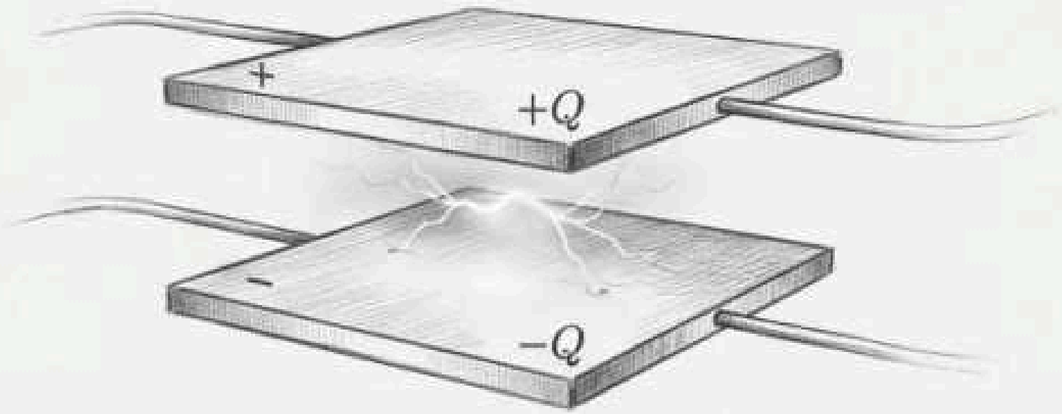
¶ 2.1

Lecture 2: Electric Potential, Voltage & Capacitors

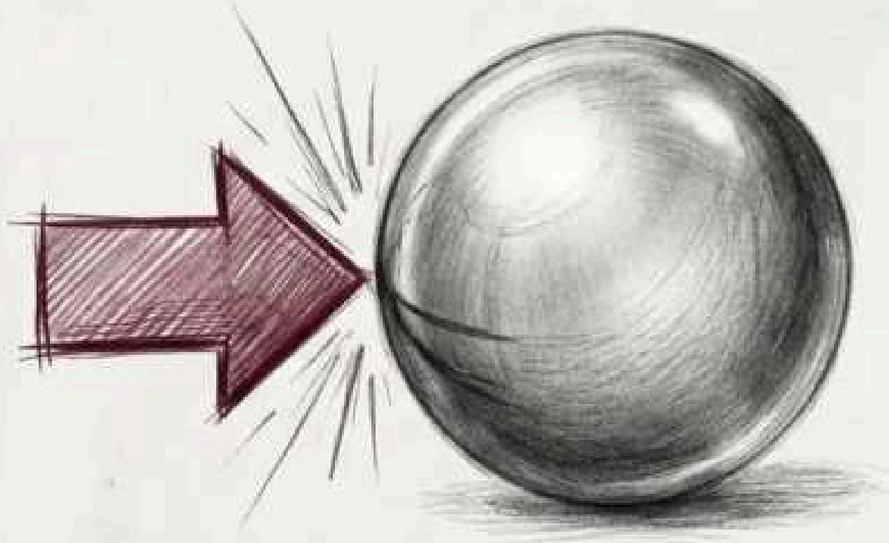


- Electric Potential
- Voltage & The Electron Volt
- Equipotential Surfaces
- Capacitors & Energy Storage

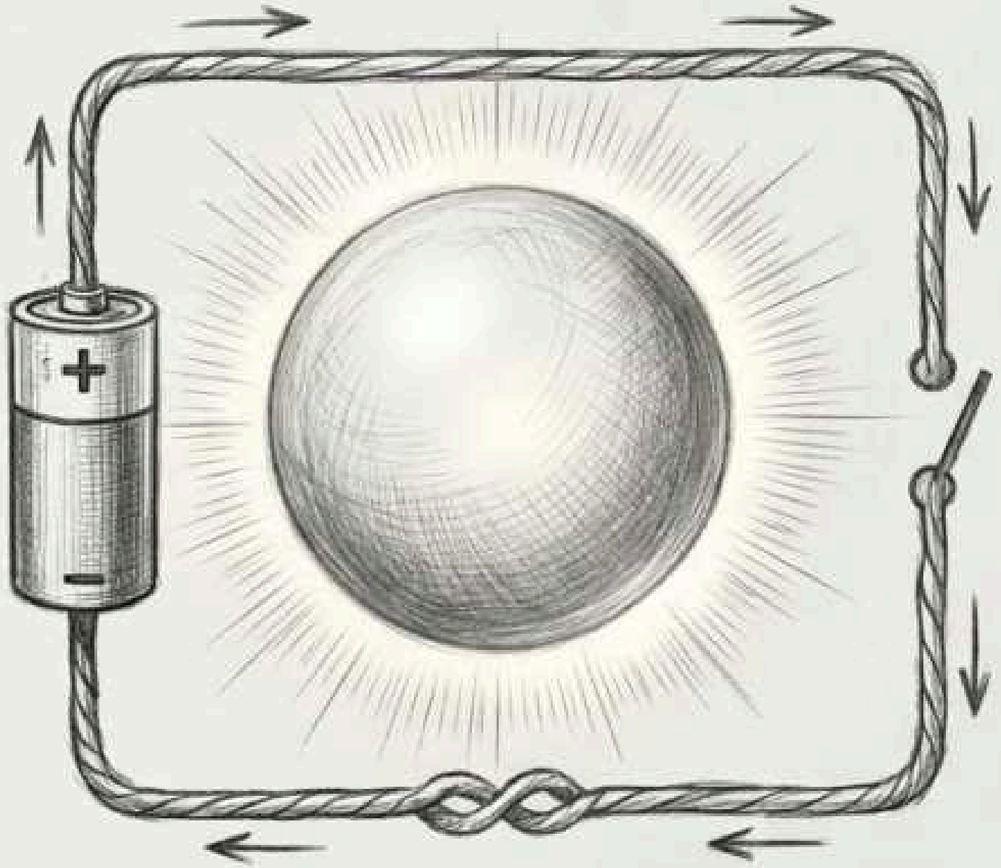
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From Force to Energy

¶ 2.2



Past: The Push on a Charge



Now: Storing Charge and Energy

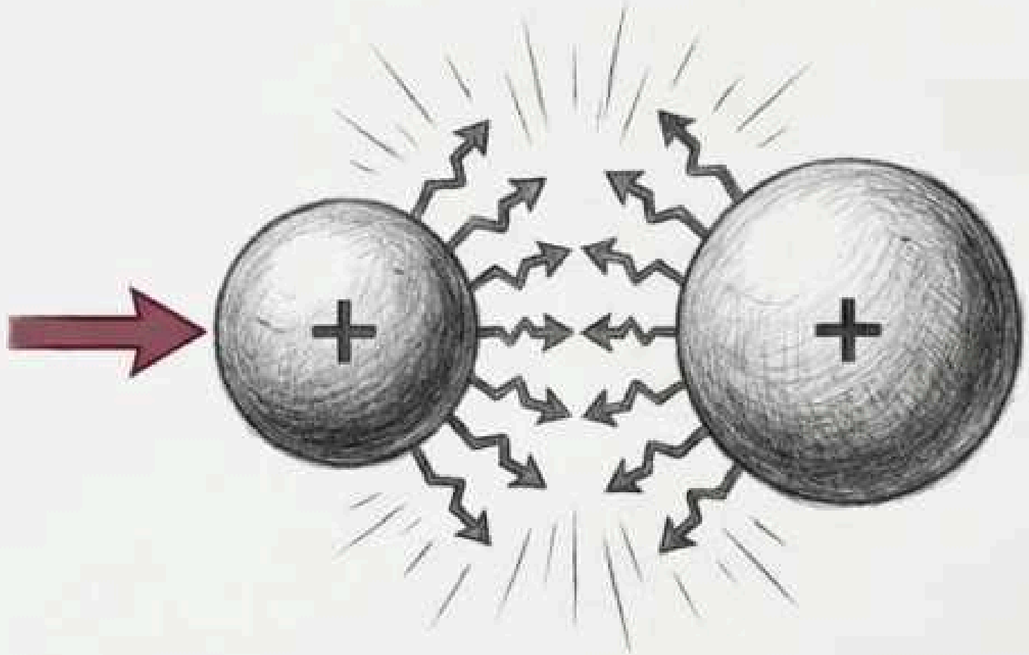
Goal: Understand what a volt measures and why a battery is labeled 12V.

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The Gravity Analogy



Lift a book = Store gravitational potential energy.



Push a positive charge = Store electric potential energy.

