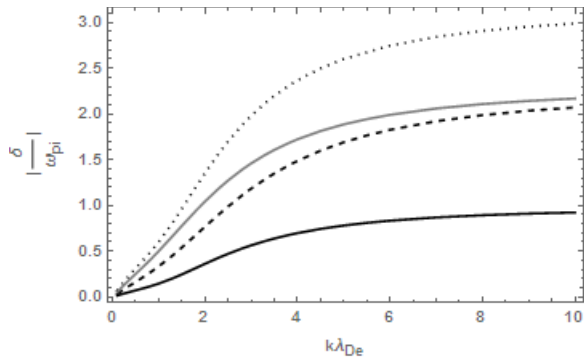Figure2,3,4,5,6,7
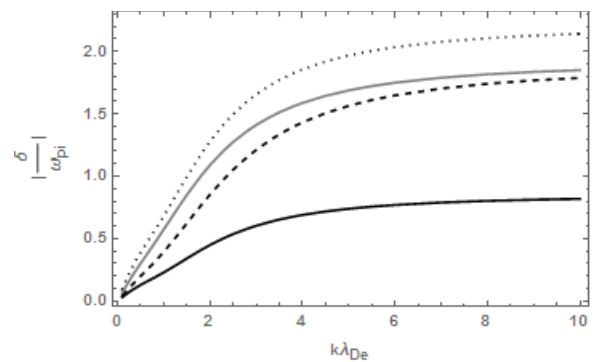
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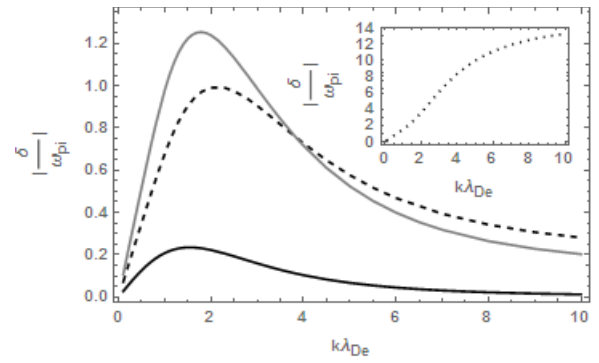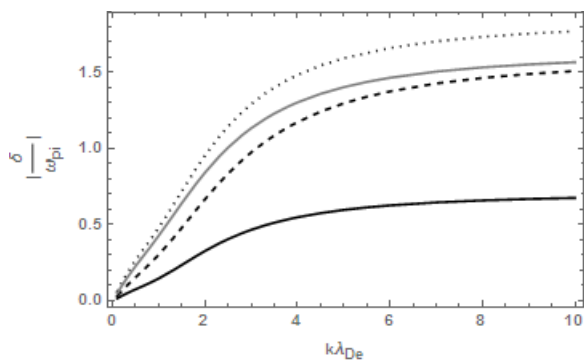
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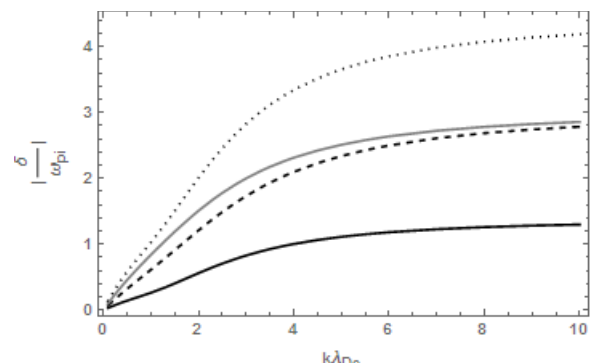
