

PHYS 2321

Week 6: Capacitance

W6 Day 3 Outline

- 1) Hwk: Ch. 24 MiscQ. 1-13 odd Due Friday
Prob. 1,5,6,7,10,11,13,16,21,22,24,38,39,40,53
- 2) Capacitors and capacitance
 - a. Examples of capacitors
 - b. $C \equiv Q/\Delta V$ = charge per volt across capacitor
 - c. $C = A\epsilon_0/d$ for parallel plate capacitor
- 3) Review Exam I (mean = 19.5/30, 65%)

Notes:

Try Practice Quiz for Ch. 24.

Watch YouTube video by Khan Academy

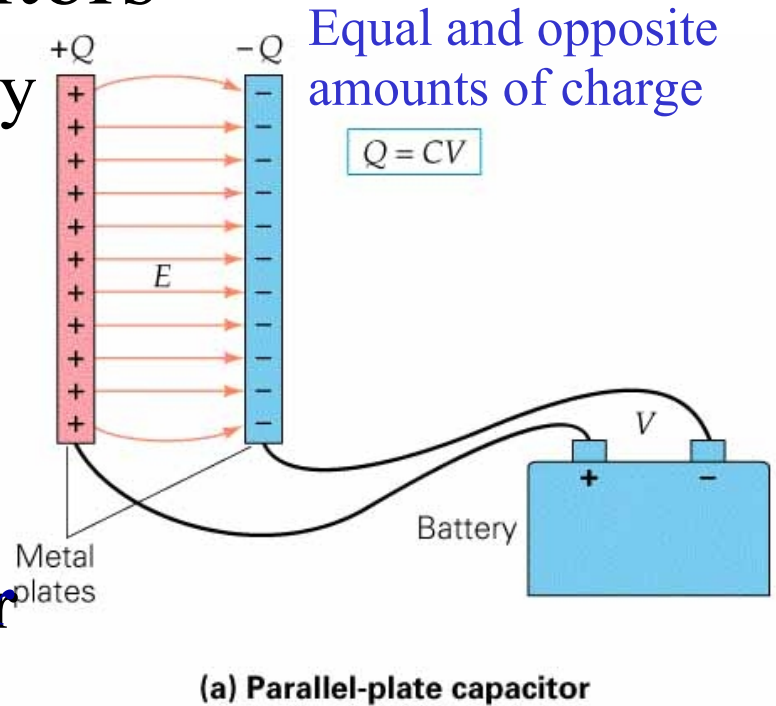
Types of capacitors



By Eric Schrader from San Francisco, CA, United States - 12739s, CC BY-SA 2.0,
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Capacitors

- Charge separation stores energy
- Parallel Plates
 - Uniform E field
 - $V = \Delta V$ between plates
- **Capacitance: the “charge per volt” on a capacitor**



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

Capacitance governs ...

How much charge is required to produce 1 volt “on” the capacitor ($Q=CV$),

What the potential difference will be if $\pm Q$ of charge is on the plates. ($V=Q/C$)

Units: 1 Farad = 1 Coulomb/Volt

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Week 7: Capacitance

W7 Day 1 Outline

- 1) Hwk: Ch. 24 MiscQ. 1-13 odd Due Friday
Prob. 1,5,6,7,10,11,13,16,21,22,24,38,39,40,53
- 2) Capacitors and capacitance
 - a. Calculating capacitance
 - b. Ex) $C = A\epsilon_0/d$ for parallel plate capacitor
- 3) Combining capacitors in series and parallel
- 4) Energy in capacitors

Notes:

Try Practice Quiz for Ch. 24.

Watch YouTube video by Khan Academy

Compute Capacitance of P.Plate Capacitor

1) Determine E-field between plates.

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$$

2) Find $|\Delta V|$.

$$|\Delta V| = Ed \equiv \frac{\sigma d}{\epsilon_0} = \frac{Qd}{A\epsilon_0}$$

3) Insert into $C = Q/\Delta V$, and

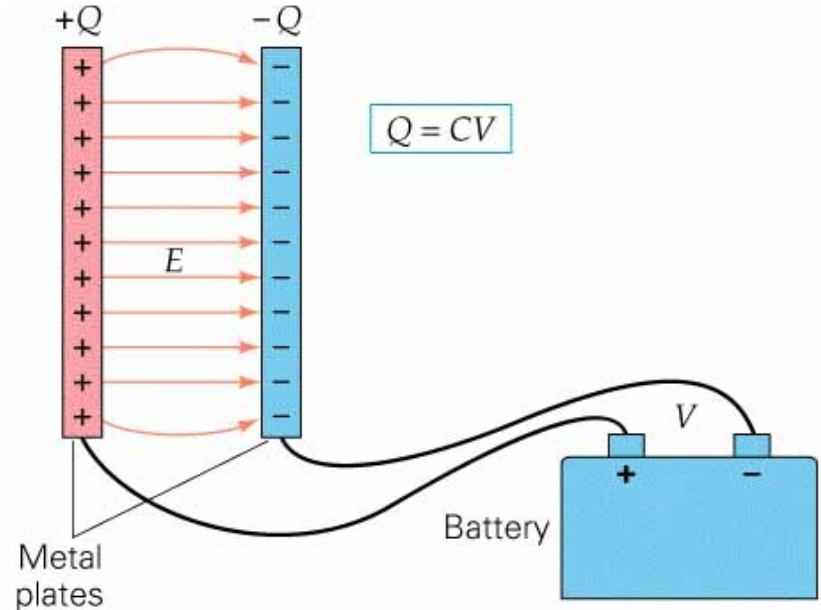
4) Eliminate Q:

