PHY401
Electromagnetic Theory I

Quick Overview of Electromagnetic Theory

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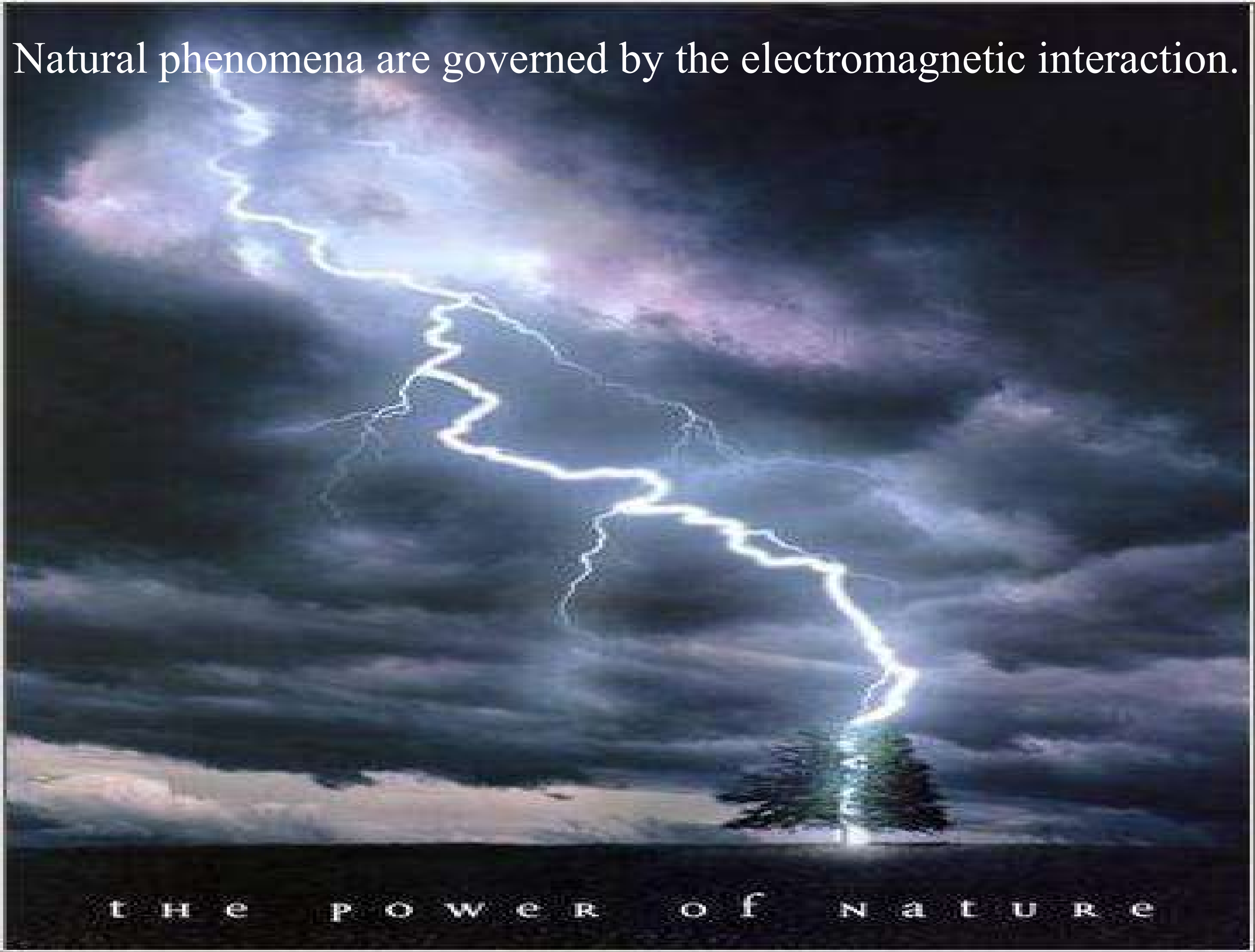
What is electrodynamics, and how does it fit into the general scheme of physics?

- Electrodynamics deals with rapidly changing electric and magnetic fields.

- Every force we experience in everyday life, with the exception of gravity, is electromagnetic in origin. Light, too, is electrical in nature.

Natural phenomena are governed by the electromagnetic interaction.