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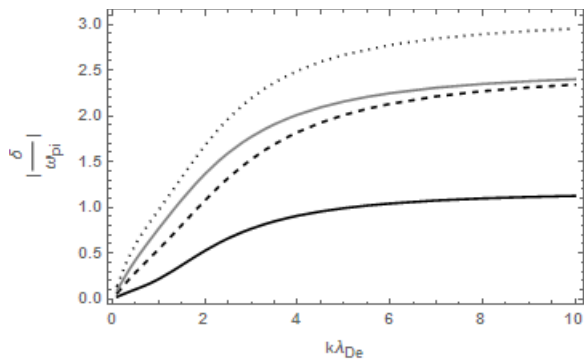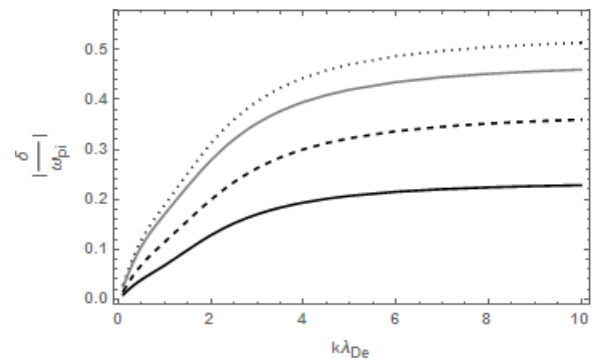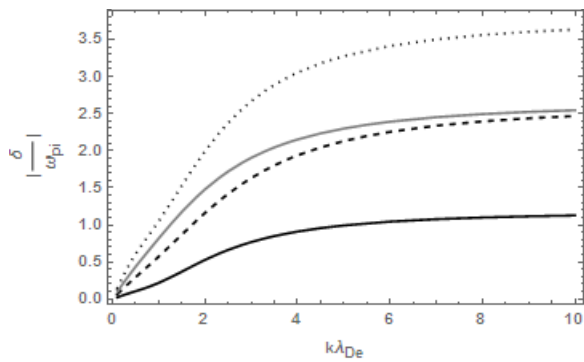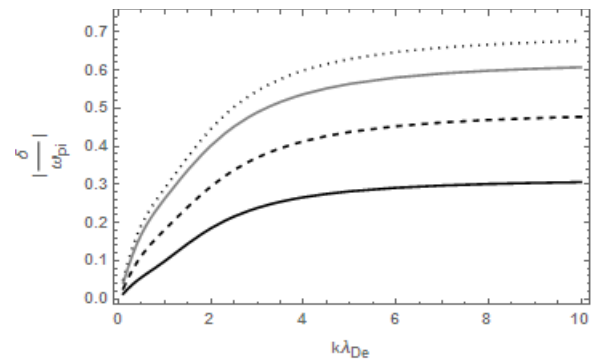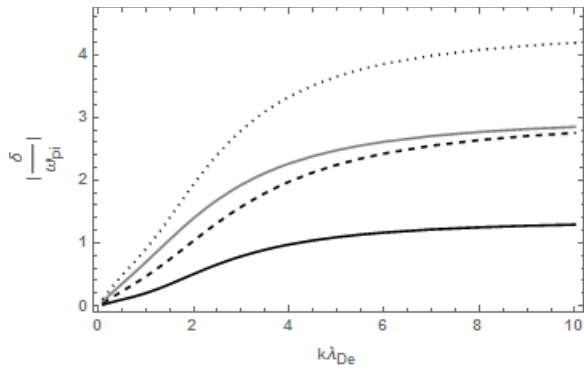
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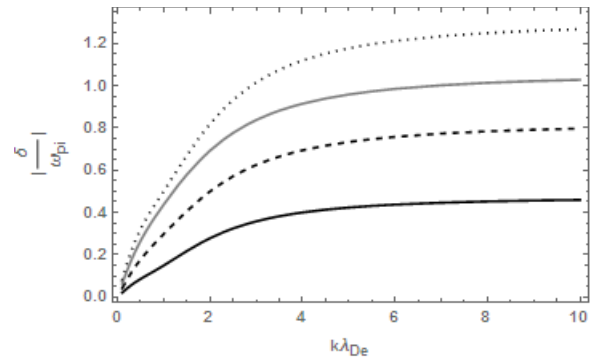