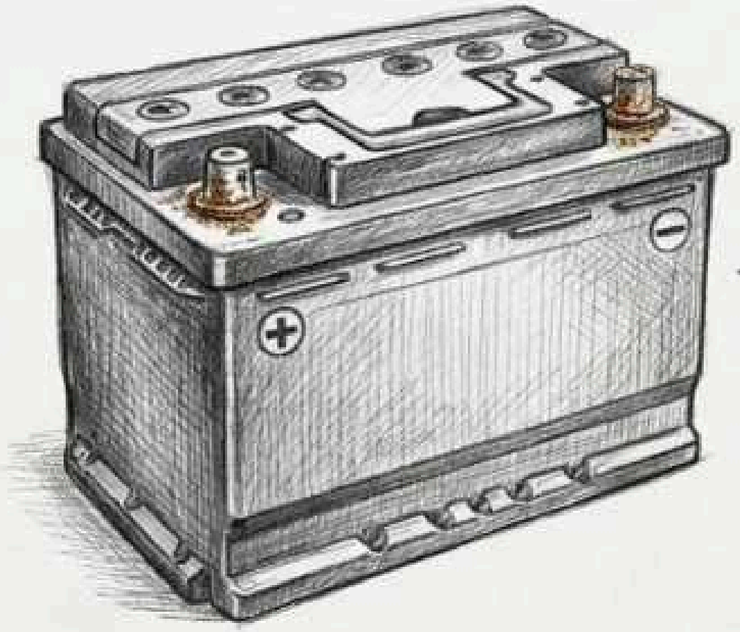
Note: Both systems return energy when released.

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Defining the Volt

Electric Potential = Potential Energy per Unit of Charge

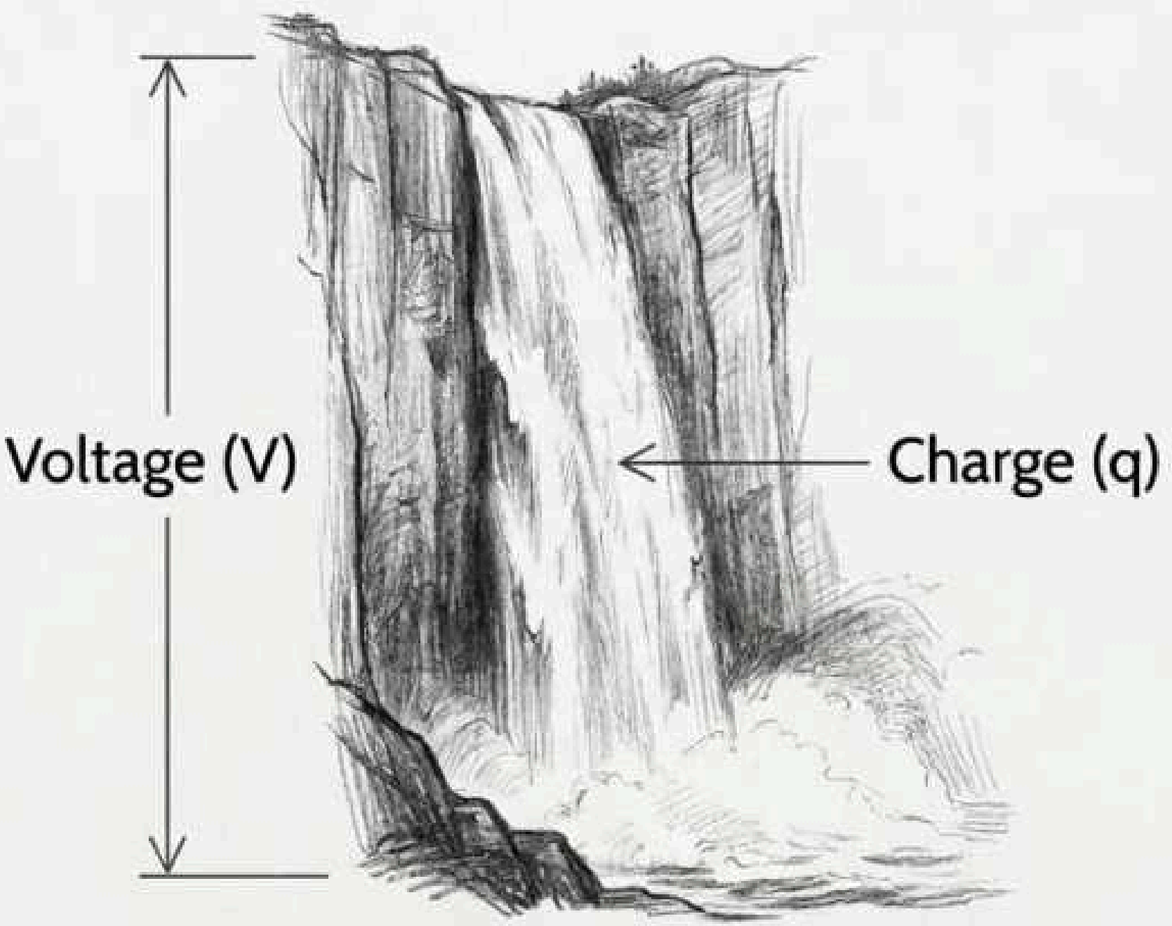
$$1\ Volt = \frac{1\ \text{Joule}}{1\ \text{Coulomb}}$$



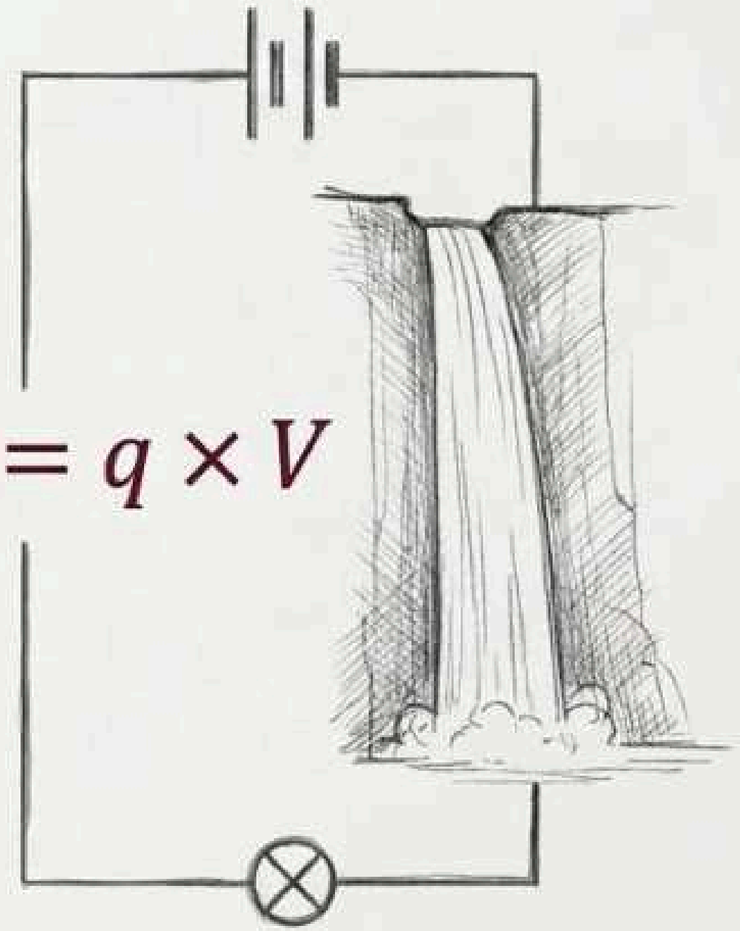
A 12V battery gives 12 Joules of energy to every Coulomb of charge passing through it.

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Voltage: The Electric Waterfall



$$\Delta \text{Energy} = q \times V$$

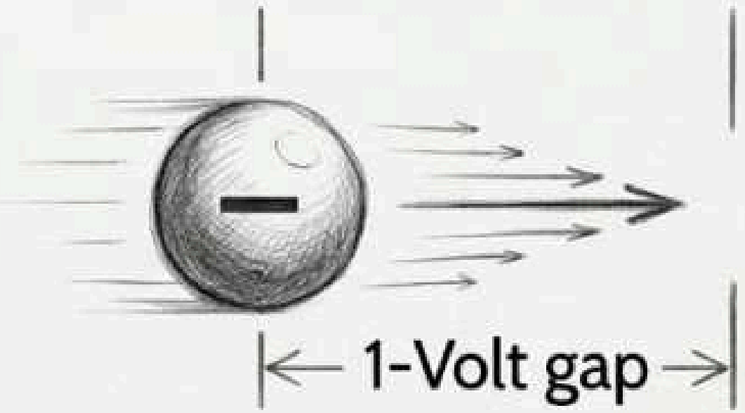


Voltage is a DIFFERENCE in potential. It dictates exactly how much energy each unit of charge delivers when it falls through a circuit.