$$C = \frac{QA\epsilon_0}{Qd} = \frac{A\epsilon_0}{d}$$

5) Add k for dielectric constant:

$$C = \kappa C_0$$

$$C = \kappa \frac{A\epsilon_0}{d}$$



(a) Parallel-plate capacitor

For Parallel Plates only.

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$$

Calculating Capacitance

1) Determine E inside capacitor. (May need Gauss's law.)

$$\Delta V = - \int_a^b \vec{E} \cdot d\vec{s}$$

2) Determine ΔV between the plates.

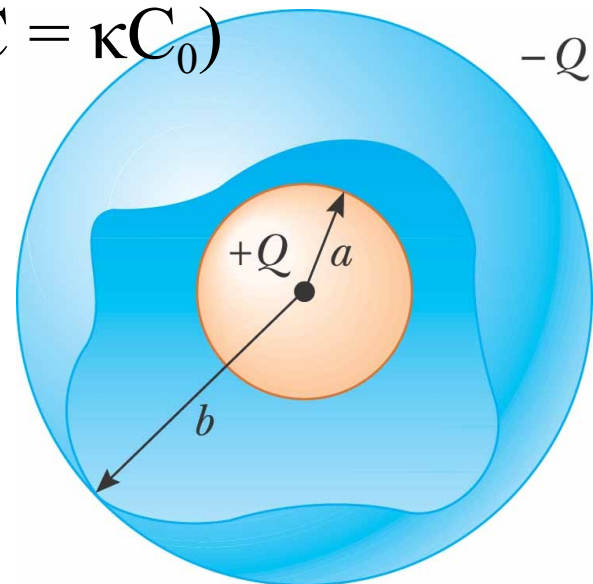
3) Insert ΔV into $C = Q/\Delta V$.

4) Cancel the Q 's.

5) Consider the dielectric filler. ($C = \kappa C_0$)

Example: concentric spheres

$$C_{\text{spheres}} = \frac{ab}{k_e(b-a)}$$



Calculating Capacitance

Other examples:

1) Parallel plates

$$C = \frac{A\epsilon_0}{d}$$

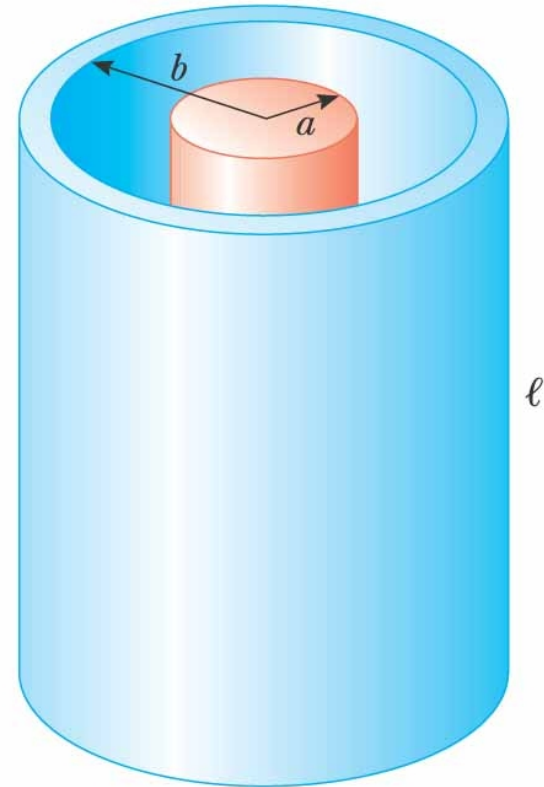
2) Concentric cylinders

$$\frac{l}{2k_e \ln(b/a)} = \frac{2\pi\epsilon_0 l}{\ln(b/a)}$$

3) Single sphere

$$C = 4\pi\epsilon_0 R$$

Example: concentric cylinders



(a)

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Week 7: Capacitance

W7 Day 2 Outline

Hwk: Ch. 24 MiscQ. 1-13 odd Due Friday

Prob. 1,5,6,7,10,11,13,16,21,22,24,38,39,40,53

- 1) Combining capacitors in series and parallel
- 2) Energy in capacitors
- 3) Energy density, u
- 4) Dielectrics

Notes:

Hwk on Ch. 23 mean=9.4/10. Checked #25,36, MQ11,13.

Try Practice Quiz for Ch. 24.

