Review: Time–Dependent Maxwell's Equations

$$\nabla \times \vec{E}(t) = -\frac{\partial \vec{B}(t)}{\partial t}$$

$$\nabla \times \vec{H}(t) = \frac{\partial \vec{D}(t)}{\partial t} + \vec{J}$$

$$\nabla \cdot \vec{D}(t) = \rho$$

$$\nabla \cdot \vec{B}(t) = 0$$

$$\vec{D}(t) = \varepsilon \, \vec{E}(t)$$

$$\vec{B}(t) = \mu \, \vec{H}(t)$$

Electromagnetic quantities:

Vector quantities in space:

$\vec{E}$	**Electric Field**
$\vec{H}$	**Magnetic Field**
$\vec{D}$	**Electric Flux (Displacement) Density**
$\vec{B}$	**Magnetic Flux (Induction) Density**
$\vec{J}$	**Current Density**
$\dfrac{\partial \vec{D}}{\partial t}$	**Displacement Current**

ρ	**Charge Density**
ε	**Dielectric Permittivity**
μ	**Magnetic Permeability**

In free space:

$$\varepsilon = \varepsilon_0 = 8.854 \times 10^{-12} \left[\mathrm{As/Vm}\right] \text{ or } \left[\mathrm{F/m}\right]$$

$$\mu = \mu_0 = 4\pi \times 10^{-7} \left[\mathrm{Vs/Am}\right] \text{ or } \left[\mathrm{Henry/m}\right]$$

In a material medium:

$$\varepsilon = \varepsilon_r\, \varepsilon_0 \quad ; \quad \mu = \mu_r\, \mu_0$$

ε_r = relative permittivity (dielectric constant)

μ_r = relative permeability

If the medium is anisotropic, the relative quantities are tensors:

$$\varepsilon_r = \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{bmatrix} \quad ; \quad \mu_r = \begin{bmatrix} \mu_{xx} & \mu_{xy} & \mu_{xz} \\ \mu_{yx} & \mu_{yy} & \mu_{yz} \\ \mu_{zx} & \mu_{zy} & \mu_{zz} \end{bmatrix}$$

Electromagnetic fields are completely described by Maxwell's equations. The formulation is quite general and is valid also in the relativistic limit (by contrast, Newton's equations of motion of classical mechanics must be corrected when the relativistic limit is approached).

The complete physical picture is obtained by adding an equation that relates the fields to the motion of charged particles.

The electromagnetic fields exert a force F on a charge q, according to the law (Lorentz force):

$$\vec{F}(t) = \underbrace{q\,\vec{E}(t)}_{\text{Electric Force}} + \underbrace{q\,\vec{v}(t)\times\vec{B}(t)}_{\text{Magnetic Force}} = q\left[\vec{E}(t) + \vec{v}(t)\times\vec{B}(t)\right]$$

where $v(t)$ is the velocity of the moving charge.