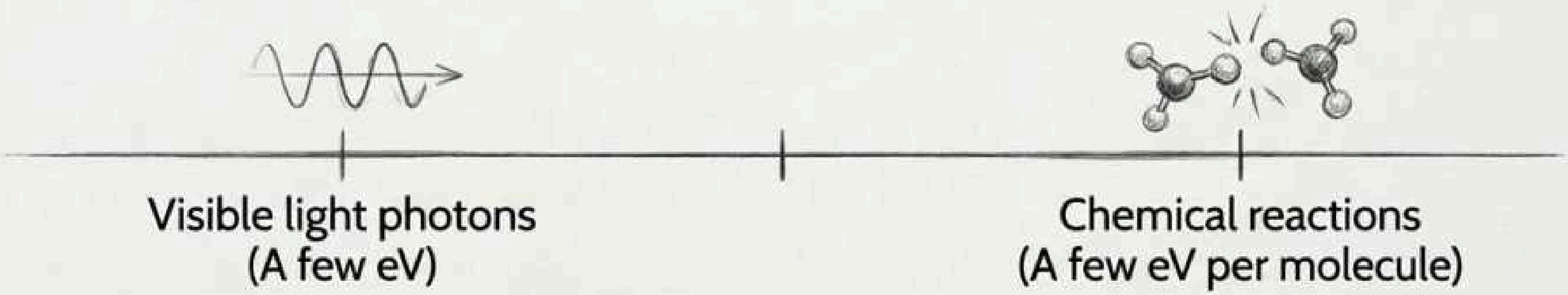
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The Electron Volt (eV)

Energy an electron gains crossing 1 Volt.

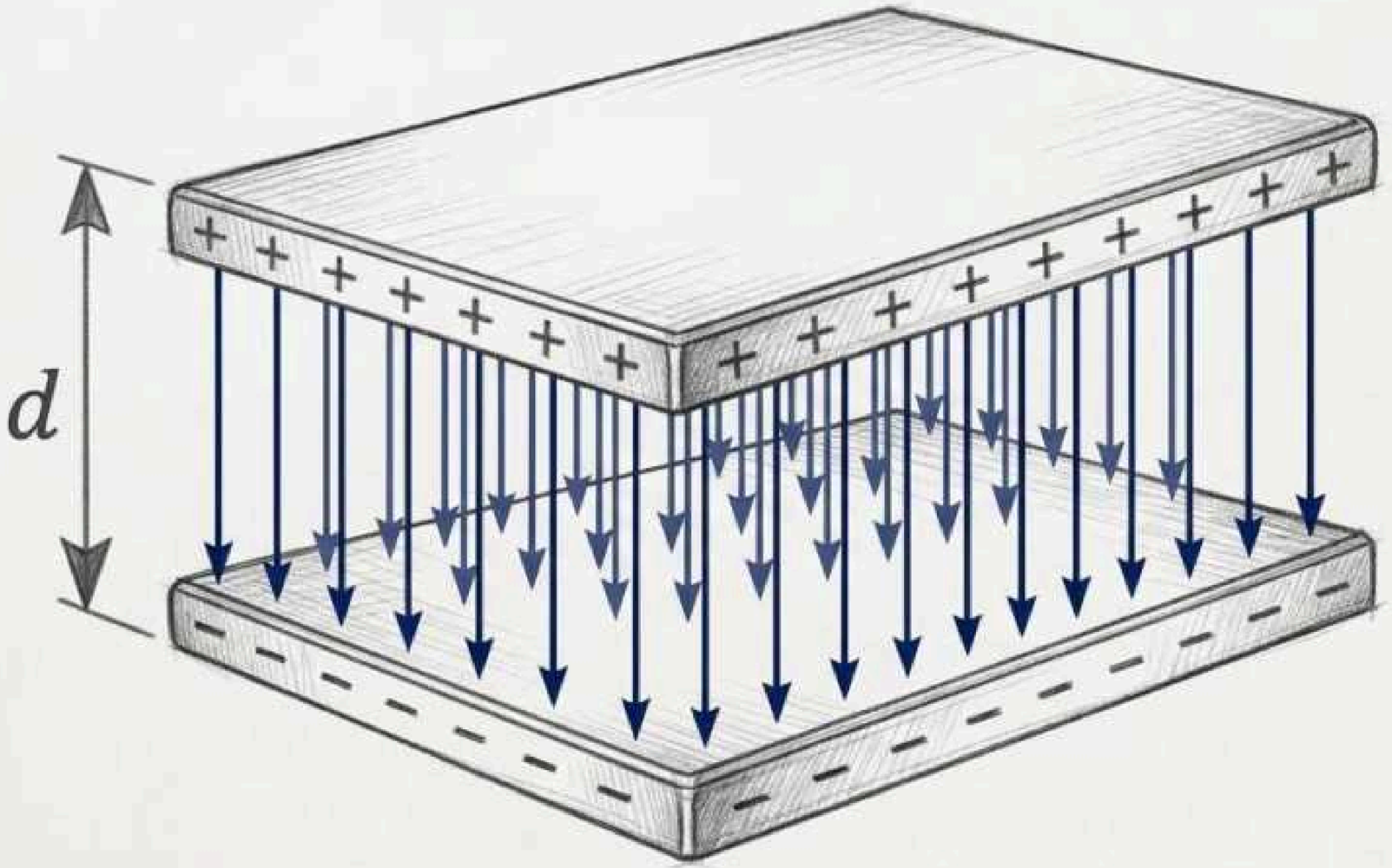


$$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{Joules}$$



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Uniform Fields Between Plates



$$E = \frac{V}{d}$$

$$\frac{1\ \text{Volt}}{\text{meter}} = \frac{1\ \text{Newton}}{\text{Coulomb}}$$

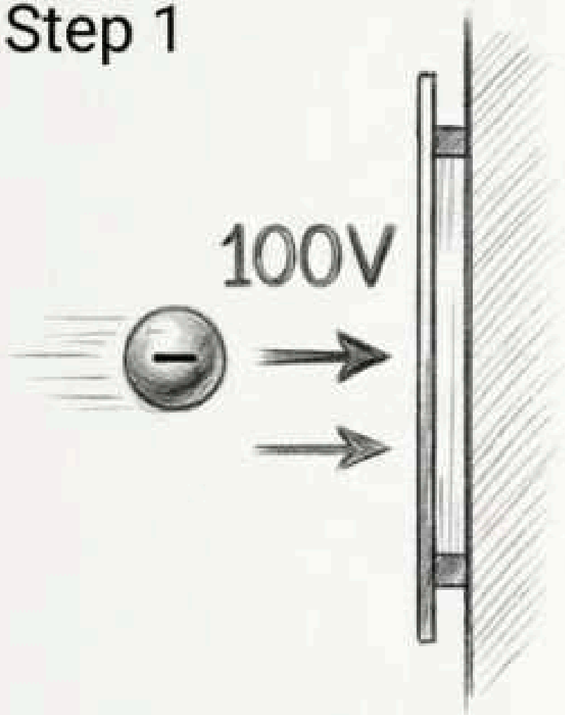
Example: 12V applied across a 1mm gap creates an electric field of 12,000 V/m.

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¶ 2.8

Calculating Electron Speed

Step 1



Step 2

$$1.6 \times 10^{-17}\ \mathrm{J} = \frac{1}{2} m v^2$$

Step 3



Energy gained:

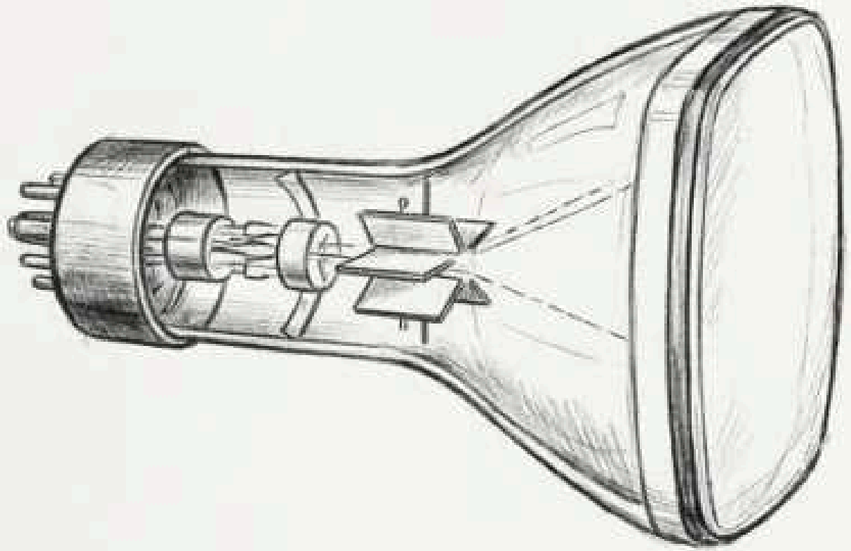
$100\ \mathrm{eV} = 1.6 \times 10^{-17}$ Joules

