

Electromagnetics I

VE230

LECTURER: NANA LIU
SUMMER 2023



JOINT INSTITUTE
交大密西根学院

Electricity

Magnetism

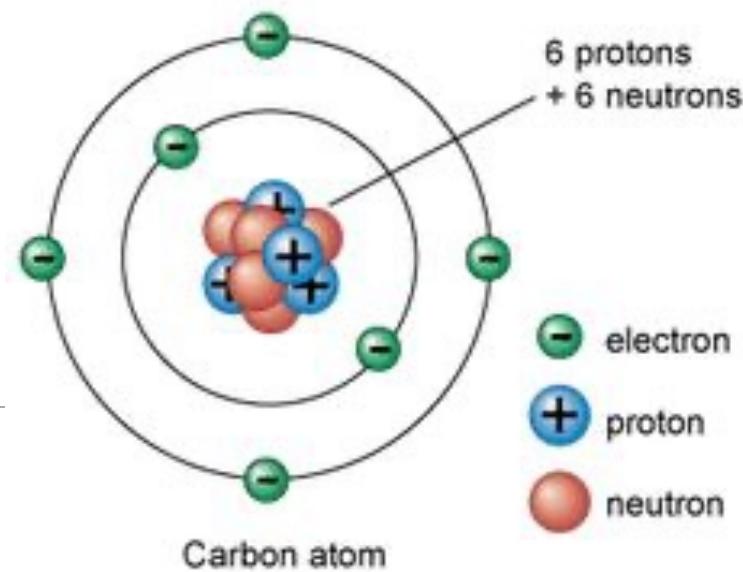
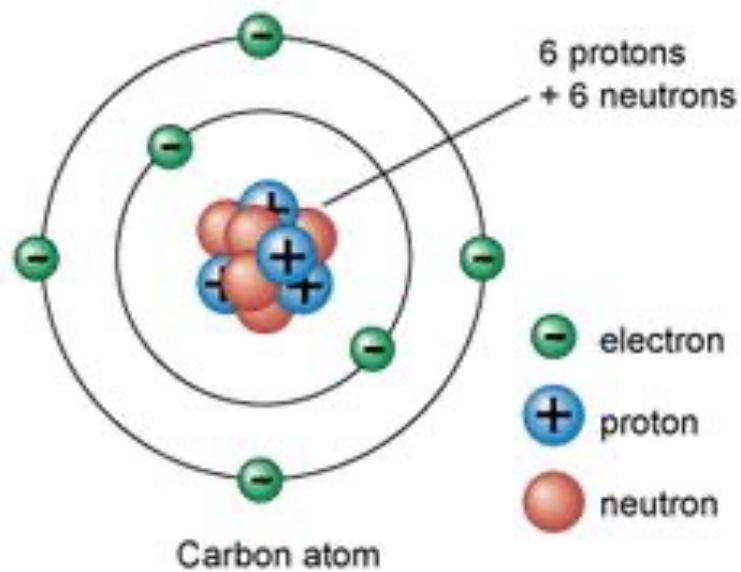


Moving matter...
electromagnetics

Electricity & Magnetism: Moving electric charges & moving magnets

You won't be here without them...

Let's start with electric forces



Power of electric forces...

Imagine you are standing an arm's length away from your friend. Nothing's happening...so far so good...

Power of electric forces...

Imagine both of you now have 1 percent more electrons than protons...so both of you are more negatively charged

Power of electric forces...

How powerful is this repelling force between you now?

Survey time!

This repulsion force would be enough to lift
the weight of...

Survey time!

This repulsion force would be enough to lift
the weight of...

An apple?



Survey time!

This repulsion force would be enough to lift
the weight of...

You eating an apple?



Survey time!

This repulsion force would be enough to lift
the weight of...

JI Building?



Survey time!

This repulsion force would be enough to lift
the weight of...

Yellow mountain?



Survey time!

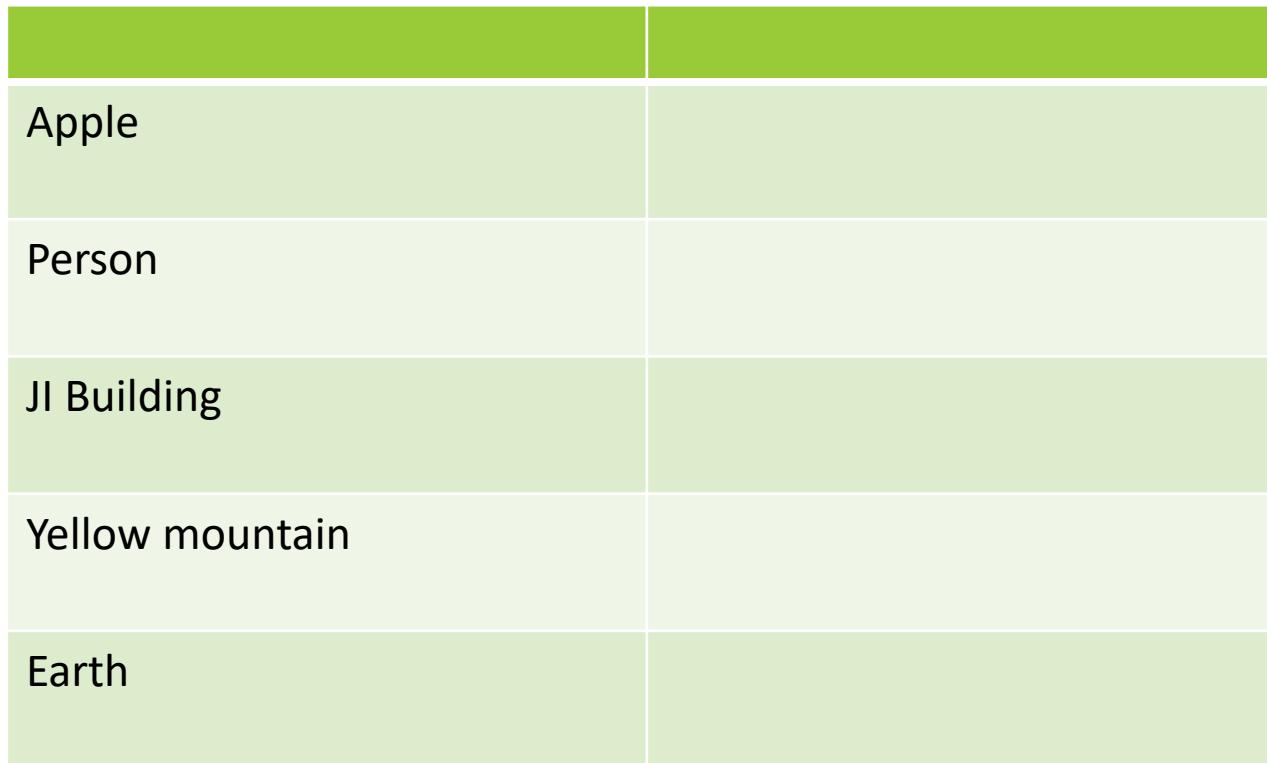
This repulsion force would be enough to lift
the weight of...

Whole Earth?



Survey time!

Your votes:



Answer?...



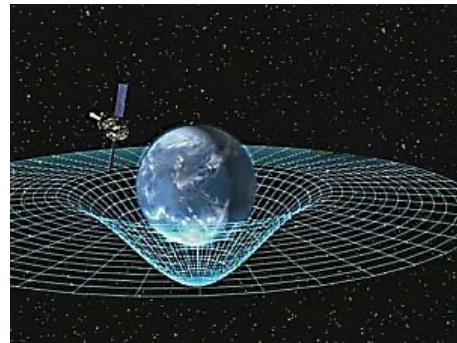
Putting electromagnetic forces in context...

In the **WHOLE** universe, there are only **FOUR** known fundamental forces...can describe almost **EVERYTHING!!!**

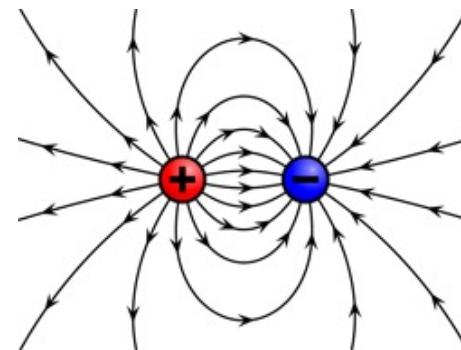
So how important is electromagnetism?

Putting electromagnetic forces in context...

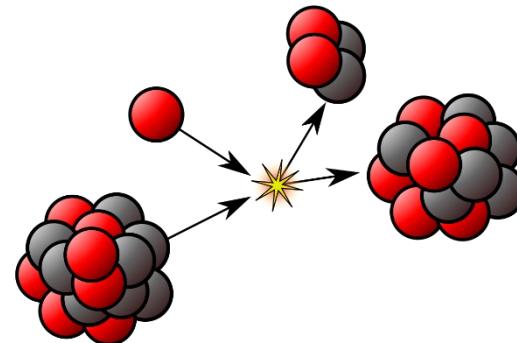
Gravity



Electromagnetism



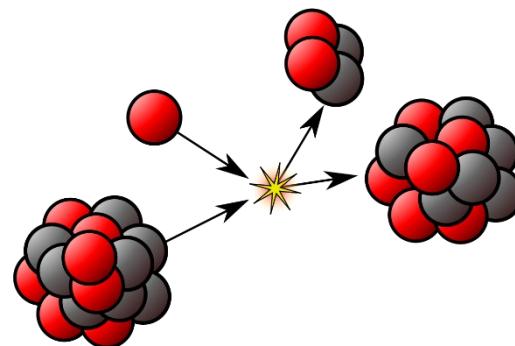
Strong nuclear forces
Weak nuclear forces



Putting electromagnetic forces
in context...

