ELECTRIC FIELD
Electrostatic Force

- For centuries, humans observed “strange” force
  - Example: Rub amber with fur → it attracts straw

- Force cannot be due to gravity
  - Gravity between amber and straw is too weak to feel

- Amber and straw must have something
  - Other than mass...
  - Which causes a noticeable force between them
  - This “stuff” is called electric charge
  - Charge is measured in “Coulombs” (C)
Electric Charge

- Electrostatic force can be attractive or repulsive
  - There must be 2 types of charge which interact differently

- Humans named these “positive” and “negative”
  - The amber has positive charge...
  - And the straw has negative charge
  - Opposite charges attract; like charges repel

- This was the limit of our understanding for thousands of years
  - More experiments → understanding electricity in 1800's
Coulomb's Law

- After much experimenting:
  
  \[ F = k \frac{q_1 q_2}{r^2} \]
  
  - \( F \) = Force
  - \( q \) = charge
  - \( r \) = distance
  - \( k = 9 \times 10^9 \) N m\(^2\) / C\(^2\)

- This is an “inverse-square law”
  
  - Just like gravity! (except it can **attractive** or **repulsive**)

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- Note: The diagram shows two charges, \( q_1 \) and \( q_2 \), attracting each other with a force \( F \) that varies inversely with the square of the distance \( r \) between them. The constant \( k \) accounts for the strength of the interaction, with values for different units of charge and distance.
Charge and Atoms

• Today we know that matter is made up of atoms
  – Positively charged nuclei with negatively charged e–
  – Positive charge → protons in nucleus

• Charge is always “attached” to a particle
  – In increments of $1.6 \times 10^{-19}$ C (the “elementary charge”)
  – If like charges repel, how do particles ever assemble?

• Charge can never be created or destroyed
  – It is conserved, just like energy!
  – Universe is electrically neutral overall...as far as we can tell!
Conductors and Insulators

- Most electrons are “bound” to the nucleus
  - i.e. They orbit around the nucleus

- Strength of this binding varies greatly
  - Some electrons are relatively easy to remove from the nucleus

- Conductors
  - Materials with lots of “free” electrons which move easily
  - Most metals are good conductors

- Insulators
  - Materials with few free electrons (rubber, glass, plastic)
Charge in Conductors

• In an ideal conductor:
  - $e^-$ move in **response** to other charges
  - $e^-$ have tiny mass $\rightarrow$ can move as fast as needed

**Charged conductor**
- charges **repel** each other
- all the way to the **surface**

**Bring charge near a conductor**
- charges in conductor **move around** due to attraction and repulsion
Charging Objects

• How can we transfer charge to an object?

• Conduction
  – Put objects made of different materials in physical contact
  – If one attracts e– better than the other → it takes them

• Induction
  – Bring a charged object near an uncharged one
  – Cut uncharged object in half
Electric Field

- How can particles exert force without touching?
  - “Action-at-a-distance” → just like gravity

- Solution: The “electric field”

- A “source charge” affects the space around it
  - If a “test charge” comes into this “field”, it feels a force
  - Newton's 3rd Law: Both particles act as source and test charges
Electric Field Mathematics

• “E field” created by a source charge
  - Defined as the electric force per coulomb of test charge
  - “If I put a test charge here, how big is the force on it?”

\[ E = \frac{F}{q_{\text{test}}} = k \frac{|q_{\text{source}}|}{r^2} \]

\[ E = k \frac{|q|}{r^2} \]

• E field is a “Vector Field”
  - At every point in space, it produces a vector
  - Points away from + and toward –
E Fields From Multiple Sources

- Total E field is the vector sum of E fields
  - Must add horizontal and vertical components separately
Electric Field Lines

- Imaginary paths drawn along E field vectors
  - Helpful for visualizing E fields
  - E field vector is always *tangent* to lines

- Conductors always have $E=0$ inside
  - So no field lines inside the conducting material!
Gauss's Law

- E Field lines **diverge** away from + charge
  - And *converge* toward – charge

- **Gauss's Law**: for a closed volume (like a box)...
  - If field lines diverge → + charge is inside volume
  - If field lines converge → – charge is inside volume

- “Electric Flux”
  - Describes divergence/convergence of field lines
  - Will be useful later on in *electromagnetic* theory