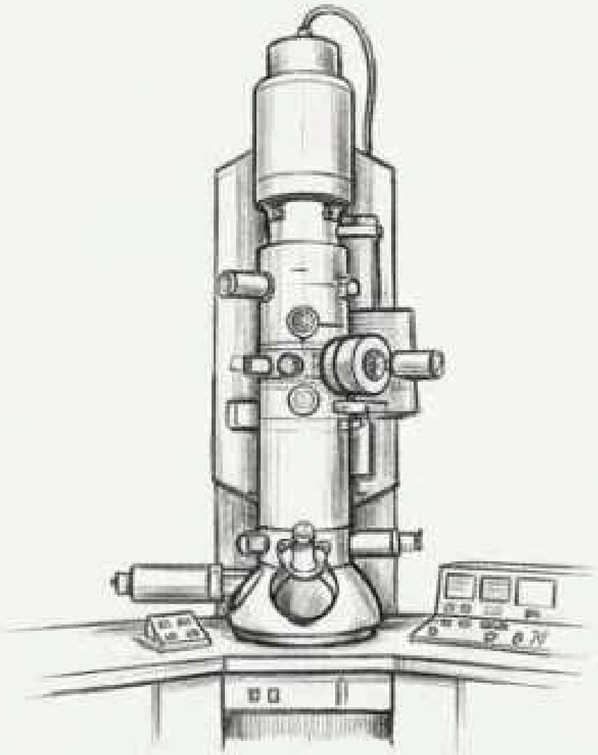
$$v \approx 5.9 \times 10^{6}\ \mathrm{m/s}$$

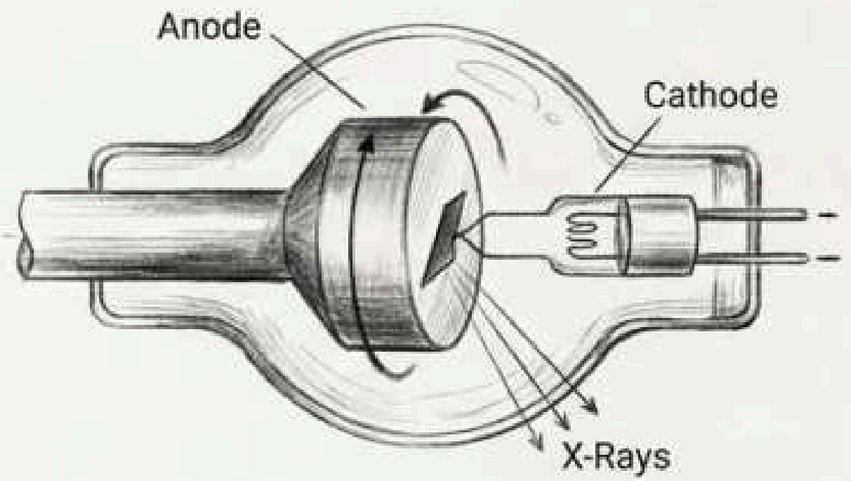
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¶ 2.9

Fast Electrons in Practice



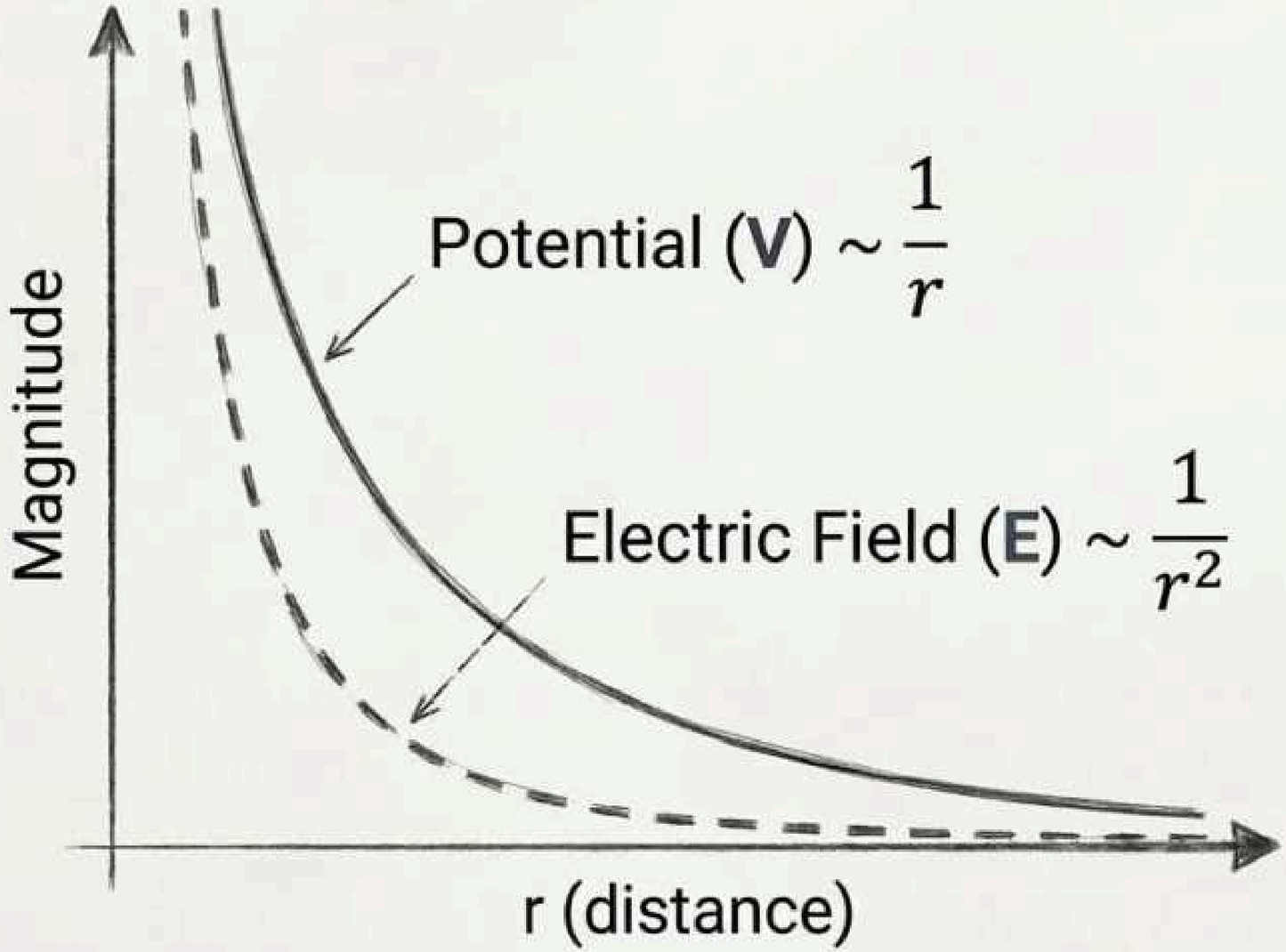




Voltage sets the **Energy** → **Energy** sets the **Speed**.

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Potential of a Point Charge



$$V = \frac{k \cdot q}{r}$$

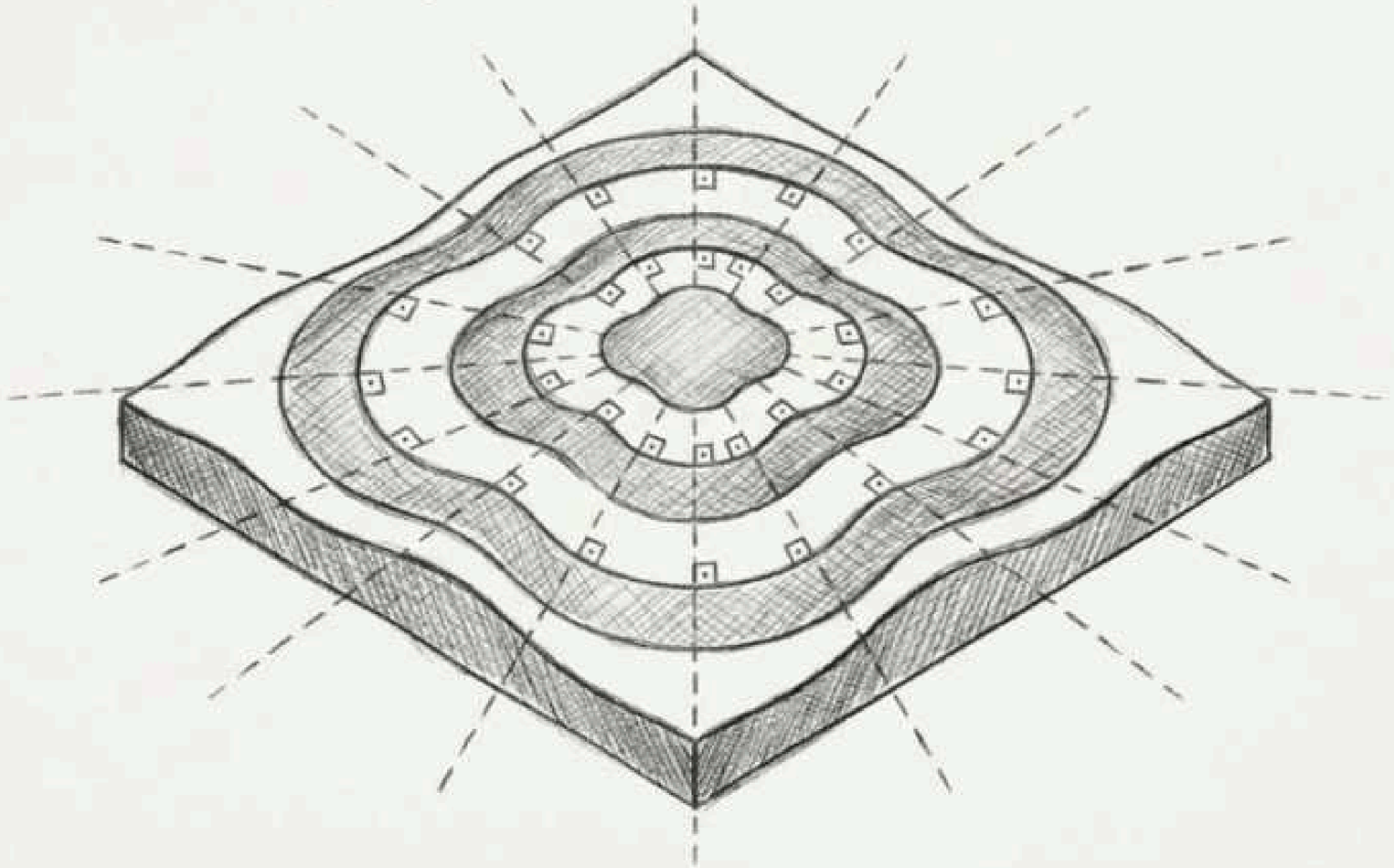
Key Insight: Potential falls off as $1/r$, not $1/r^2$.

