Alex Meng's Notes

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Preface

If you are reading this, you may be interesed in seeing what is “Alex’s Notes”.

These notes are just things that I am documenting, that I wish could become a useful resource for my future students, either when I TA or become a professor.

Here’s how to learn anything:

1. Write it out! (Document, Code along)
2. EXPERIMENT and explore
3. Visualize things you don’t understand
4. Ask Questions
5. Answer Exercise and Problems (stretch your knowledge)
6. Share with like-minded individuals

Part I

ELECTROMAGNETICS

Maxwell's Equations - Dan Fleisch

Website: [Official Website]

1 Gauss's law for electric fields

Introduction

Expand

- What are the two kinds of Electric Fields in Maxwell's Equation?

Answer

- Electrostatic Fields (from electric charge)
- Induced Electric Field (from changing magnetic field)

- What type of fields does Gauss's law deal with?

Answer

Electrostatic Fields (from electric charge)

Integral Form of Gauss's Law

Expand

Electric charge produces an electric field. The flux of that field passing through any closed surface is proportional to the total charge contained within that surface.

$$\oint_S \vec{E} \cdot \hat{n} da = \frac{q_{enc}}{\epsilon_0}$$

Expand To Learn About Left Hand Side

- What does the left hand side represent?

Answer
The number of electric field lines (AKA electric flux) passing through a closed surface S.

- What is Electric field?

Answer
The electrical force exerted on one coulomb of charge at that point in space is the electric field at that location.

$$\vec{E} = \frac{\vec{F}_e}{q_0}$$

$\vec{E}$ has units of $\frac{N}{C} = \frac{V}{m}$
Spacing of electric field lines tells you the strength of it.

- Electric field lines go from positive to negative
- Electric field lines vector sums, so they never cross

- Why do physicists and engineers always talk about small test charges?

Answer
Because the job of this charge is to test the electric field at a location, not to add another electric field into the mix (although you can't stop it from doing so). Making the test charge infinitesimally small minimizes the effect of the test charge's own field.

- What is the dot product? Why are we taking the dot product between $\vec{E}$ and $\hat{n}$ in Gauss's Law?

Answer
Consider vectors $\vec{A}$ and $\vec{B}$ in space.
What is the projection of $\vec{A}$ onto $\vec{B}$? From trig, it's $|A|\cos\theta$.
Now the dot product is that projection, multiplied by the magnitude of $\vec{B}$.

$$\vec{A} \cdot \vec{B} = |A||B|\cos\theta$$

- What is $\hat{n}$?

Answer
It is the unit normal vector, which has a length of one, and points in the direction perpendicular to the surface.
Note that since da is the tiny amount of area we are considering

$$\hat{n}da = d\vec{a}$$

- What is the difference between closed surface and open surface?

Answer

- Open Surface - any surface for which it is possible to get from one side to the other without going through the surface
- Closed Surface - a surface that divides space into an "inside" and "outside". Unit Normal Vector $\hat{n}$ always points outwards, away from the volume enclosed by the surface.

- What does $\vec{E} \cdot \hat{n}$ represent?

Answer
The component of the electric field vector that is perpendicular to the surface.

$$\vec{E} \cdot \hat{n} = |\vec{E}| \cos\theta$$

- How do you find the mass of a surface with varying density function $\sigma(x, y)$?

Answer
Since mass is density times volume, we can write:

$$Mass = \sigma \cdot Area$$

$$Mass_S = \Sigma_{i=1}^{N} \sigma_i \cdot Area_i$$

If we let Areas to become infinitesimally small dA, we get

$$Mass = \int_S \sigma dA$$

This is a *surface intergal*.

- What does $\int_S \vec{A} \cdot \hat{n} da$ represent?

Answer
It represents the flux of a vector field.
What's a vector field?
It is magnitude and direction quantities distributed in space.

- Scalar Field - something like temperature distribution in a room, where at each point theres a number
- Vector Field - something like flow of fluid, there at every point it has a speed and direction

- What's flux Φ?

Answer
Flux Φ of a field over a surface is the amount of flow through that surface.

$$\Phi = \vec{A} \cdot \hat{n} \times (SurfaceArea)$$

Expand To Learn About Right Hand Side

- What is the right hand side in words?

Answer
The total amount of enclosed charge normalized by the permittivity of free space.

- What is ϵ_0 and why is it there?

Answer
It is called the permitivity of free space or "vacuum permitivity".

$$\epsilon_0 = 8.854 \times 10^{-12} \frac{F}{m}$$

When we say the permitivity of a material, when are referring to its reponse to an electric field. It is also the key parameter in determining the speed at which an electromagnetic wave propagates through that medium.
High permitivity means it provides higher capacitance.
In Gauss's Law, ϵ_0 acts as a proportionality constant that relates electric flux to enclosed charge.

Exercises

- Five point charges are enclosed in a cylindrical surface S. If the values of the charges are $q_1 = +3nC$, $q_2 = -2nC$, $q_3 = +2nC$, $q_4 = +4nC$, and $q_5 = -1nC$, find the total flux through S.

