PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 6:

1. Electrostatic capacitance (Chapter 26)
2. Voltage and capacitance in circuits
3. Energy storage in capacitors

i-clicker exercise

Exam feedback

A. Exam was too easy
B. Exam was too hard
C. Exam was about right

i-clicker exercise

Would you like to schedule a session to go over the exam?

A. Yes
B. No

i-clicker exercise

On the possibility of an optional 4th exam

A. Would like to take a 4th exam
B. Would not like to take a 4th exam

No.	Lecture Date	Topic	Text Sections	Problem Assignments	Assignment Due Date
1	01/19/2012	Coulomb's law	23.1-23.4	23.6,23.8a,23.13	01/24/2012
2	01/24/2012	Electric field	23.4-23.7	23.22,23.20,23.61a	01/26/2012
3	01/26/2012	Gauss's Law	24.1-24.3	24.22a,24.23,24.40	01/31/2012
4	01/31/2012	Electric potential	25.1-25.4	25.12,25.23,25.34,25.01	02/02/2012
5	02/02/2012	Electric potential	25.5-25.8	(Review for exam)	
	02/07/2012	Exam			
6	02/09/2012	Capacitance and dielectrics	26.1-26.7	26.4,26.13,26.30	02/14/2012
7	02/14/2012	Current and resistance	27.1-27.6	27.3,27.12,27.29	02/16/2012
8	02/16/2012	Direct current circuits	28.1-28.2	28.3,28.7,28.19	02/21/2012
9	02/21/2012	Direct current circuits	28.3-28.5	28.23,28.25,28.34	02/23/2012
10	02/23/2012	Review	26.1-28.5	(Review for exam)	
	02/28/2012	Exam			
11	03/01/2012	Magnetic fields	29.1-30.6		
12	03/06/2012	Faraday's law	31.1-31.5		

Remember to send in your chapter reading questions…

First – a word from our sponsors:

http://www.wfu.edu/physics

The Physics Department will host a reception for all prospective Physics majors on Monday, February 13 from 3-4:30 p.m. in the Olin foyer.

Wake Forest Research Fellowship Program

http://college.wfu.edu/research-fellowship/

Purpose

The Wake Forest Research Fellowship Program is designed to encourage individual Wake Forest undergraduates to join their professors as junior partners on scholarly research and creative projects. These mentored projects provide invaluable opportunities for students to experience the excitement of performing innovative scholarly work.

About the Award

These projects are performed during the 10 weeks of the Wake Forest University summer school sessions. The award provides a $4,000.00 stipend. If on-campus housing is desired, the award will also provide for one-half the cost of a double room for both summer sessions. So that students can devote their entire energies toward their projects, Wake Forest Research Fellowship recipients may not enroll in summer school courses. It is hoped that many projects begun in the Fellowship program might continue in the form of independent study or directed research courses in subsequent years.

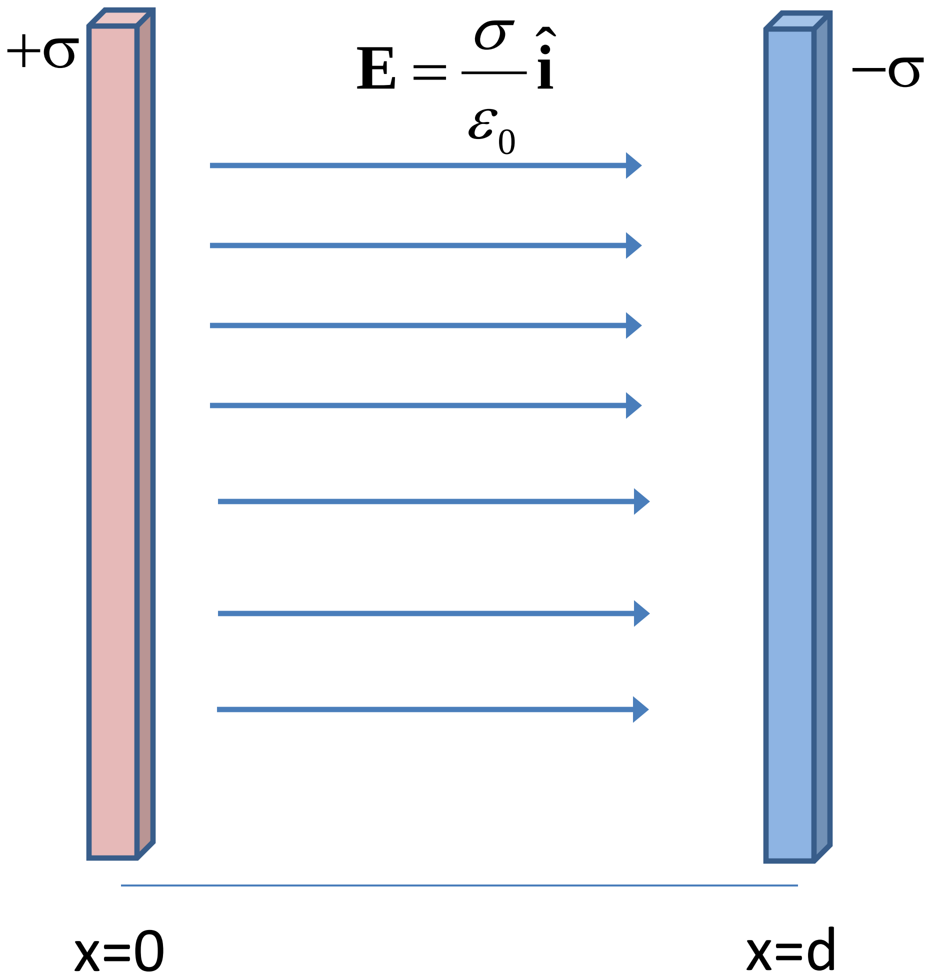
If required for the work, the student and mentor may request up to $500 support for supplies.