Example: A 1 nC charge creates a potential of $\approx$ ~90V at a distance of 10 cm.

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Equipotential Surfaces

¶ 2.11



Potentials add as scalars (ordinary numbers), not vectors.

Zero Work: No work is done moving a charge anywhere along an equipotential surface.

Conductors: A conductor in equilibrium is an equipotential surface with zero internal field.

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The Faraday Cage Effect

¶ 2.12



The Faraday Cage Effect:

Charge spreads entirely over the outer metallic skin; the inside volume remains at one constant potential.

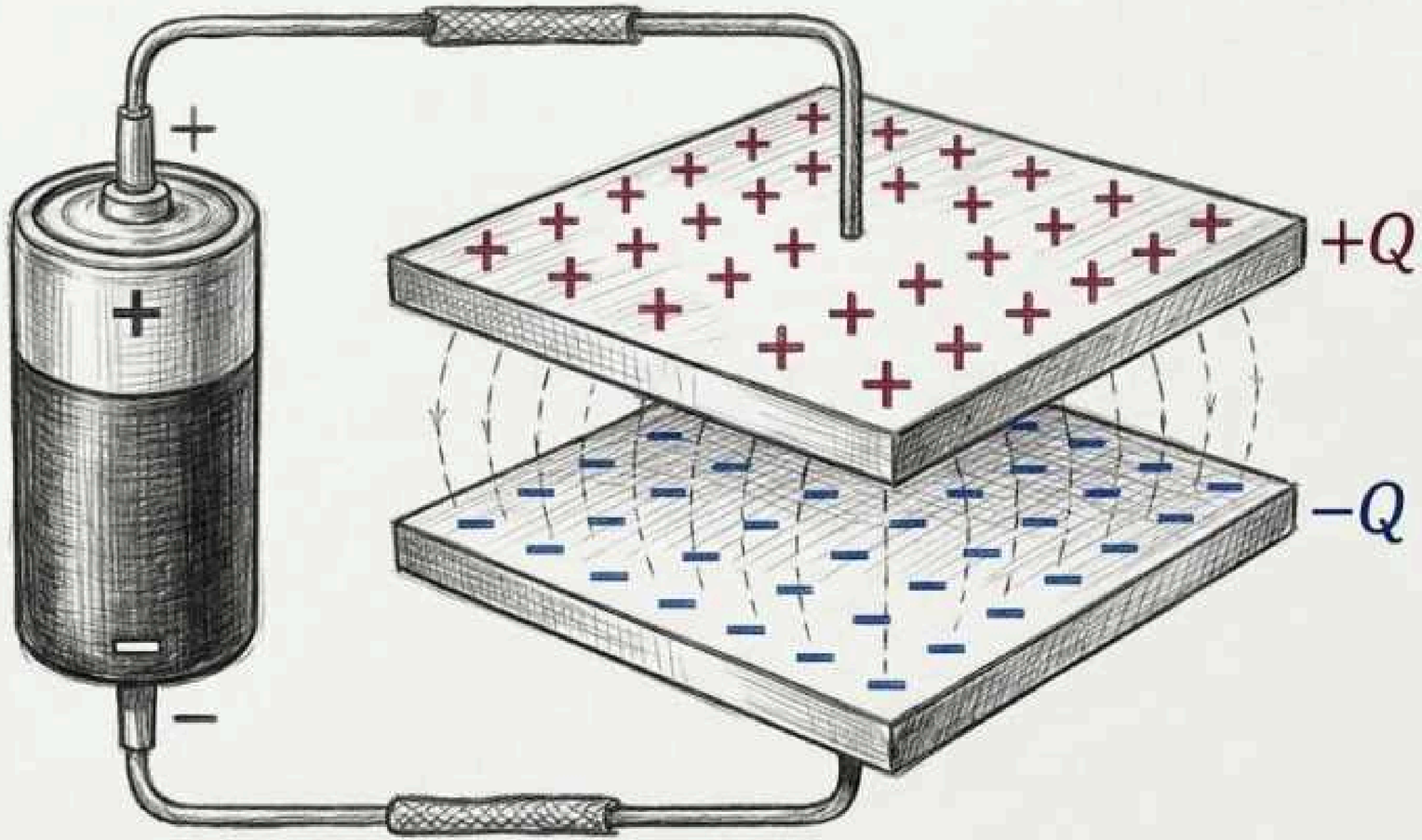
Applications:

- Lightning protection for passengers
- Shielding for sensitive electronics
- The reason cell signals drop inside metal elevators

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Anatomy of a Capacitor

¶ 2.13



Definition:

A device that stores charge and energy by holding voltage to match a connected battery.

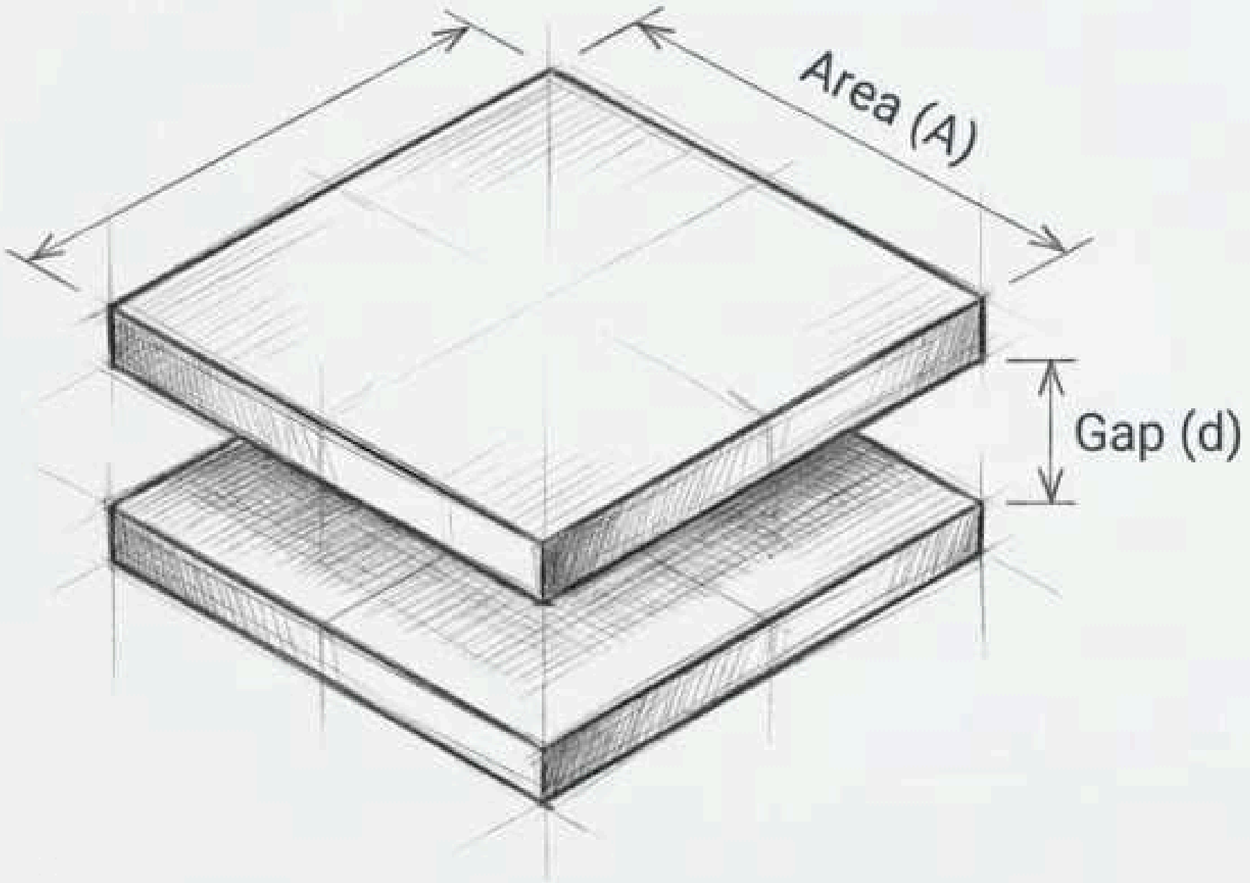
$$C = \frac{Q}{V}$$

Unit: The Farad (F)