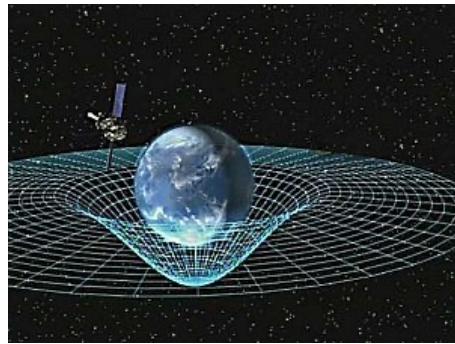
Very short range...
so usually we don't notice...

Strong nuclear forces
Weak nuclear forces

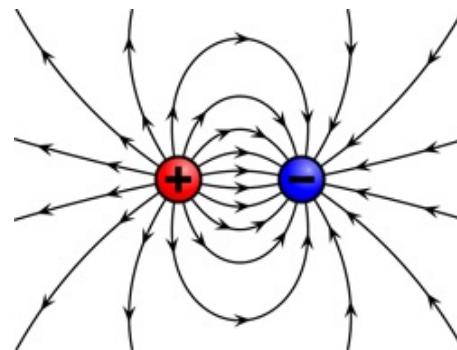


Putting electromagnetic forces in context...

Gravity

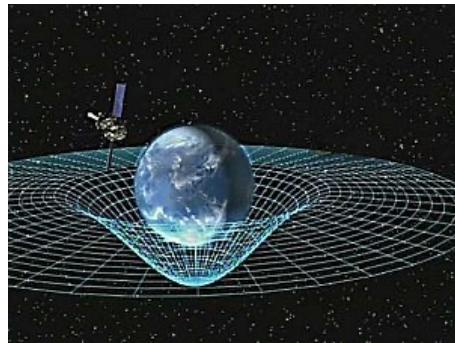


Electromagnetism

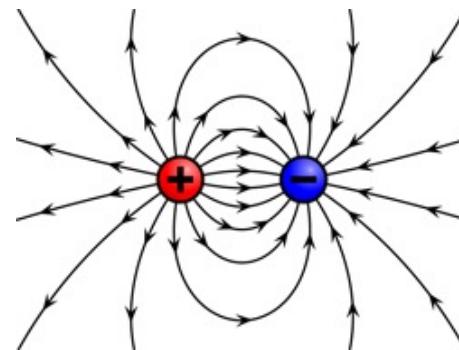


Putting electromagnetic forces in context...

Gravity



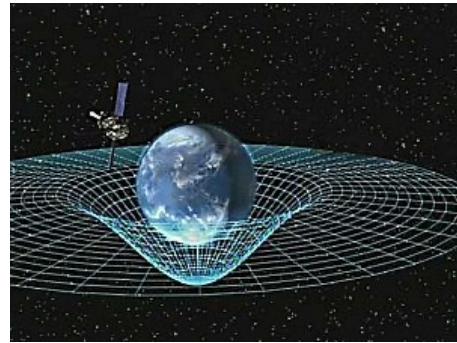
Electromagnetism



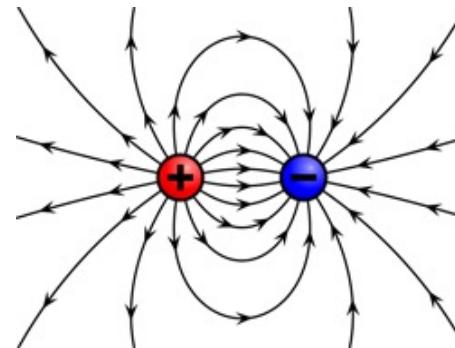
Both long range....

Putting electromagnetic forces in context...

Gravity



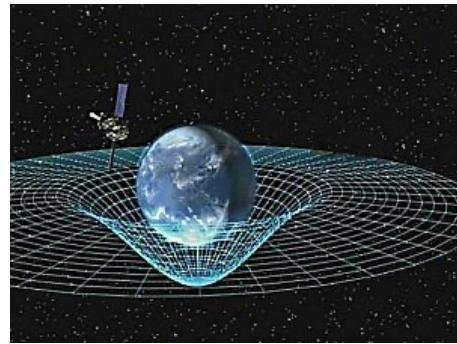
Electromagnetism



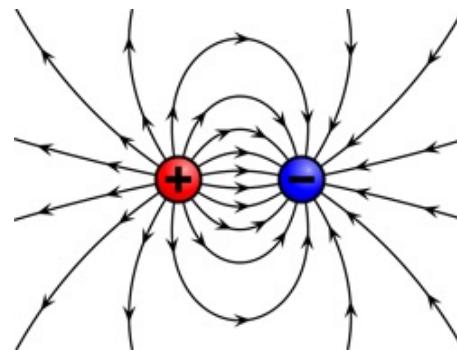
Gravity much much weaker...

Putting electromagnetic forces in context...

Gravity



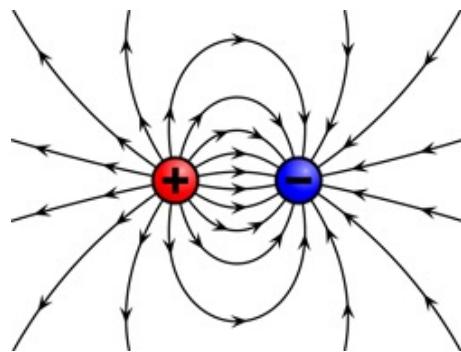
Electromagnetism



10^{36} times weaker....

Putting electromagnetic forces in context...

Electromagnetism



Basically all
you'll really
need to
worry
about...

And this amazing force can all
be described on your T-Shirt...

