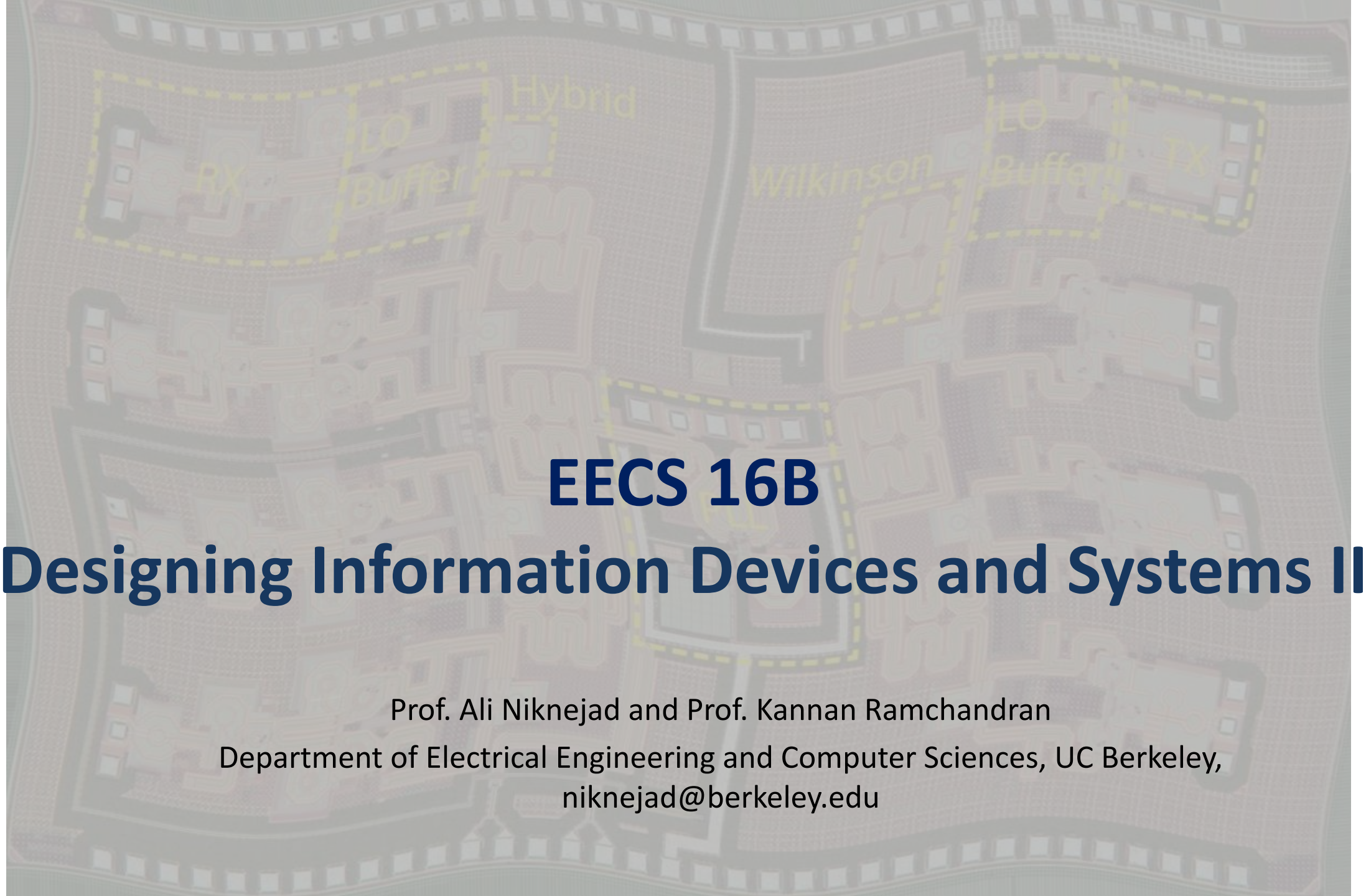


EECS 16B
Designing Information Devices and Systems II

Prof. Ali Niknejad and Prof. Kannan Ramchandran

Department of Electrical Engineering and Computer Sciences, UC Berkeley,
niknejad@berkeley.edu

Module 1: Capacitors

EECS 16B

Reading Material

For the first ~10 classes we will loosely follow (optional)

Electrical Engineering: Principles and Applications (6th Edition)

Allan R Hambley

- See notes link on the website

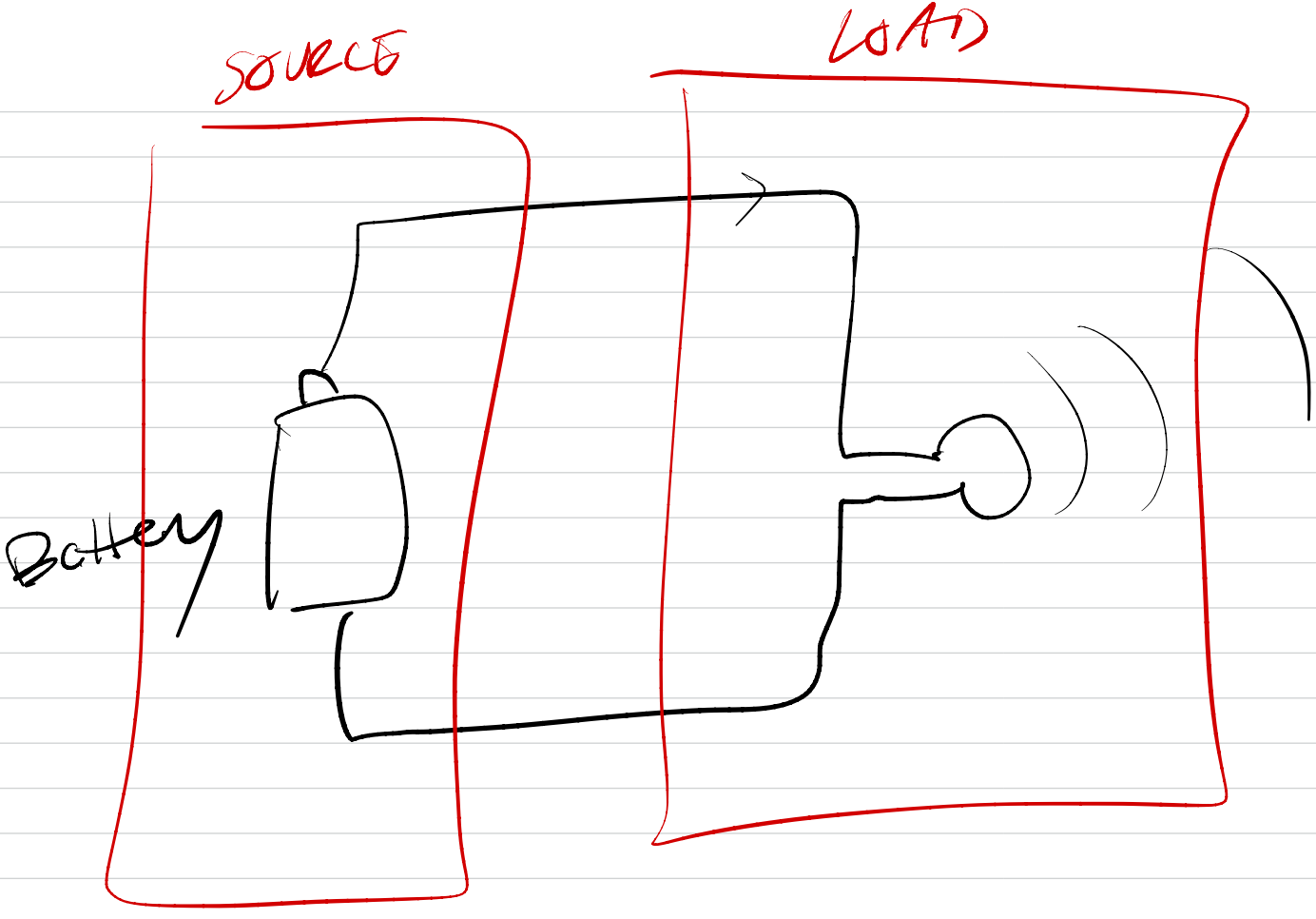
EE 16A and 105 “Readers”

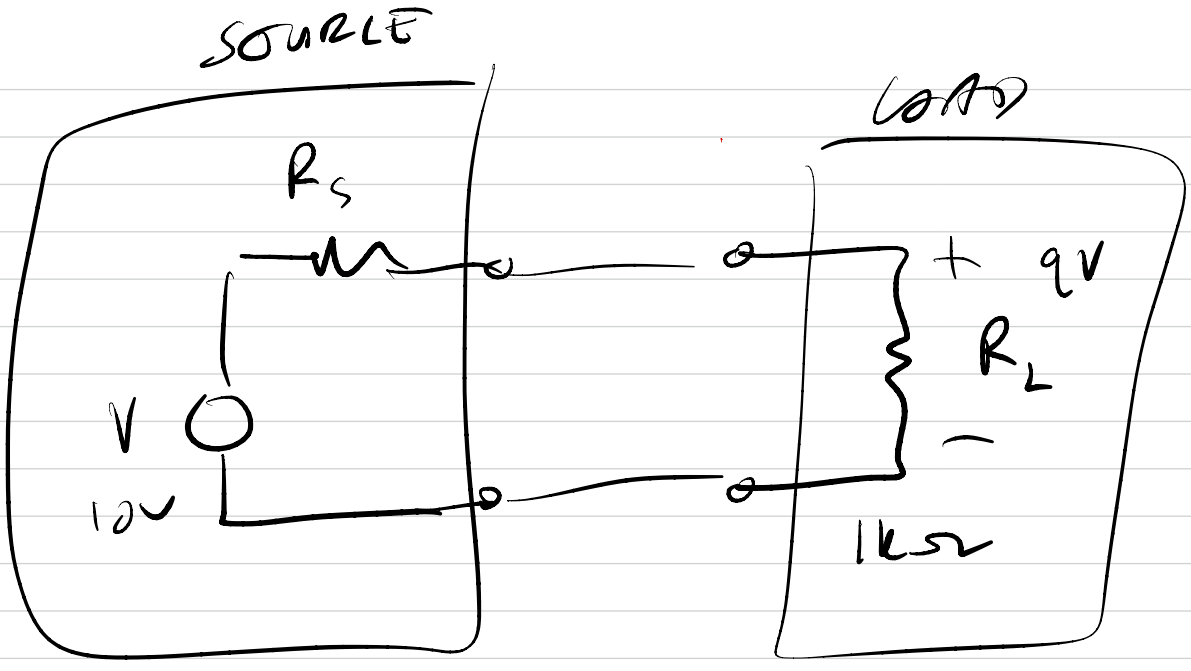
16A Reader

- Mini-textbooks
- 105 reader chapters 1-2 useful as a reference for this course (read it in the end or as we go along)

