

Flashlights

Turn off all electronic devices

Observations about Flashlights

They emit light when you switch them on
 Brighter flashlights often 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 transform chemical energy into electrostatic energy
 Bulbs transform electrostatic energy into light energy
 Since this energy transfer is ongoing, we consider power

- ◊ Power is energy per unit of time
- ◊ The SI unit of power: 1 watt is 1 joule/second

Battery

A battery is a chemically powered pump for charge

- ◊ It pumps charge from its $-$ terminal to its $+$ terminal
- ◊ It does work pushing charge toward higher voltage
- ◊ It turns chemical potential energy into electrostatic potential energy
- ◊ It develops a voltage rise from its $-$ terminal to its $+$ terminal
 - ◊ typically 1.5 volts for alkaline AAA, AA, C, and D cells
 - ◊ typically 3 volts for lithium cells
- ◊ Useful analogies: lifting skiers or pressurizing water

In a typical flashlight with two alkaline-cells

- ◊ the total voltage rise in the battery chain is 3.0 V
- ◊ the total electric power provided by batteries is 6 watts

Lightbulb Filament

A lightbulb filament is an energy-consuming conductor of charge

- ◊ It allows charge to flow from its $+$ end to its $-$ end
- ◊ It does negative work on that charge as it flows toward lower voltage
- ◊ It turns electrostatic potential energy into thermal energy and glows
- ◊ Useful analogies:
 - ◊ Skiers skiing downhill against friction and air resistance
 - ◊ Water struggling to flow through old pipes

In a typical flashlight with two alkaline-cells

- ◊ total voltage drop in the filament is 3.0 V
- ◊ total electric power consumed by the filament is 6 watts

Question 2

Q: How does power flow from the batteries to the lightbulb?

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

Current measures the rate at which charge is moving.

- ◊ Current is the electric charge crossing a boundary per unit of time.
- ◊ The SI unit of current is the ampere: 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

- ◊ Unfortunately, negative charges (electrons) carry most currents

Fortunately, it is usually difficult to distinguish between

- ◊ negative charges flowing to the right
- ◊ positive charges flowing to the left

For simplicity,

- ◊ we ignore the actual carriers of electric charge (electrons)
- ◊ we pretend that electric currents are the flow of positive charges

Electric Current in a Flashlight

Current in the flashlight is

1. pumped from lower voltage to higher voltage by the batteries
power provided = current · voltage rise
 2. flows through a wire to the lightbulb
 3. flows from higher voltage to lower voltage in the lightbulb
power consumed = current · voltage drop
 4. flows through a wire to the batteries
- ◊ and repeat... the current is traveling around a circuit

Current's job is to deliver power, not charge, so recycle the charge!

About Wires and Filaments

Metals are imperfect conductors

- ◊ Electric charges lose kinetic energy while moving through metals
- ◊ Electric charges will not coast through metals and must be pushed through
- ◊ Because electric fields push on electric charges,
- ◊ current flows through metal only if that metal has an electric field in it

A voltage drop causes current to flow through metal

- ◊ A voltage drop produces a voltage gradient and therefore an electric field
- ◊ That electric field is directed from higher voltage to lower voltage
- ◊ Electric current flows from the higher voltage end to the lower voltage end

Currents waste power in metal wires & filaments

- ◊ Wires should waste as little power as possible (copper, aluminum)
- ◊ Filaments waste much power and become hot (tungsten, steel, nichrome)

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 the charge can be recycled and doesn't simply pile up somewhere

A flashlight's electric circuit is

- ◊ closed (complete) when you turn the switch on
- ◊ open (incomplete) when you turn the switch off

Question 4

Q: How can a battery be recharged?

A: It recharges when you push current through it backward.

Battery provides power to the current passing through it when

- ◊ current flows through it forward: from its - terminal to its + terminal
- ◊ and that current experiences a voltage rise.
- ◊ The battery acts as a provider of electric power and it discharges

Battery receives power from the current passing through it when

- ◊ current flows through it backward: from its + terminal to its - terminal
- ◊ and that current experiences a voltage drop.
- ◊ The battery acts as a consumer of electric power and it recharges

Effects of Current Direction

Batteries typically establish the direction of current in a device

- ◊ Current flows from batteries' + terminal, through device, to - terminal

The direction of current doesn't affect

- ◊ wires, heating elements, or lightbulb filaments.

The direction of current is critically important to

- ◊ electronic components such as transistors and LEDs
- ◊ and some electromagnetic devices such as motors.

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 (we say that the circuit is "short").
- ◊ Since there is no designated consumer of electric power anymore,
- ◊ the wires consume the electric power instead and they become hot.

Short circuits can cause fires!

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 lowers the current's voltage