

**Electromagnetic Longitudinal Waves**

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The vacuum, for frequencies  $> 1 \times 10^{26} \text{ Hz}$  behaves as a plasma of electrons and positrons.

Cut off frequency

$$f_M = \frac{c}{\sqrt{k}} = \sqrt{\frac{n_e q_e^2}{\epsilon_0 m_e}} \quad \Leftrightarrow \quad n_e = 1.52 \times 10^{47} \text{ m}^{-3}$$

Debye length

$$\sqrt{k} = \sqrt{\frac{\epsilon_0 E_e}{q_e^2 n_e}} \quad ; \quad E_e = m_e c^2 = 0.511 \text{ MeV}$$

Speed of the longitudinal waves

$$w = \sqrt{k} f \quad ; \quad f \text{ -- frequency}$$

The wavelength is a constant

$$x = \sqrt{k} = 1.4 \times 10^{-17} \text{ m}$$

Mass

$$m = -\frac{h}{kf}$$

Energy is also a constant

$$E = -\frac{hc}{\sqrt{k}} = -89.6 \text{ GeV}$$