Answer

$$\sum_{i=1}^{5} q_i = 3 - 2 + 2 + 4 - 1 = 6nC = 6 \times 10^{-9}C$$

$$\Phi_E = \frac{q_e nc}{\epsilon_0} = \frac{6 \times 10^{-9}C}{8.854 \times 10^{-12} \frac{C}{V \cdot m}} = \boxed{678\ Vm}$$

Differential Form of Gauss's Law

Expand

The electric field produced by electric diverges from positive charge and converges upon negative charge.

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

Expand To Learn About Left Hand Side

- What does the left hand side represent?

Answer
The tendency of electric field to flow away from a point in space - AKA the divergence.

- What is the difference between differential and integral form of Gauss's Law?

Answer
Differential deals with individual points in space, whereareas integral deals with a closed surface.

- What is $\vec{\nabla}$?

Answer
It is called "del" or "nabla". It tells you to take the derivative of what ever quantity comes after it.

$$\vec{\nabla} = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$$

It is an *mathematical operator*, which just means that it needs something to act on and cannot just appear by itself.
$\vec{\nabla}$ is gradient, $\vec{\nabla}\cdot$ is divergence, and $\vec{\nabla}\times$ is curl.

- What is $\vec{\nabla}\cdot$ specifically?

Expand
Oliver Heaviside suggested the word "divergence" to describe the rate at which electric field flow outwards from a positive charge.

- source - diverge from that point (positive charge for electric field)
- sink - converge to that point (negative charge for magnetic field)

Expand To Learn About Right Hand Side

- What is the right hand side in words?

Answer

Exercises

- Five point charges are enclosed in a cylindrical surface S. If the values of the charges are $q_1 = +3nC$, $q_2 = -2nC$, $q_3 = +2nC$, $q_4 = +4nC$, and $q_5 = -1nC$, find the total flux through S.

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Advanced Engineering Electromagnetics - C. Balanis

Link: Internet Archive

1 Time-Varying and Time-Harmonic Electromagnetic Fields

Maxwell's Equations

Expand

- Who is James Clerk Maxwell?