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Parallel Plate Geometry

¶ 2.14



$$C = \frac{\varepsilon_0 A}{d}$$

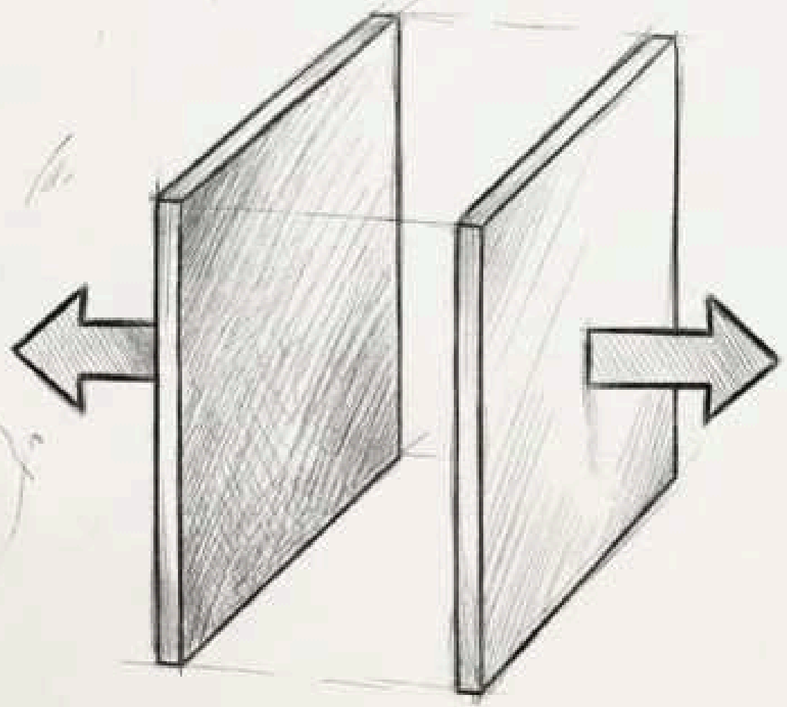
Constant: $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F/m}$

Scale Example: Plates measuring $10\text{cm} \times 10\text{cm}$ separated by a 1mm gap yield $8.85 \times 10^{-11}\ \mathrm{F}$, or just 89 pF.

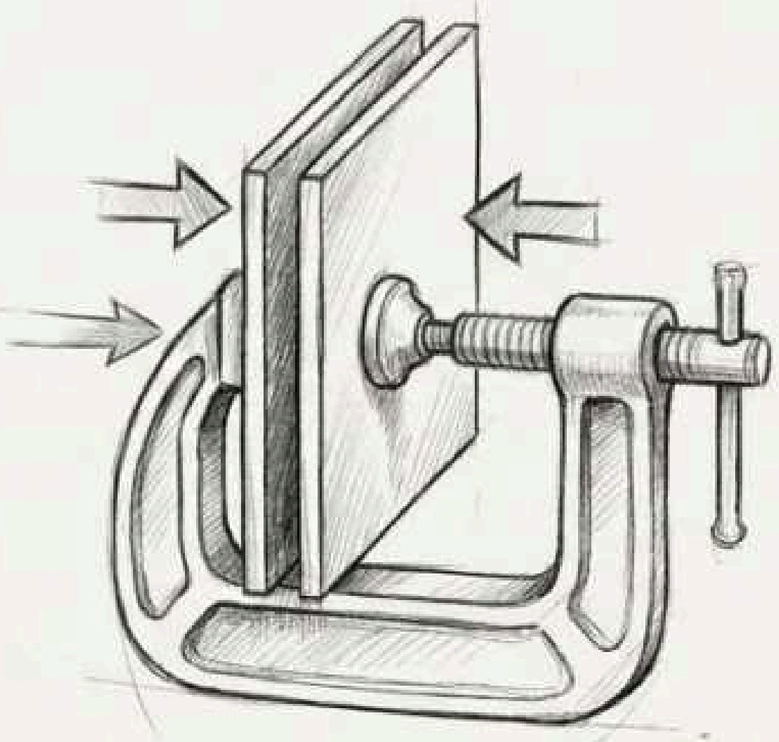
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Maximizing Capacitance

