APECpedia

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Contents

Preface

Throughout this text vectors are displayed in bold face.

Part I

Physical Models

Chapter 1

Quantum Mechanics

1.1 Dirac equation

$$(i\gamma^\mu \partial_\mu - m)\,\psi = 0$$

where
γ^μ are the gamma matrices.

Chapter 2

Classical Mechanics

2.1 Newton's Law of Gravitation

$$\mathbf{F} = -G\frac{m'm}{r^3}\mathbf{r}$$

Chapter 3

Electromagnetism

SI units are used throughout this chapter.

3.1 Force Fields in Terms of Potential Fields

$$\mathbf{E} = -\nabla\phi - \frac{\partial \mathbf{A}}{\partial t} \tag{3.1}$$

$$\mathbf{B} = \nabla \times \mathbf{A} \tag{3.2}$$

3.2 Maxwell's Equations

Coulomb's law:

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon} \tag{3.3}$$

Gauss law:

$$\nabla \cdot \mathbf{B} = 0 \tag{3.4}$$

Faraday's Law of Induction:

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{3.5}$$

Ampere's Law with Maxwell's correction:

$$\nabla \times \mathbf{B} = \mu\mathbf{J} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t} \tag{3.6}$$

Constitutive Relations (isotropic medium):

$$\mathbf{D} = \epsilon\mathbf{E}$$

$$\mathbf{B} = \mu\mathbf{H}$$

$$\mathbf{J} = \sigma \mathbf{E}$$

Other:

$$c = \frac{1}{\sqrt{\mu\epsilon}}$$

Where:
$\mathbf{E}$ = Electric field intensity/strength
$\mathbf{H}$ = Magnetic field intensity/strength
$\mathbf{B}$ = Magnetic induction / Magnetic flux density
$\mathbf{D}$ = Electric displacement / Electric flux density
c = velocity of light in the medium
σ = Conductivity

Note that if the medium is not isotropic then ϵ and μ become tensors. For instance, in the presence of a gravitational field the refractive index of the vacuum changes due to its effect on virtual electron-positron pairs.

When using the Maxwell's equations on problems where we have paths, surfaces and/or volumes changing with time, in such cases the integral form of the equations must be used.

3.3 Lorentz Force

$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$$

3.4 Scalar Waves

Scalar waves result when the electric and magnetic field components are zero, but not so the electric and/or magnetic potentials.

In scalar waves the Lorentz gauge needs not to be zero, but becomes instead an scalar field S [1]:

$$S = -\frac{1}{c^2}\frac{\partial \phi}{\partial t} - \nabla \cdot \mathbf{A} \tag{3.7}$$

By replacing equations 3.1, 3.2 and 3.7 in Maxwell's equations 3.3-3.6 we get the two potential wave equations:

$$\left(\frac{1}{c^2}\frac{\partial^2 \phi}{\partial t^2} - \nabla^2 \phi\right) + \frac{\partial S}{\partial t} = \frac{\rho}{\epsilon}$$

$$\left(\frac{1}{c^2}\frac{\partial^2 \mathbf{A}}{\partial t^2} - \nabla^2 \mathbf{A}\right) - \nabla S = \mu \mathbf{J}$$

If the electric field is zero, then from equation 3.1 we have [2]:

$$\nabla\phi + \frac{\partial \mathbf{A}}{\partial t} = 0 \tag{3.8}$$

Equation 3.8 can always be satisfied if a scalar field χ exists such that

$$\mathbf{A} = \nabla\chi \tag{3.9}$$

and

$$\phi = -\frac{\partial \chi}{\partial t} \tag{3.10}$$

If in addition the scalar field S is zero, then by replacing equations 3.9 and 3.10 in 3.7 we get the wave equation for the new scalar field χ:

$$\frac{1}{c^2}\frac{\partial^2 \chi}{\partial t^2} - \nabla^2\chi = 0 \tag{3.11}$$

Chapter 4

Einstein's Relativity Theory

4.1 Special Relativity

Composition law for velocities [3]:

$$v_{AC} = \frac{v_{AB} + v_{BC}}{1 + v_{AB}v_{BC}}$$

4.2 General Relativity

Einstein's Field Equations:

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$R_{\mu\nu}$is the Ricci Tensor
R is the Curvature Scalar
$T_{\mu\nu}$is the Energy-Momentum Tensor

Chapter 5

Glossary

5.1 Electromagnetism

Current: The flow through a given surface or boundary of electric charge per unit of time. Its SI unit is the *ampere*.