Answer

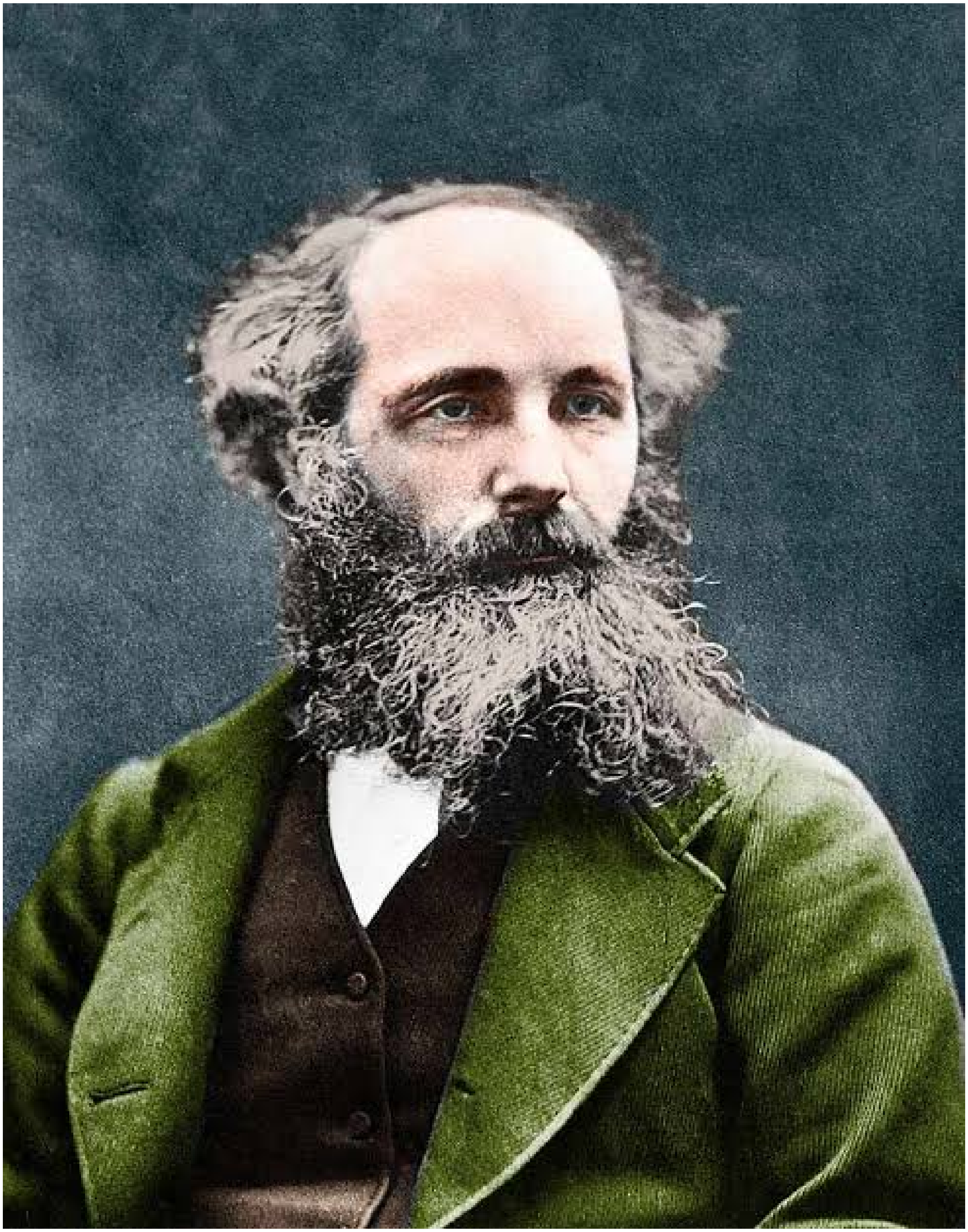

Figure 1: James Clerk Maxwell

A Scottish physicist and mathematician that lived from 1831 to 1879.

The Father of Modern Physics

See my notes on Dan Fleisch's A student's guide to Maxwell's Equations for detailed explanation of the differential and integral forms of the four maxwell's equations.

Constitutive Parameters and Relations

Expand

Circuit-Field Relations

Expand

- What is Circuit Theory?

Answer

A special case of electromagnetic theory, when the physical dimensions of the circuit are small compared to the wavelength.

KVL

KCL

Element Laws

Boundary Conditions

Expand

Finite Conductivity Media

Infinite Conductivity Media

Sources Along Boundaries

Power and Energy

Expand

Time-Harmonic Electromagnetic Fields

Expand

Maxwell's Equations in Differential and Integral Forms

Boundary Conditions

Power and Energy

Exercises

Expand

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2 Electrical Properties of Matter

Introduction

Expand

Dielectrics, Polarization, and Permittivity

Expand

Magnetics, Magnetization, and Permeability

Expand

Current, Conductors, and Conductivity

Expand

Current

Conductors

Conductivity

Semiconductors

Expand

Superconductors

Expand

Metamaterials

Expand

Linear, Homogeneous, Isotropic, and Nondispersive Media

Expand

Exercises

Expand

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3 Wave Equation and Its Solutions

Introduction

Expand

Time-Varying Electromagnetic Fields

Expand

Time-Harmonic Electromagnetic Fields

Expand

Solution to the Wave Equation

Expand

Rectangular Coordinate System

Cylindrical Coordinate System

Spherical Coordinate System

Exercises

Expand

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4 Wave Propagation and Polarization

Introduction

Expand

Transverse Electromagnetic Modes

Expand

Transverse Electromagnetic Modes in Lossy Media

Expand

Polarization

Expand

Exercises

Expand

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5 Reflection and Transmission

Introduction

Expand

Normal Incidence - Lossless Media

Expand

Oblique Incidence - Lossless Media

Expand

Perpendicular Polarization

Parallel Polarization

Total Transmission - Brewster Angle

Total Reflection - Critical Angle

Part II

MACHINE LEARNING

Deep Learning with PyTorch

Instructor: Daniel Bourke

Youtube

PyTorch Docs

Wikipedia: Deep Learning

Introduction

AI includes machine learning, which includes deep learning. All three aim to approximate the rules of a system from examples.

Before using machine learning, ask: Can you write down all the rules to solve this problem? If yes, use a rule-based system—it's simpler, faster, and more interpretable.

But when rules are too complex or unclear, machine learning or deep learning helps.

Deep Learning is good for:

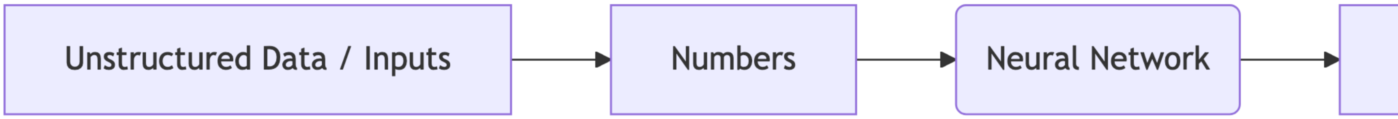
- Problems with long lists of rules
- Continually changing environments
- Discovering insights within large collections of data

Deep Learning is not good for:

- When you need explainability
- When the traditional approach is a better option
- When errors are unacceptable

Machine Learning is better than Deep Learning at structured Data, neural networks typically work best with unstructured data.

What are "Neural Networks"?



Anatomy of Neural Networks

Each layer is a combination of functions, linear or non-linear.

Learning Paradigms

Supervised	Unsupervised & Self-supervised	Transfer	Reinforcement
Lot of Data that are labeled	Just Data	Building on top of already learned model	Action and Reward

What are deep learning used for?

If you can encode something into numbers, you can build a deep learning model to find pattern in those numbers.

Computer Vision, NLP, Recommendation, and literally anything complex.

PyTorch Workflow