Watch YouTube video by Khan Academy

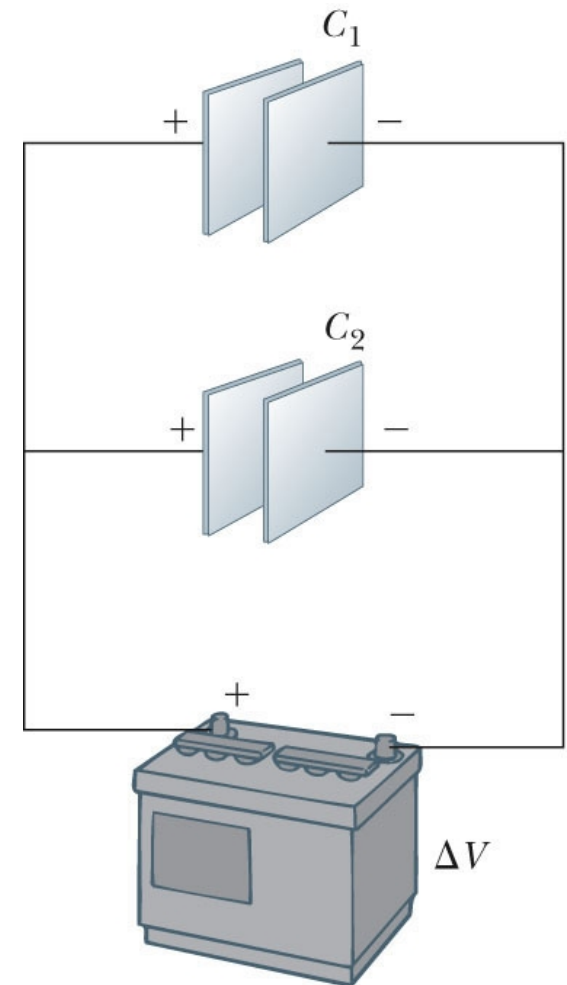
Midterm Grade will be based on 50% exam, 25% quiz, 25% hwk.

Combining Capacitors

- Two fundamental arrangements: parallel and series.
- Characteristics of a parallel connection:

- 1) The same ΔV is across each capacitor.
- 2) If $C_1 \neq C_2$, then $Q_1 \neq Q_2$. (In general, the charges are unequal.)
- 3) Since the total area of the plates is greater for 2 capacitors than 1, the equivalent capacitance goes up.
- 4) For N capacitors in parallel:

$$C_{eq} = C_1 + C_2 + C_3 + \dots + C_N$$



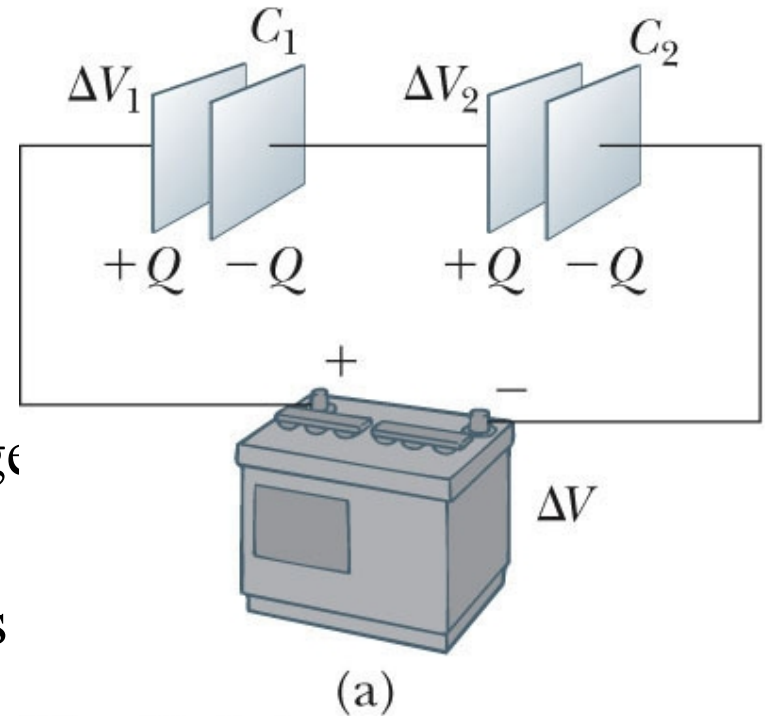
(a)

Combining Capacitors

- Characteristics of a series connection:

- 1) The same charge Q exists on each plate!
- 2) If $C_1 \neq C_2$, then $\Delta V_1 \neq \Delta V_2$. (The voltage can be different on each cap..)
- 3) The sum of the ΔV 's is the ΔV across the battery.
- 4) The equivalent capacitance is less than even the smallest capacitor in series.
- 5) For N capacitors in series:

