(i) Gauss Law in Presence of Dielectrics (The Electric Displacement)

Within the dielectric, the total charge density can be written as $\rho = \rho_b + \rho_f$ where ρ_b is volume bound charge ρ_f **free charge** density.

From Gauss Law; $\vec{\nabla}.\vec{E} = \dfrac{\rho}{\varepsilon_0} \Rightarrow \varepsilon_0\left(\vec{\nabla}.\vec{E}\right) = \left(\rho_b + \rho_f\right) = -\vec{\nabla}.\vec{P} + \rho_f$

where $\vec{E}$ is now the **total field**, not just that portion generated by polarization.

$$\Rightarrow \vec{\nabla}.\left(\varepsilon_0\vec{E} + \vec{P}\right) = \rho_f$$

$\Rightarrow \vec{\nabla}.\vec{D} = \rho_f$ where $\vec{D} = \varepsilon_0\vec{E} + \vec{P}$ is known as the **electric displacement.**

Thus Gauss' law reads, $\vec{\nabla}.\vec{D} = \rho_f$ or, in integral form $\oint \vec{D}.d\vec{a} = Q_{f_{enc}}$, where $Q_{f_{enc}}$ denotes the total free charge enclosed in the volume.