Static Electricity

Turn off all electronic devices

Observations about Static Electricity

- Objects can accumulate static electricity
- Clothes in the dryer often develop static charge
- Objects with static charge may cling or repel
- Static electricity can cause shocks
- Static electricity can make your hair stand up

6 Questions about Static Electricity

1. Why do some clothes cling while others repel?
2. Why do clothes normally neither cling nor repel?
3. Why does distance weaken static effects?
4. Why do clingy clothes stick to uncharged walls?
5. Why do clingy clothes crackle as they separate?
6. Why do some things lose their charge quickly?

Question 1

Q: Why do some clothes cling while others repel?

A: They carry electric charges that attract or repel.

- Electric charges comes in two types:
  - Charges of the same type (“like charges”) repel
  - Charges of different types (“opposite charges”) attract
  - Franklin named the types “positive” and “negative”
- Charge is actually a single conserved quantity

Question 2

Q: Why do clothes normally neither cling nor repel?

A: Clothes normally have zero net charge.

- Electric charge
  - is intrinsic to some subatomic particles
  - is quantized in multiples of the fundamental charge
  - is +1 f.c. for a proton, –1 f.c. for an electron
- Equal protons and electrons → zero net charge
- Objects tend to have zero net charge → neutral

Charge Transfers

- Contact can transfer electrons between objects
  - Surfaces have different chemical affinities for electrons
  - One surface can steal electrons for another surface
- Rubbing different objects together ensures
  - excellent contact between their surfaces
  - significant charge transfer from one to the other.
- A dryer charges clothes via these effects

Question 3

Q: Why does distance weaken static effects?

A: Forces between charges decrease as $1/\text{distance}^2$.

- These electrostatic forces obey Coulomb's law:

$$\text{force} = \frac{\text{Coulomb constant} \cdot \text{charge}_1 \cdot \text{charge}_2}{(\text{distance between charges})^2}$$

- Electric charge is measured in coulombs
- One fundamental charge is 1.6×10^{-19} coulombs

Question 4

Q: Why do clingy clothes stick to uncharged walls?

A: The charged clothes polarize the wall.

- When a negatively charged sock nears the wall,
  - the wall's positive charges shift toward the sock,
  - the wall's negative charges shift away from it,
  - and the wall becomes electrically polarized.
  - Opposite charges are nearest → attraction dominates

Question 5

Q: Why do clingy clothes crackle as they separate?

A: Separating opposite charges boosts voltages.

- Charge has electrostatic potential energy (EPE)
- Voltage measures the EPE per unit of charge
  - Work raises the voltage of positive charge
  - Work lowers the voltage of negative charge
- Voltage is measured in volts (joules/coulomb)

Question 6

Q: Why do some things lose their charge quickly?

A: Charge can escape through electric conductors.

- Insulators have no mobile electric charges
- Conductors have mobile electric charges,
  - usually electrons (metals), but can be ions (salt water)
  - that will accelerate (and flow) toward lowest EPE
- Conductors allow charges to cancel or escape

Summary about Static Electricity

- All objects contain countless charges
- Objects can transfer charge during contact
- Clothes often develop net charges during drying
- Oppositely charged clothes cling to one another
- and spark as separation raises their voltages.
- Conductivity tends to let objects neutralize.

Xerographic Copiers

Turn off all electronic devices

Observations About Copiers

- Copiers consume colored powder or “toner”
- After jams, you can wipe off the powder images
- Copies are often warm after being made
- Copies are sometimes clingy with static electricity

3 Questions about Xerographic Copiers

1. How can light arrange colored powder on paper?
2. How does a copier spray charge onto a surface?
3. How does a copier make its copies permanent?

Question 1

Q: How can light arrange colored powder on paper?
A: That light can control static electricity.

- A xerographic copier or printer
  - sprays static electric charge onto an insulating surface
  - uses light from a document to selectively erase charge
  - lets the remaining charge attract colored toner particles
  - bonds the particles to paper to produce a copy

Question 2

Q: How does a copier spray charge onto a surface?
A: It uses a corona discharge to charge the air

- A fine wire having a large voltage (+ or –)
  - is covered with tightly packed “like” charges (+ or –)
  - repulsive forces are intense and push charges into air
  - this flow of charge into the air is a corona discharge
- That discharge is caused by a strong electric field

Electric Field

- Two views of electrostatic forces:
  - Charge_1 pushes on Charge_2
  - Charge_1 creates electric field that pushes Charge_2
- Electric field isn’t a fiction; it actually exists!
  - a structure in space and time that pushes on charge
  - a vector field: a vector at each point in space and time
  - observed using a + test charge at each point

Voltage Gradient

- A + test charge accelerates along
  - electric field
  - path that reduces its total potential energy quickest
- Voltage is electrostatic potential energy per charge
  - decreasing voltage is decreasing potential energy
  - path of quickest potential decrease is voltage gradient
  - voltage gradient is effectively the “slope” of voltage
- A voltage gradient <u>is</u> an electric field

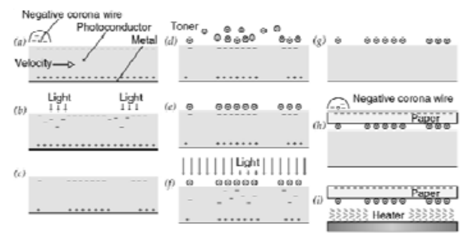
Metals, Fields, & Corona Discharges

- Inside a metal, charge can move
  - At equilibrium: voltage is uniform, electric field is zero
  - Charge resides only on the metal's surface
- Outside a metal, charge cannot move
  - At equilibrium: both voltage and electric field can vary
- Near a thin wire or sharp point at large voltage,
  - voltage varies rapidly with distance, so big electric field
  - charge is pushed into the air: a corona discharge

Question 3

Q: How does a copier make its copies permanent?

