London's Equation:

London's equations (formulated by brothers Fritz and Heinz London in 1935) are a set of equations that describe the electromagnetic properties of superconductors. These equations are fundamental to understanding the behaviour of superconductors, particularly how they expel magnetic fields (the Meissner effect) and conduct electricity without resistance.

The London equations are derived based on the assumption that superconductors are perfect conductors and exhibit perfect diamagnetism (the complete expulsion of magnetic fields).

The two key London equations are:

1. **First London Equation:**

$$\frac{\partial J}{\partial t} = \frac{nse^2}{m}\mathbf{E} \text{ ---------------------------(1)}$$

where, $\boldsymbol{J}$ is the current density.

E is the electric field.

n_s is the density of superconducting electrons.

e is the charge of an electron.

m is the mass of an electron.

This equation implies that in a superconductor, the acceleration of the superconducting electron current is directly proportional to the applied electric field. In normal conductors, this relationship would include a term for resistance, but in a superconductor, the absence of resistance leads to this simplified form.

2. **Second London Equation:**

$$\nabla\times\mathbf{J} = -\frac{n_s e^2}{m}\mathbf{B} \text{ -------------------------(2)}$$

where **B** is the magnetic field.

This equation describes how the current density in a superconductor is related to the magnetic field. It implies that the magnetic field inside a superconductor decays exponentially, leading to the phenomenon where a magnetic field is expelled from the interior of a superconductor.

Penetration Depth:

The penetration depth, often denoted by λ_L, is a crucial concept in superconductivity and is derived from the second London equation. It characterizes the distance over which an external magnetic field can penetrate into a superconductor before it is exponentially attenuated.

The London penetration depth is given by:

$$\lambda_L = \sqrt{\frac{\mathrm{m}}{\mu_0\, n_s e^2}}$$

where, μ_0 is the permeability of free space.

The penetration depth varies with temperature and typically increases as the temperature approaches the critical temperature (T_c) of the superconductor. At T=0 K, the penetration depth is at its minimum value.

The penetration depth is crucial for understanding the Meissner effect, where the magnetic field is expelled from the interior of a superconductor. In a Type I superconductor, the field is expelled entirely below a critical magnetic field. In contrast, in Type II superconductors, the field penetrates partially in the form of vortices above a certain threshold.

[Summary:

London's equations provide a theoretical framework for understanding the electromagnetic properties of superconductors, particularly the phenomena of zero electrical resistance and the expulsion of magnetic fields. The penetration depth describes how deeply a magnetic field can penetrate into a superconductor and is key to understanding the Meissner effect and the behavior of superconductors in magnetic fields.]