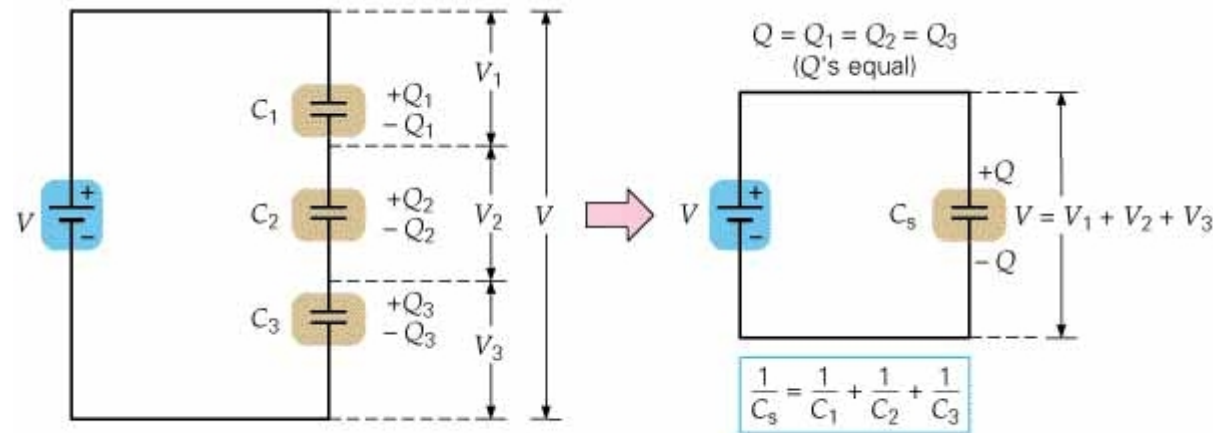
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_N}$$



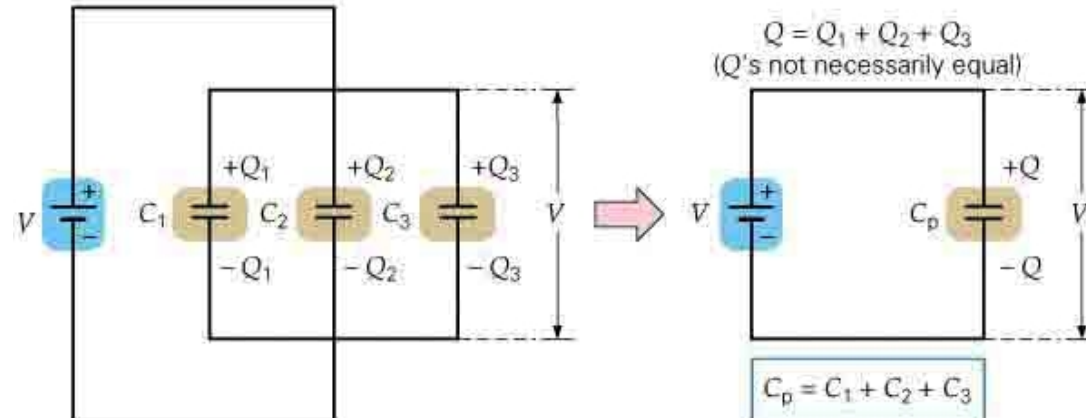
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Combining Capacitors