A: It fuses or melts the powder onto the paper.



Summary about Xerographic Copiers

- It sprays charge from a corona discharge
- That charge precoats a special insulating surface
- It projects a light onto surface
- The charge escapes from illuminated regions
- The remaining charge attracts toner particles
- Those particles are fused to the paper as a copy

Flashlights

Turn off all electronic devices

Observations about Flashlights

- You emit light when you switch them on
- Brighter flashlights usually have more batteries
- Flashlights grow dimmer as their batteries age
- Sometimes hitting a flashlight brightens it

6 Questions about Flashlights

1. Why does a flashlight need batteries and a bulb?
2. How does power flow from batteries to bulb?
3. How does a flashlight's switch turn it on or off?
4. How can a battery be recharged?
5. Why does a short-circuited flashlight get hot?
6. How do lightbulbs differ?

Question 1

Q: Why does a flashlight need batteries and a bulb?

A: Batteries power the bulb, which then emits light.

- Batteries: chemical energy → electrostatic energy
- Bulb: electrostatic energy → light energy
- Since this energy transfer is ongoing, think power
  - Power is energy per unit of time
  - The SI unit of power: 1 watt is 1 joule/second

Battery

- Battery is chemically powered pump for charge
  - pumps charge from its – end to + end
  - develops a voltage rise from – end to + end
    - typically 1.5 volts for alkaline AAA, AA, C, and D cells
    - typically 3 volts for lithium cells
  - does work pushing charge to higher voltage
  - turns chemical potential into electrostatic potential
- In a typical flashlight with two alkaline-cells
  - total voltage rise in the battery chain is 3.0 V
  - total electric power provided by batteries is 6 watts

Lightbulb Filament

- Lightbulb filament lets charges flow through it
  - carries charge from its entry end to its exit end
  - develops a voltage drop from entry end to exit end
  - receives energy from charge flowing to lower voltage
  - turns electrostatic potential into thermal energy
- In a typical flashlight with two alkaline-cells
  - total voltage drop in lightbulb filament is 3.0 V
  - total electric power consumed by lightbulb is 6 watts

Question 2

Q: How does power flow from batteries to bulb?

A: Power is carried by a current of charge in wires.

- Current measures the rate of charge motion,
  - electric charge crossing a boundary per unit of time,
  - The SI unit of current: 1 ampere is 1 coulomb/second
- Batteries provide power to electric currents
- Lightbulbs consume power from electric currents

The Direction of Current

- Current is defined as the flow of positive charge
  - but negative charges (electrons) carry most currents.
- It's difficult to distinguish between:
  - Negative charges flowing to the right
  - Positive charges flowing to the left.

Electric Current in a Flashlight

- Current in the flashlight
  - pumped from low voltage to high voltage by batteries

    power provided = current · voltage rise
  - flows through a wire to the lightbulb
  - flows from high voltage to low voltage in lightbulb

    power consumed = current · voltage drop
  - flows through a wire to the batteries
  - repeat… the current is traveling around a circuit
- The current's job is to deliver power, not charge!

Static Electricity 31

About Wires and Filaments

- Metals are imperfect conductors
  - electric currents can't coast through them
  - electric fields are needed to keep currents moving
- For a current to flow through a metal,
  - that metal must have an electric field in it
  - caused by a voltage drop and the associate gradient
- Currents waste power in metal wires & filaments
  - Wires waste as little power as possible
  - Filaments waste much power and become very hot

Static Electricity 32

Question 3

Q: How does a flashlight's switch turn it on or off?

A: It opens or closes the circuit.

- Steady current requires a "closed" circuit
  - so charge loops and doesn't accumulate anywhere
- A flashlight's electric circuit is
  - closed (complete) when you turn the switch on
  - open (incomplete) when you turn the switch off

Static Electricity 33

Question 4

Q: How can a battery be recharged?

A: Push current through it backward.

- Battery provides power when
  - current flows forward from – end to + end
  - current experiences a voltage rise
- Battery receives power (and recharges) when
  - current flows backward from + end to – end
  - current experiences a voltage drop

Static Electricity 34

Effects of Current Direction

- Batteries typically establish the current direction
- Current direction doesn't affect
  - wires, heating elements, or lightbulb filaments,
- Current direction is critically important to
  - electronic components such as transistors and LEDs
  - and some electromagnetic devices such as motors.

Static Electricity 35

Question 5

Q: Why does a short-circuited flashlight get hot?

A: Current bypasses the bulb and heats the wires.

- If a conducting path bridges the filament,
  - current bypasses the filament → circuit is "short"
  - there is no appropriate destination for the energy
  - energy loss and heating occurs in the wires
- Short circuits can cause fires!

Static Electricity 36

Question 6

Q: How do lightbulbs differ?

A: They have different electrical resistances.

- Current undergoes a voltage drop in a conductor
- That voltage drop is proportional to the current:

$$\text{voltage drop} = \text{resistance} \cdot \text{current}$$

where resistance is a characteristic of the conductor.

- This relationship is known as Ohm's law.

Resistance and Filaments

- Batteries determine the filament's voltage drop
- The smaller a filament's resistance,
  - the more current it carries
  - the more electric power it consumes
- A lightbulb filament is chosen to have
  - enough resistance to limit power consumption
  - enough surface area to dissipate the thermal power

Summary about Flashlights

- Current carries power from batteries to bulb
- The switch controls the flashlight's circuit
- Current flows only when the circuit is closed
- The batteries raise the current's voltage
- The lightbulb lower the current's voltage