Our eyes can see only a limited part of the electromagnetic spectrum

The colorful rainbow seen in Taiwan during almost 9 hours (world record)

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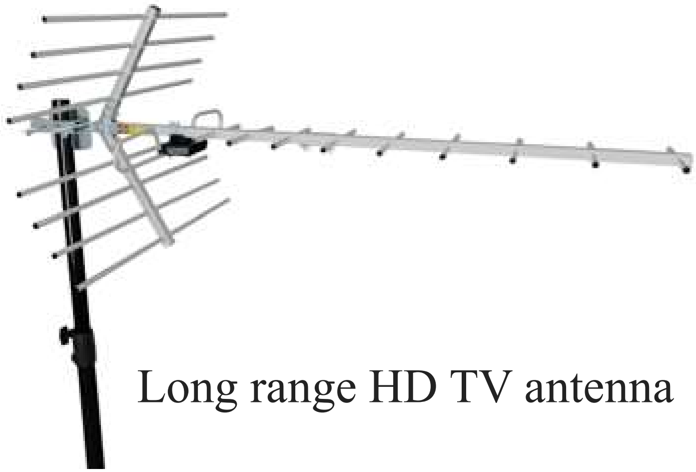
Electrodynamic technology is utilized in modern world in many ways.

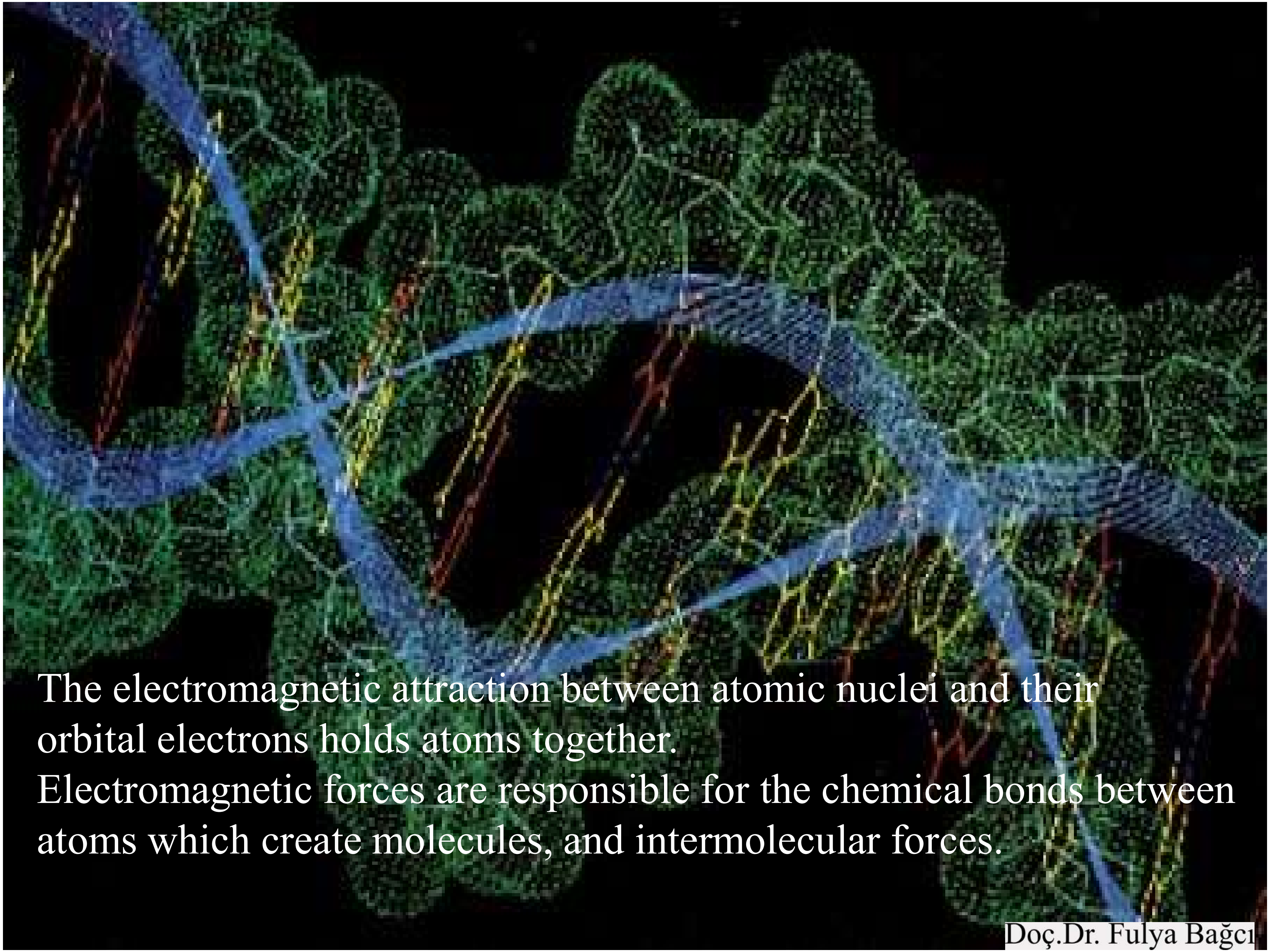
Maglev trains uses electromagnetic suspension principle.