- Goal: combine them into one *equivalent capacitance*



(a) Capacitors in series

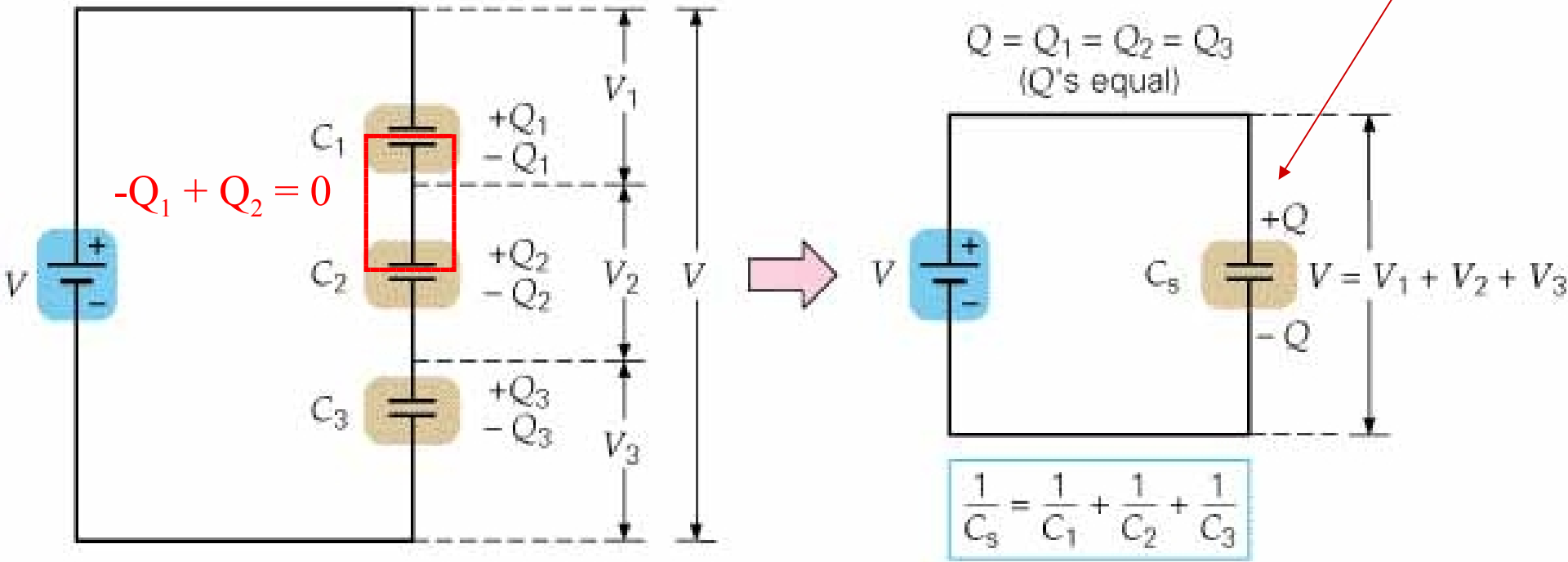


(b) Capacitors in parallel

Capacitors in Series

Equivalent capacitor

- Charge in each plate is the same



(a) Capacitors in series

$$C_1 = \frac{Q}{V_1}, C_2 = \frac{Q}{V_2}, C_3 = \frac{Q}{V_3}$$

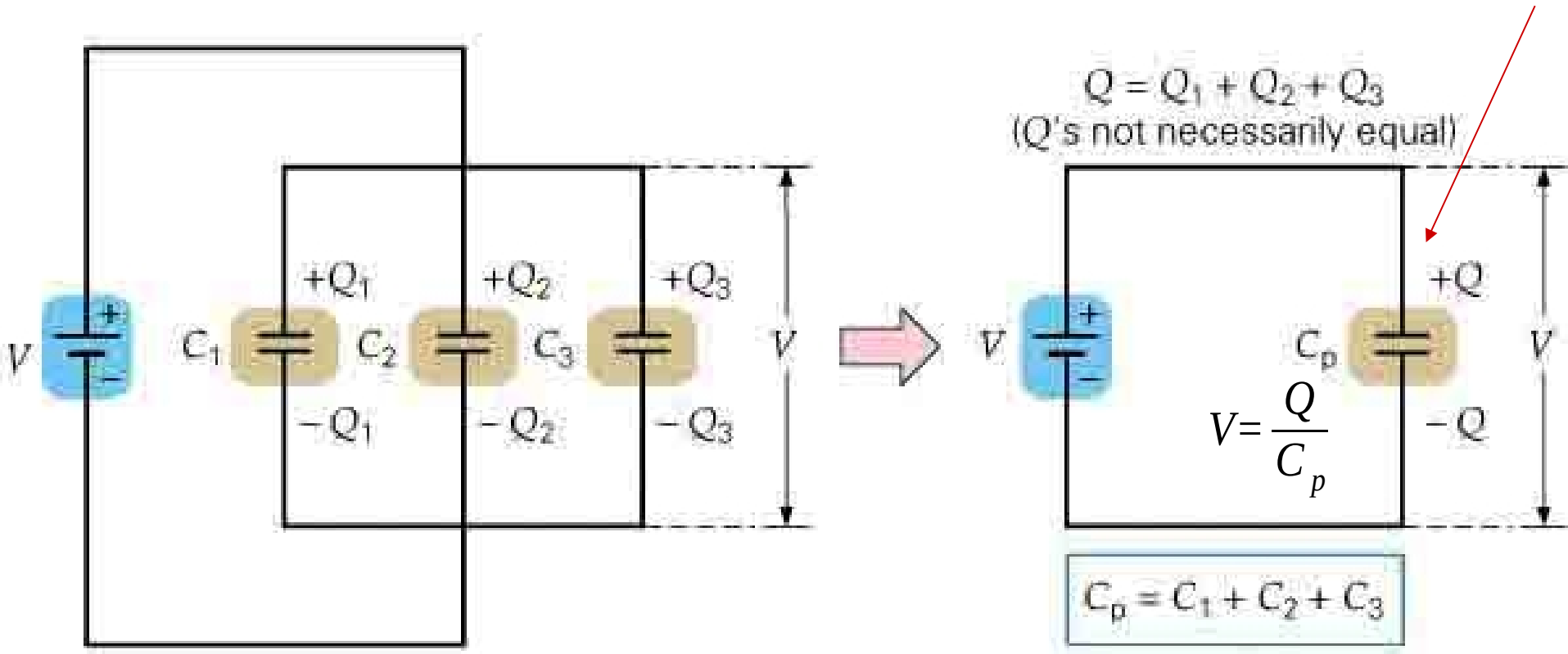
$$V_1 = \frac{Q}{C_1}, V_2 = \frac{Q}{C_2}, V_3 = \frac{Q}{C_3}$$