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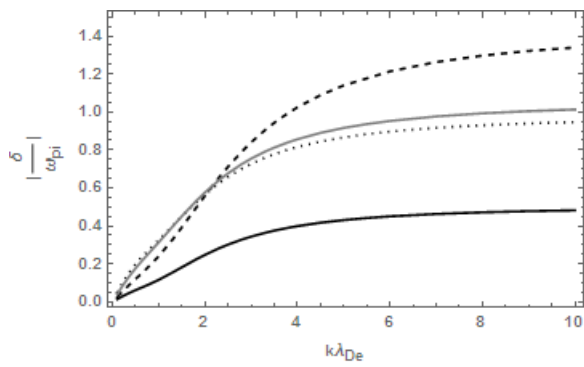
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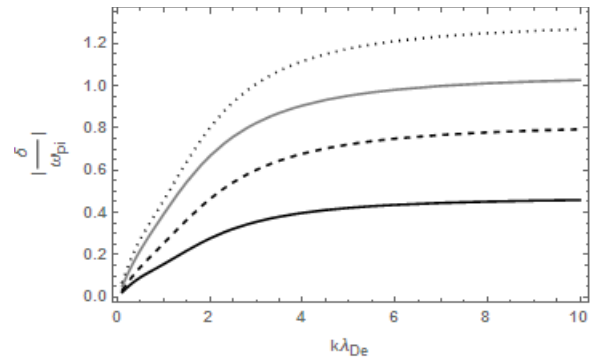
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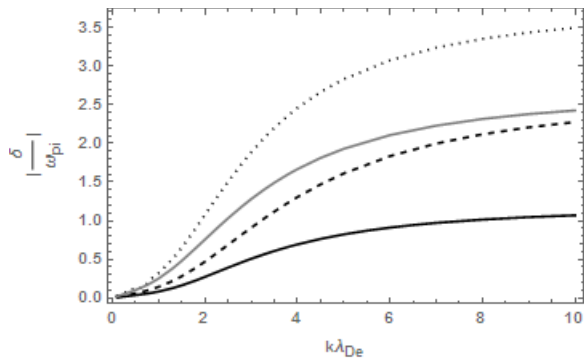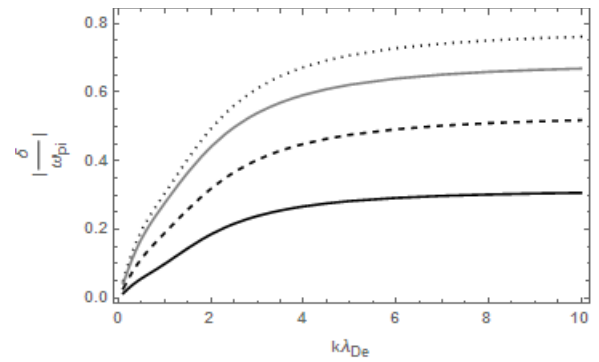