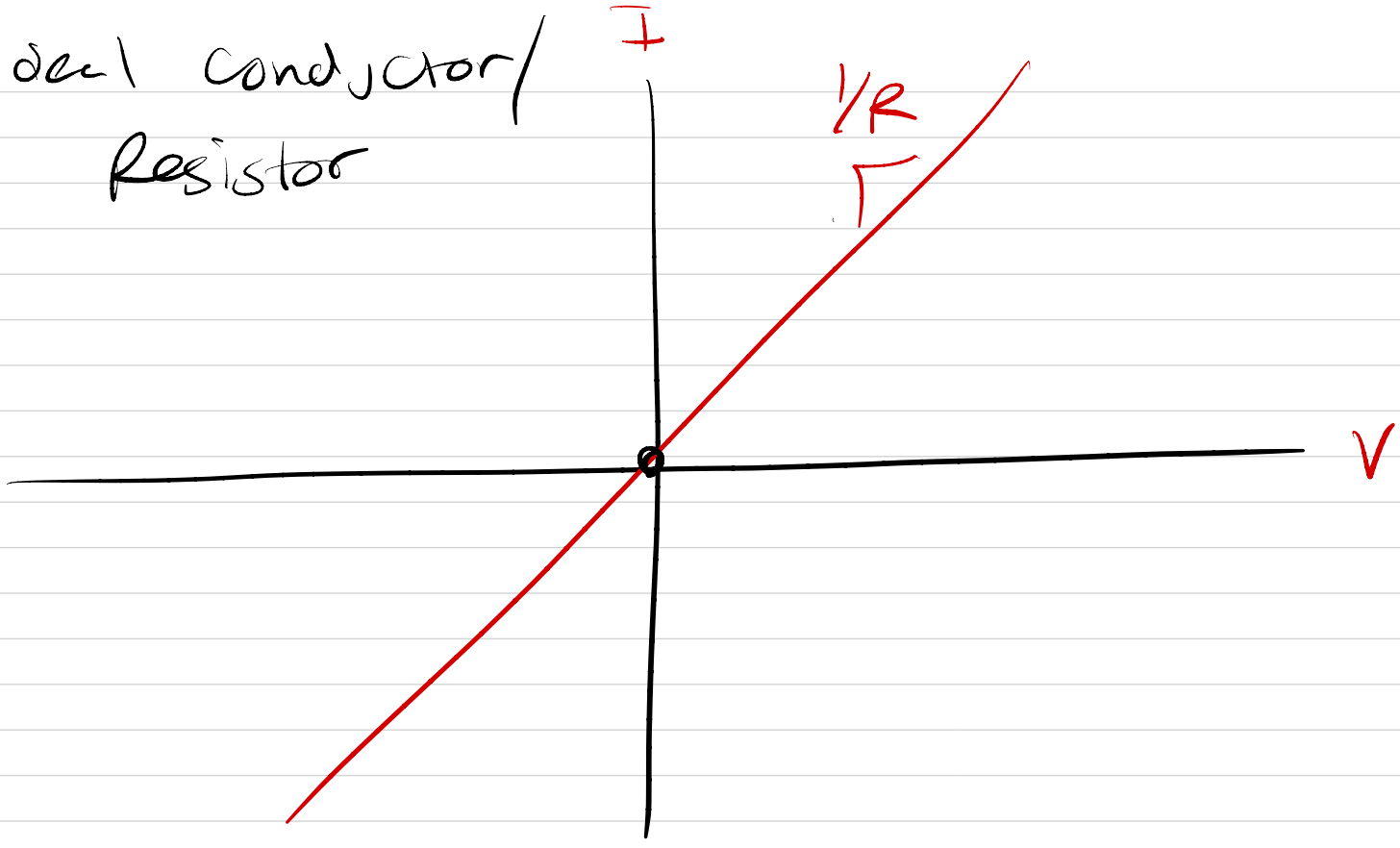
EE 16A Assumptions

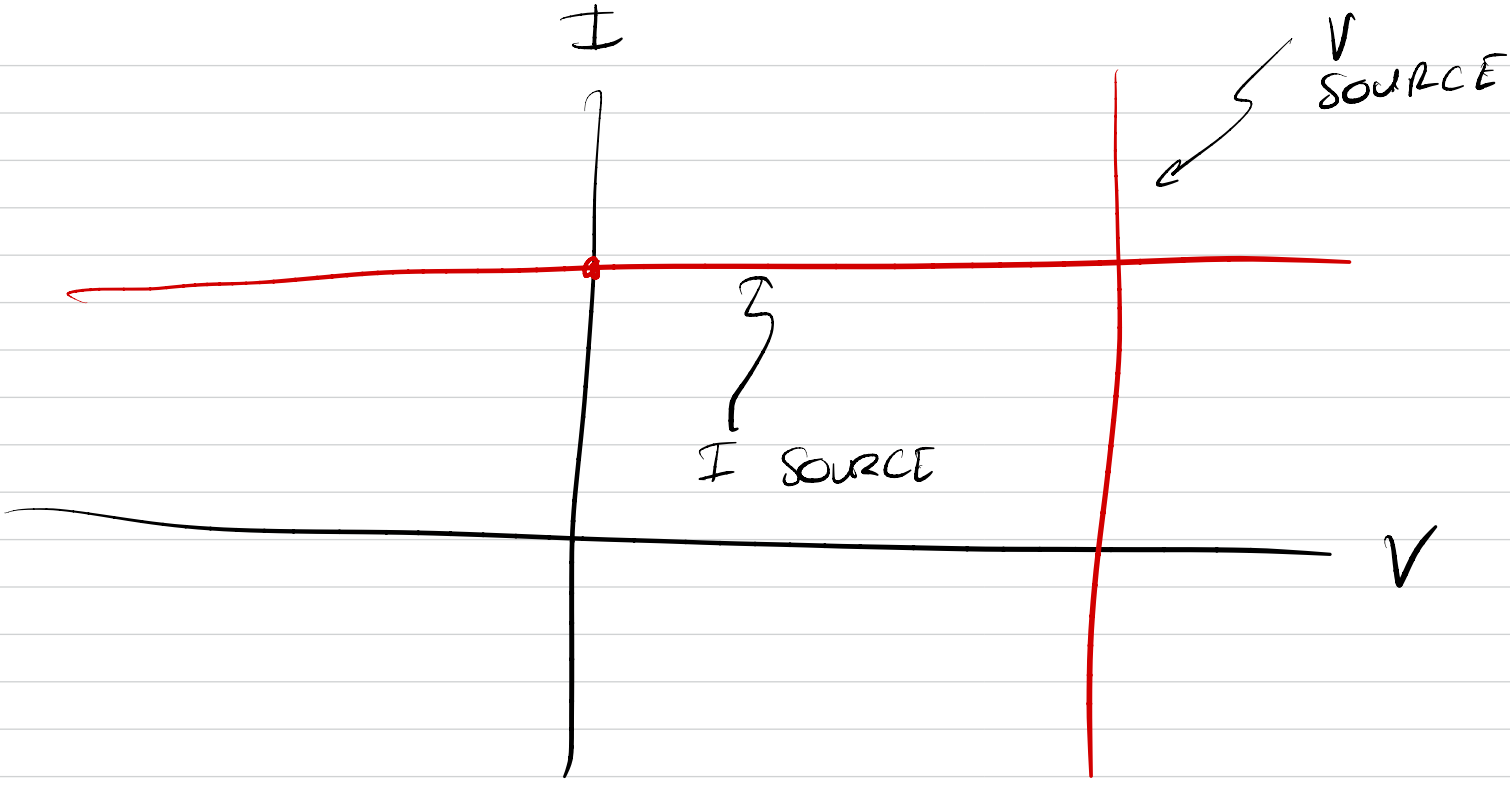
- Voltage, Charge, Current
- Energy, Power (?)
- Resistors, Voltage / Current Sources, Dependent Sources
- Capacitors (will review)
- KCL/KVL, Nodal Equations
- Voltage/Current Dividers
- Linearity, Superposition
- Norton/Thevenin Equivalents (Source Transformations)
- Loads / Source Resistance