$$V = V_1 + V_2 + V_3, V = \frac{Q}{C_s}$$

Capacitors in Parallel

- Voltage on each plate is the same $V = V_1 = V_2 = V_3$

Equivalent capacitor



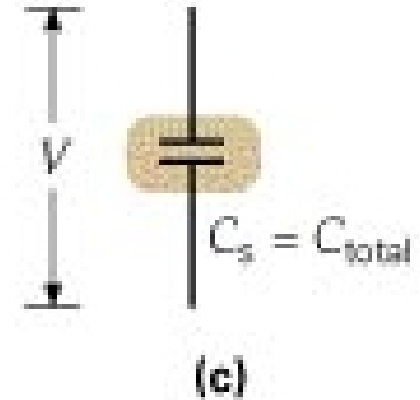
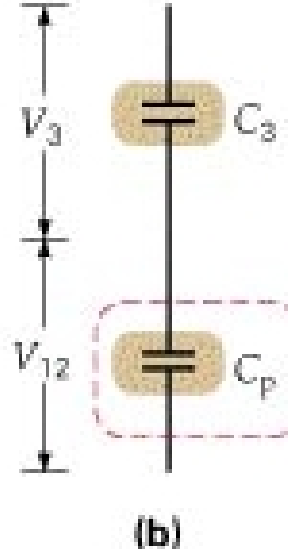
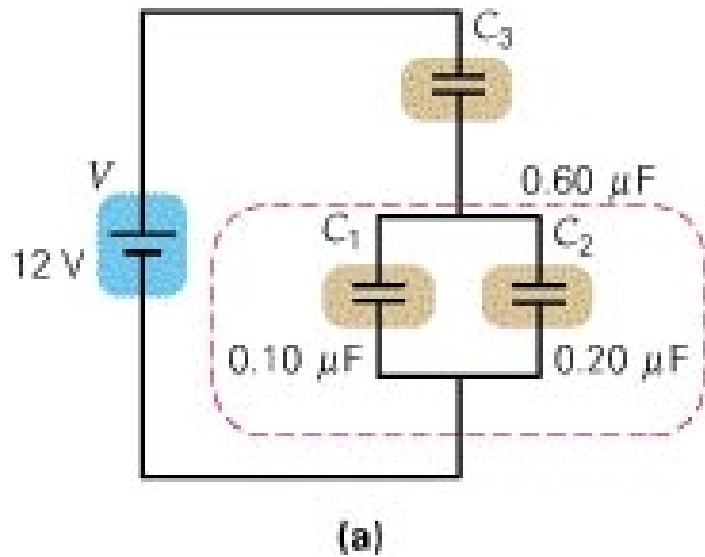
(b) Capacitors in parallel

$$Q = Q_1 + Q_2 + Q_3$$

$$Q_1 = C_1 V \quad Q_2 = C_2 V \quad Q_3 = C_3 V$$

Combinations of Series and Parallel

- Get to one equivalent capacitor



First combine C_1 and C_2 that are in parallel

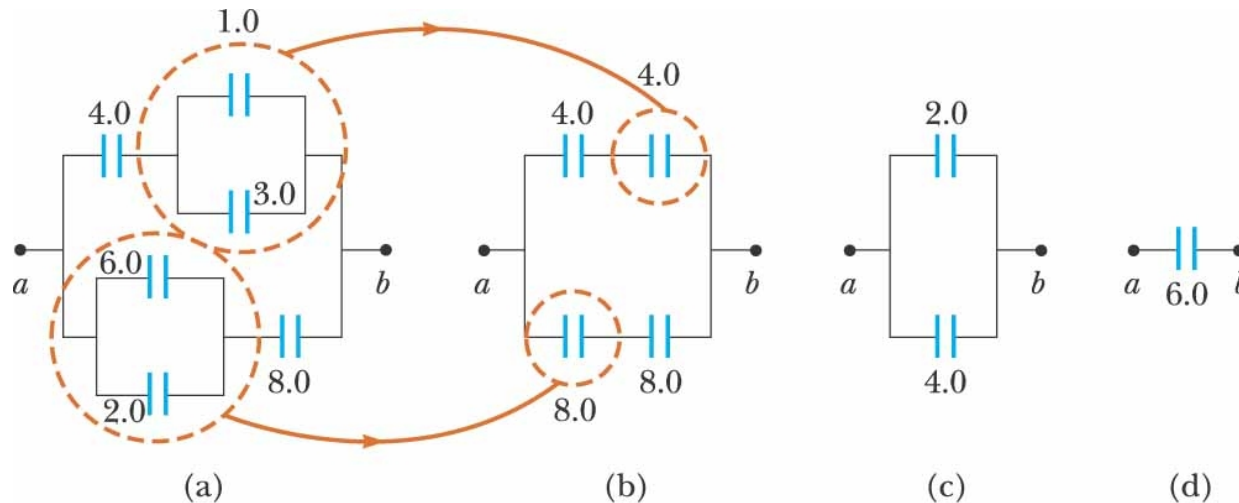
Second combine C_{12} (C_p in diagram) and C_3 in series

CANNOT DO THE FOLLOWING:

C_3 and C_1 in series, then C_2 in parallel or series. Or,

C_3 and C_2 in series, then C_1

Equivalent Capacitance, Example



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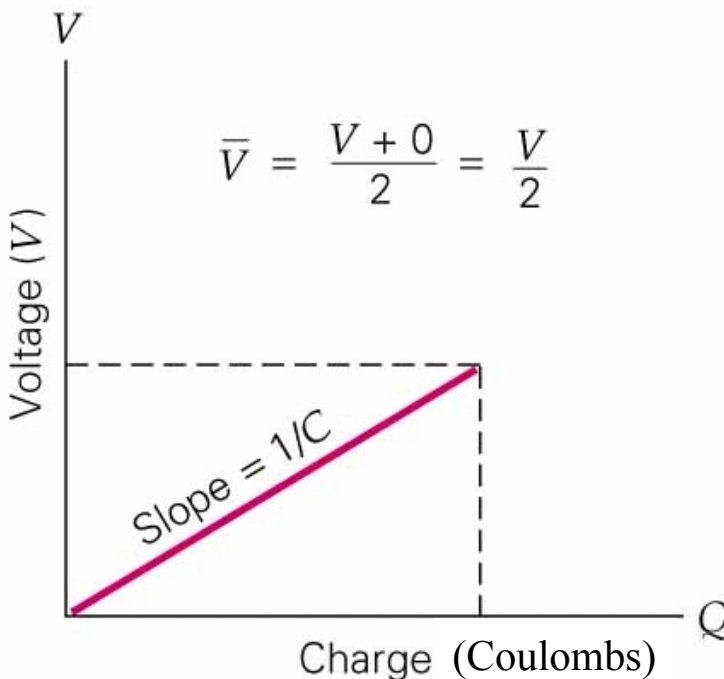
The 1.0- μF and 3.0- μF capacitors are in parallel as are the 6.0- μF and 2.0- μF capacitors

These parallel combinations are in series with the capacitors next to them

The series combinations are in parallel and the final equivalent capacitance can be found

Energy in a capacitor

- It takes energy to separate charge (& create E-field)
- The battery provides it, but that involves chemistry.
- Instead imagine charging plates “by hand”
 - Work by hand to move charge dq : $dW = dq\Delta V = dq q / C$
 - Total work to move all charge:



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

OR ... area under V vs Q
is energy!

$$U_c = \frac{1}{2} QV = \frac{Q^2}{2C} = \frac{1}{2} CV^2$$

Energy of a charged capacitor

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Week 7: Capacitance / Current

W7 Day 3 Outline

Hwk: Ch. 24 MiscQ. 1-13 odd Due **today** (< 2 pm)

Prob. 1,5,6,7,10,11,13,16,21,22,24,38,39,40,53

Next: Ch. 25 P. 2,3,6,9,12-14,16,19,28,29,33,47,55,56

Read 25 sec 1-5,7,8

Ch. 26 MisQ 1-9 odd

Read 26-1 to 26-4

1) Ch. 24: Energy density, u

2) Ch. 24: Dielectrics

3) Ch. 25: Current $I = dq/dt$, $I_{\text{avg}} = \Delta q / \Delta t$

4) Ch. 25: Current density, $j = I/A = nqv_d$

Notes:

Quiz on capacitance and current next Friday.

Try practice quizzes for Ch. 24 and 25.

Midterm Grade will be based on 50% exam, 25% quiz, 25% hwk.

Dielectrics

- Capacitor charged and **battery disconnected**
 - Q is constant - nowhere to go!