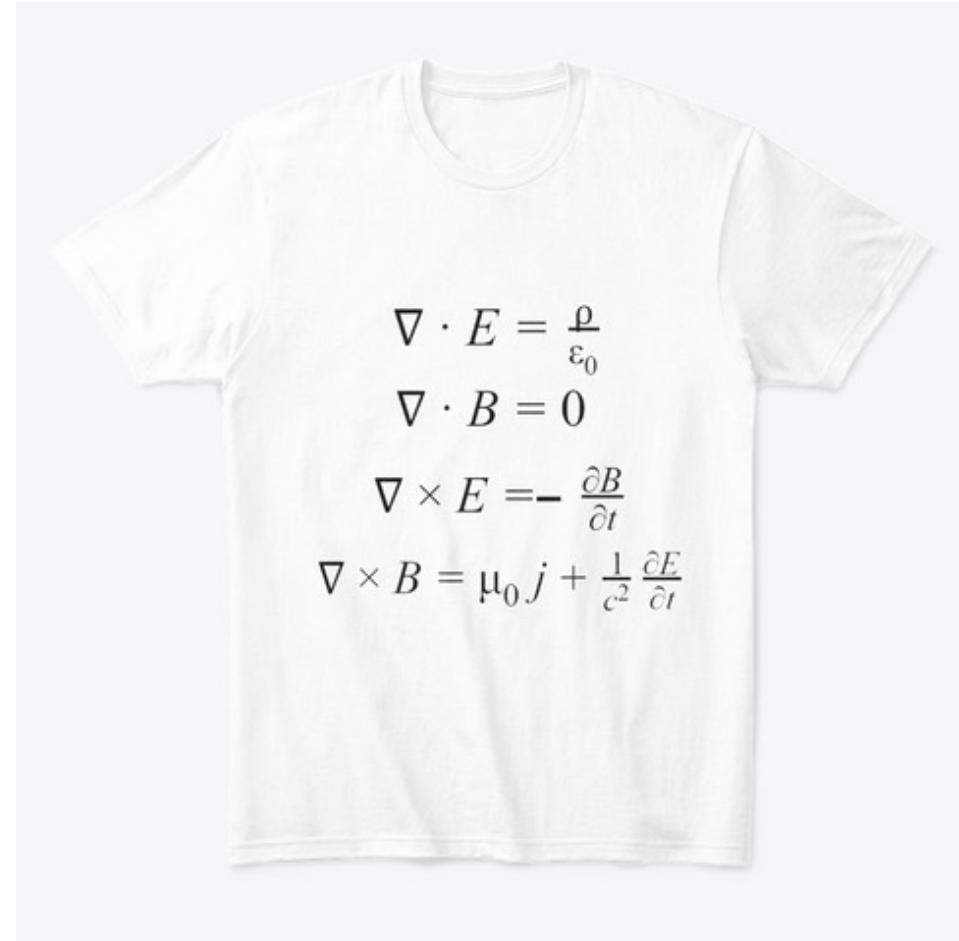
Electromagnetic Laws

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

$$\nabla \cdot B = 0$$

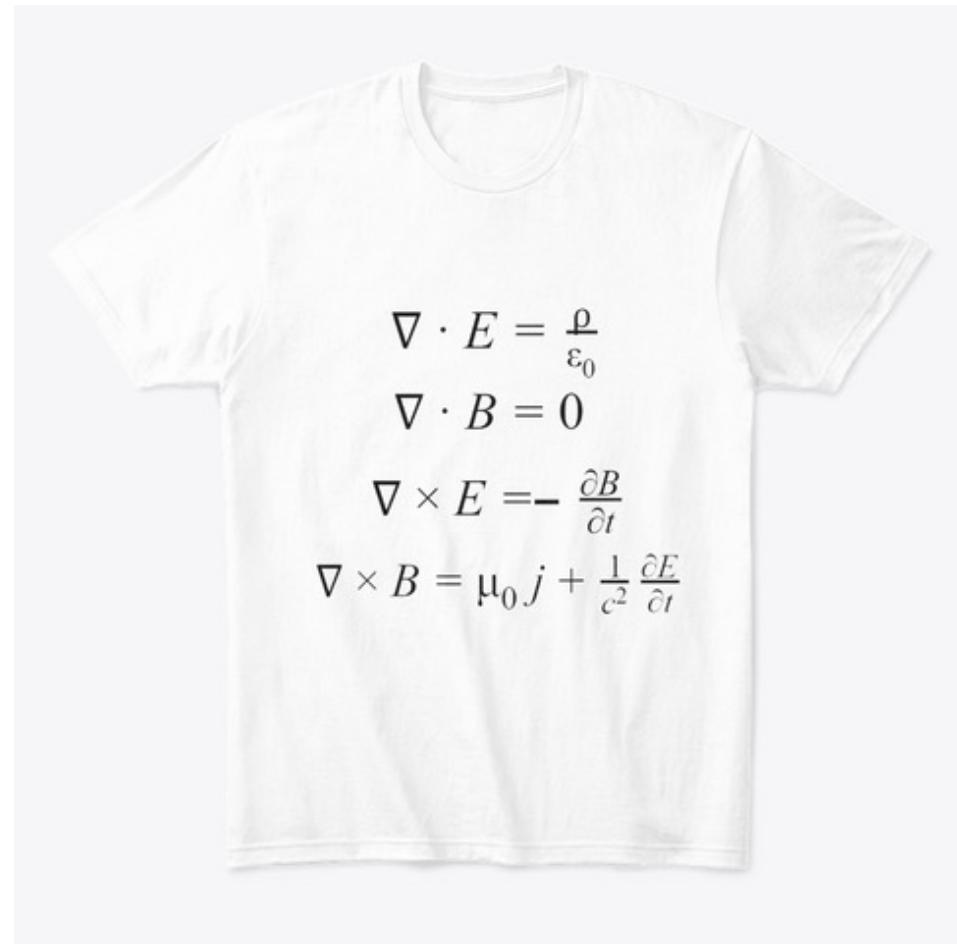
$$\nabla \times E = - \frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 j + \frac{1}{c^2} \frac{\partial E}{\partial t}$$

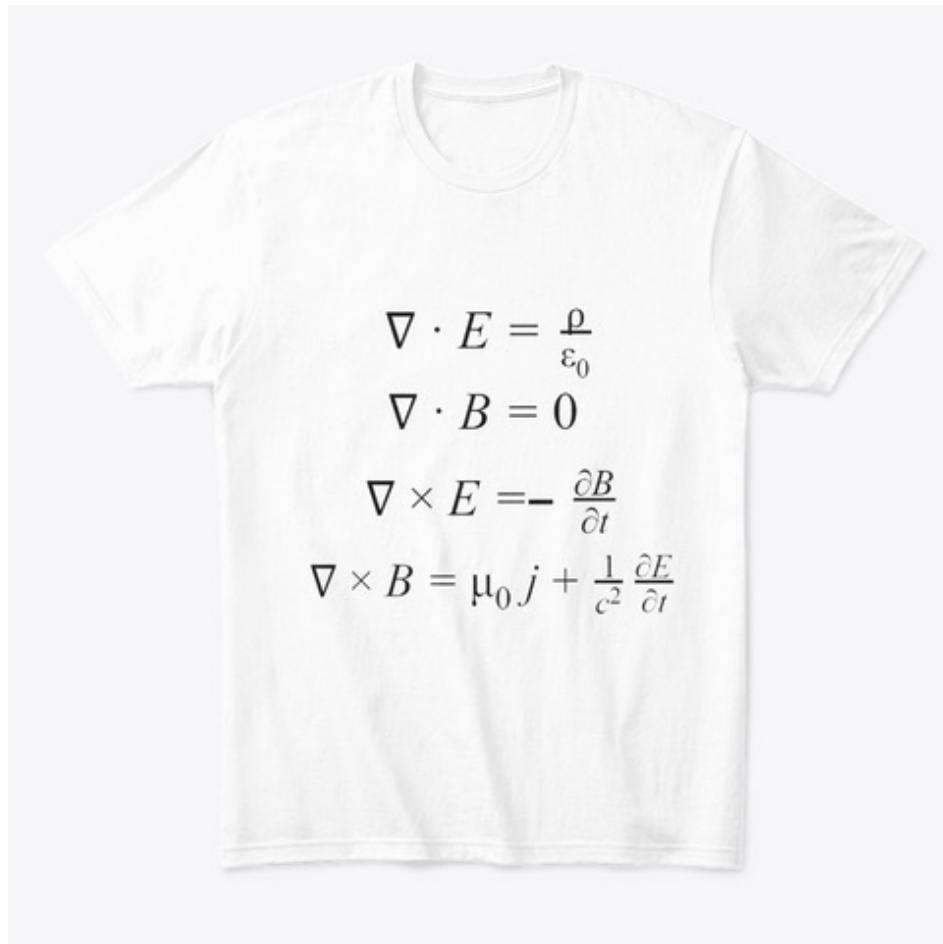


Basically we are just unpacking this T-shirt for this whole summer...

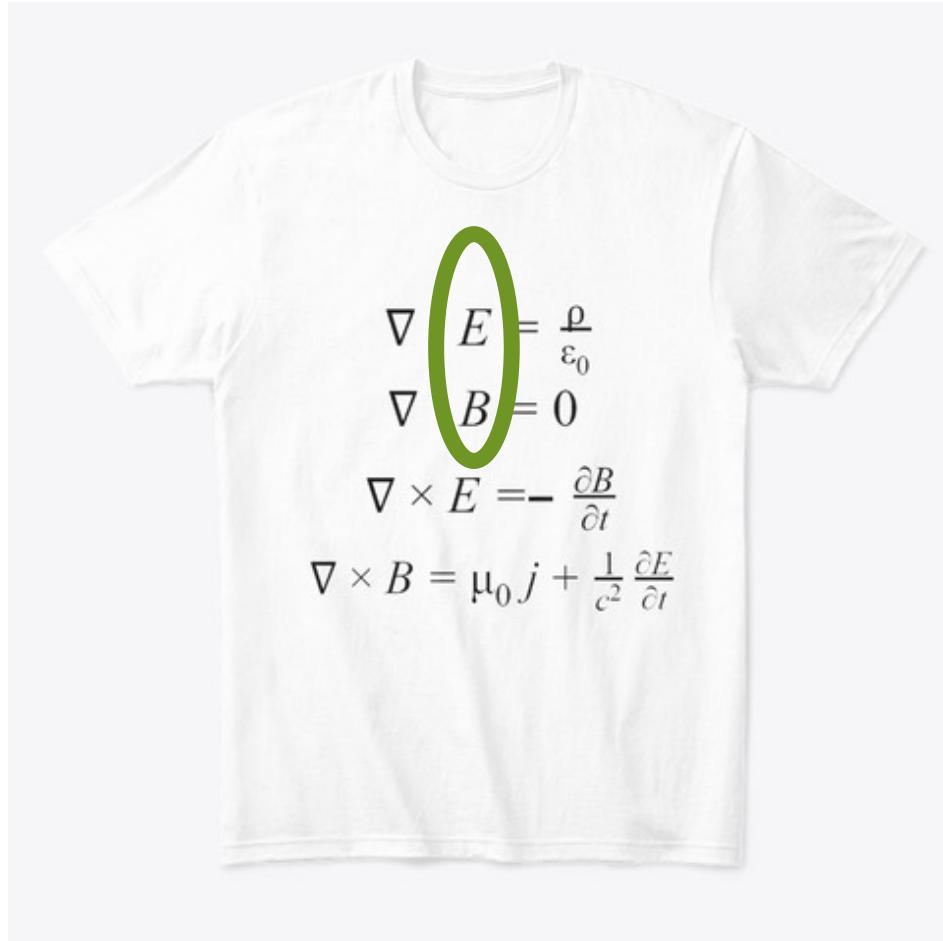
Electromagnetic Laws: Summary of course



Some basic things we can already see...

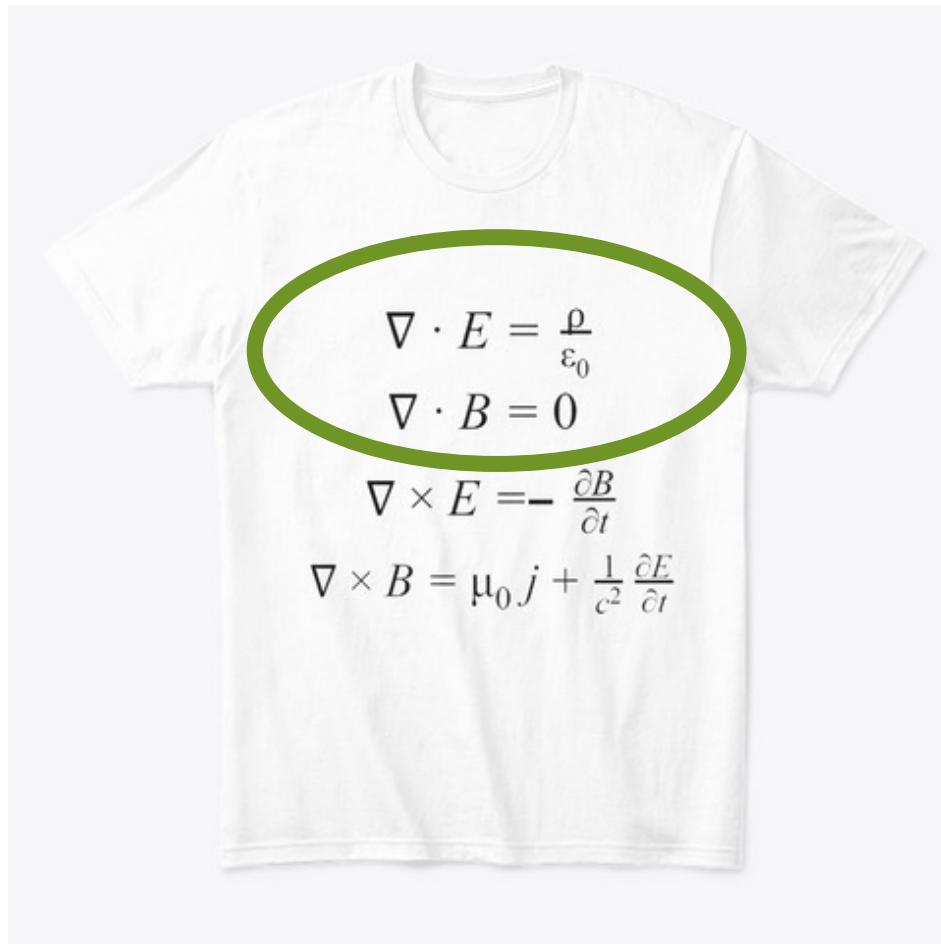


Some basic things we can already see...