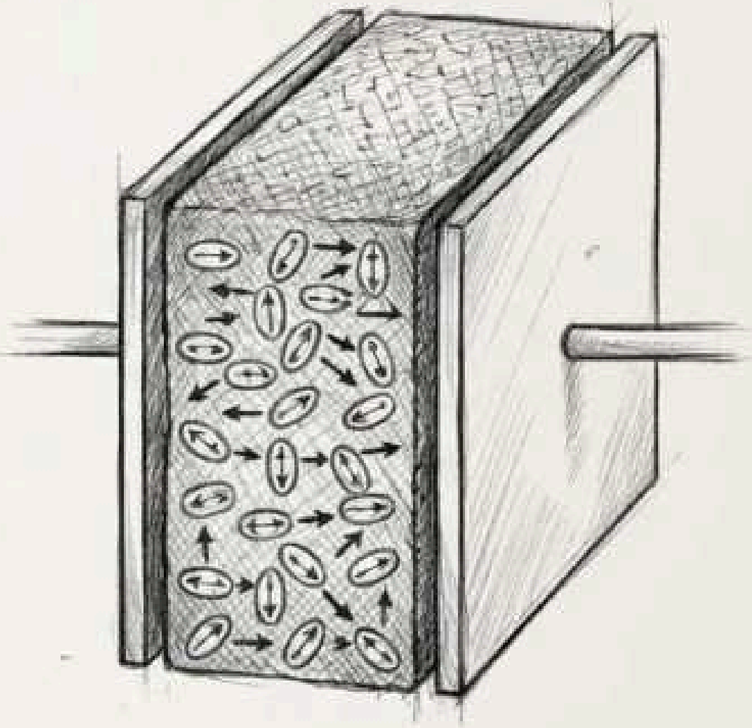
¶ 2.15



1. Increase Area (↑ A)



2. Decrease Gap (↓ d)



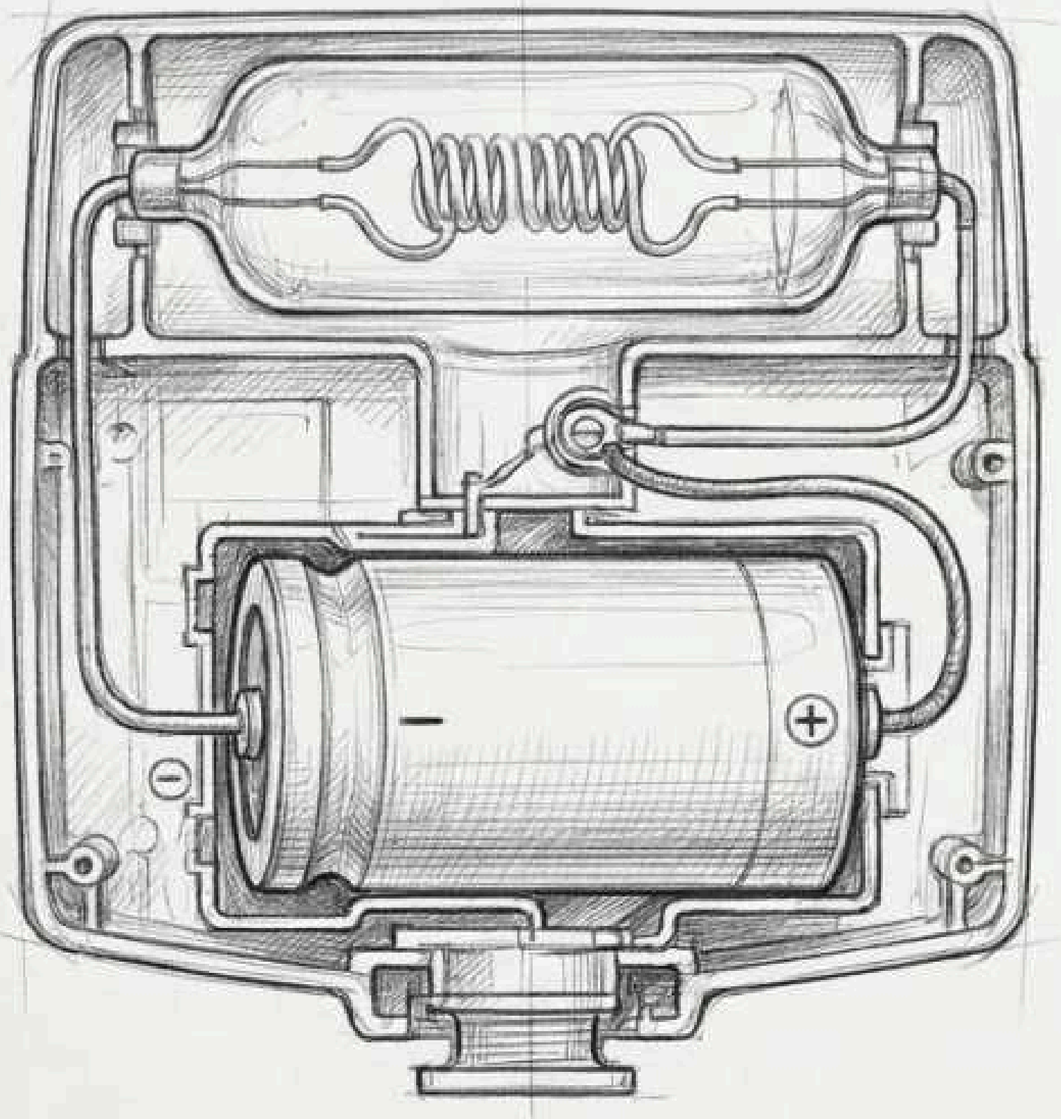
3. Add Dielectric

A Farad is massive; real units are μF (micro), nF (nano), pF (pico).

Dielectrics are insulators that cancel internal fields, allowing vastly more charge to be stored.

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Energy Storage & Power Release



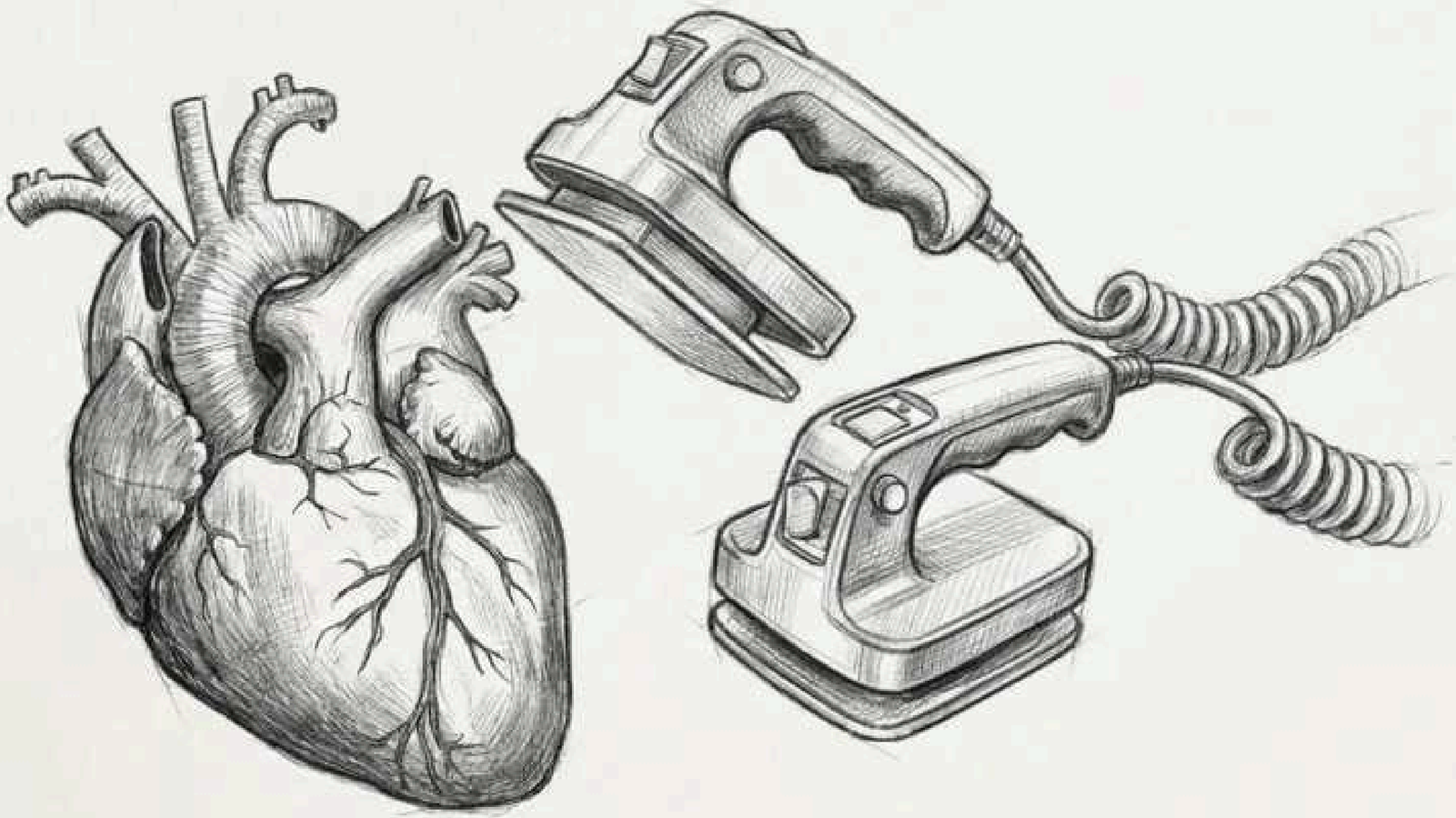
$$E = \frac{1}{2} C V^2$$

Standard Circuit:	A 100 µF capacitor at 12V holds just 0.0072 Joules.
The Flash:	A **1000 µF capacitor at 300V** holds **45 Joules**.

The Result: Releasing 45J in mere thousandths of a second creates immense Power (Energy / Time), producing a blinding flash.

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Medical Application: Defibrillators



Medical Specs:
~70 µF charged to 3,000V
→ **315 Joules.**

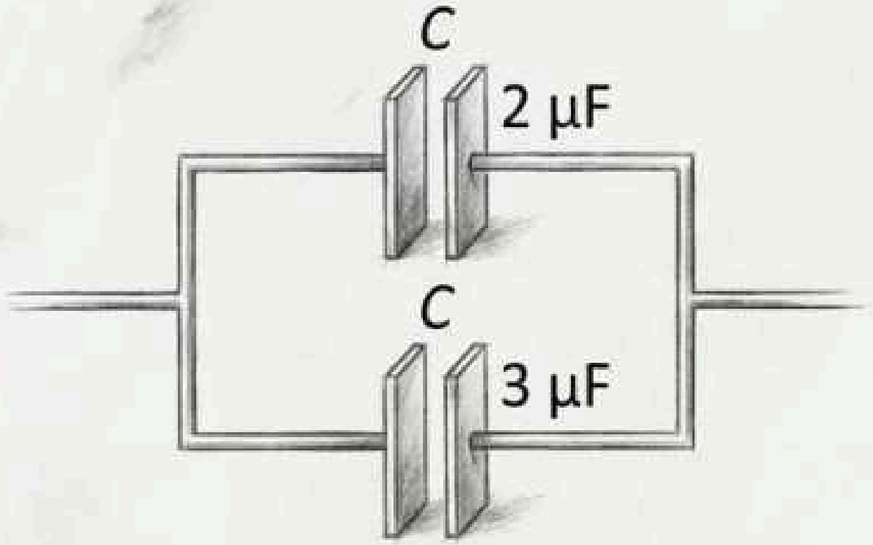
Action:
Energy delivered in milliseconds to force a heart restart.

WARNING: Capacitors retain lethal charges long after power is disconnected. Never open a flash unit or power supply.