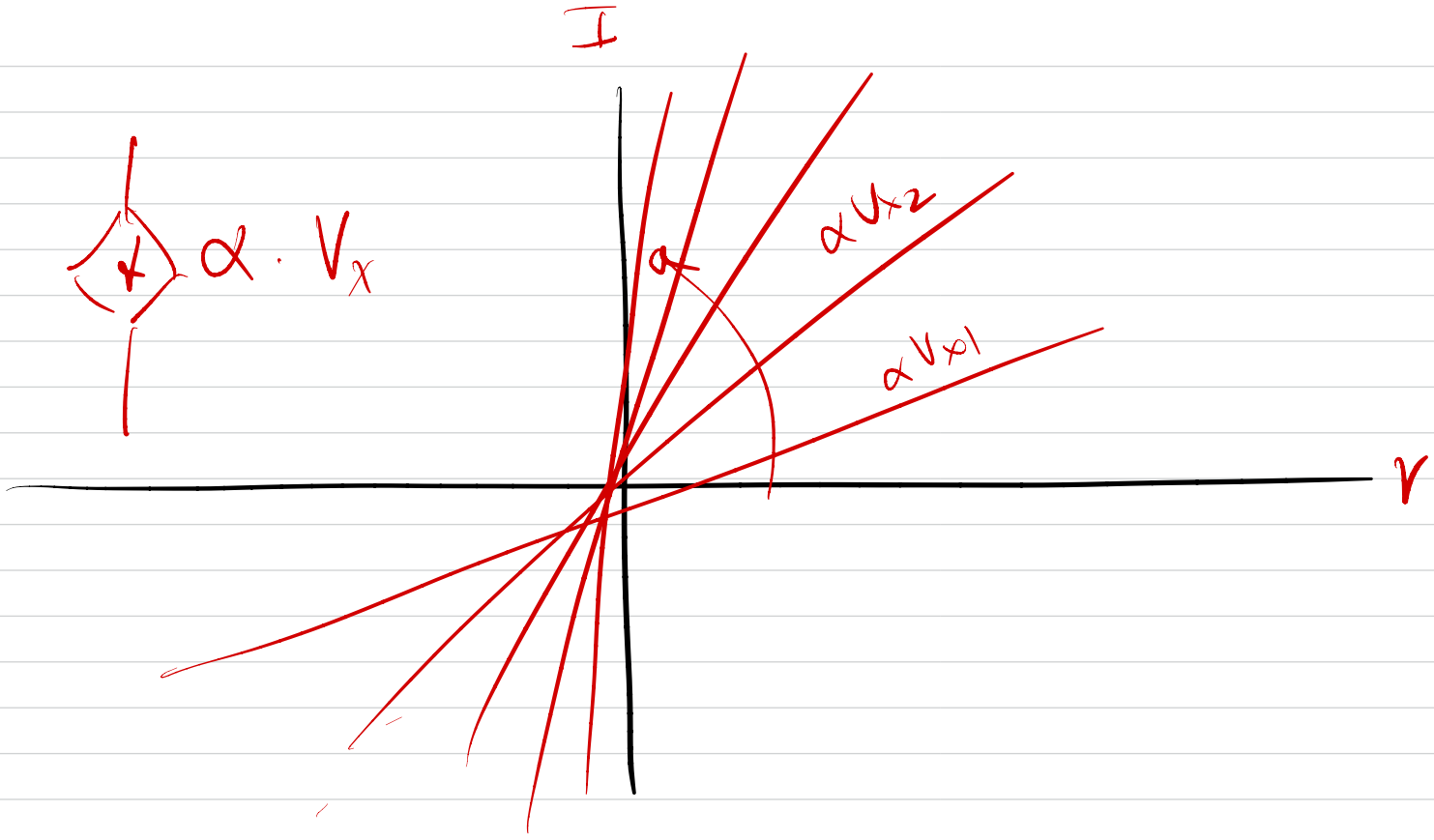

SOURCE
LOAD
Battery


SOURCE
LOAD
R_S
V
10V
+ qV
R_L
−
1kΩ

Ideal Conductor/
Resistor

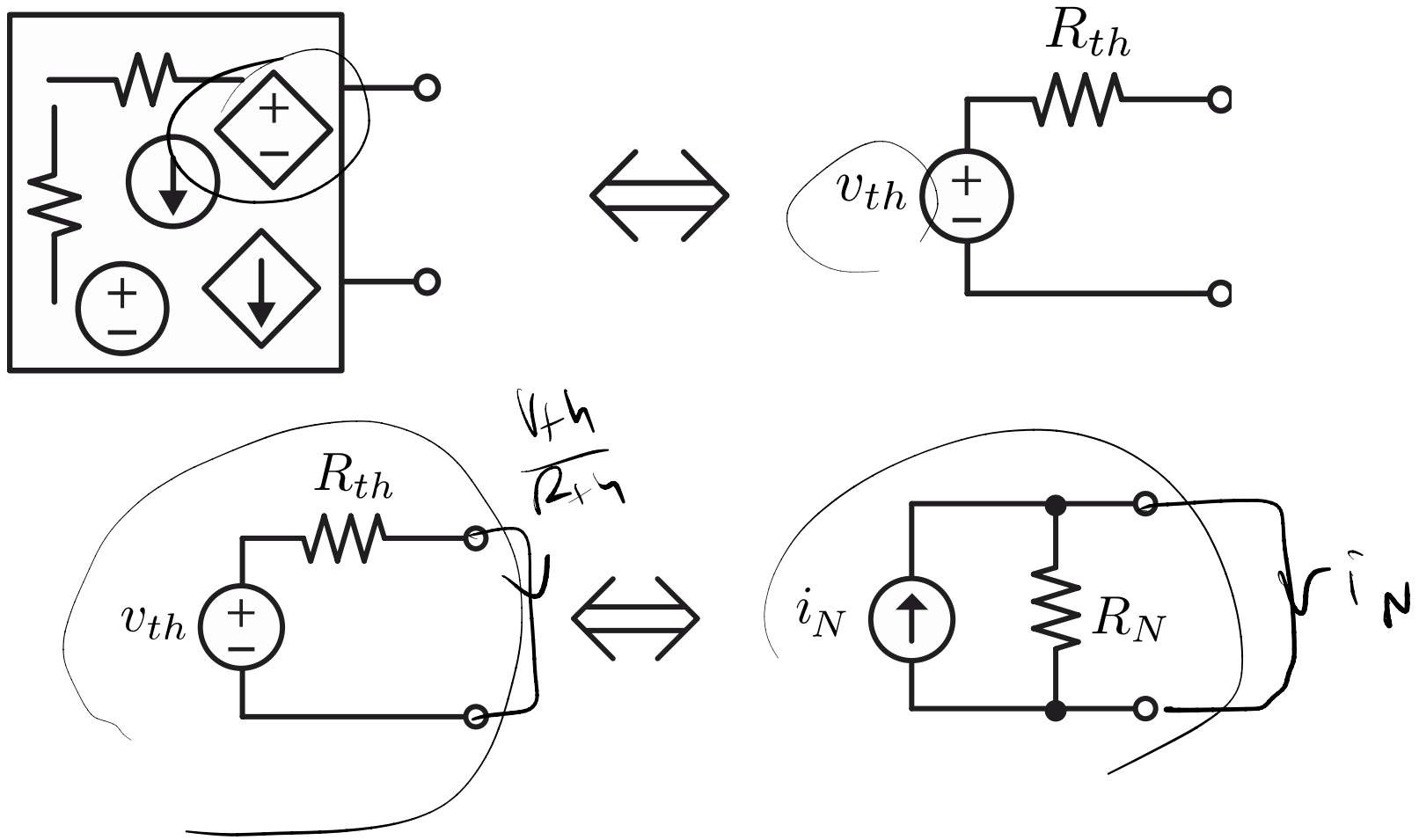



I
V
SOURCE
I SOURCE
V



CONTROLLED SOURCE

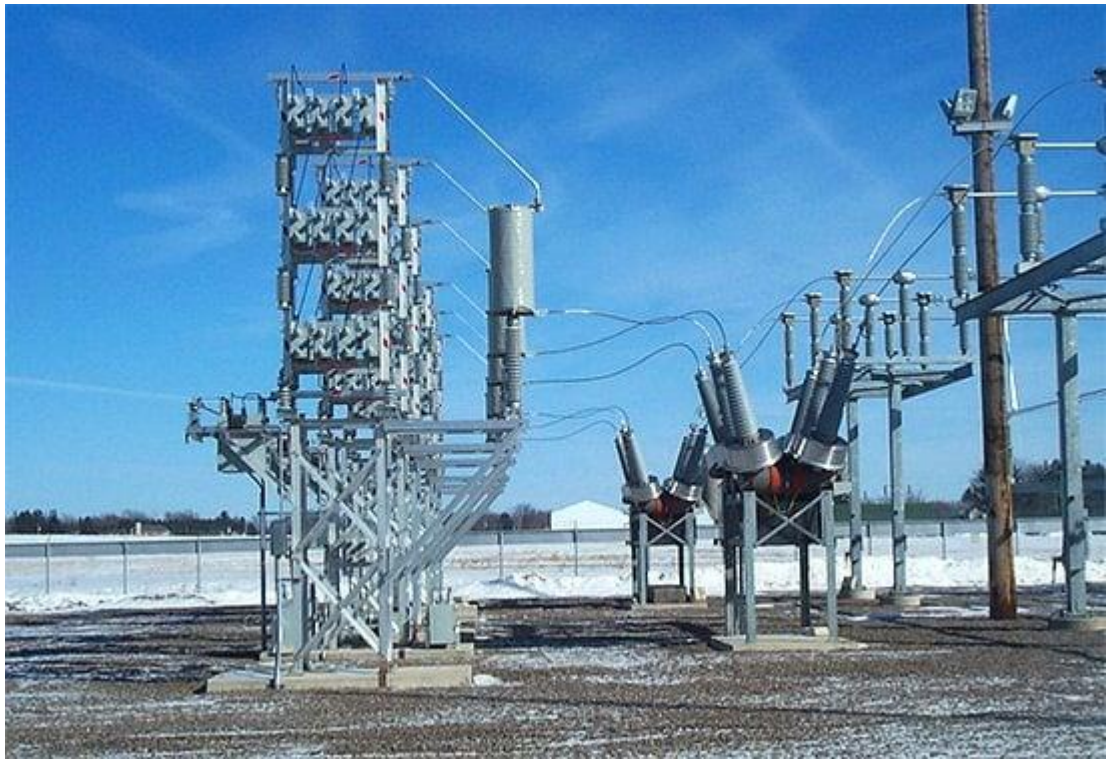
Thevenin/Norton



Capacitance

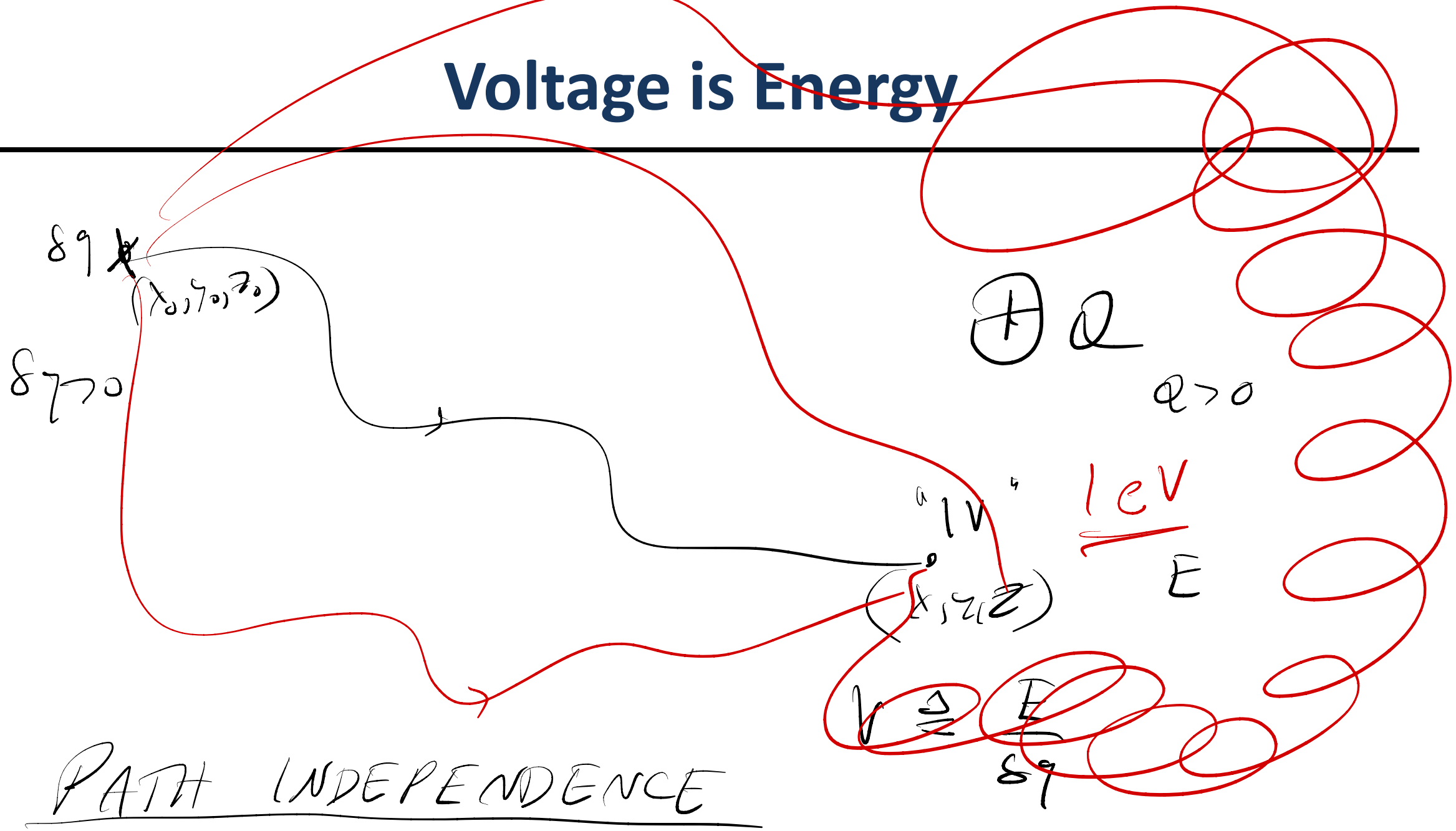
- Comes from the word “capacity”
- Units:
  - In “natural” units it’s simply a dimension
  - Faraday (in honor of Michael Faraday 1791-1867)
- Capacitance is the capacity to store charge

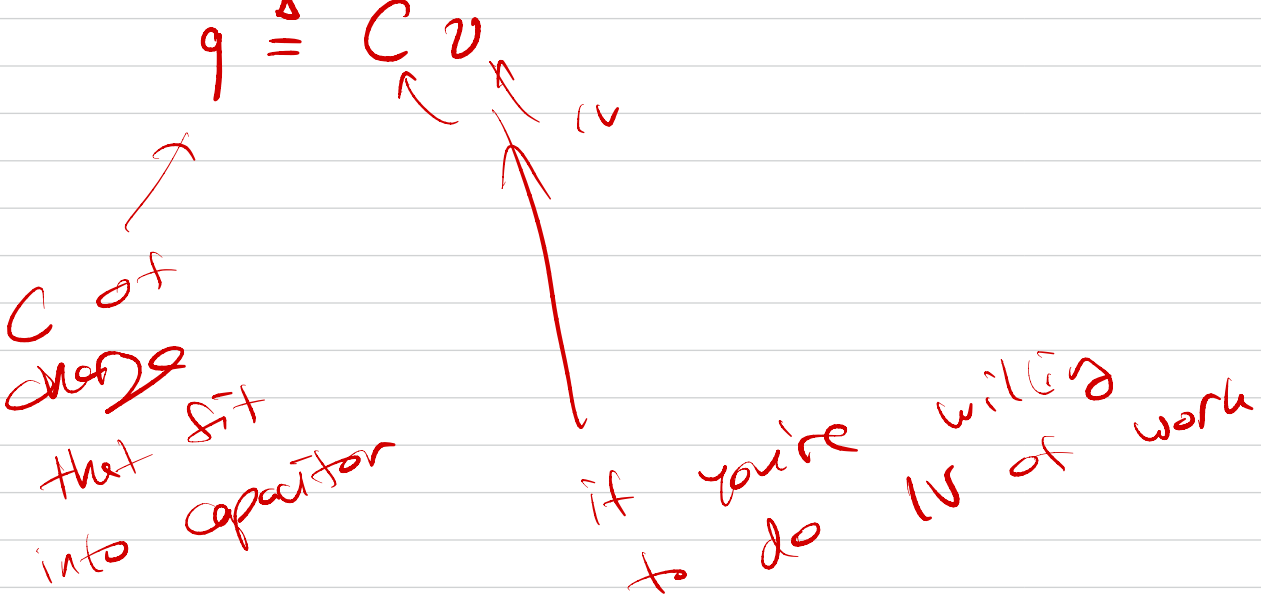
Capacitors