Qualifications and Requirements

Student applicants must have a cumulative 3.0 grade point average at the time of application. Sophomore standing (25 or more hours passed) is required by the time the research project begins.

Proposals are due by February 22, 2012.

Electric potential for constant electric field:



$$V = -\int_{x_{ref}}^{x} \mathbf{E}\cdot d\mathbf{s}$$

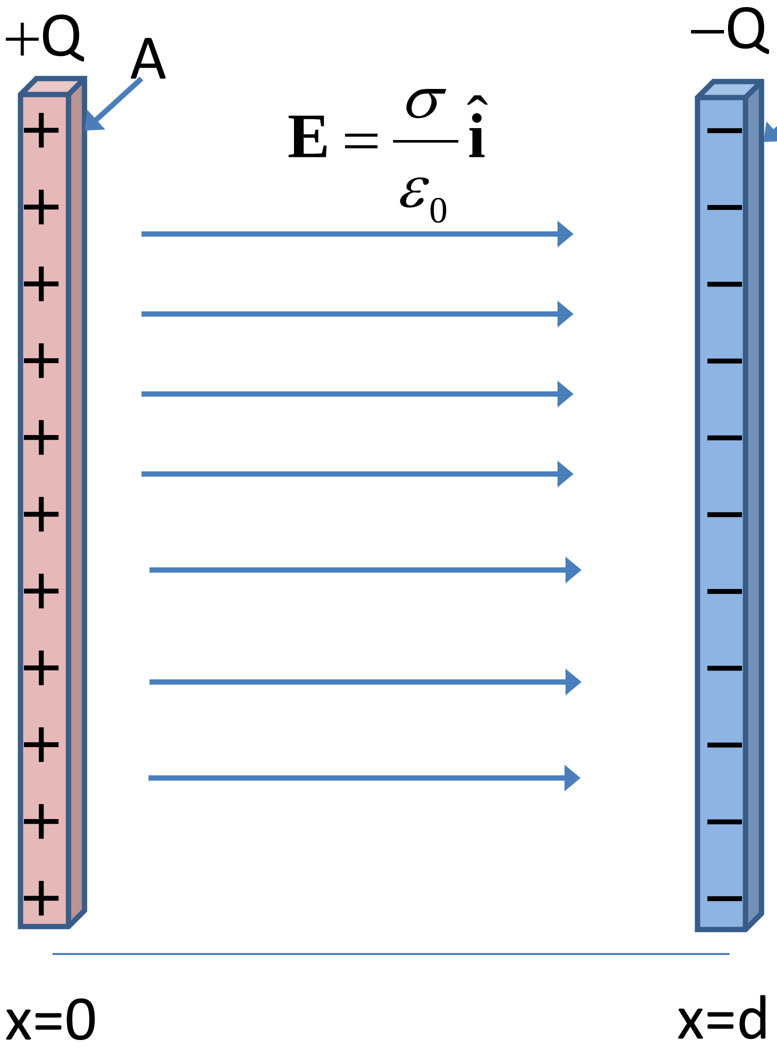
$$= -\int_{0}^{x} \frac{\sigma}{\varepsilon_0} dx'$$

$$= -\frac{\sigma}{\varepsilon_0} x \quad \text{for } 0 \le x \le d$$

$$\Delta V = V(d) - V(0) = -\frac{\sigma}{\varepsilon_0} d$$

$$\sigma = \frac{Q}{A} \quad \Rightarrow \Delta V = -Q\frac{d}{A\varepsilon_0}$$

Electric potential between parallel plates with charge Q



$$\mathbf{E} = \frac{\sigma}{\varepsilon_0}\hat{\mathbf{i}}$$

$$V = -\int_{x_{ref}}^{x} \mathbf{E}\cdot d\mathbf{s}$$

$$\Delta V = V(d) - V(0) = -\frac{\sigma}{\varepsilon_0} d$$

$$\sigma = \frac{Q}{A} \quad \Rightarrow \Delta V = -Q\frac{d}{A\varepsilon_0}$$

$$\Delta V = -\frac{Q}{A\varepsilon_0 / d} \equiv -\frac{Q}{C}$$

$$\Rightarrow C = A\varepsilon_0 / d$$

General formulation of capacitance

Ignoring sign: $Q = C\ \Delta V$

Charge on + and – terminals of capacitor

Depends on geometry and material composition of capacitor

Voltage drop across capacitor terminals

Units: $C = \dfrac{\text{Coulombs}}{\text{Volt}} \equiv \text{Farad}$

For parallel plate capacitors in vacuum (or air):

$$C = A\varepsilon_0 / d$$

For parallel plate capacitors in dielectric medium:

$$C = A\kappa\varepsilon_0 / d$$

$\kappa \equiv$ dielectric constant (typically $\kappa > 1$)