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Combining Capacitors

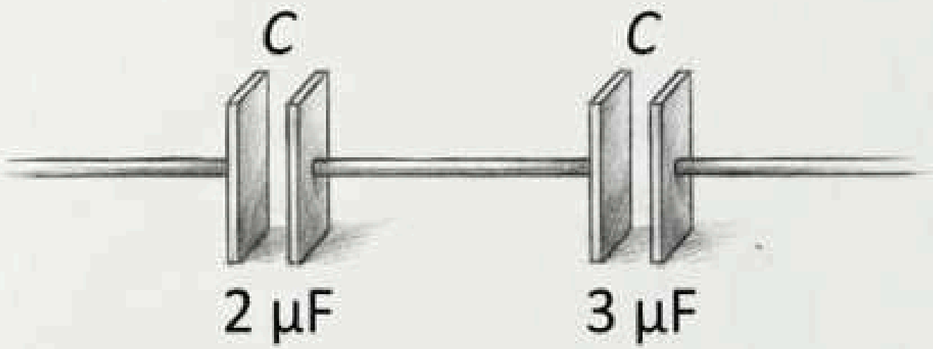
¶ 2.18



Parallel

Capacitances simply add.

$2\ \mu F + 3\ \mu F = 5\ \mu F$



Series

Reciprocals add.

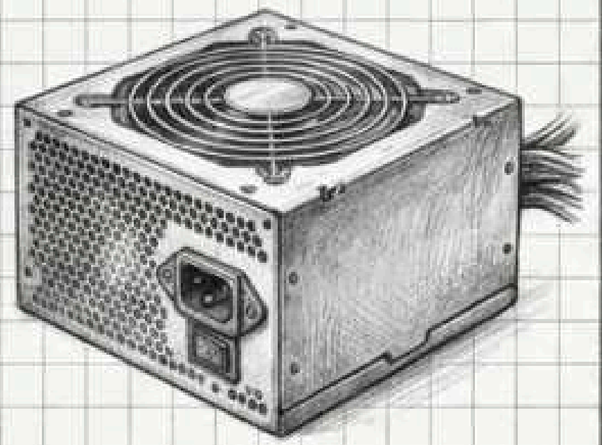
$1/2 + 1/3 \rightarrow 1.2\ \mu F$

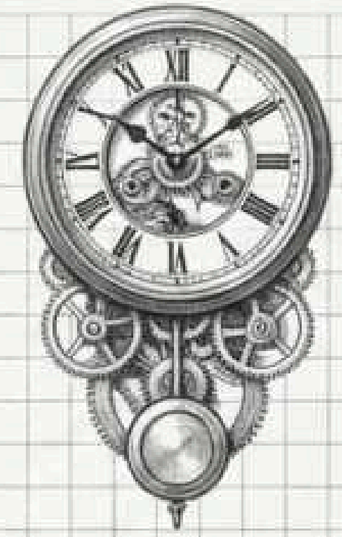
*Critical Note: This math is the exact opposite of the rule for combining resistors.

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Capacitors are Everywhere

Power: Smoothing voltage outputs.

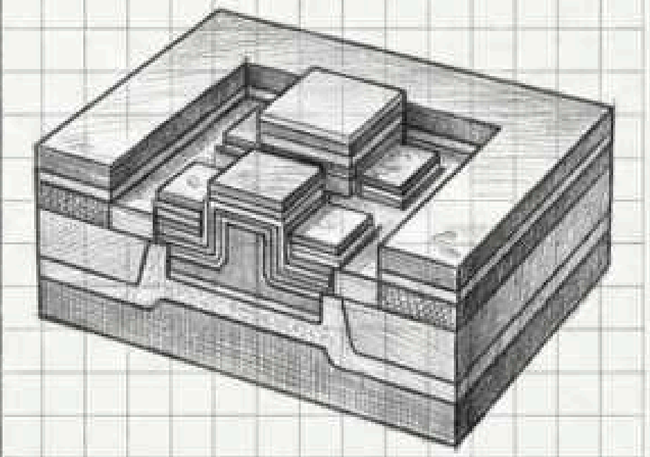




Timing: Setting clock beats and tuning radios.

Sensing: Touchscreens detecting tiny capacitance changes from a finger.



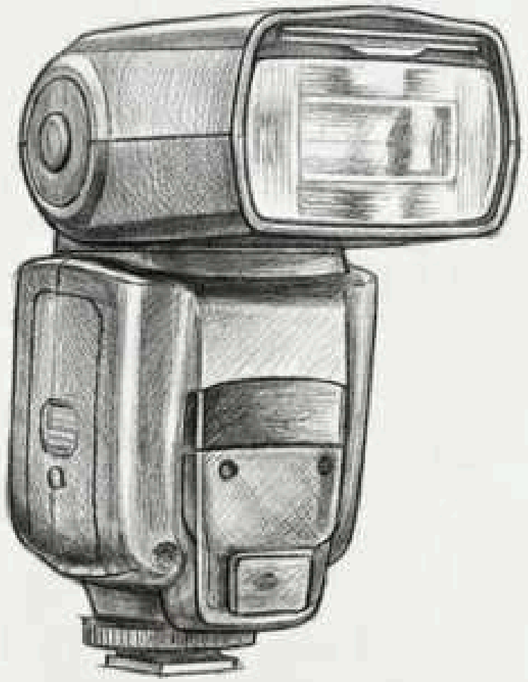


Memory: Storing digital bits as charge on microscopic capacitors.

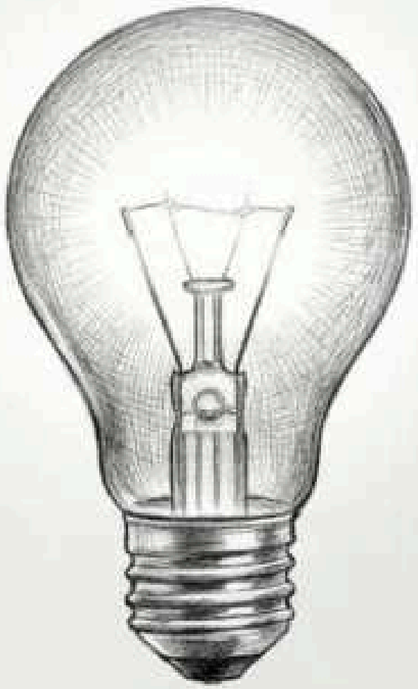
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Lecture Question

¶ 2.20



45J in 0.002s



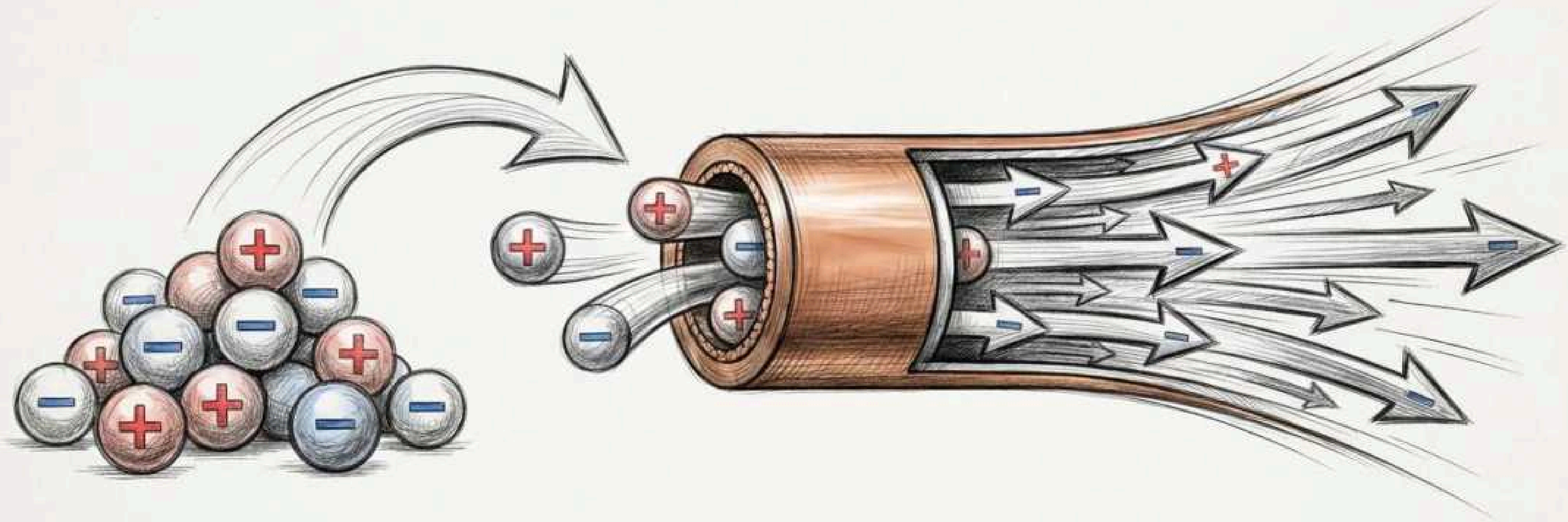
100W Continuous

The Challenge: What average power does the flash capacitor deliver? Compare this output to a standard 100W light bulb. Explain why the flash can be so blindingly bright despite using very little total energy overall.

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¶ 2.21

Looking Ahead: Lecture 3



Next: We let the charge move.

Electric Current Resistance Continuous Circuits

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