nichicon
4700μF 35v
VITAMIN Q
CAPACITOR
193-10 8216
189-505-5
103k
500V
151

Voltage is Energy




$q \triangleq C v$
C of
charge
that sit
into capacitor
if you're willing
to do 1V of work

Capacitor vs Battery vs Steak

- Capacitor for EV
  - 580 uF, 450V max voltage, 1 kg weight
  - 59 J
- Tesla 3rd generation battery
  - 333 Wh/kg = 1.1 MJ
- Beef Steak, 1kg
  - 10.5 MJ

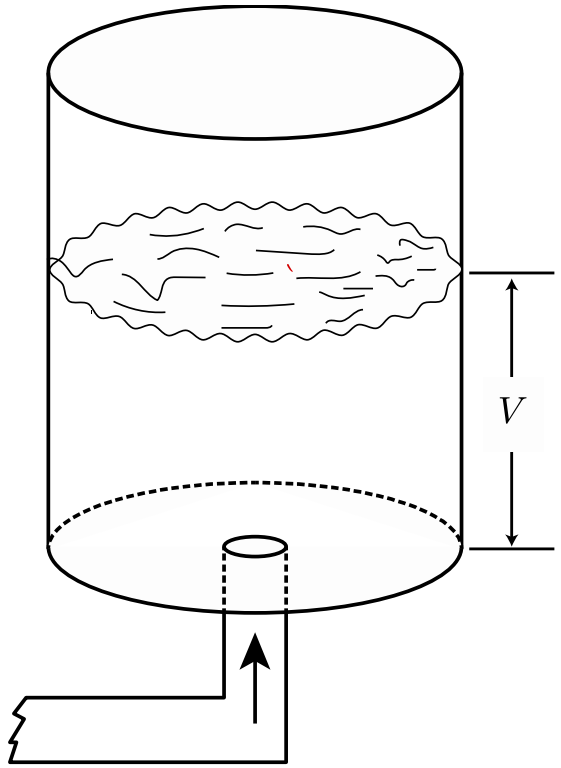
$q = CV$

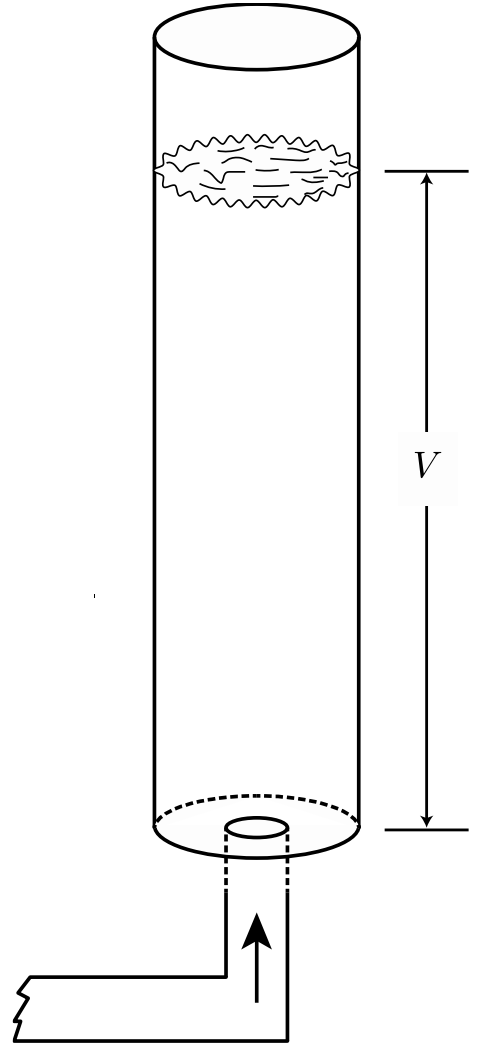
$E = qV$

$= CV^2$ ✗

Wrong Answer B/C the work depends on the charge already on the capacitor...