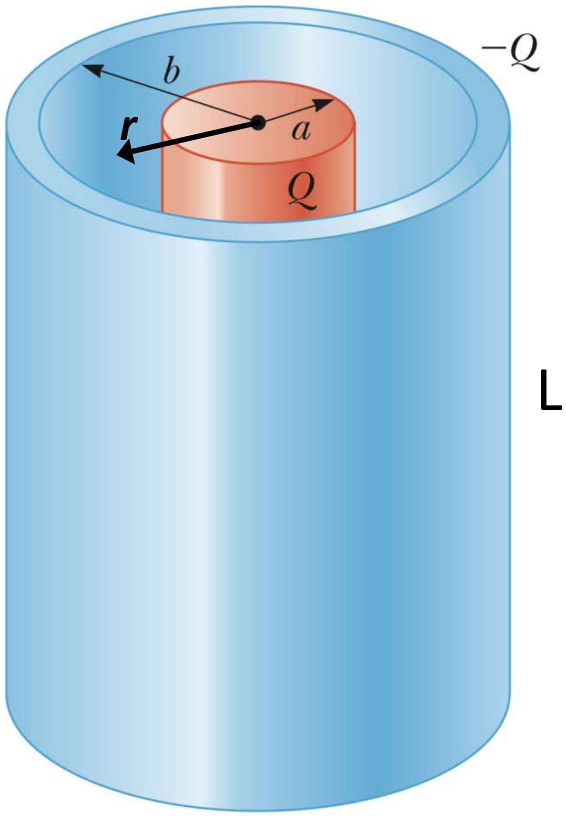
Cylindrical geometry capacitor:

$$\mathbf{E} = \frac{Q}{2\pi\varepsilon_0 L}\frac{\hat{\mathbf{r}}}{r} \qquad \text{for} \quad a \le r \le b$$

$$V_b - V_a = -\int_a^b \mathbf{E} \cdot d\mathbf{r}$$

$$= -\frac{Q}{2\pi\varepsilon_0 L}\int_a^b \frac{dr}{r}$$

$$= -\frac{Q}{2\pi\varepsilon_0 L}\ln\frac{b}{a}$$



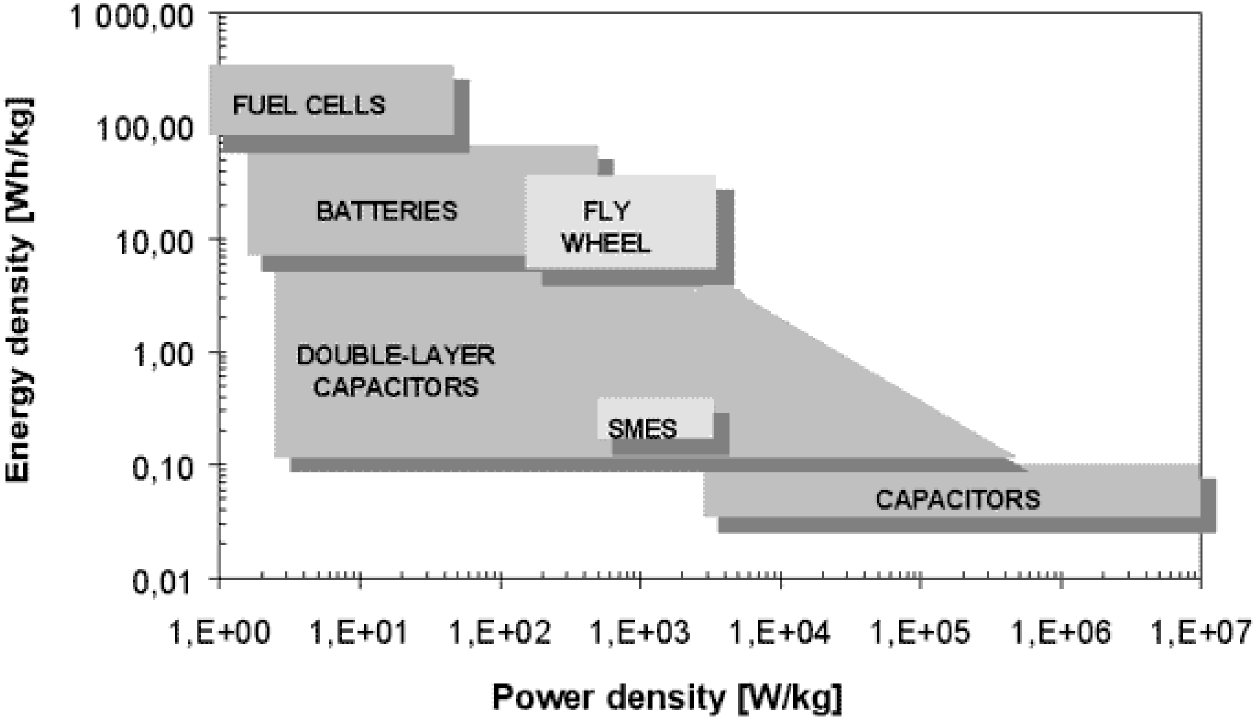
$$Q = C\,\Delta V$$

$$\Rightarrow C = \frac{2\pi\varepsilon_0 L}{\ln(b/a)} \quad \text{(in vacuum or air)}$$

$$\Rightarrow C = \frac{2\pi\kappa\varepsilon_0 L}{\ln(b/a)} \quad \text{(dielectric medium)}$$

Capacitor usage in energy storage:

