attributed a wave-like character to matter (material particles). The waves associated with the moving material particles are called matter waves or de Broglie waves.

9. The de Broglie wavelength ($\lambda$) associated with a moving particle is related to its momentum $p$ as: $\lambda = h/p$. The dualism of matter is inherent in the de Broglie relation which contains a wave concept ($\lambda$) and a particle concept ($p$). The de Broglie wavelength is independent of the charge and nature of the material particle. It is significantly measurable (of the order of the atomic-planes spacing in crystals) only in case of sub-atomic particles like electrons, protons, etc. (due to smallness of their masses and hence, momenta). However, it is indeed very small, quite beyond measurement, in case of macroscopic objects, commonly encountered in everyday life.
10. Electron diffraction experiments by Davisson and Germer, and by G. P. Thomson, as well as many later experiments, have verified and confirmed the wave-nature of electrons. The de Broglie hypothesis of matter waves supports the Bohr's concept of stationary orbits.

| Physical Quantity | Symbol | Dimensions | Unit | Remarks |
|---|---|---|---|---|
| Planck's constant | $h$ | $[ML^2T^{-1}]$ | J s | $E = h\nu$ |
| Stopping potential | $V_0$ | $[ML^2T^{-3}A^{-1}]$ | V | $eV_0 = K_{max}$ |
| Work function | $\phi_0$ | $[ML^2T^{-2}]$ | J; eV | $K_{max} = E - \phi_0$ |
| Threshold frequency | $\nu_0$ | $[T^{-1}]$ | Hz | $\nu_0 = \phi_0 / h$ |
| de Broglie wavelength | $\lambda$ | [L] | m | $\lambda = h/p$ |

## POINTS TO PONDER

1. Free electrons in a metal are free in the sense that they move inside the metal in a constant potential (This is only an approximation). They are not free to move out of the metal. They need additional energy to get out of the metal.
2. Free electrons in a metal do not all have the same energy. Like molecules in a gas jar, the electrons have a certain energy distribution at a given temperature. This distribution is different from the usual Maxwell's distribution that you have learnt in the study of kinetic theory of gases. You will learn about it in later courses, but the difference has to do with the fact that electrons obey Pauli's exclusion principle.
3. Because of the energy distribution of free electrons in a metal, the energy required by an electron to come out of the metal is different for different electrons. Electrons with higher energy require less additional energy to come out of the metal than those with lower energies. Work function is the least energy required by an electron to come out of the metal.