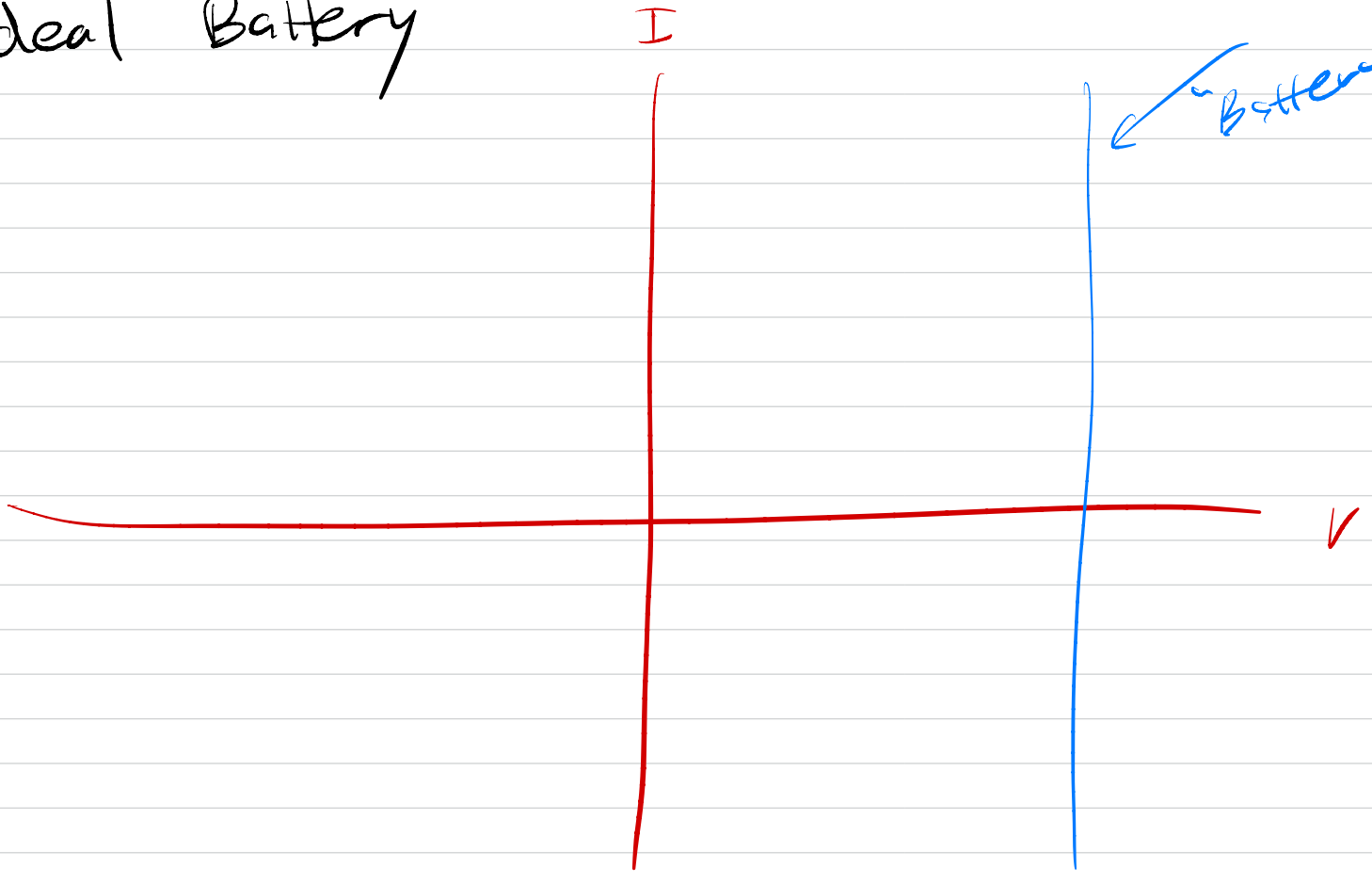
Bathtub Analogy



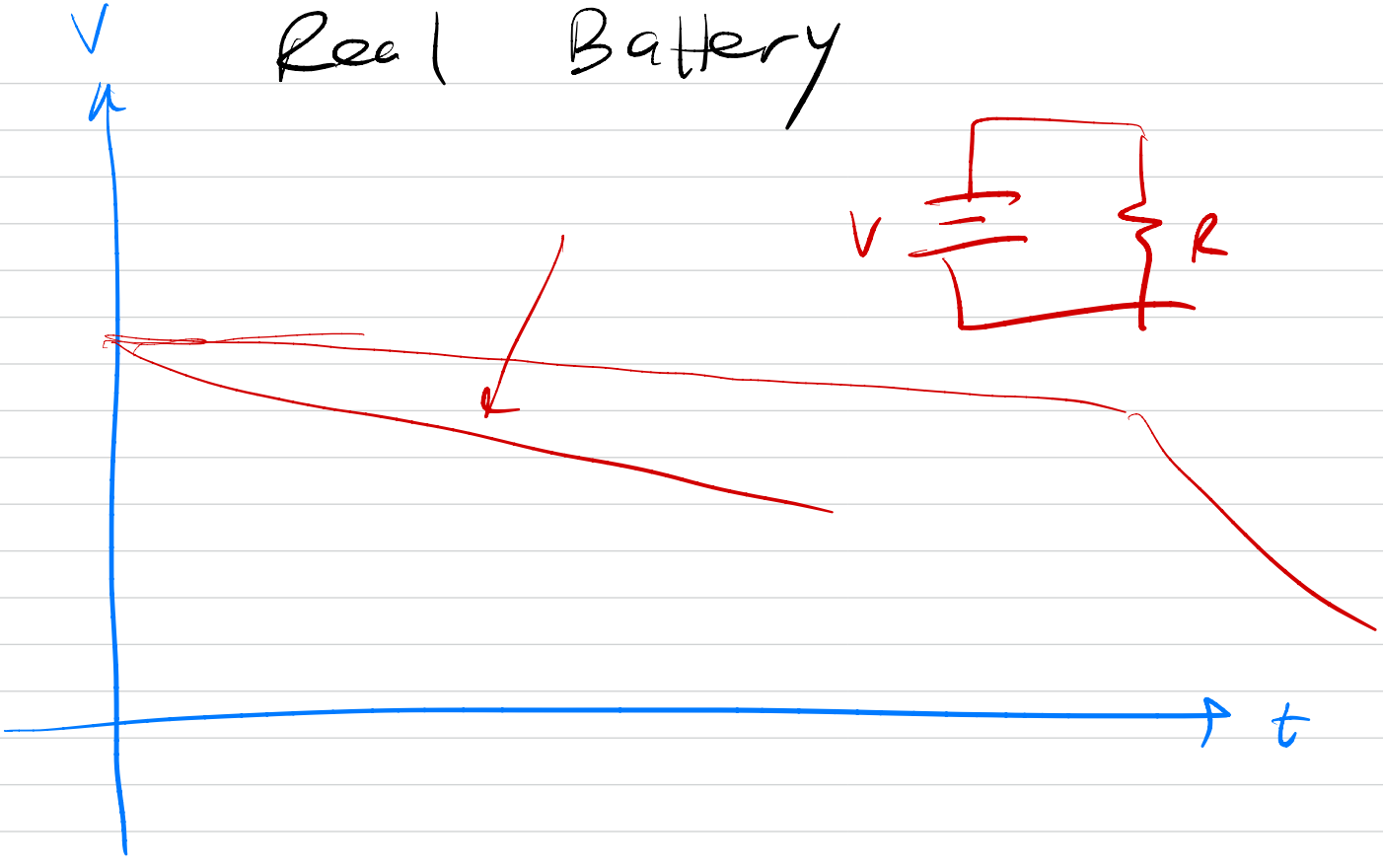


height is potential energy (gravitational)

Ideal Battery



Real Battery



ENERGY STORED IN A CAPACITOR

$$dE = q\,dV \qquad q = CV$$

$$\int dE = \int C V\,dV \qquad dq = C\,dV$$

$$E = C\frac{V^2}{2} \Rightarrow$$ energy stored in a capacitor

Bathtub Analog – Where is inlet/outlet?

- Why does it matter?

Bottom ... it takes increasingly more work to charge a capacitor.