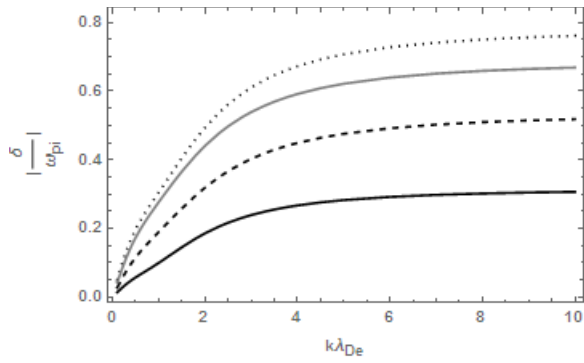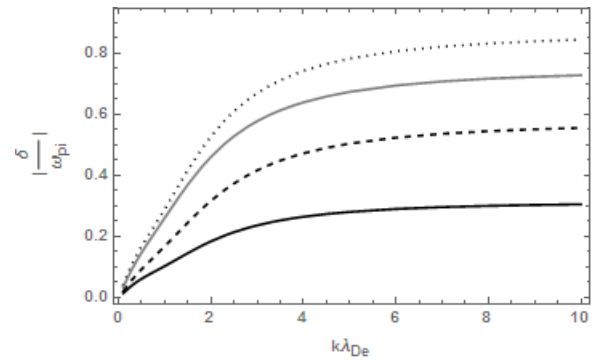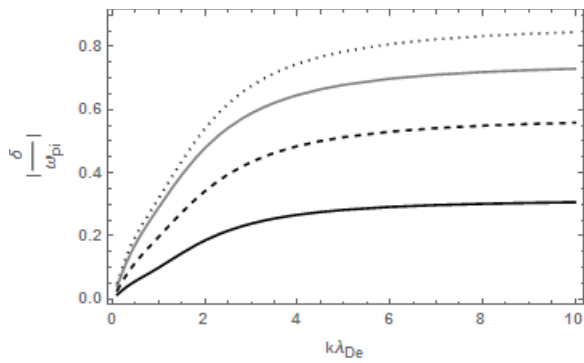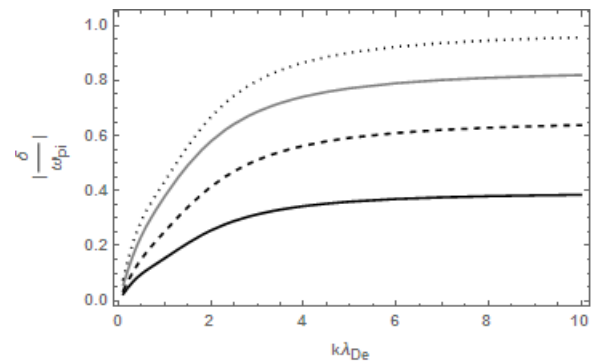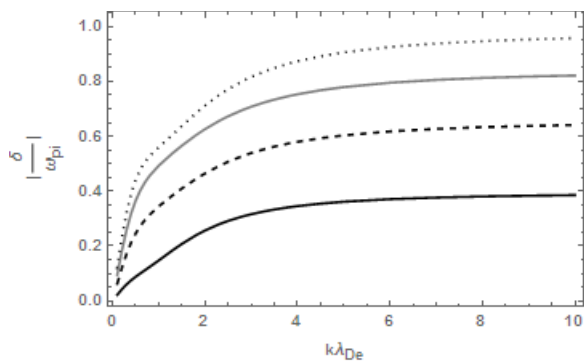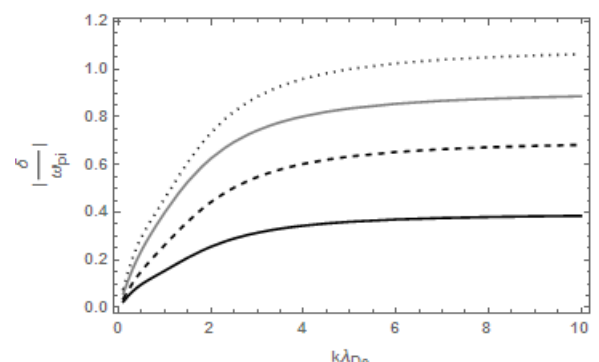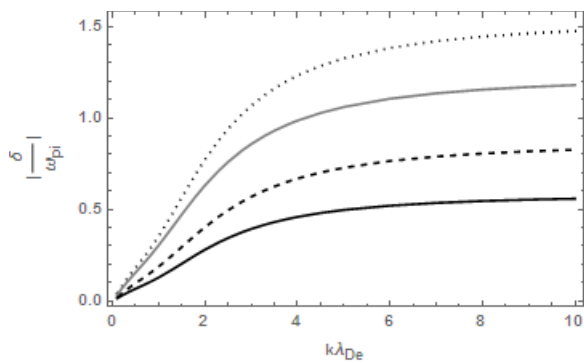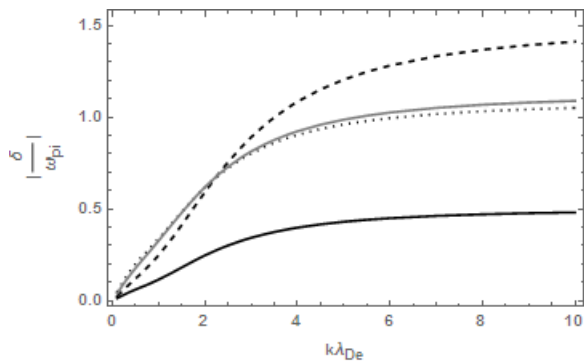