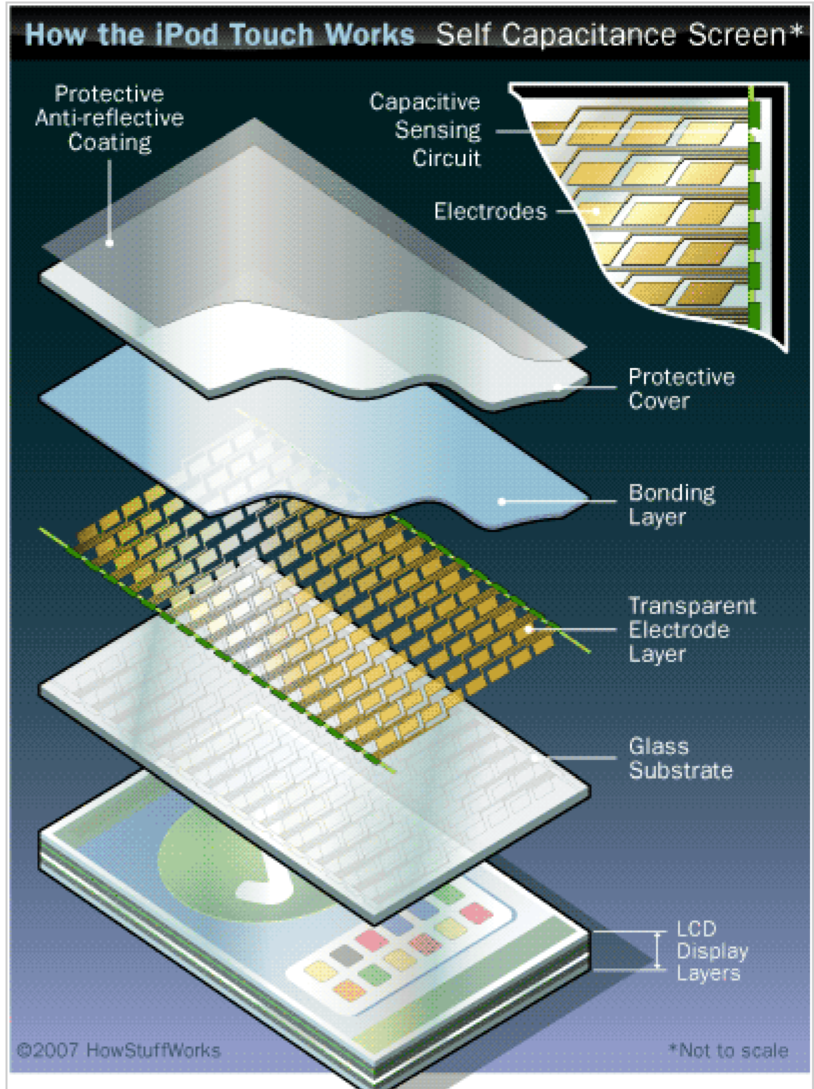
http://www.mpoweruk.com/alternatives.htm



Questions about usefulness of electric fields outside of physics class.

Example: ipad touch screen (from HowThingsWork web page)

- **Self capacitance:** Circuitry monitors changes in an array of electrodes.
- **Mutual capacitance:** A layer of **driving lines** carries current. A separate layer of **sensing lines** detects changes in the electrical charge when you place your finger on the screen.

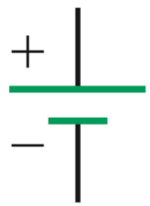


Regardless of which method the screen uses, you change the electrical properties of the screen every time you touch it. The iPod records this change as data, and it uses mathematical algorithms to translate the data into an understanding of where your fingers are. In the next section, we'll explore what the iPod touch does with this data and how to navigate through its features.

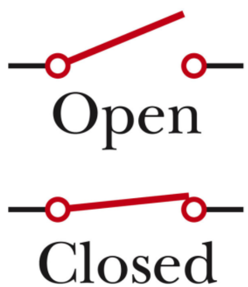
Electrical circuits using capacitors and voltage source