Introducing
idea
of electric
and
magnetic fields...

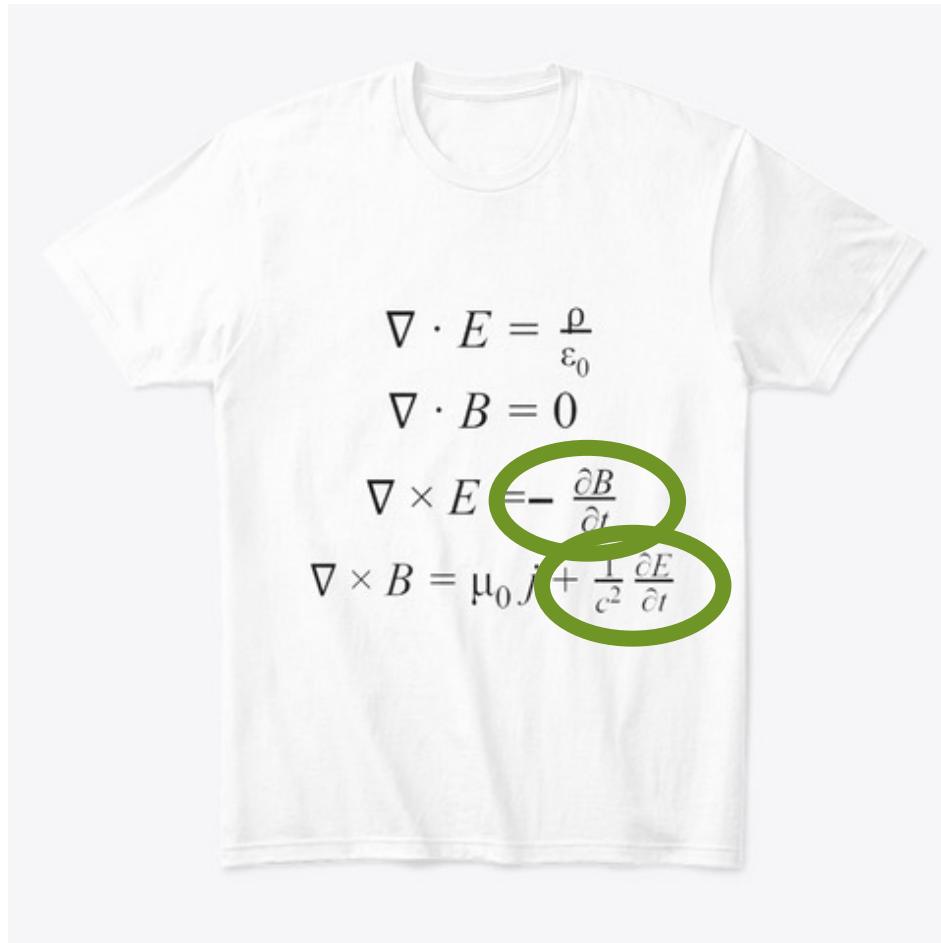
Some basic things we can already see...



Electricity and magnetism are treated differently...

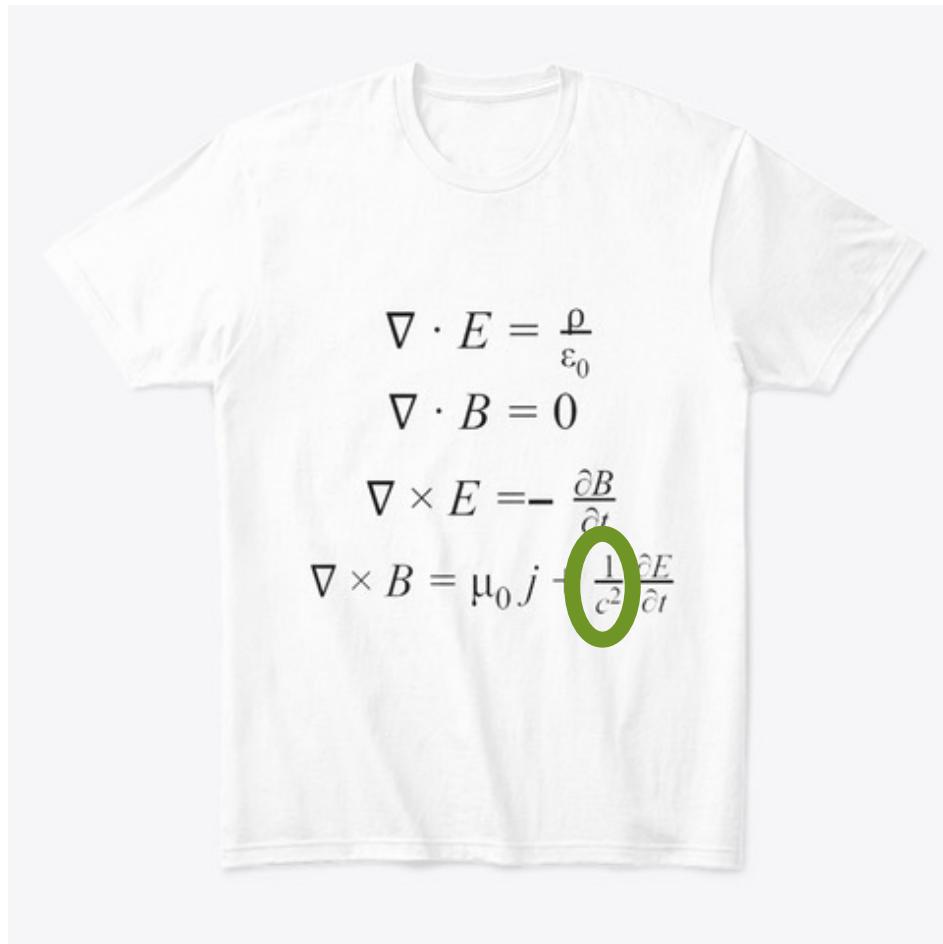
no magnetic monopoles

Some basic things we can already see...



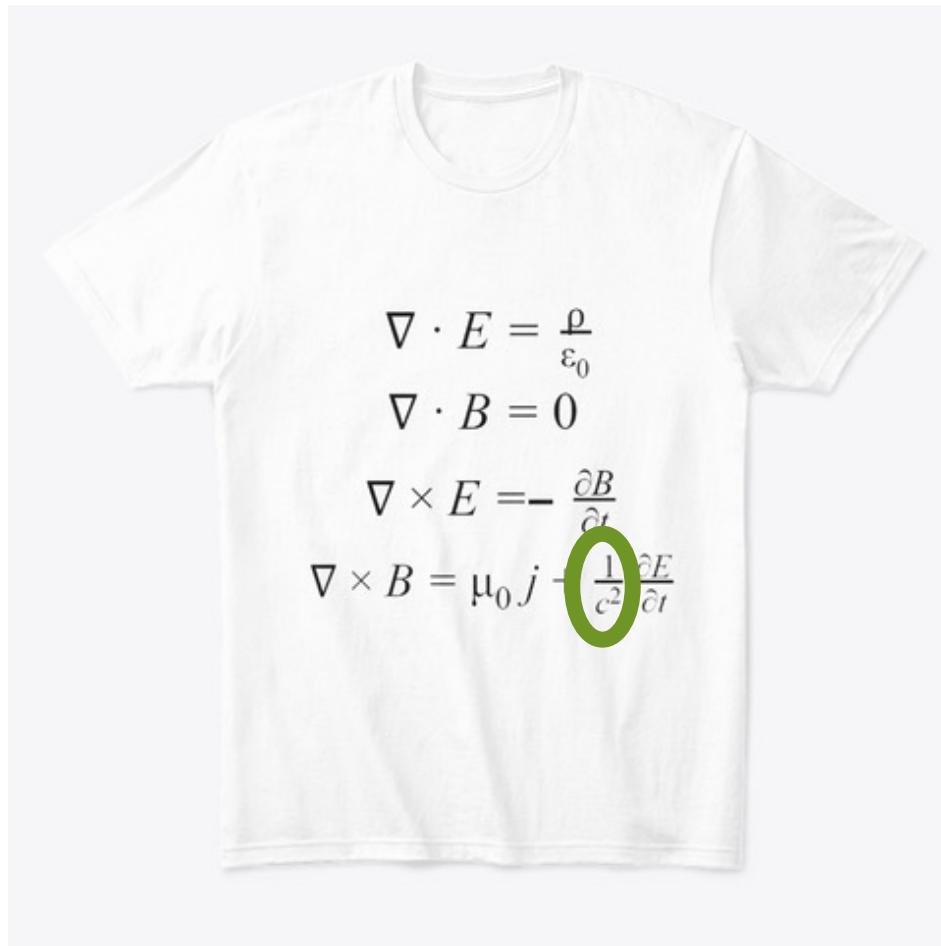
Changing magnetic fields related to electric fields and vice-versa...

Some basic things we can already see...



This dynamics has something to do with the speed of light...

Some basic things we can already see...



If we let light speed go to infinity...
last term drops off...

So relativity is already in here!

How much work throughout history it took to get to those insights on this T-shirt...



Discovering electricity and magnetism

Ancient history

Amber (static electricity)
and other materials...