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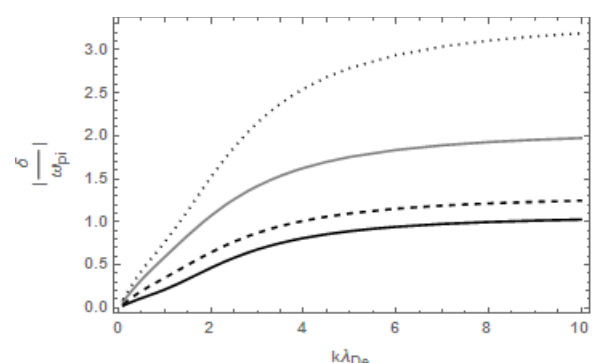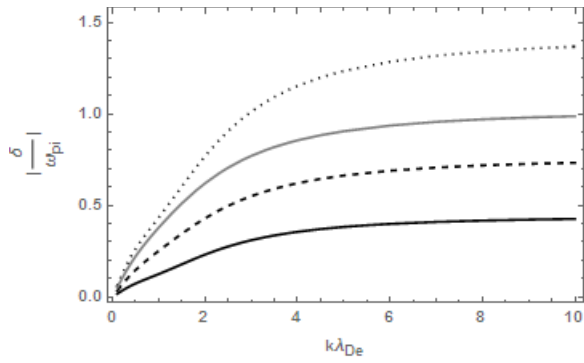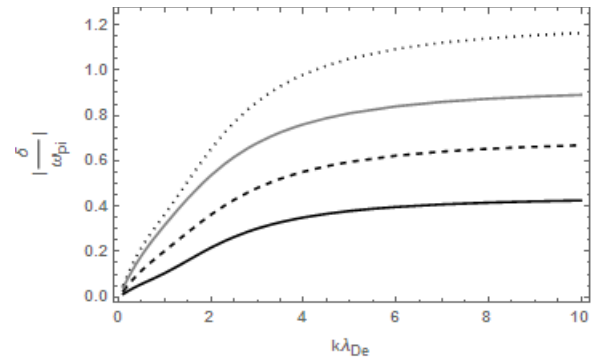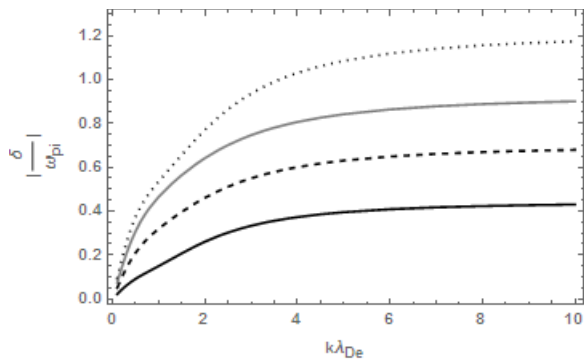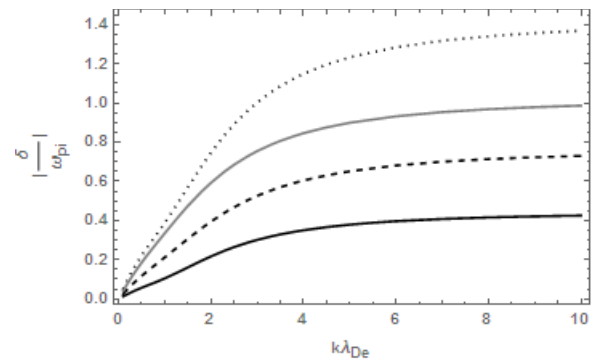
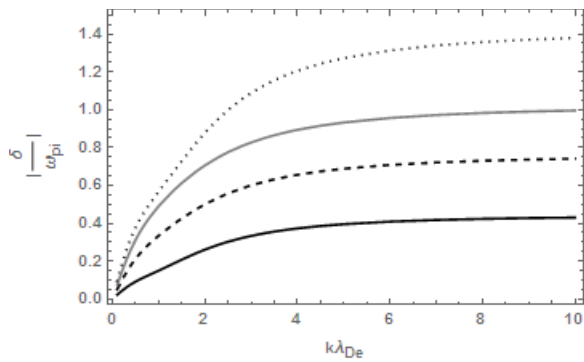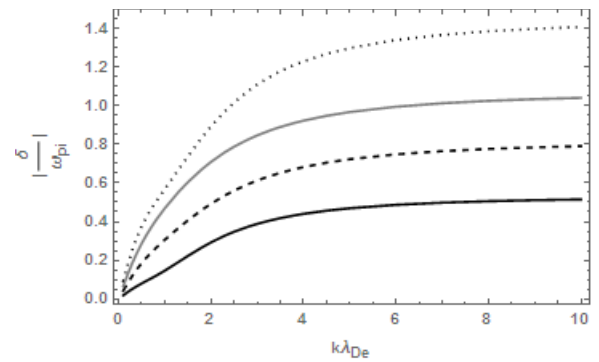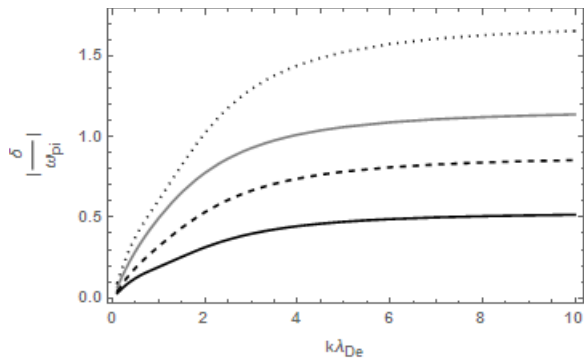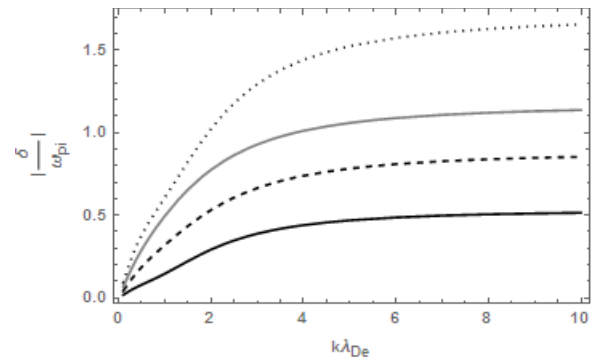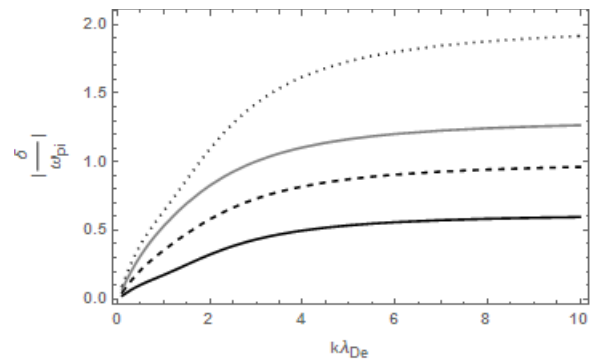