Capacitor symbol

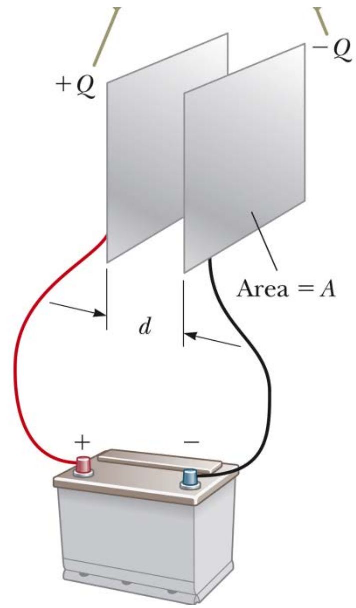
Battery symbol

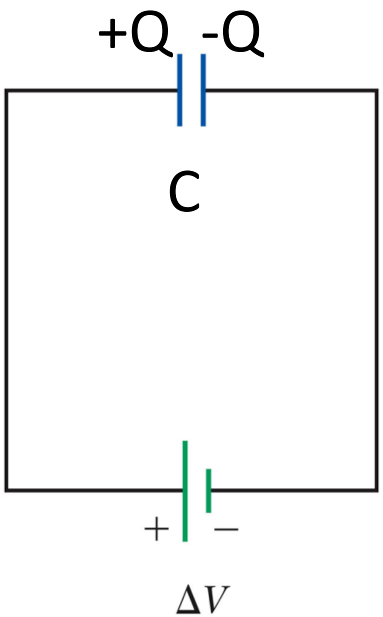


Switch symbol



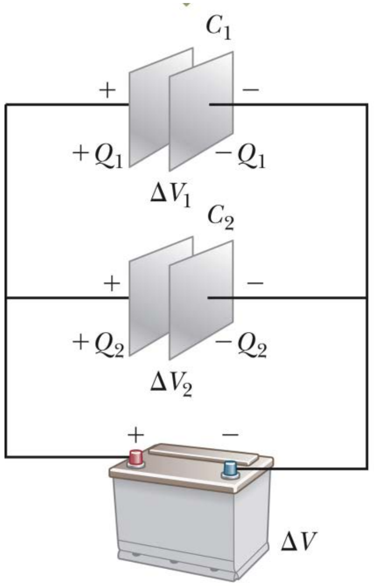
Wire connection

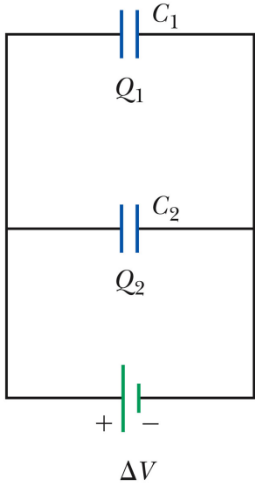




$$\Delta V = \frac{Q}{C}$$

More complicated circuits –
Capacitors connected in parallel





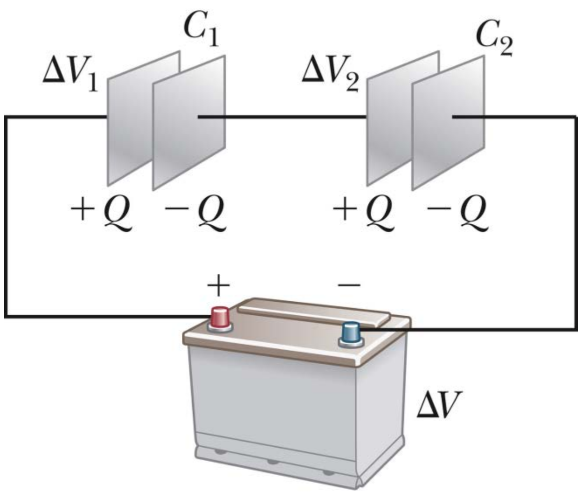
$$\Delta V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} \equiv \frac{Q_{tot}}{C_{eq}}$$

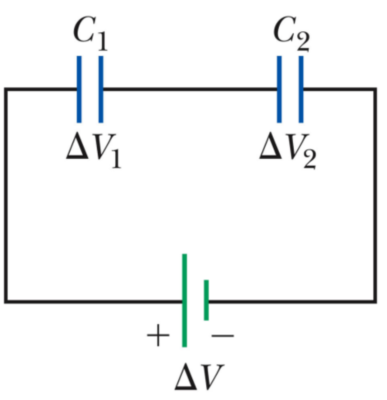
$$Q_{tot} = Q_1 + Q_2 = C_1 \Delta V + C_2 \Delta V$$

$$= \left(C_1 + C_2\right) \Delta V$$

$$\Rightarrow C_{eq} = C_1 + C_2$$

More complicated circuits –
Capacitors connected in series





$$\Delta V = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} \equiv \frac{Q_{tot}}{C_{eq}}$$

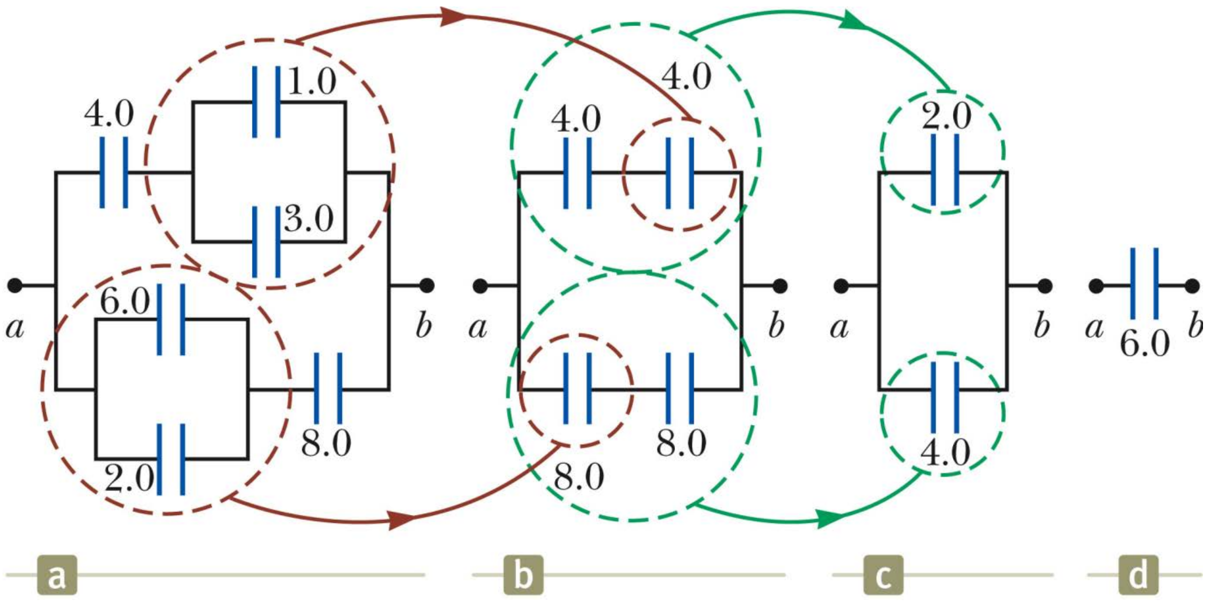
$$Q_{tot} = Q_1 = Q_2 = C_{eq}\Delta V$$

$$\Rightarrow C_{eq} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}}$$

Equivalent capacitance circuits

$$\text{Parallel connections: } C_{eq} = C_1 + C_2 + C_3 + \cdots$$

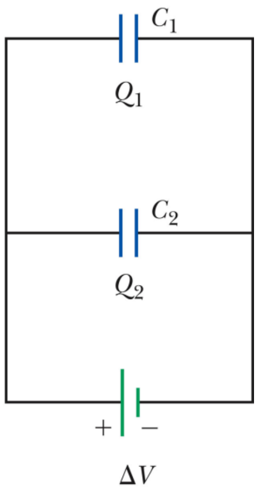
$$\text{Series connections: } C_{eq} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \cdots}$$



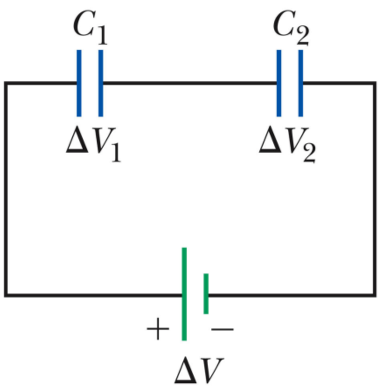
i-clicker question

Consider the circuit diagrams shown below. In each the voltage is ΔV=100V and C_1=C_2=1μF. Which circuit can store the most total charge?