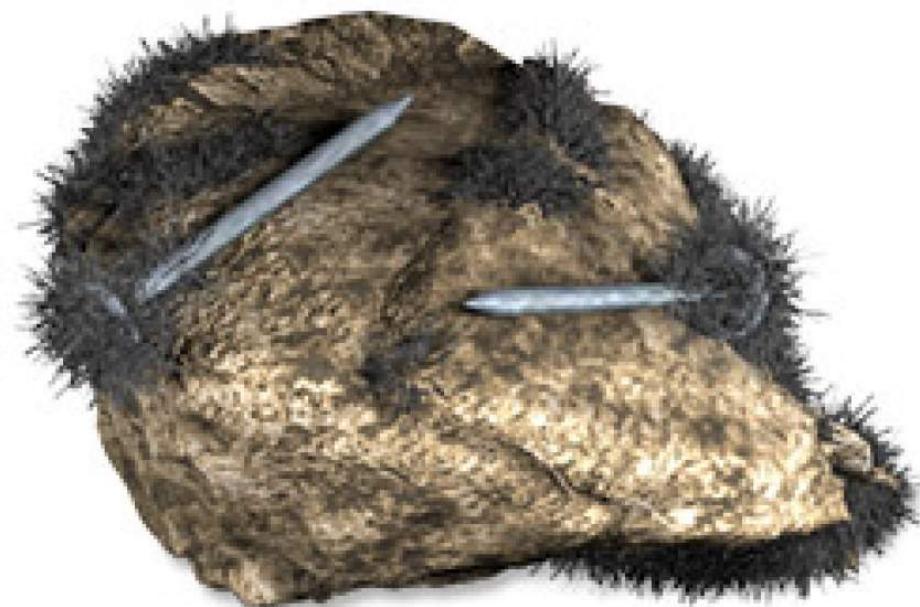
Discover that there're
basically two types of
these strange forces: ones
that repel and ones
That attract



Discovering electricity and magnetism

Ancient history

Lodestones (“leading stone”), 11th century



Discovering electricity and magnetism

Electric stingrays

Inspiration
behind the
modern battery!

Lots of capacitors
inside...



Discovering electricity and magnetism

Lightning



Proposed by Benjamin Franklin in 18th C that this could be an electrical phenomenon

18th Century

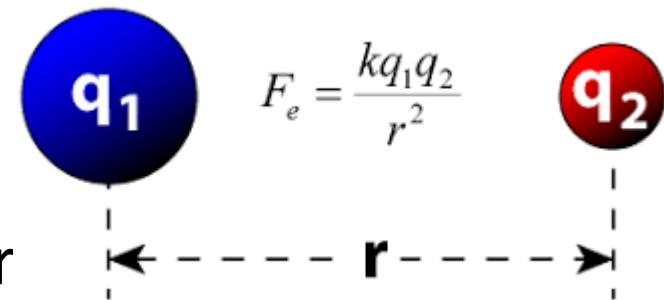
Electricity and magnetism were considered separate forces...

1. Concept of electrostatic forces and charges

2. Coulomb's law (1785)

3. Leiden jar (1745): early capacitor

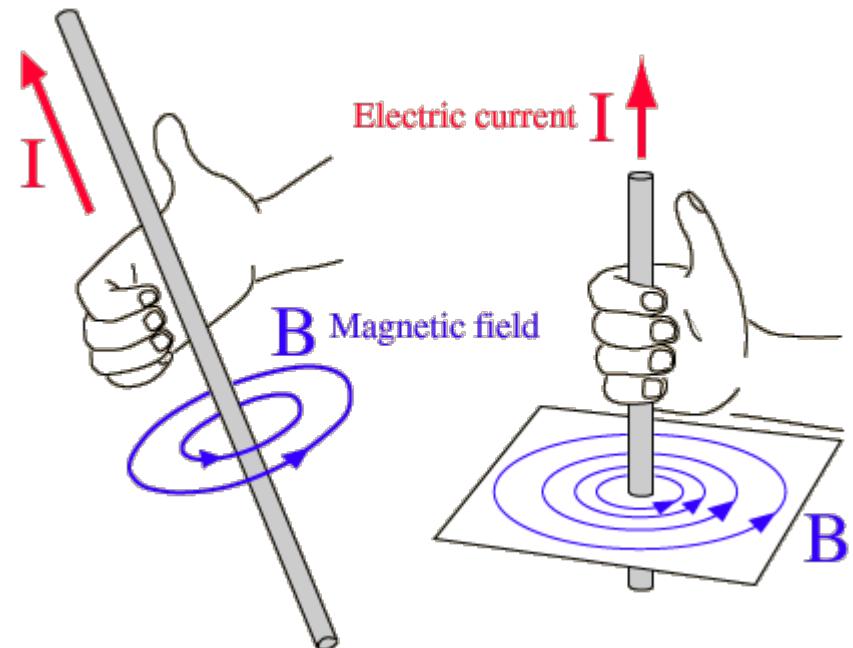
4. The first commercial magnet (1740)



Early 19th Century

Electricity and magnetism are perhaps not independent after all! Idea of fields!

1. Oersted (Danish): in 1819, the deflecting effect of an electric current traversing a wire upon- a suspended magnetic needle

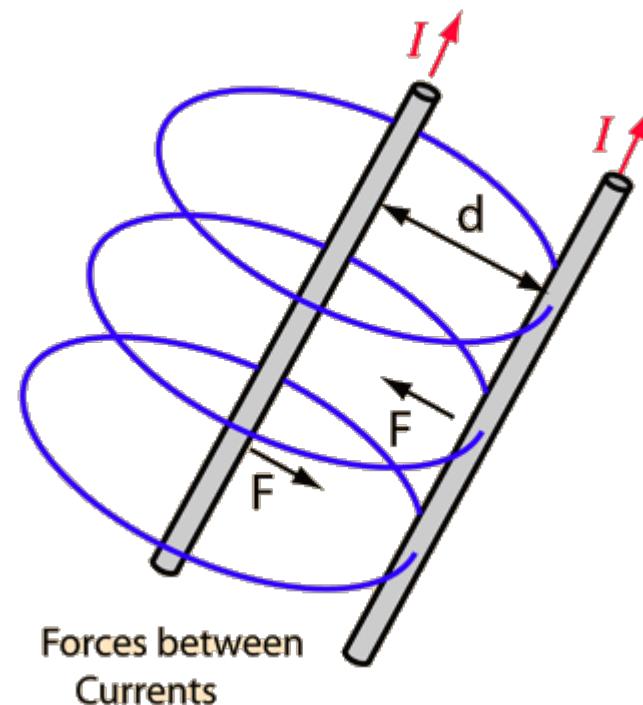


Early 19th Century

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2. Ampère (French): in 1821, the force between two current-carrying wires



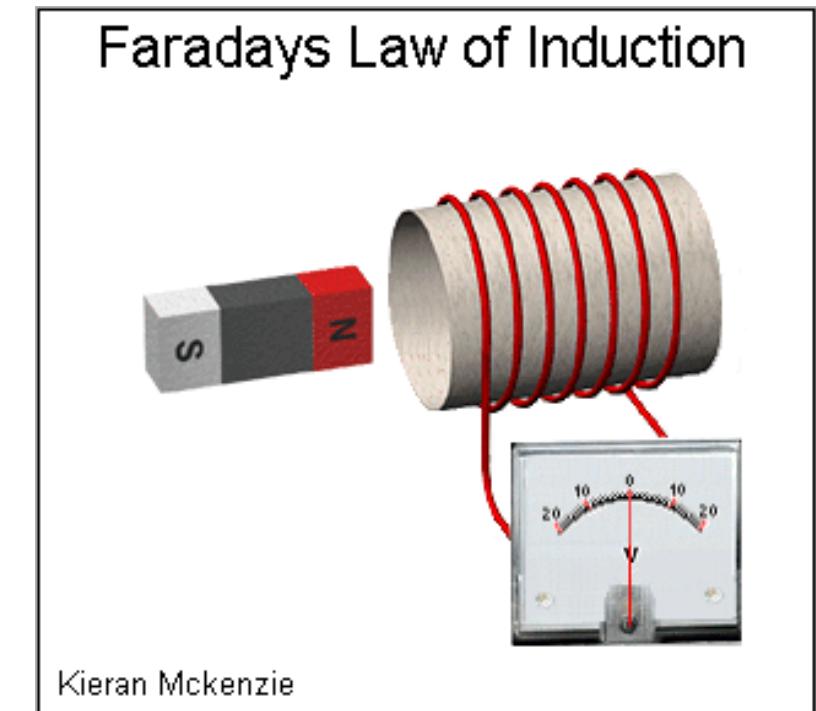
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3. Faraday (English): in 1831, EM induction



Early 19th Century

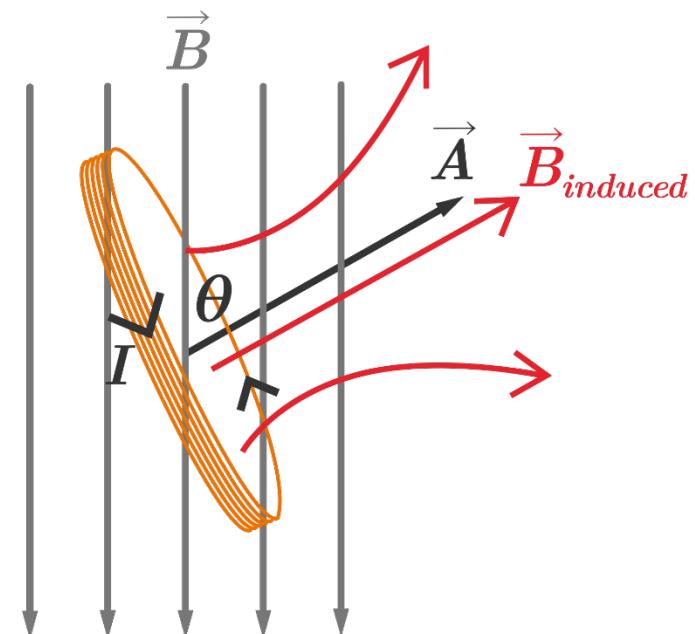
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2. Ampère (French): in 1821, the force between two current-carrying wires

3. Faraday (English): in 1831, EM induction

4. Lenz (Russian): in 1834, the current direction of EM induction



Later 19th Century

James Clerk Maxwell (English): in 1864,
EM theory of light: unification!