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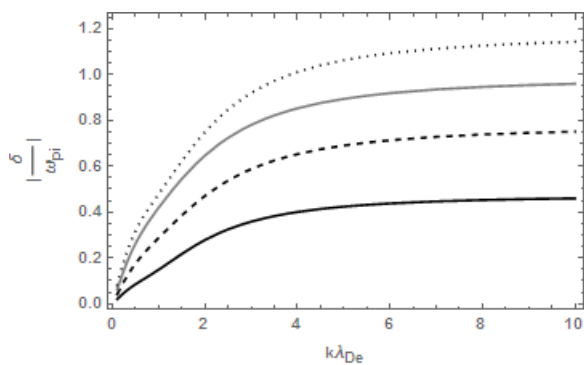
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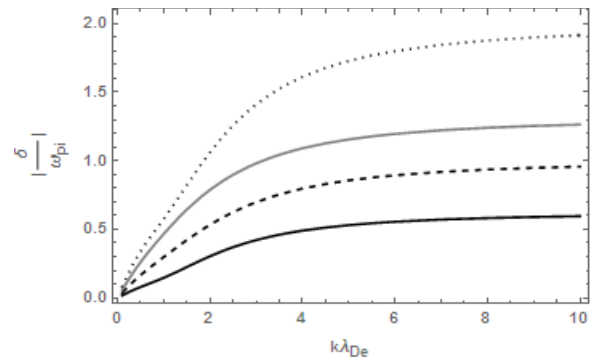
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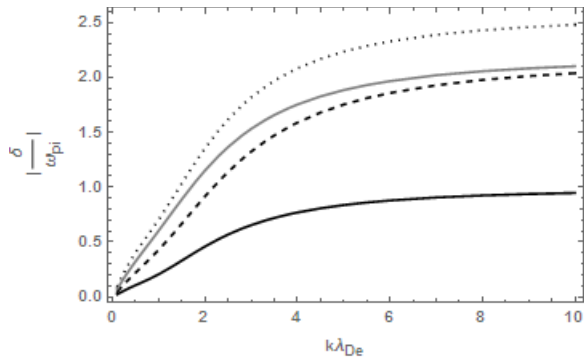
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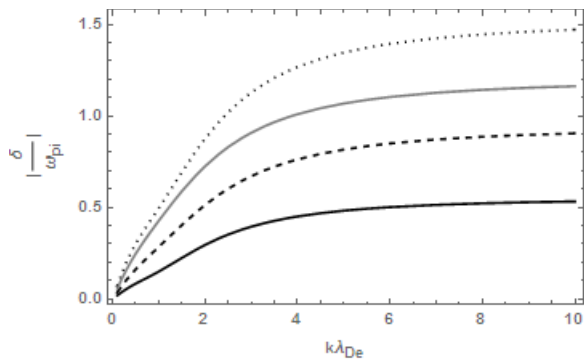
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Conclusion

