Planck Plasma and the Debye Length

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Abstract

The Debye length plays a central role in plasma physics and also for semiconductors. We are investigating what the Debye length would be for a hypothetical plasma consisting of Planck mass particles; in other words, what we could coin: Planck plasma. This, we think, could be of interest as the Planck scale is assumed to play a central role in quantum gravity theory and potentially also quantum gravity computers.

Key Words: Plasma physics, Debye length, Planck mass particle, Planck length, quantum gravity computers.

1 Background

Max Planck [1, 2] in 1899 assumed there were three universal constants: the Newton gravitational constant G, the speed of light, and the Planck constant. Then, based on dimensional analysis, he came to a unique length: $l_p = \sqrt{\frac{G\hbar}{c^3}}$, time $t_p = \sqrt{\frac{G\hbar}{c^5}}$, mass $m_p = \sqrt{\frac{\hbar}{Gc}}$, and a temperature $T_p = \sqrt{\frac{\hbar}{Gc^5}}$.

Einstein [3] in 1916 already suggested that a quantum gravity theory would be the next step to understanding gravity even better than his general relativity theory allowed for. Eddington [4] in 1918 was likely the first to suggest that such a quantum gravity theory likely had to be linked to the Planck length.

Max Planck had said little about what the, for example, Planck mass represented in the physical world or why it was so special. Loyd Motz [5, 6], when working at the Rutherford laboratories, was likely the first to suggest there could be a Planck mass particle. He was well aware that this particle had much larger mass ($m_p \approx 2.17 \times 10^{-8}$ kg) than any observed particle. He therefore suggested it had been created in the big bang and radiated into all the particles we have today.

Markov [7] in 1967 was the first to suggest that the Planck mass was the smallest mass that could create a gravitational collapse; in other words, a micro black hole. Hawking [8] suggested basically the same as Markov in 1971 and similar ideas were also presented by Motz and Eppstein [9] in 1979. The research of Markov has gone unnoticed in the west, perhaps because it was published in the Soviet Union during the cold war. Still, no micro black holes of the type suggested have been detected. This could mean the micro black holes are very hard to detect, or that there exist very few of them in our part of the universe, or that there is something we have not yet understood here.

Haug [10, 11] has suggested that the Planck mass particle only lasts the Planck time, but that it is the building block of all elementary particles. The idea is simply that, for example, an electron consists of two indivisible particles moving back and forth over the reduced Compton [12] wavelength of the electron at the speed of light. At every Compton time, the two indivisible particles collide and are then mass; the collision itself is mass. This mass is the Planck mass but, since it only lasts the Planck time, then the mass of an electron will be:

$$m_e = f_e m_p t_p = 9.31 \times 10^{-31} kg \tag{1}$$

where $f_e = \frac{c}{\bar{\lambda}_e}$, that is the reduced Compton frequency of the electron. In other words, the Planck mass is everywhere; it is the building blocks of everything and is essential to understand quantum gravity. We do not expect the reader to accept any of the hypotheses above easily as they all are speculative, but we just want to point out there is a series of hypotheses about the Planck mass particle and what role it potentially plays. Here we will go one step forward and also look at the hypothetical plasma properties of the Planck mass particle.

Most researchers working with quantum gravity theory seems to think the Planck length and other Planck units will play a central role in a unified quantum gravity theory; see [13–16]. Other researchers are sceptical about whether the Planck units can be anything more than units coming out of dimensional analysis; see [17].

We will, however, claim there has been considerable progress in understanding the Planck scale in recent years as it has been demonstrated that the Planck length and other Planck units also can be found without any knowledge off G and h and even c; see [18–21]. This means the Planck units have been detected in a much more direct way from a series of gravity observations; they do not seem to only be something we can calculate from dimensional analysis from other physical constants.

It is therefore, in our view, worthwhile also investigating if the Planck scale could be linked to plasma physics. In this paper, we simply investigate what the Debye length would be for a Planck mass particle plasma.