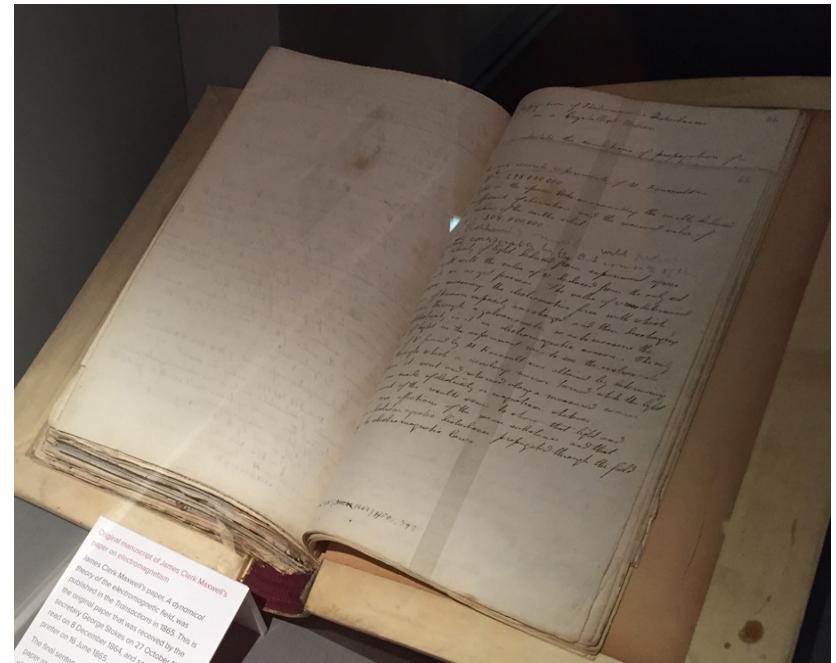
A simplified model of Faraday's work

Predicted EM waves and calculated
the speed: 310,740,000 m/s

The understanding of the nature of
light

Heinrich Hertz (German): in 1887, proved
the actual existence of EM waves

Oliver Heaviside (English): in 1887,
reformulated Maxwell's equations



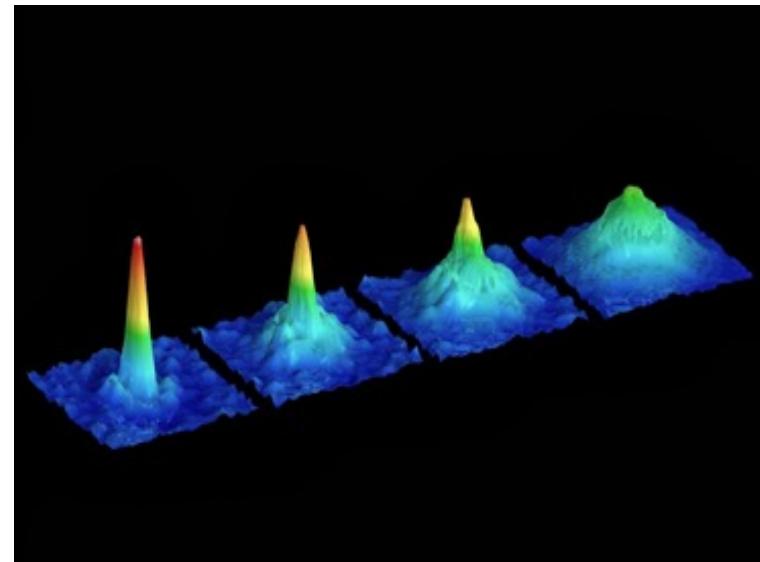
20th Century

1. Various units adopted: volt (from the Italian Volta), ampere (from the French scientist), henry (from the American scientist), etc.
2. 1900-1910: all forces of nature are of EM origin?? The ether is a medium for EM waves??

Albert Einstein, 1905:

- a) Photoelectric effect: **contradict** contemporary wave theories of light
- b) Special relativity: **contradict** the idea of ether

TODAY: quantum optics...



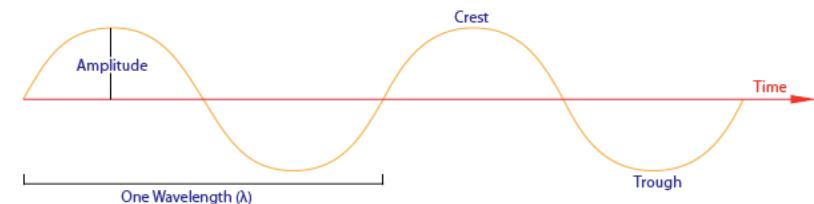
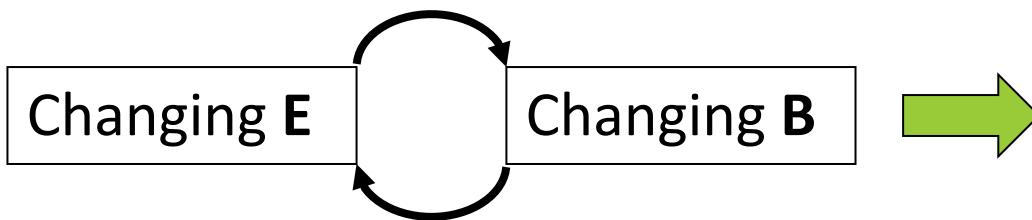
EM Waves

Charges at rest → E fields

Charges in motion → B fields

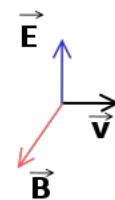
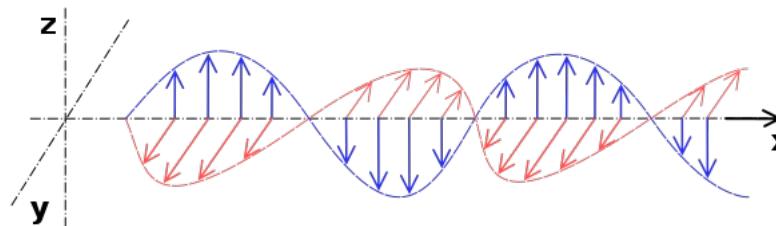
Changing E → B

