Notes for ECE 30500 - Semiconductor Devices

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These are lecture notes for Fall 2025 ECE 30500 by professor Elliott at Purdue. Modify, use, and distribute as you please.

Contents

Gradient, Divergence, and Curl

Gradient

The gradient describes the spatial slope of a 3-dimensional function.
It can only be applied to a scalar field.

Rectangular:

$$\nabla f = a_x \frac{\delta d}{\delta x} + a_y \frac{\delta d}{\delta y} + a_z \frac{\delta d}{\delta z}$$

Cylindrical:

$$\nabla f = a_\rho \frac{\delta d}{\delta \rho} + a_\phi \frac{1}{\rho} \frac{\delta d}{\delta \phi} + a_z \frac{\delta d}{\delta z}$$

Spherical:

$$\nabla f = a_R \frac{\delta d}{\delta R} + a_\theta \frac{1}{R} \frac{\delta d}{\delta \theta} + a_\phi \frac{1}{R \sin(\theta)} \frac{\delta d}{\delta \phi}$$

Divergence

Describes the rate of change of a vector function.

Rectangular:

$$\nabla \cdot D = \left(a_x \frac{\delta}{\delta x} + a_y \frac{\delta}{\delta y} + a_z \frac{\delta}{\delta z} \right) \cdot \left(a_x D_x + a_y D_y + a_z D_z \right) = \frac{\delta D_x}{\delta x} + \frac{\delta D_y}{\delta y} + \frac{\delta D_z}{\delta z}$$

Curl

Describes the rotation of a vector function.
Rectangular:

$$\nabla \times D = a_x \left(\frac{\delta D_z}{\delta y} - \frac{\delta D_y}{\delta z} \right) + a_y \left(\frac{\delta D_x}{\delta z} - \frac{\delta D_z}{\delta x} \right) + a_z \left(\frac{\delta D_y}{\delta x} - \frac{\delta D_x}{\delta y} \right)$$

Cylindrical:

$$\nabla \times D = a_\rho \left(\frac{\delta D_z}{\delta \phi} - \frac{\delta \rho D_\phi}{\delta z} \right) + \rho a_\phi \left(\frac{\delta D_\rho}{\delta z} - \frac{\delta D_z}{\delta \rho} \right) + a_z \left(\frac{\delta \rho D_\phi}{\delta \rho} - \frac{\delta D_\rho}{\delta \phi} \right)$$

Identities

1. $\nabla \times \nabla V = 0$: the gradient does not rotate.
2. $\nabla \cdot (\nabla \times A) = 0$: the curl of a vector function does not diverge (grow).
3. A vector field whose divergence and curl are known is completely determined.

Electrostatics and Coulomb's Law

Coulomb's law was determined using a torsion pendulum.

Using his experimental results, the following properties were derived:

- Direction is always along $\mathbf{r_2} - \mathbf{r_1}$
- Decreases in magnitude proportional to $|\mathbf{r_2} - \mathbf{r_1}|^{-2}$
- It can be repulsive or attractive depending on the sign of $q_1 q_2$.

$$\mathbf{F_{12}} = \frac{q_1 q_2 \mathbf{a_{12}}}{4\pi\epsilon_0 |\mathbf{r_2} - \mathbf{r_1}|^2}$$

On the other hand the electric field at a point, due to a charge is defined as:

$$\mathbf{E}(r_2) = \frac{q_1 \mathbf{a_{12}}}{4\pi\epsilon_0 |\mathbf{r_2} - \mathbf{r_1}|^2} = \frac{q_1 (\mathbf{r_2} - \mathbf{r_1})}{4\pi\epsilon_0 |\mathbf{r_2} - \mathbf{r_1}|^3}$$

Which in turn leads to the superposition property, which states:

$$\mathbf{E}_{total} = \sum_{\text{all charges},i} \mathbf{E}_i$$