Electrostatics Review (optional)

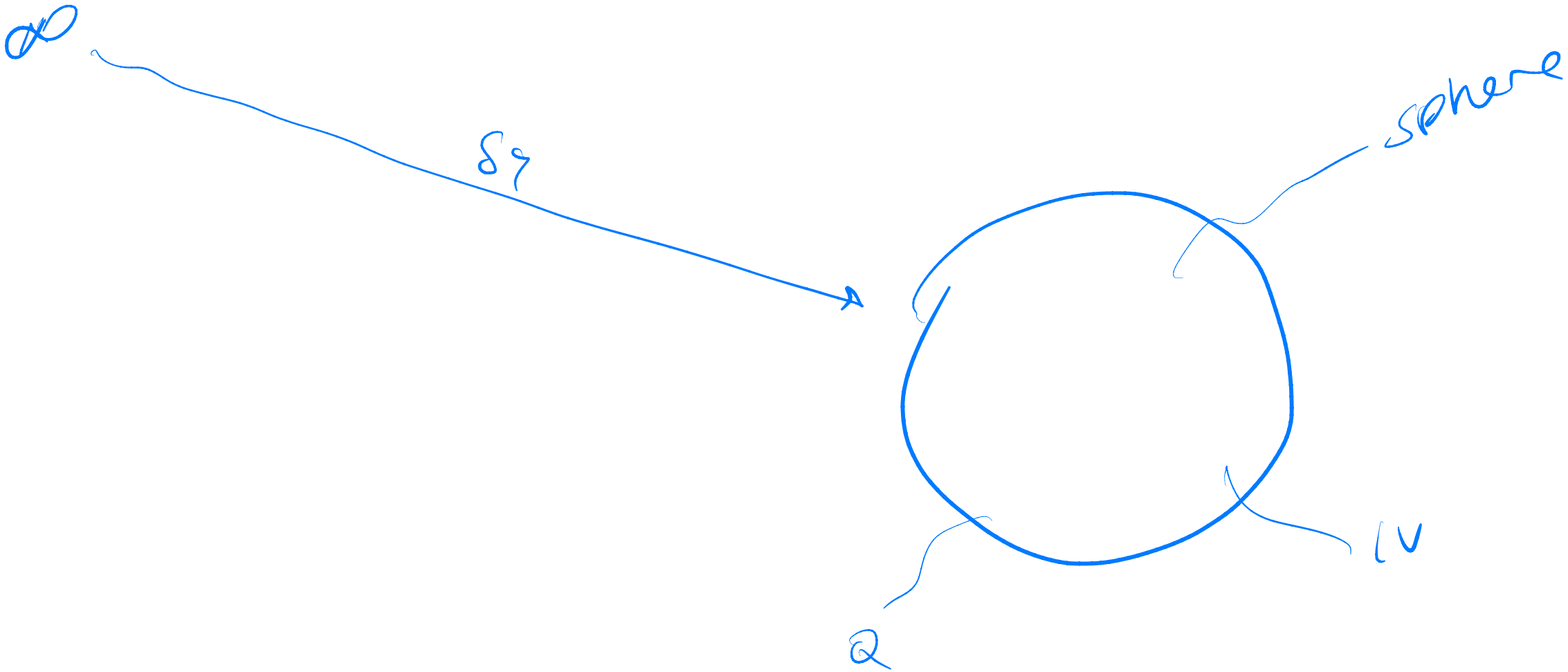
- Charge, Voltage (potential), Electric Field

ϕ : Electrostatic Potential

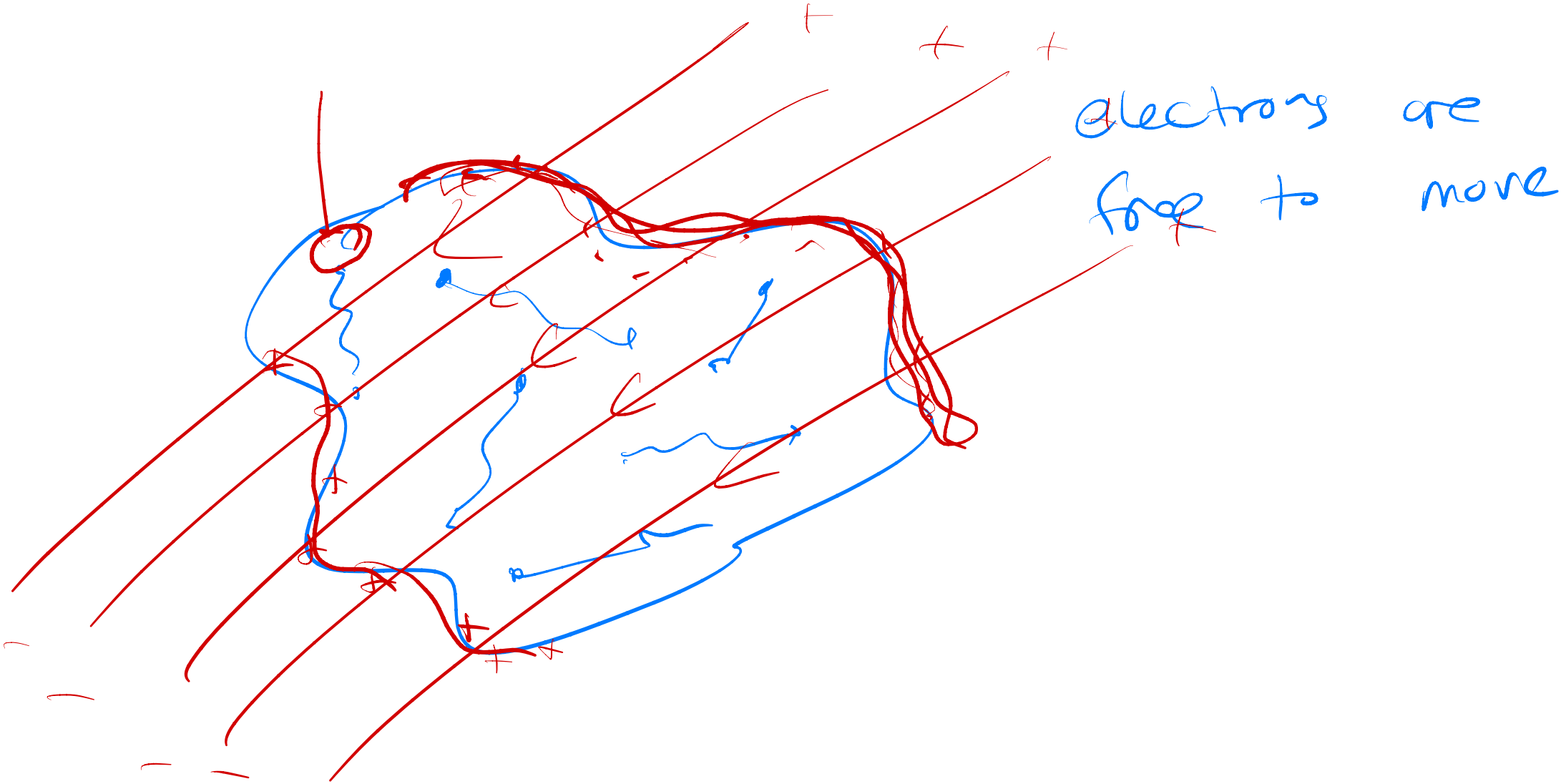
$\vec{E}$: Electric Field

ε_0 : permittivity of free space

What's the capacitance of a conductive sphere?