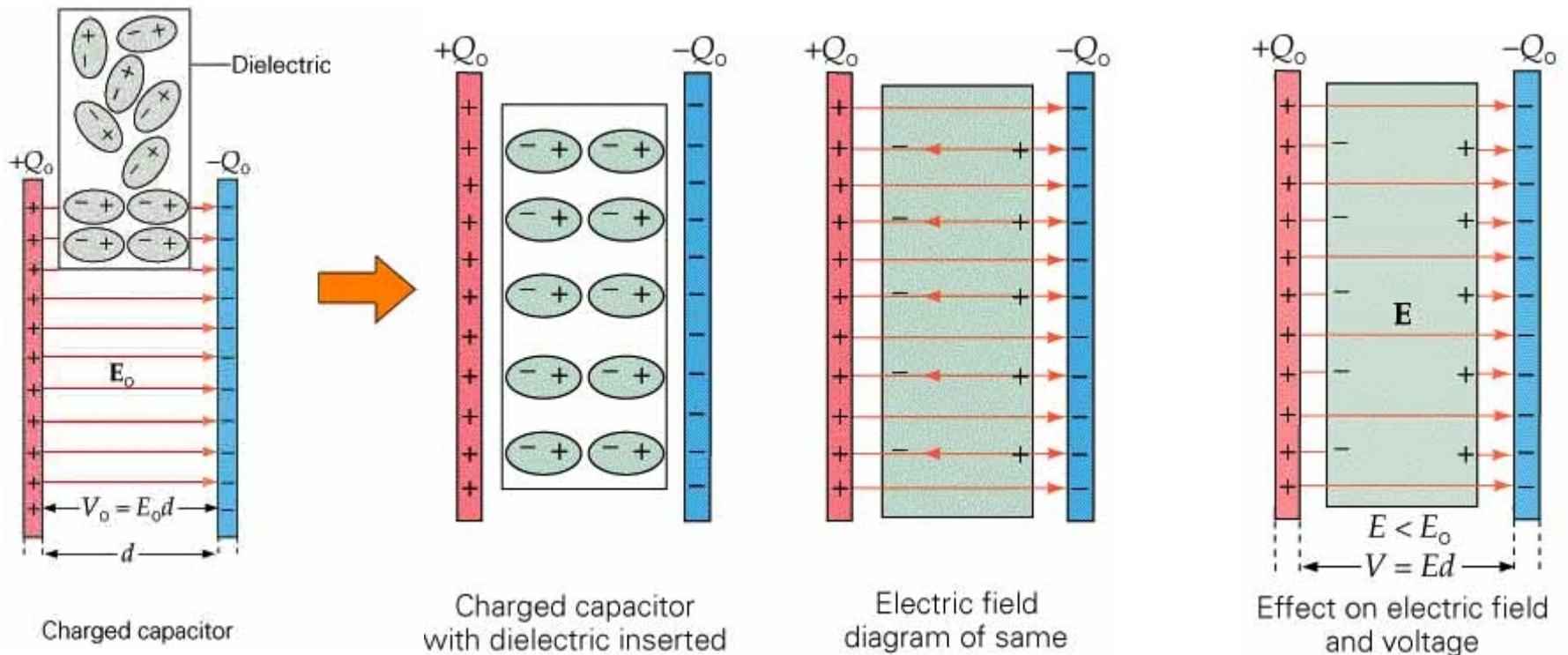


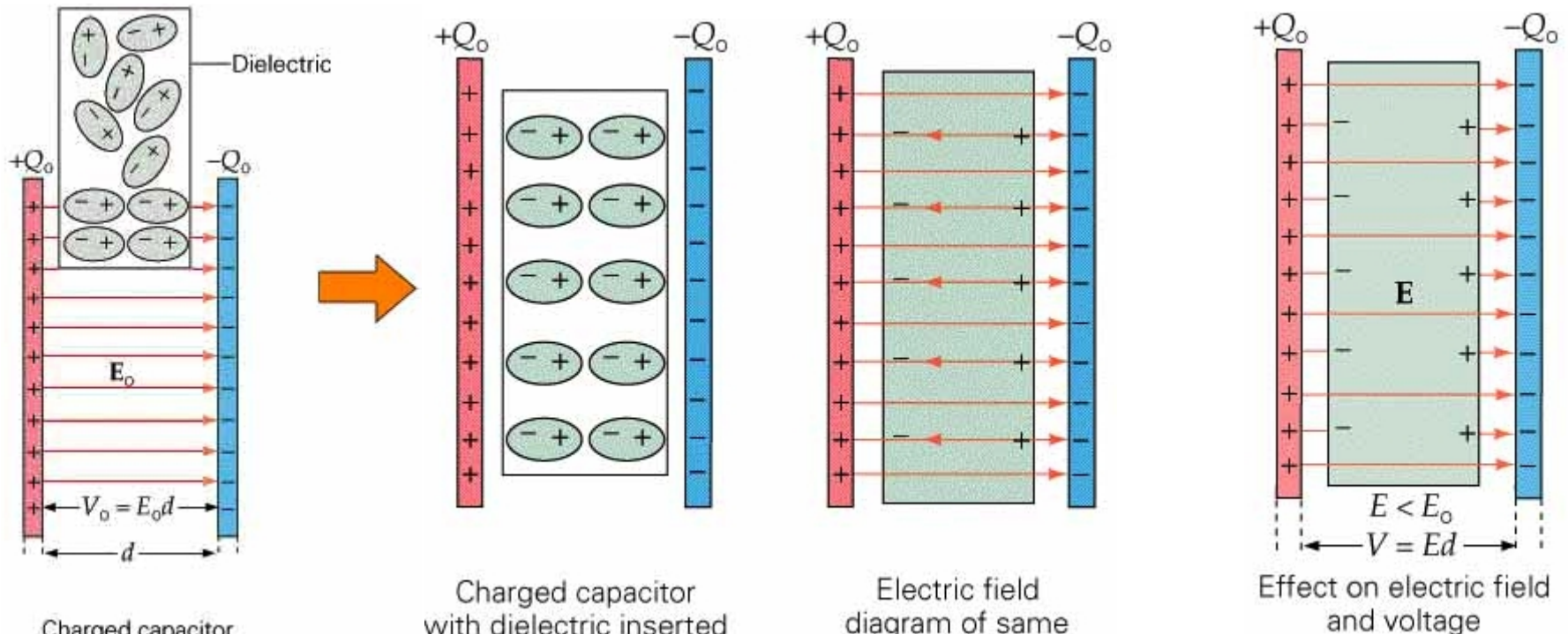
TABLE 26.1**Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature**

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.

Dielectrics

- Determine whether κ is greater than or less than 1:
 - 1) Molecules in dielectric get polarized
 - 2) Electric field between plates is reduced (Q is constant)
 - 3) ΔV across plates is reduced (remember $\Delta V = -Ed$)
 - 4) $U = 1/2 Q\Delta V$ is reduced, and so will be $U = 1/2 Q^2/C$
 - 5) Q is constant, so C must have increased.
 - 6) $C = \kappa C_0$ so $\kappa > 1$



Dielectrics

- Parallel Plates

$$C_o = \epsilon_o \frac{A}{d}$$

$$C = \epsilon \frac{A}{d} = K \epsilon_o \frac{A}{d}$$

Dielectric permittivity $\epsilon = K \epsilon_o$