Electrical waves are transformed into audible sound and/or light, allowing you to see the images, hear the music, etc.

The working principle of an antenna is that it converts electrical currents (carried along by metallic conductors) into electromagnetic radiation in free space — or vice versa.



Long range HD TV antenna



The electromagnetic attraction between atomic nuclei and their orbital electrons holds atoms together.
Electromagnetic forces are responsible for the chemical bonds between atoms which create molecules, and intermolecular forces.

Classical Mechanics
Newton

small

Quantum Mechanics
Bohr, Heisenberg,
Schrödinger, ...

fast

Special Relativity
Einstein

Quantum Field Theory
Dirac, Pauli, Feynman,
Schwinger, ...

Electric Charge (q, Q)

1. Charge exists as +q and –q. At the same point: +q-q=0
2. Charge is conserved (locally).
3. Charge is quantized. +q =n (+e), -q = m (-e), m, n, integer

electron: –e, positron: +e, proton: +e, C-nucleus: 6(+e)
Charge conservation in the micro world:
p + e -> n (electron capture)

Macro world: q $\sim 10^{23}$e

Quantization is unimportant. Imagine charge as some kind of jelly.

Four kinds of forces - interactions

1. Strong	Keeps nuclei and nucleons together.
2. Electromagnetic	Most common phenomena.
3. Weak	β-decay $n \to p+e+\nu$
4. Gravitational	Keeps the Universe together.

Unification

electric + magnetic $\longrightarrow$ electromagnetic

electromagnetic + optic $\longrightarrow$ electrodynamic

electrodynamic + weak $\longrightarrow$ electroweak

SI-Units

Systeme Internationale

Mechanics

length: meter (m)

mass: kilogram (kg)

time: second (s)

force: newton ($N = kg\,m\,s^{-2}$)

work: joule ($J = N\,m$)

Power: watt (W = J/s)

Electromagnetism

current: ampere (A)

charge: coulomb ($C = As$)

voltage: volt (V)

work: ($W\,s = V\,A\,s$)

power: watt ($W = V\,A$)

The equations of EM contain

$$\varepsilon_0 = 8.859 \times 10^{-12}\,\frac{As}{Vm}, \quad \mu_0 = 4\pi \times 10^{-7}\,\frac{Vs}{Am} = \frac{1}{\varepsilon_0 c^2}, \quad \frac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9\,\frac{Nm^2}{C^2} = 9 \times 10^9\,\frac{Vm}{As}$$

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Maxwell's Equations in Integral Form

TABLE 29.2 Maxwell's Equations

Law	Mathematical Statement	What It Says
Gauss for $\vec{E}$	$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$	How charges produce electric field; field lines begin and end on charges.
Gauss for $\vec{B}$	$\oint \vec{B} \cdot d\vec{A} = 0$	No magnetic charge; magnetic field lines don't begin or end.
Faraday	$\oint \vec{E} \cdot d\vec{r} = -\frac{d\Phi_B}{dt}$	Changing magnetic flux produces electric field.
Ampère	$\oint \vec{B} \cdot d\vec{r} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$	Electric current and changing electric flux produce magnetic field.

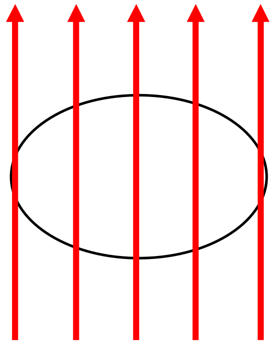
Try converting Maxwell's equations from integral to differential form.

Maxwell's Equations in Differential Form

$$\vec{\nabla}\vec{D} = \rho$$

$$\vec{\nabla}\vec{B} = 0$$

Faraday's law $$\vec{\nabla}\times\vec{E} = -\frac{\partial B}{\partial t}$$



closed loop

Φ_B changing in time

Current is induced.
(Faraday's law)

$$\underbrace{\vec{\nabla}\times\vec{B} = \mu_0\vec{J}}_{\text{Ampere's law}} + \mu_0\varepsilon_0\frac{\partial\vec{E}}{\partial t} \longrightarrow \text{In matter}: \vec{\nabla}\times\vec{H} = \vec{J} + \frac{\partial\vec{D}}{\partial t}$$

Maxwell's contribution

With Maxwell's contribution, the law satisfies the continuity equation:

$$\vec{\nabla}\left(\vec{\nabla}\times\vec{H}\right) = 0 \longrightarrow \vec{\nabla}\vec{J} + \frac{\partial\rho}{\partial t} = 0$$

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