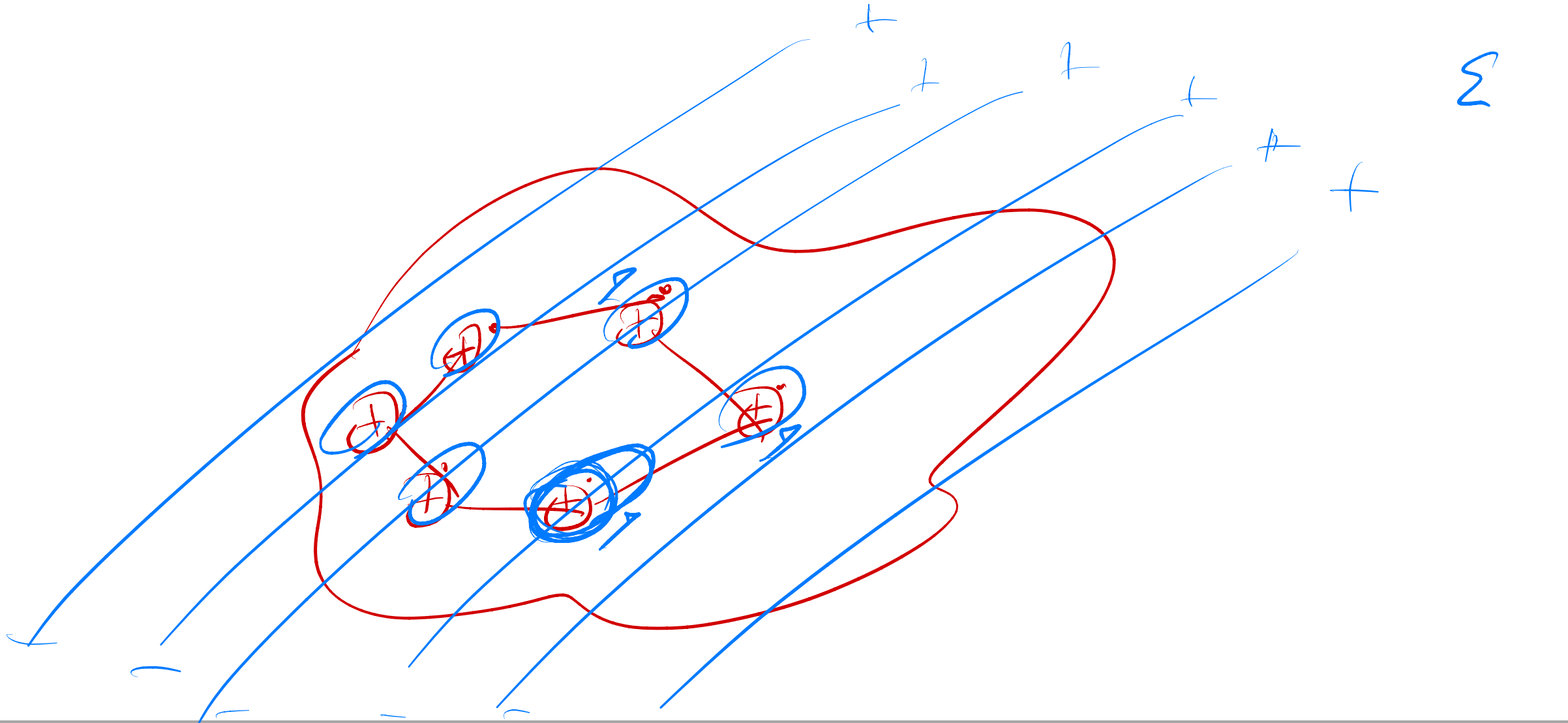


Review: Conductor



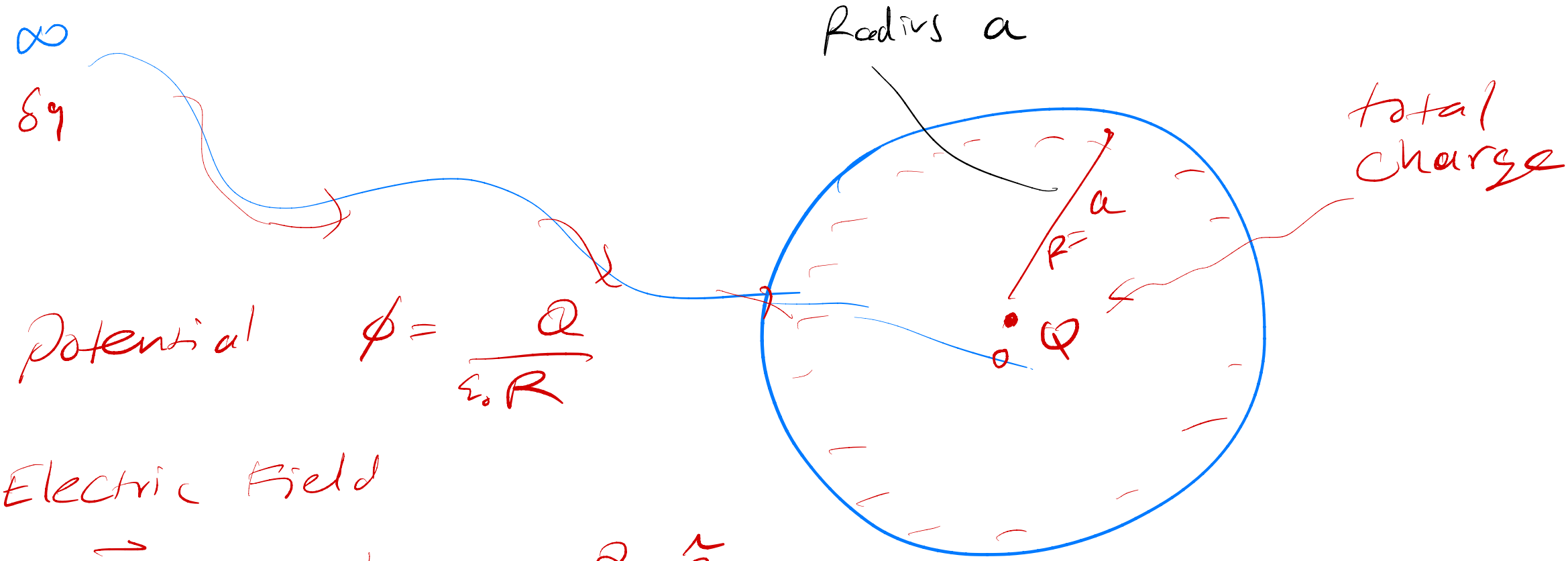
Review: Insulator

Dielectric



Preview: Semiconductor

① Sphere Capacitance (optional)



Potential $\phi = \frac{Q}{\epsilon_0 R}$

Electric Field

$$\vec{E} = -\nabla\phi = \frac{Q}{\epsilon_0 R^2}\hat{R}$$

(2) Sphere Capacitance

Let q represent the charge on the sphere at any given time. To add an increment of charge dq onto sphere, we must do work:

$$dW = dq \cdot \int_{-\infty}^{a} \vec{E} \cdot d\hat{R} = \frac{dq \cdot q}{\varepsilon_0} \int \frac{dR}{R^2}$$

$$= \frac{dq \cdot q}{a \varepsilon_0}$$

$$W = \int_0^Q dW = \frac{1}{\varepsilon_0 a} \int_0^Q q\, dq = \frac{1}{a\varepsilon_0} \frac{q^2}{2} \Big|_0^Q = \frac{1}{\varepsilon_0 a} \frac{Q^2}{2}$$

② Sphere Capacitance

Note it take energy to charge a capacitance. Since $q = CV$

$$dE = dq \cdot V \qquad E = \int V\,dq = \int_0^Q \frac{q}{C}\,dq$$

$$= \frac{1}{C}\frac{Q^2}{2}$$

$$E = W$$

$$\Rightarrow \frac{1}{C}\frac{Q^2}{2} = \frac{1}{4\pi\varepsilon_0 a}\frac{Q^2}{2}$$