According to the ideal condition, the figures were obtained for the relevant problem. In dusty sonic ion waves, with increment of energetic particle the attenuation increased and also charge fluctuation had significant influence on increase of propagation and attenuation. In dusty sonic waves, we studied plasma for two conditions. When we consider Maxwell distribution for comprising particles of plasma, the charge fluctuation showed increase in propagation. In plasma with kappa distribution and Maxwell for heavy negative ion dust, with increment of energetic particles we observed increase in attenuation. According to the results shown in the above graphs, with increasing the energetic particle presence and ratio of electron volumetric density to dust particles for similar systems, increment in attenuation rate by normalized wave number has been observed. However, attenuation trends were different. It's shown form the graphs that dusty sonic waves cause decrease in wave attenuation and charge fluctuation increases the attenuation and the effect of negative is higher and shows larger drop. In Langmuire waves with increment of energetic particles by wave number, we achieve increase in attenuation. In this study in all investigated materials, Landau attenuation was zero. These graphs represent for different systems to the extent possible. According to the results shown in the above graphs in most systems, The increase of K and charge fluctuation corresponds to increasing damping ratio with wave number.

Reference

1. Hasegawa, K. Mima, M. Duong-van, Phys. Rev. Lett. 58 (1985) 2608. https://doi.org/10.1103/PhysRevLett.54.2608

2. D. Summers, R.M. Thorne, Phys. Fluids B 3 (1991) 1835. https://doi.org/10.1063/1.859653

3. N.S. Saini, I. Kourakis, AIP Conf. Proc. 1041 (2008) 263. https://doi.org/10.1063/1.2996979

4. V.M. Vasyliunas, J. Geophys. Res. 73 (1968) 2389. https://doi.org/10.1029/JA073i023p07519

5. Abraham-Shrauner, W.C. Feldman, J. Plasma Phys. 17 (1977) 123.

6. Abraham-Shrauner, J.R. Asbridge, S.J. Bame, W.C. Feldman, J. Geophys. Res. 84 (1979) 553. https://doi.org/10.1029/JA084iA02p00553

7. M.P. Leubner, J. Geophys. Res. 87 (1982) 6335. https://doi.org/10.1029/JA087iA08p06335

8. Z. Meng, R.M. Thorne, D. Summers, J. Plasma Phys. 47 (1992) 445. https://doi.org/10.1017/S002237780002434X

9. R.L. Mace, G. Amery, M.A. Hellberg, Phys. Plasmas 6 (1999) 44. https://doi.org/10.1063/1.873256

10. M.A. Hellberg, R.L. Mace, Phys. Plasmas 9 (2002) 1495. https://doi.org/10.1063/1.1462636

11. T. Kim, M.-J. Lee, J. Phys. D Appl. Phys. 41 (2008) 245204. https://doi.org/10.1088/0022-3727/41/24/245204

12. Vladimirov, Phys. Plasmas 1, 2762 (1994). https://doi.org/10.1063/1.870511

13. D.Summers and R.M.Thoren, phys.Fluids B3, 1835 (1991). https://doi.org/10.1063/1.859653

14. M.C.de Juli and R.S.Schneider, L.F.Ziebell, and V.Jatenco-Pereira, *Phys. Plasmas* 12,052109 (2005). https://doi.org/10.1063/1.1899647

15. A.Hasegawa, K. Mima, M. Duong-van, *Phys, Lett.* 58 (1985) 2608. https://doi.org/10.1103/PhysRevLett.54.2608

16. P.K.Shukla and A.A Mamum, "Introduction to Dusty Plasma Physics," Institute of Physics Publishing, Bristol. (2002). https://doi.org/10.1887/075030653X

17. Myoung-Jae Lee," Effects of suprathermal particles on the dust ion-acoustic waves in a complex plasma, "*Sience Direct*.(2010). https://doi.org/10.1016/j.cap.2010.04.005

18. L. Landau, J. Phys. U.S.S.R. 10 (1946) 25. https://doi.org/10.3406/ingeo.1946.5138

19. V.Baumjohann and R.Treumann, "*Basic space plasma physics*," Imperial College Press

20. Francis F.Chen, "*Basic space plasma physics*," Introduction to Plasma Physics and Controlled Fustion 2 nd ed.

21. A.F.Alexandrov, L.S.Bogdankevich, A.A.Rukhadze "*Principles of plasma Electrodynamics*," springer-verlag Berlin Heidelberg New York