2 Debye length for Planck mass particles

The Debye length is used actively in plasma physics and is given by

$$\lambda_D = \sqrt{\frac{\epsilon_0 k_B T}{\rho q^2}} \tag{2}$$

where q is the charge (normally the electron charge), k_B is the Boltzmann constant, T is the temperature, ρ is the density (typically) of electrons, and ϵ_0 is the permittivity of free space. We have that:

$$\epsilon_0 = \frac{1}{4\pi 10^{-7} c^2} \tag{3}$$

While the elementary charge of an electron is given by: $e = \sqrt{\frac{\hbar}{c}\alpha 10^7} \approx 1.6 \times 10^{-19}$ coulombs, the Planck charge is given by:

$$q_p = \sqrt{\frac{\hbar}{c}10^7} \approx 1,87 \times 10^{-18} \text{ coulombs} \tag{4}$$

It must be said that while the charge of an electron has been carefully measured we have never measured the Planck charge, so it is a theoretical value given in the literature. Further, assume all the rest-mass of the Planck mass is used to create temperature; in other words, the well-known Planck temperature:

$$T_p = \sqrt{\frac{\hbar c^5}{G k_B^2}} = \frac{m_p c^2}{k_B} \tag{5}$$

and since the temperature in the Debye length formula is multiplied with k_B, we see the Boltzmann constant cancels out. The Planck density is given by $\frac{m_p}{l_p^3}$, so the density per Planck mass particle is given by:

$$\rho_p = \frac{1}{l_p^3} \tag{6}$$

Further, we know that the Planck mass is given by:

$$m_p = \sqrt{\frac{\hbar c}{G}} = \frac{\hbar}{l_p}\frac{1}{c} \tag{7}$$

We can now replace these back into the Debye length formula (Eq. 2) and we get:

$$\lambda_D = \sqrt{\frac{\frac{1}{4\pi 10^{-7} c^2}\frac{\frac{\hbar}{l_p}\frac{1}{c}c^2}{k_B}}{\frac{1}{l_p^3}\frac{\hbar}{c}10^7}} = \frac{l_p}{\sqrt{4\pi}} \tag{8}$$

This is close to the Planck length, but still shorter than the Planck length, something that is not possible. Well, we indirectly assumed that a Planck mass particle can be placed inside a cube l_p^3. However, we think it would be more realistic it is inside a sphere with a radius l_p; in other words, that the density per Planck mass particle is:

$$\rho_p = \frac{1}{\frac{4}{3}\pi l_p^3} \tag{9}$$

This would lead to a Debye length of $\lambda_D = \frac{l_p}{\sqrt{3}}$. This is closer to the Planck length than in the calculations above, but still somewhat below, this could indicate that the Debye length needs modifications at the Planck scale or that it breaks down at the Planck scale, this we leave up to other future research to investigate further.

In semiconductors, the Debye length is typically calculated as:

$$\lambda_D = \sqrt{\frac{n_0 k_B T}{q^2 N_0}} \tag{10}$$

where N_0 is the net density of dopants. Let us, for Planck mass particles, assume also N_0 had the Planck density, then the Debye length in quantum gravity semiconductors would be the same as we calculated above. In other words, such computers would likely be extremely dense and extremely powerful. We have done initial calculations on their potential computational powers, but as this involves long discussions of quantum gravity, we will come back to it in another article.

The topic of quantum gravity computers has recently gained some attention; see [22, 23]. The likely reason it is still little written about is naturally that we not have a reliable quantum gravity theory yet. Superstring theory and quantum loop theory were nice attempts, but they seem to have led to little real progress. However, this could perhaps be changing as new alternative quantum gravity theories have been suggested [10, 16]. If there is much to these new theories or not, only time can tell when researchers have scrutinized them. If we achieve a breakthrough in quantum gravity theory, we expect the field of quantum gravity computers to also gain much more interest in the future.

3 Conclusion

We have calculated the Debye length of a hypothetical Planck particle plasma. The Debye length for the Planck mass particle is close to the Planck length. As there is considerable progress in understanding the Planck scale and quantum gravity, this could hopefully ultimately be a small step in the direction of powerful quantum gravity computers in the future. This is naturally speculative, but any new field has typically started out with speculative ideas. Only future research can show if there is something to Planck plasma.

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