$$\Rightarrow C = 4\pi\varepsilon_0 a$$

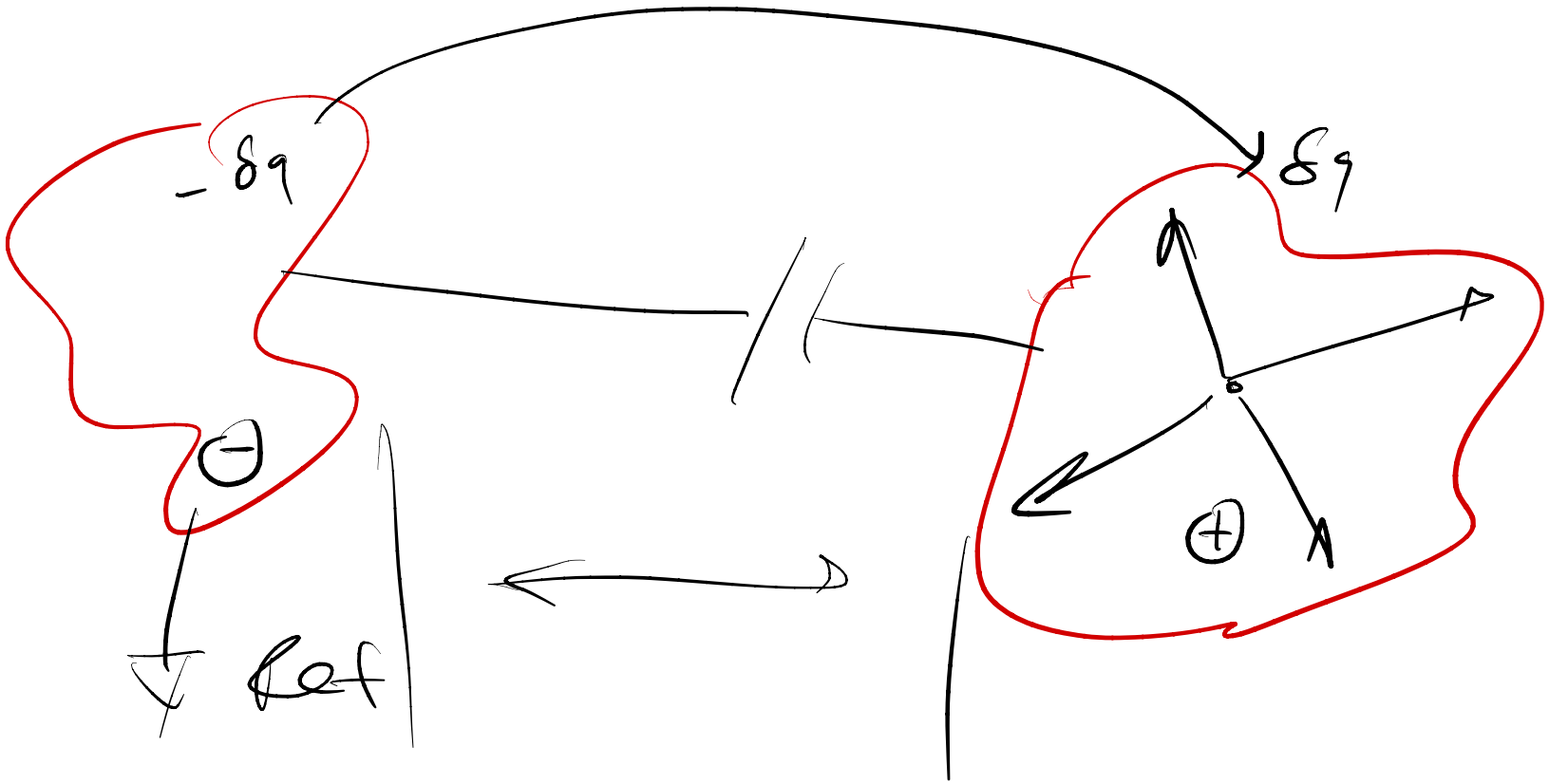
a: Radius of sphere

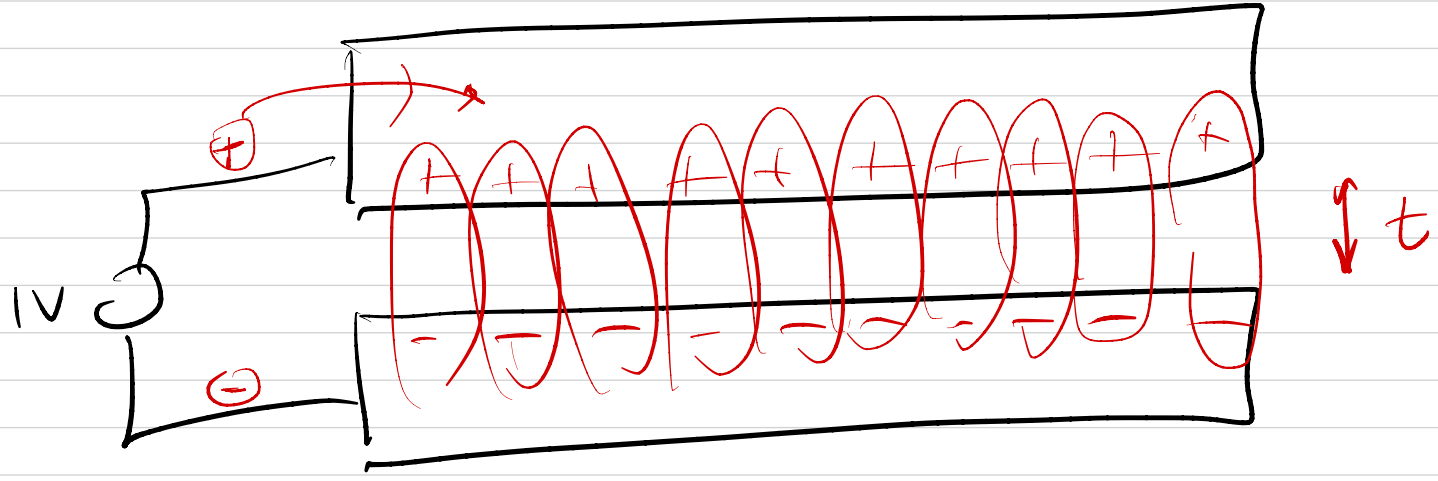
Units: $\varepsilon_0 \times$ dimension

Bus Analogy

Ground

Capacitance Between Conductors



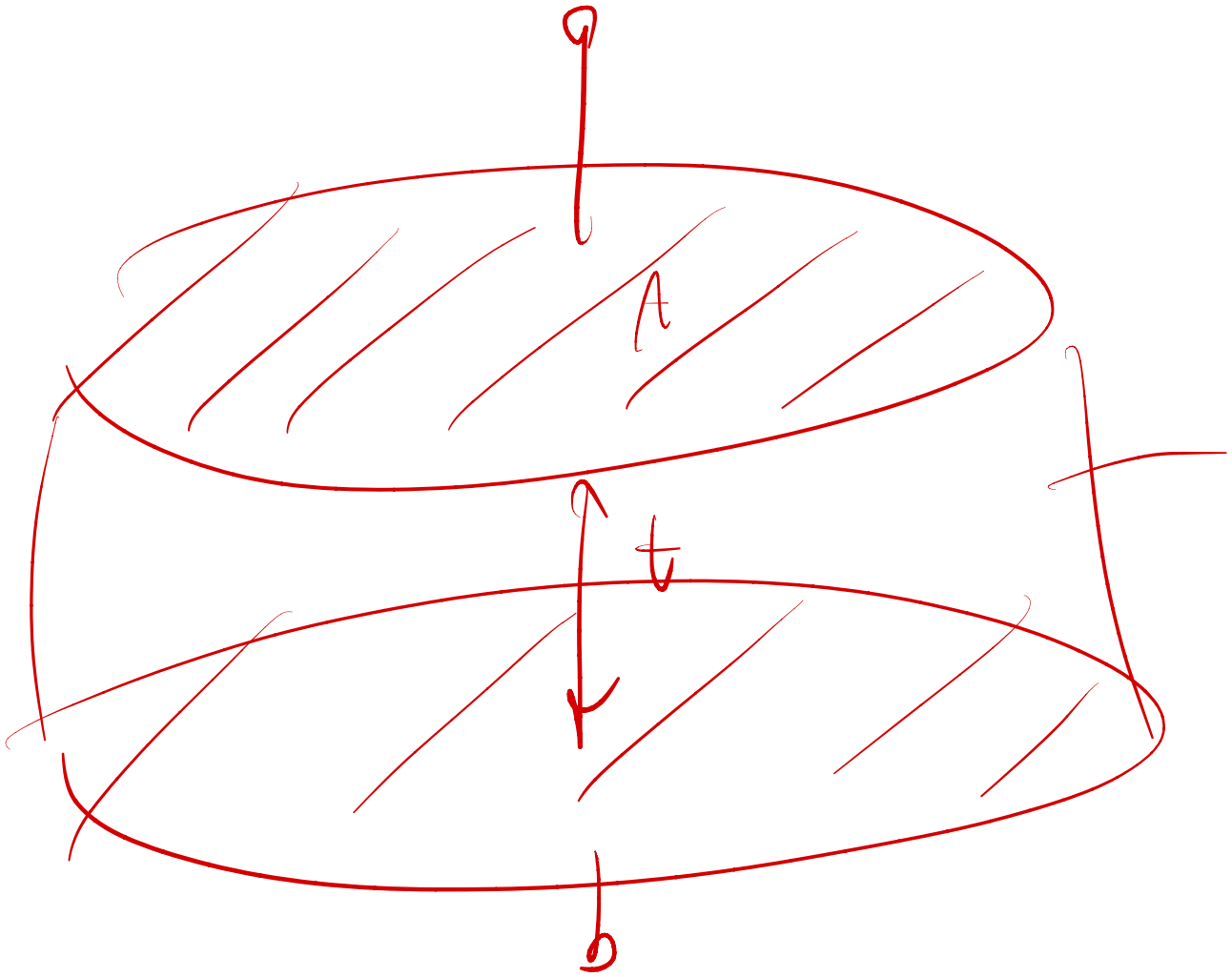


$q = CV$


&9

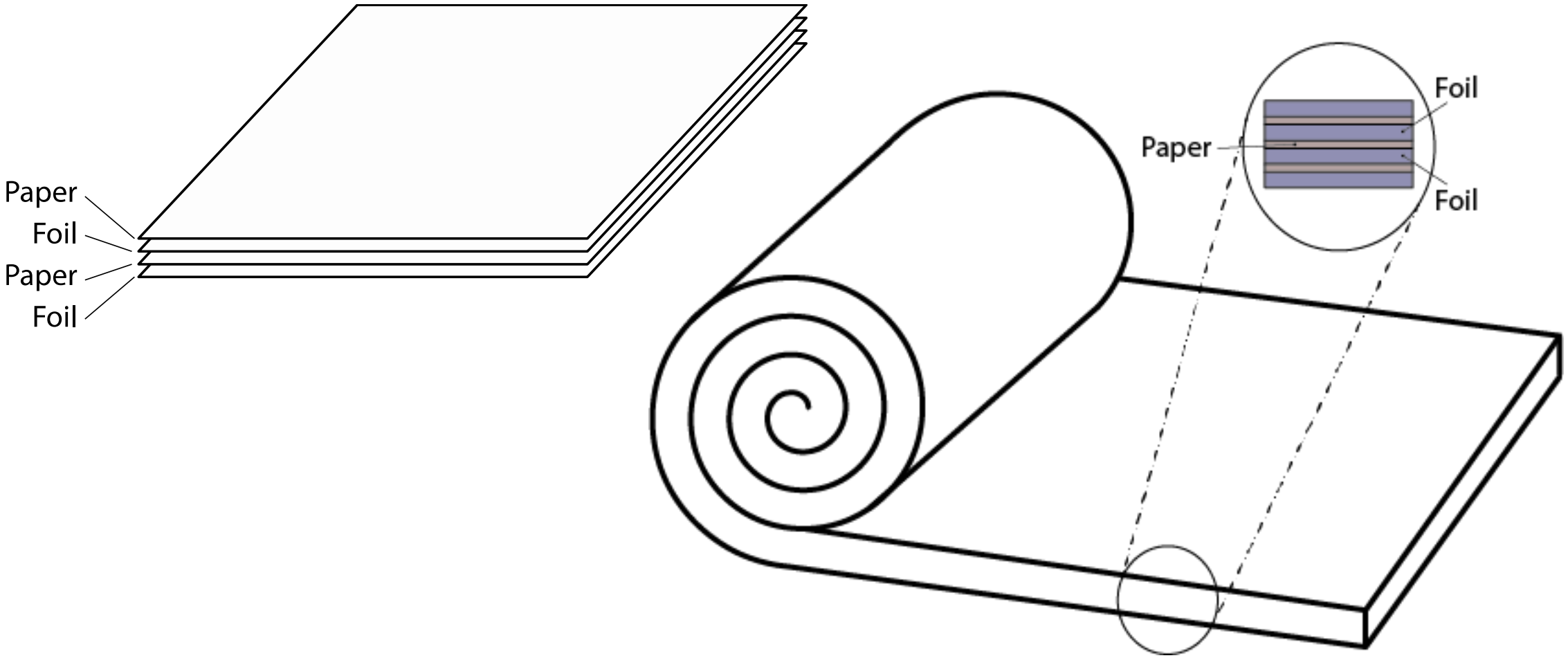
Double Decker Bus

Parallel Plate Capacitor



$$C = \varepsilon_0 \left(\frac{A}{t} \right)$$

Capacitor Fabrication



Integrated Circuit Capacitors