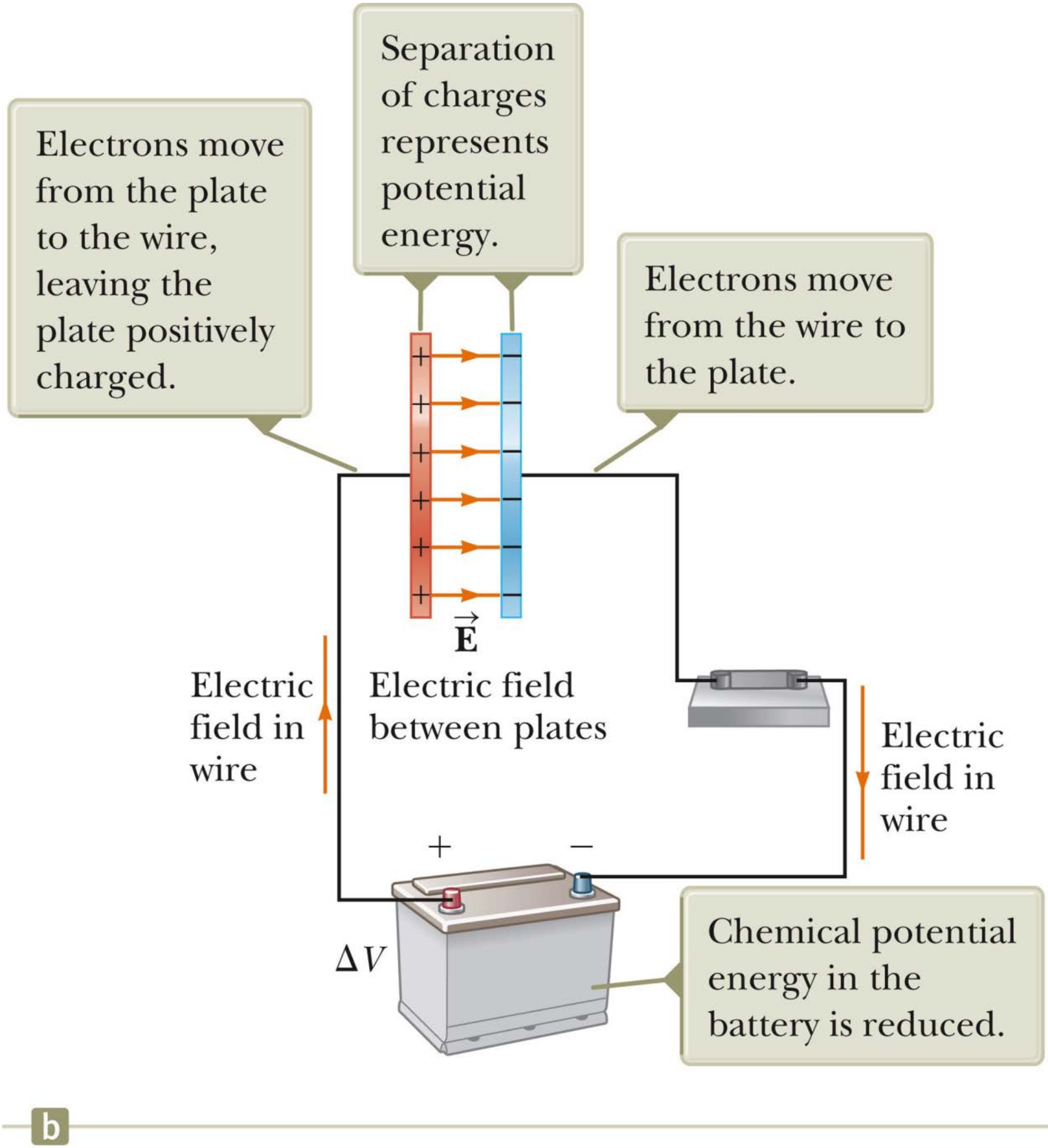
A.



B.