Changing B → E

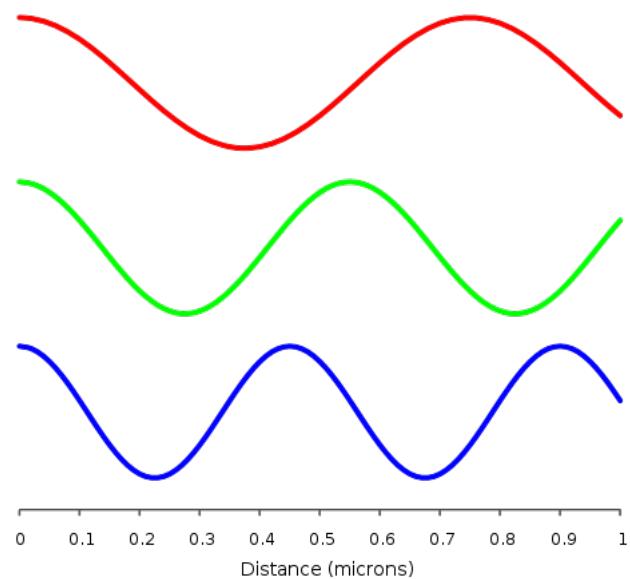


EM Waves

EM waves

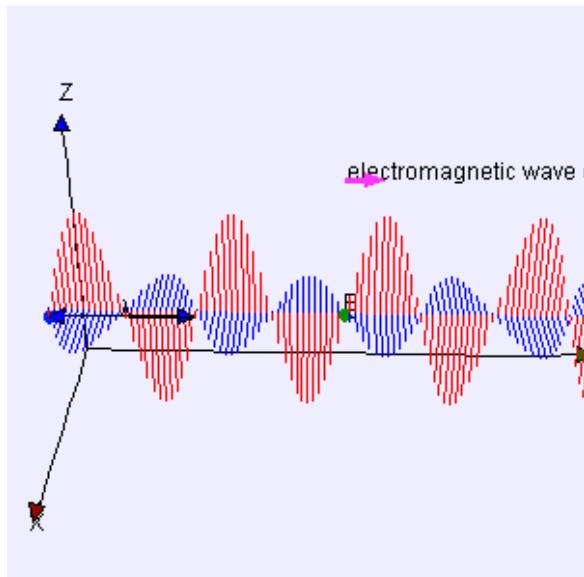


One particular example: visible light

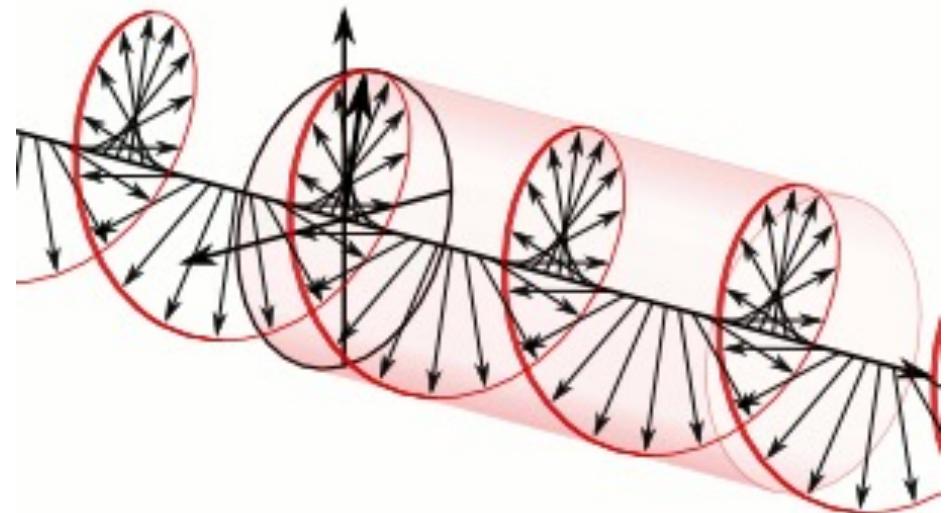


EM Waves

3D animations



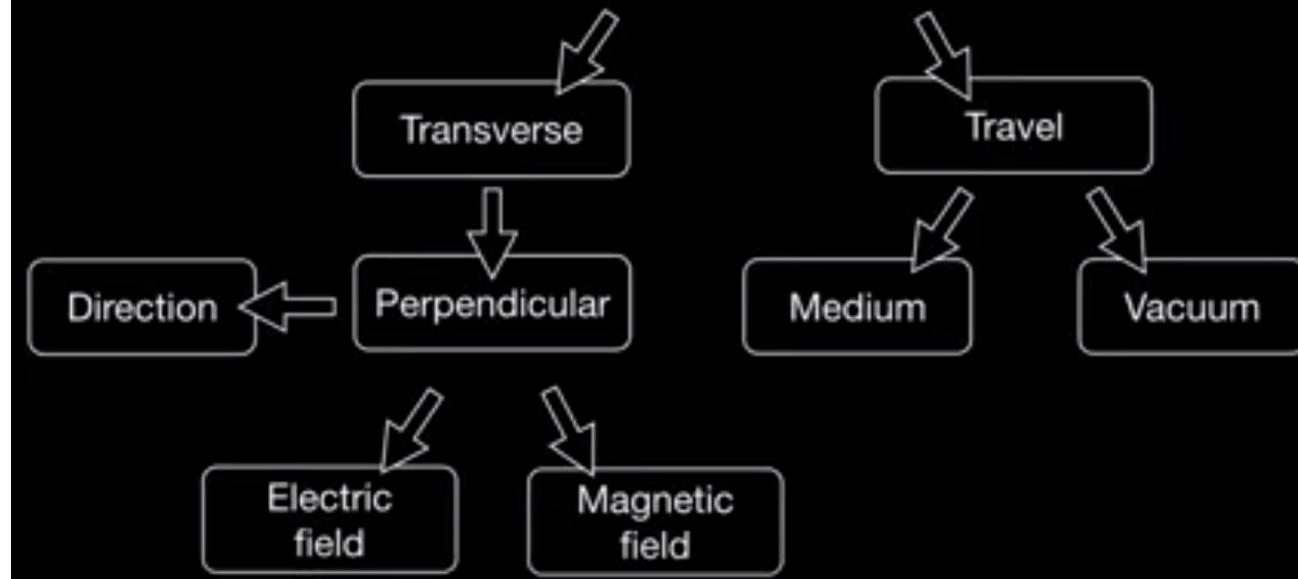
Linearly polarized



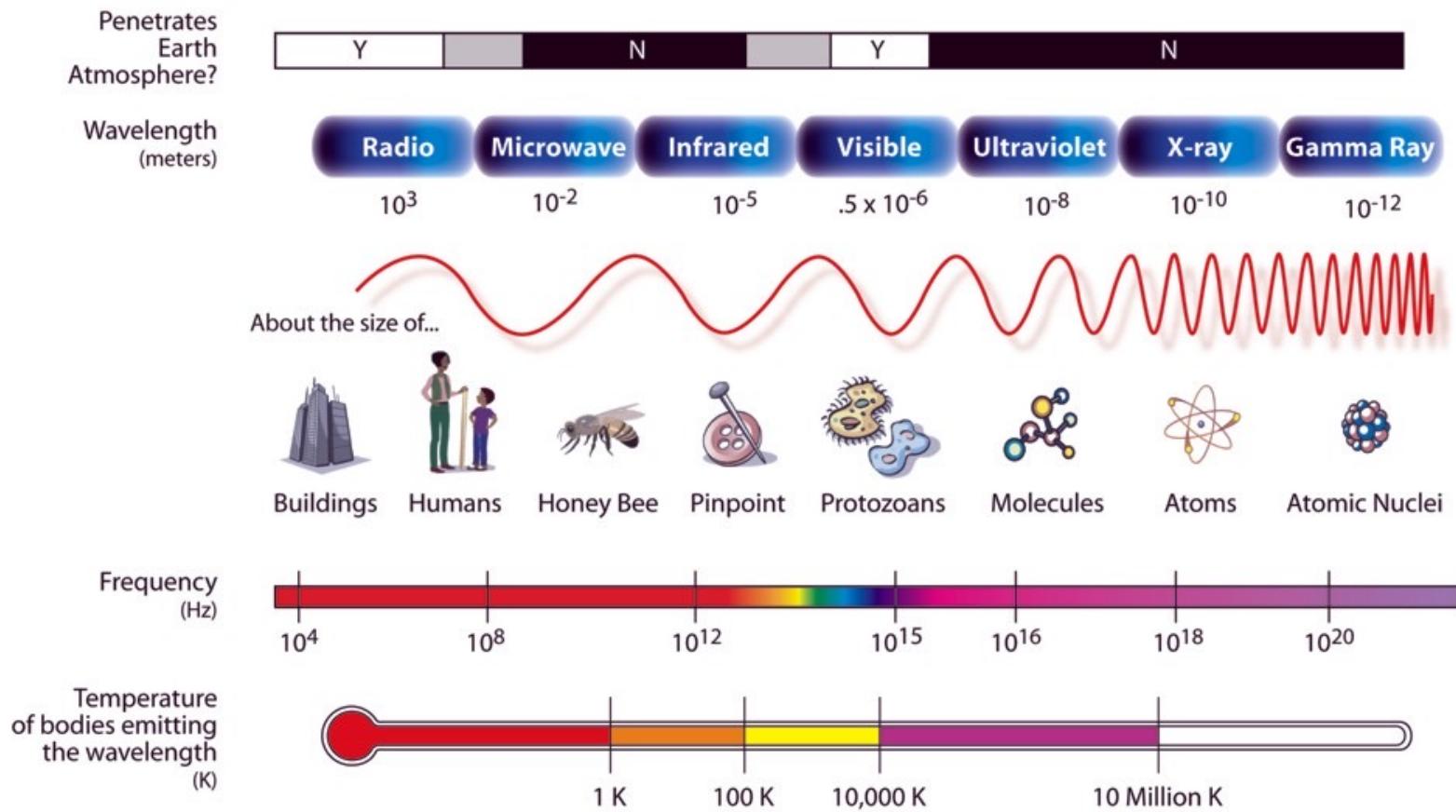
Circularly polarized
(only **E** shown here)