Current density: The flow of electric charge per unit of surface and per unit of time.

Dielectric: An electrically insulating material that can be polarized by an applied electric field.

Displacement current: The quantity $\partial D/\partial t$ appearing in Maxwell's equations that is defined in terms of the rate of change of D, the electric displacement field. Displacement current density has the same units as electric current density, and it is a source of the magnetic field just as actual current is. However it is not an electric current of moving charges, but a time-varying electric field. In physical materials (as opposed to vacuum), there is also a contribution from the slight motion of charges bound in atoms, called dielectric polarization.

Electric charge: The capacity of some fundamental particles to produce an electric field around them. Its SI unit is the *coulomb*. Electric charge can be positive or negative.

Free charge Charge not bound to any atomic nucleus.

Bound charge Charge bound to an atomic nucleus.

Electric charge density: The amount of electric charge per unit volume.

Electric field: The force field that surrounds electrically-charged particles and exerts force on all other charged particles in the field, either attracting or repelling them.

Gauge theory: A physical theory that has gauge symmetry, this meaning that the theory has a parameter called the *gauge*, whose value does not affect the value of the measurable (i.e. observable) variables.

Magnetic field: The force field corresponding to the magnetic influence between moving electric charges, electric currents, and magnetic materials.

Magnetic vector potential: A vector potential whose curl is equal to the magnetic field.

Magnetism: the physical phenomenon consisting in the presence of a magnetic field.

Magnetization: The vector field that expresses the density of permanent or induced magnetic dipole moments in a magnetic material. The origin of the magnetic moments responsible for magnetization can be either microscopic electric currents resulting from the motion of electrons in atoms, or the spin of the electrons or the nuclei. Net magnetization results from the response of a material to an external magnetic field. Paramagnetic materials have a weak induced magnetization in a magnetic field, which disappears when the magnetic field is removed. Ferromagnetic and ferrimagnetic materials have strong magnetization in a magnetic field, and can be magnetized to have magnetization in the absence of an external field, becoming a permanent magnet. Magnetization also describes how a material responds to an applied magnetic field as well as the way the material changes the magnetic field, and can be used to calculate the forces that result from those interactions. It can be compared to (di-)electric polarization, which is the response of a material to an electric field. Physicists and engineers usually define magnetization as the quantity of magnetic moment per unit volume.

Polarization:

Wave polarization: The direction in which a wave's displacement occurs.

Dielectric polarization: Charge separation in insulating materials under the influence of an electric field.

Potential

Debye potential:

Hertz vector potentials: An alternative to the usual electromagnetic scalar and vector potentials, the Hertz vector potentials can be used in some cases to simplify the calculation of the electric amd magnetic fields, specially when dealing with antennas and waveguides.

Scalar electric potential: Electric potential energy that a unit charge test particle has when it is under the influence of the electric field produced by another charge.

Scalar potential: A scalar field whose gradient is a given vector field.

Vector potential: A vector field whose curl is a given vector field.

Whittaker potential:

Voltage: A.k.a. electric potential difference, it is the difference in electric potential (i.e. energy of a unit charge test particle) between two points in space under the influence of the electric field of an/other charge/s. In a static electric field it is defined as the work needed per unit of charge to move a test charge between the two points. Its SI unit is the *volt*.

Bibliography

[1] van Vlaenderen, Koen J. *A generalisation of classical electrodynamics for the prediction of scalar field effects.* 2003 (physics/0305098v1).

[2] Dea, Jack. *Fundamental fields and phase information.* Planetary Association for Clean Energy Newsletter, Vol. 4, Number 3.

[3] d'Inverno. *Introducing Einstein's Relativity.* Oxford.