Energy storage within a capacitor

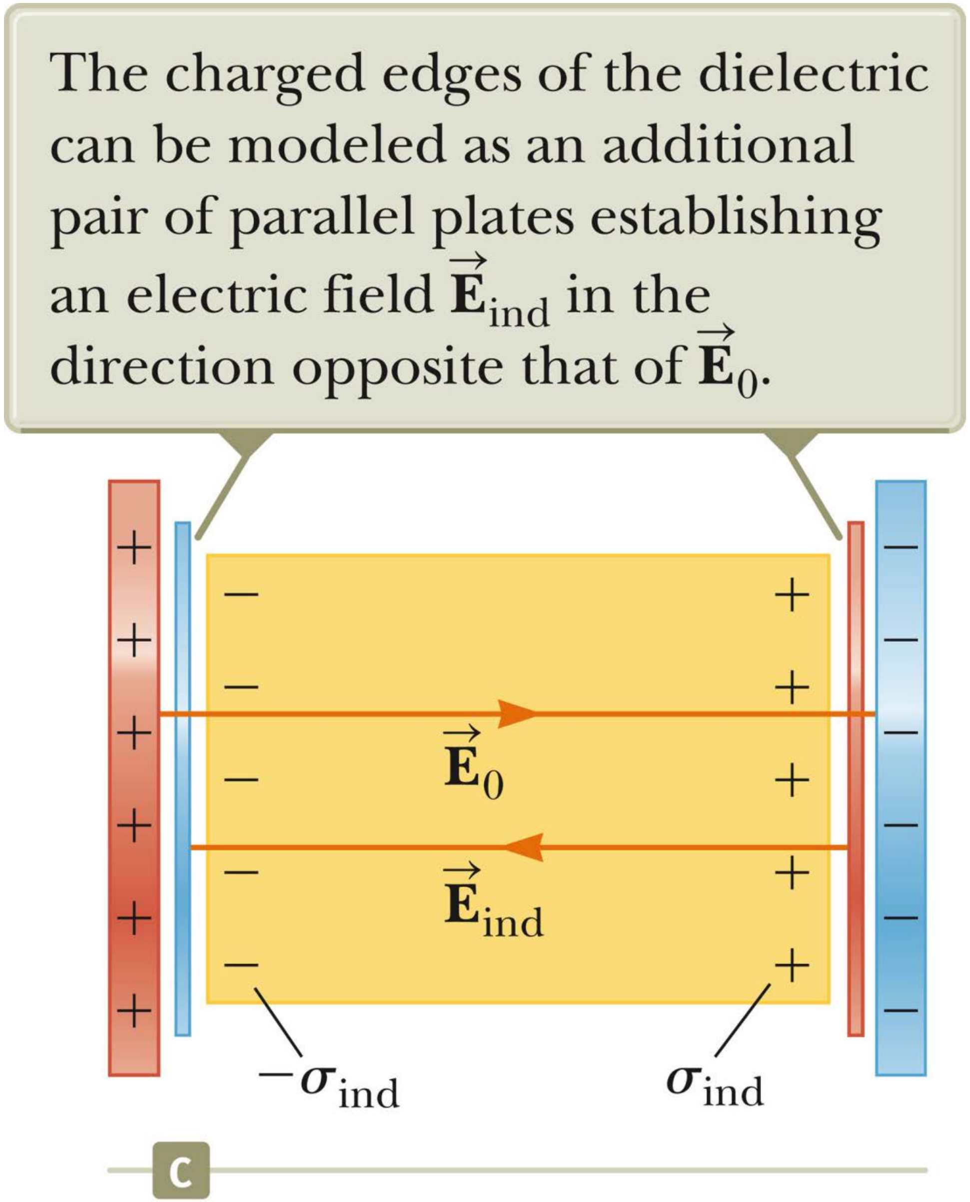


$$dU = \frac{q}{C}dq$$

$$U = \int_0^Q \frac{q}{C}dq = \frac{1}{2}\frac{Q^2}{C}$$

$$U = \frac{1}{2}C(\Delta V)^2$$

Effects of dielectric materials in capacitors



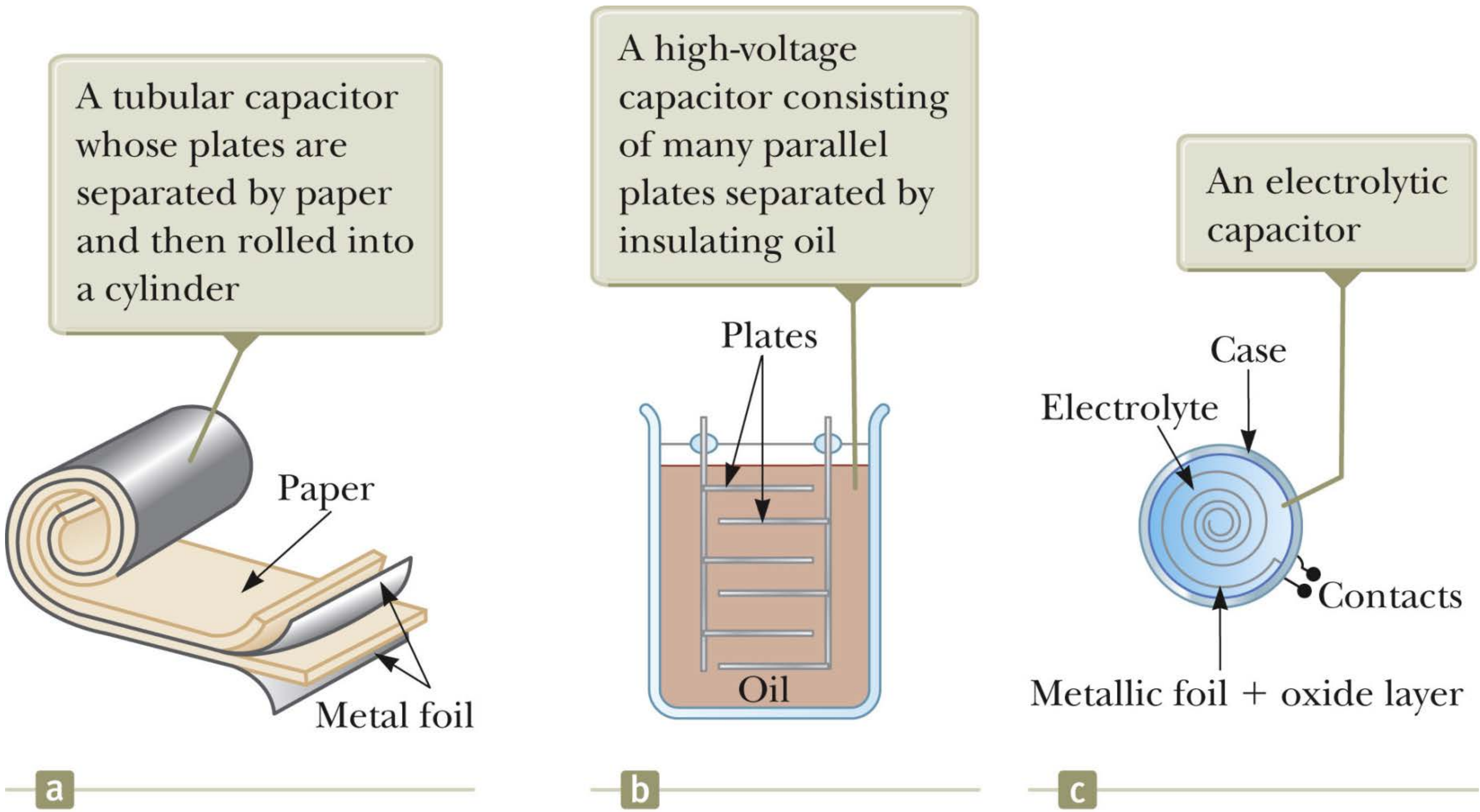
$$\mathbf{E}_{total} = \mathbf{E}_0 - \mathbf{E}_{ind}$$