Electromagnetic Waves



THE ELECTROMAGNETIC SPECTRUM

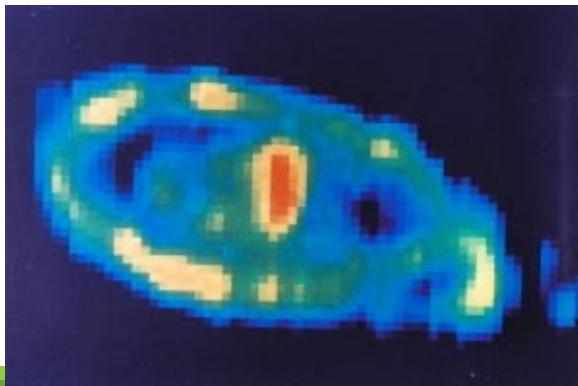


EM Radiation in Space

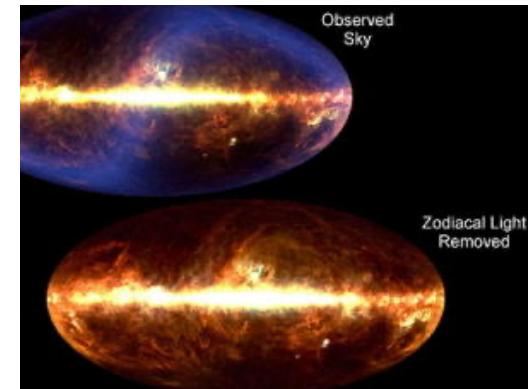
- Radio waves



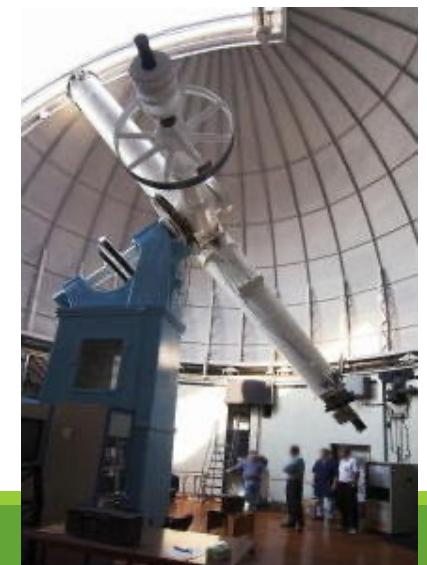
- Infrared



- Microwaves



- Visible light

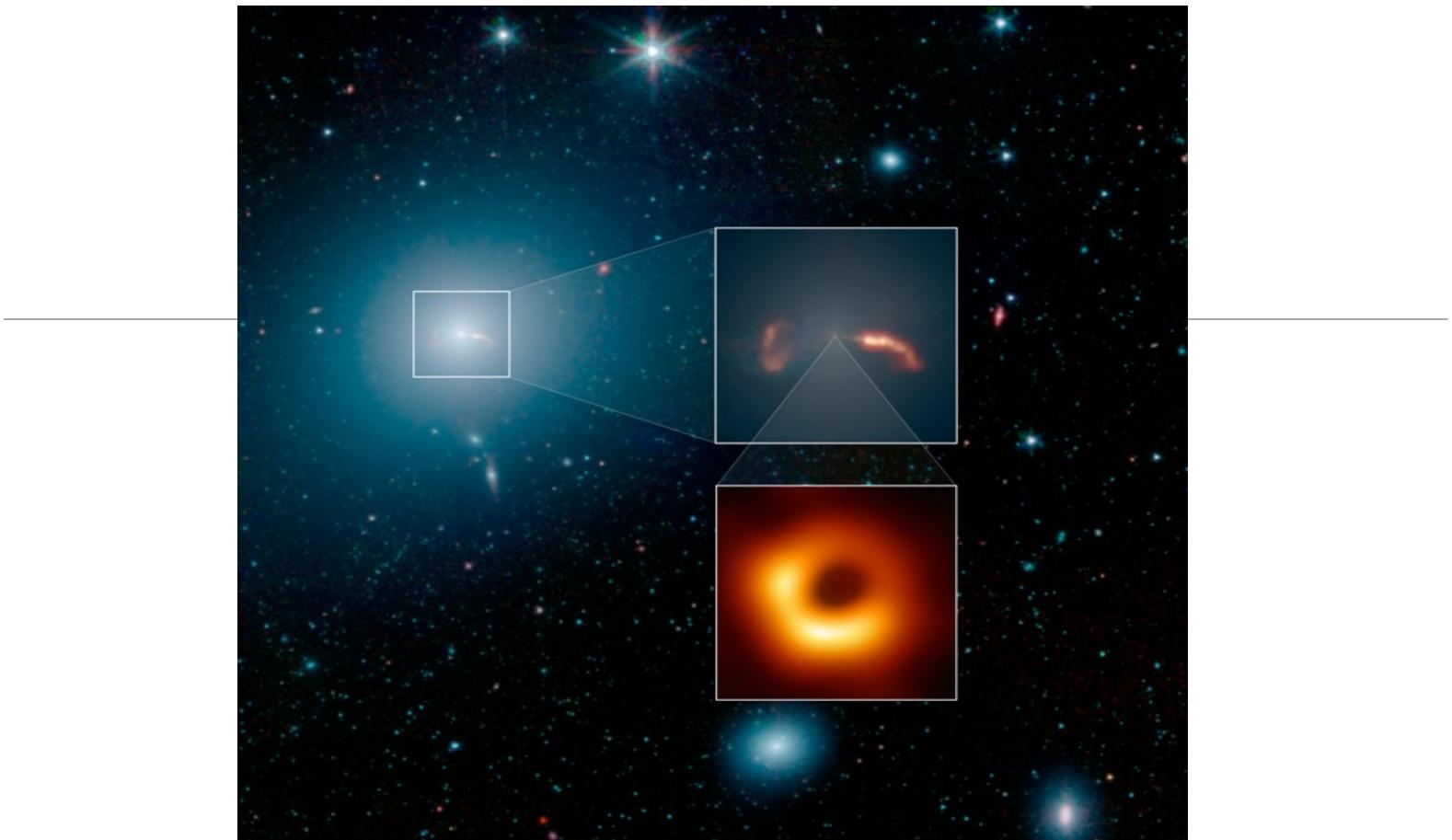


EM Radiation in Space

- Radio waves:

1st image of black hole 2019





2019.4.10

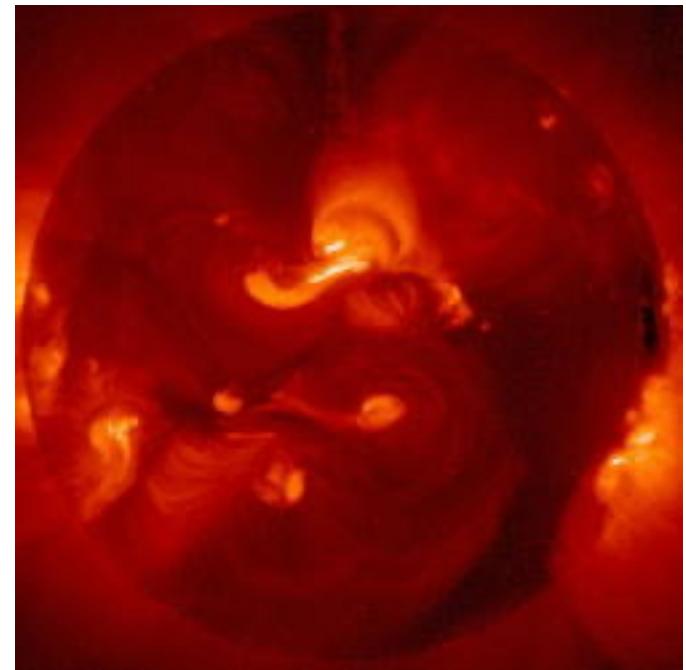
A composite image of galaxy M87, showing an infrared view from the Spitzer Space Telescope at left, a magnified look at the galaxy's central regions, top right, and the Event Horizon Telescope's enormously zoomed-in radio image of the galaxy's central black hole, lower right. Image: NASA/JPL-Caltech/IPAC/Event Horizon Telescope Collaboration

EM Radiation in Space

■ UV light



■ X-rays



For your interest...

An interesting documentary you can watch with your friends over dinner on the weekend:

Fascinating history of the development of the theory of electromagnetism and devices made from electricity:

[The Story of Electricity](#)

<https://www.youtube.com/watch?v=hVu844ZcCdU&t=3778s>

Topics to Be Covered

Part I: Math review

Part II: Static EM fields

Part III: Time-varying EM fields (or EM waves)

Topics to Be Covered

Part I: Math review

- 1. Vector addition and subtraction
- 2. Products of vectors
- 3. Orthogonal coordinate systems
- 4. Integrals containing vector functions
- 5. Gradient, divergence, and curl

Part II: Static EM fields

- 1. Electrostatics
 - Coulomb's law; Gauss's law
 - Electrical potential
 - Conductors and dielectrics in static E field
 - Electric flux density
 - Boundary conditions
 - Electrostatic energy and forces

Topics to Be Covered

- Poisson’s and Laplace’s eqs
- Uniqueness
- Method of images
- Boundary-value problems
- **2. Electric currents**
 - Current density and Ohm’s law
 - Electromotive force
 - Equation of continuity
- **3. Magnetostatics**
 - Magnetic potential
 - Magnetization
 - Magnetic circuits
 - Boundary conditions
 - Magnetic energy and forces

Topics to Be Covered

Part III: Time-varying EM fields (or EM waves)

- 1. Maxwell’s equation
 - Faraday’s law
 - Maxwell’s equations
 - Potential functions
 - Wave equations
 - Time-harmonic fields
- 2. Plane wave propagation
 - Plane waves in lossless and lossy media
 - Group velocity
 - Flow of EM power and the Poynting vector
 - Normal incidence
 - Oblique incidence

Course Expectation and Requirements

Pre-requisites:

Math Vs285, Phys Vp240 (or 260), ECE Ve215

Basic college math and physics

- Scalar & Vector
- Differentiation & Integration
- Electric Charge
- Current & Voltage

If you feel unfamiliar with these concepts, please revise and let me and your TAs know

Schedule

Part I: Math review

(7%)

- 1. Vector analysis

2 lectures

Part II: Static EM fields

(59%)

- 2. Electrostatics

9 lectures

- 3. Electric currents

2 lectures

- 4. Magnetostatics

5 lectures

Part III: Time-varying EM fields (or EM waves) (33%)

- 5. Maxwell's equation

3 lectures

- 6. Plane wave propagation

6 lectures

Questions?



Circuits and EM

Circuit:

- Lumped-parameter system (variables independent of space)
- Ordinary differential equations
- Most of time, scalar quantities
- Not applicable to free space
- Useful only at low frequencies

EM:

- Variables are functions of space
- Partial differential equations
- Many are vectors
- Applicable to free space
- Useful at all frequencies, particularly at high frequencies

Inadequacy of Circuit Theory



FIGURE 1–1
A monopole antenna.

Inadequacy of Circuit Theory

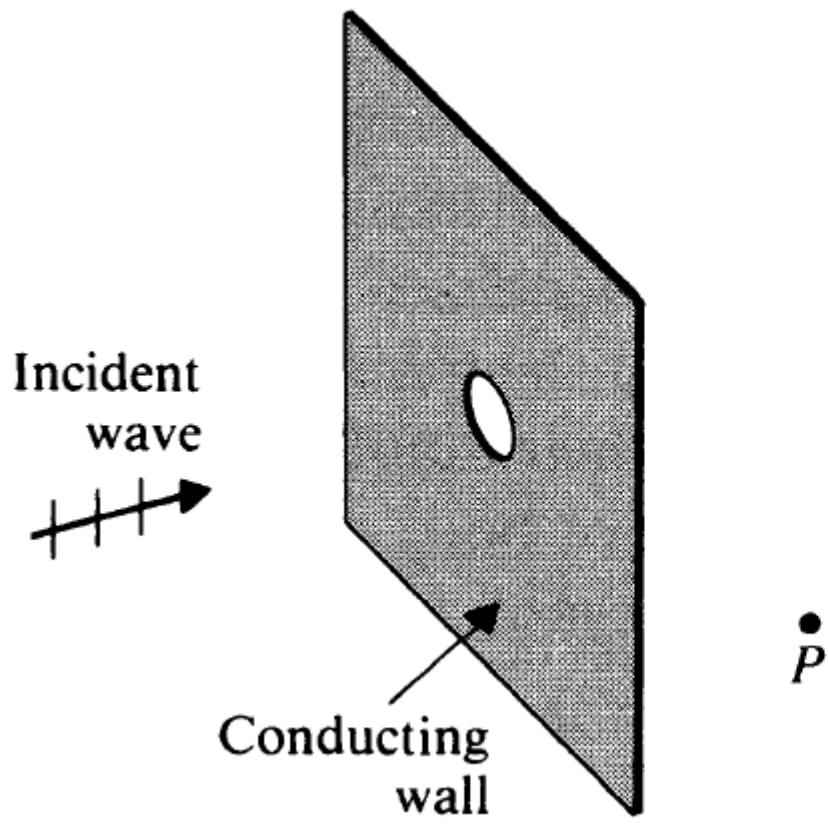


FIGURE 1–2
An electromagnetic problem.

Lumped and distributed

A lumped system is one in which the dependent variables of interest are a function of time alone.

A distributed system is one in which all dependent variables are functions of time and one or more spatial variables.