$$\mathbf{E}_{ind} = \chi \mathbf{E}_{total}$$

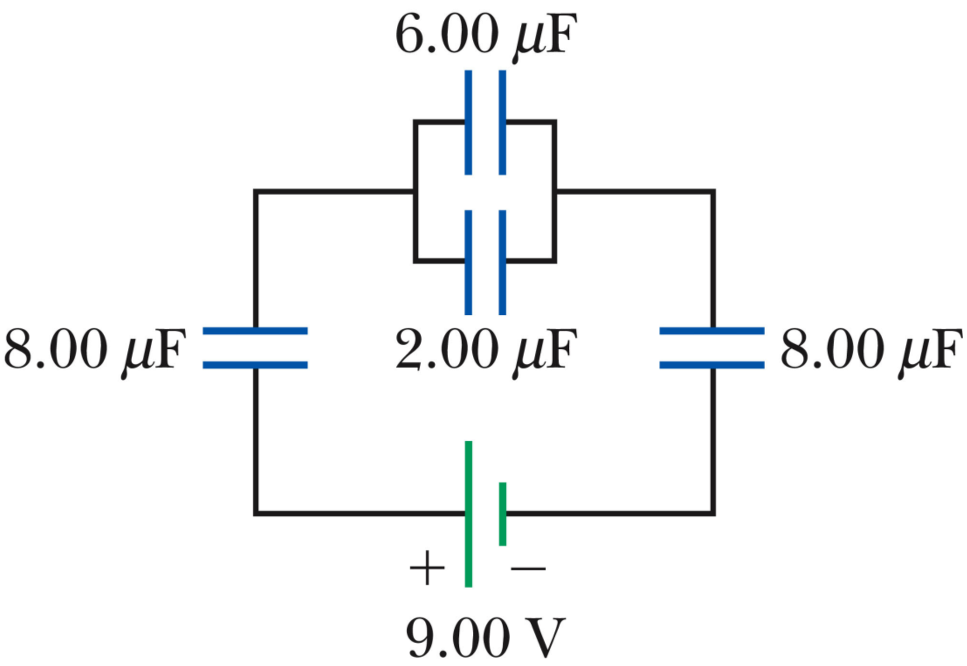
$$\mathbf{E}_{total} = \frac{1}{1+\chi}\mathbf{E}_0 \equiv \frac{1}{\kappa}\mathbf{E}_0$$

$$\Delta V_{total} = \frac{1}{\kappa}\Delta V_0 = \frac{Q}{\kappa C_0}$$

$$\Rightarrow C = \kappa C_0$$


A tubular capacitor whose plates are separated by paper and then rolled into a cylinder
Paper
Metal foil
a
A high-voltage capacitor consisting of many parallel plates separated by insulating oil
Plates
Oil
b
An electrolytic capacitor
Case
Electrolyte
Contacts
Metallic foil + oxide layer
c

Example:



Find equivalent capacitance:

$$C_{eq} = \frac{1}{\frac{1}{8} + \frac{1}{6+2} + \frac{1}{8}} \mu F = \frac{8}{3} \mu F$$

Find total charge:

$$Q = C_{eq} \Delta V = \frac{8}{3} \times 10^{-6} \cdot 9 \text{ Coul}$$

$$= 2.4 \times 10^{-5} \text{ Coul}$$

TABLE 26.1 *Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature*

Material	Dielectric Constant κ	Dielectric Strength[a] (10^6 V/m)
Air (dry)	1.000 59	3
Bakelite	4.9	24
Fused quartz	3.78	8
Mylar	3.2	7
Neoprene rubber	6.7	12
Nylon	3.4	14
Paper	3.7	16
Paraffin-impregnated paper	3.5	11
Polystyrene	2.56	24
Polyvinyl chloride	3.4	40
Porcelain	6	12
Pyrex glass	5.6	14
Silicone oil	2.5	15
Strontium titanate	233	8
Teflon	2.1	60
Vacuum	1.000 00	—
Water	80	—

[a]The dielectric strength equals the maximum electric field that can exist in a dielectric without electrical breakdown. These values depend strongly on the presence of impurities and flaws in the materials.