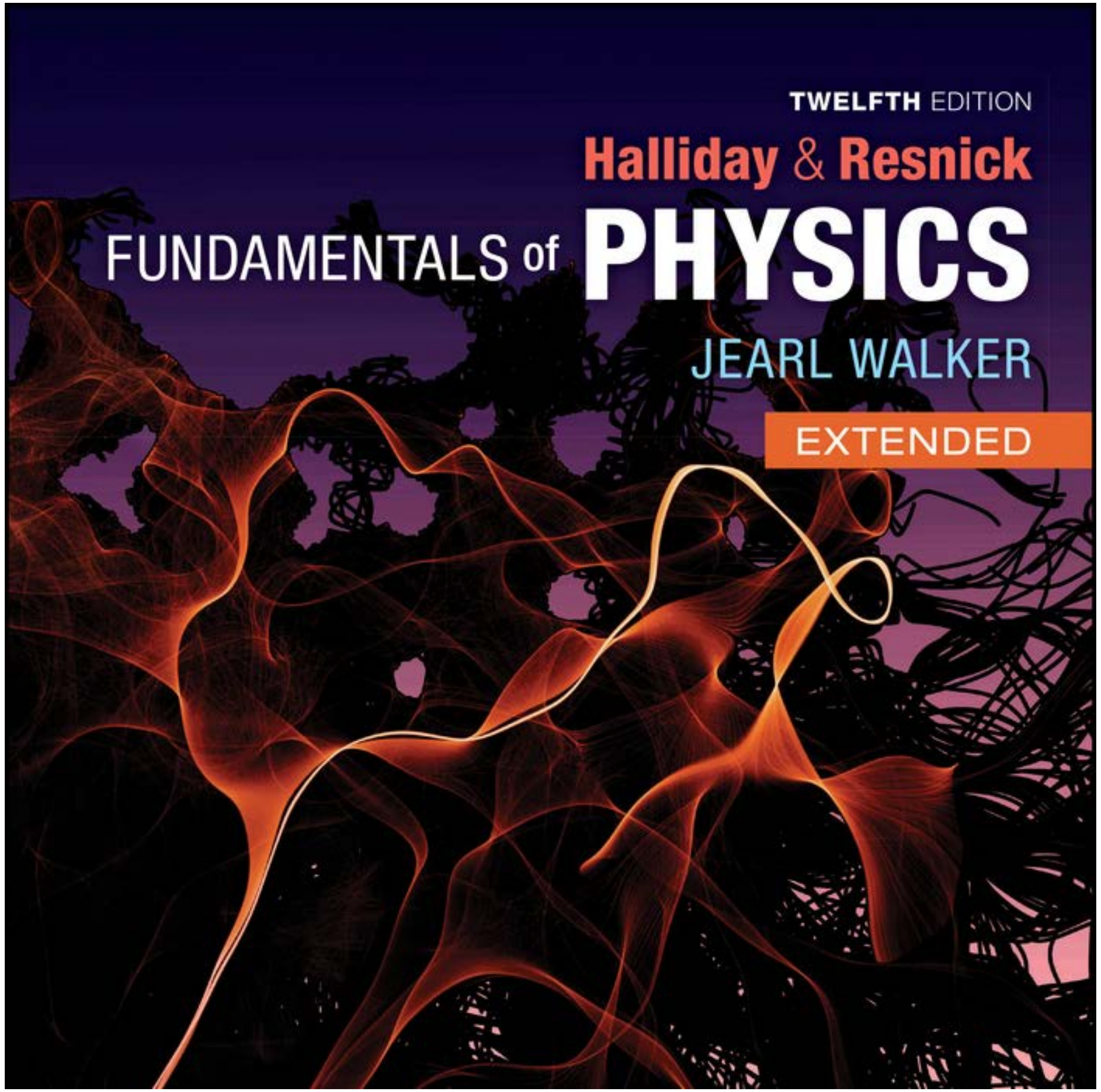
Wed 28 Jan

Fundamentals of Physics, Twelfth Edition. Halliday & Resnick, Walker

Chapter 25

Capacitance



Chapter 25
Capacitance

- min 4-5 grades
- more than 10 marks on Kirchoff's law

capacitor : store charge and energy
(device)

lamps/ TV/ charger

- 25.1 Capacitance
- 25.2 Calculating the Capacitance
- 25.3 Capacitors in Parallel and in Series
- 25.4 Energy Stored in an Electric field
- 25.5 Capacitors with a Dielectric

2 aluminum foil → store charge/energy
(conducting plates)
between insulator : dielectric → before it was air/ vacuum
when inserted can make as thin as possible

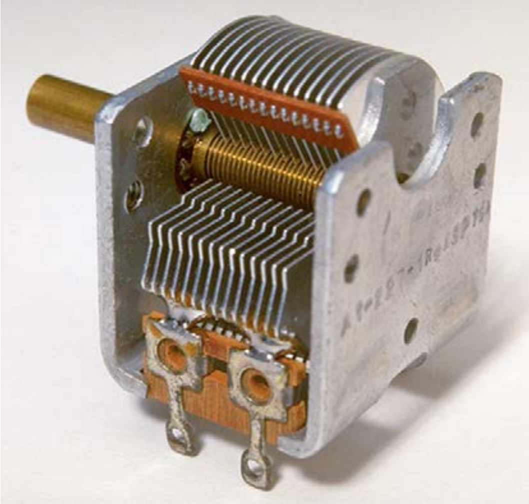
Section 25.1 Capacitance

spherical
cyclendrical :

parallel-plate:

Capacitance: Definition

A capacitor consists of two isolated conductors (the plates) with charges $+q$ and $-q$. Its **capacitance** C is defined from



$$q = CV.$$

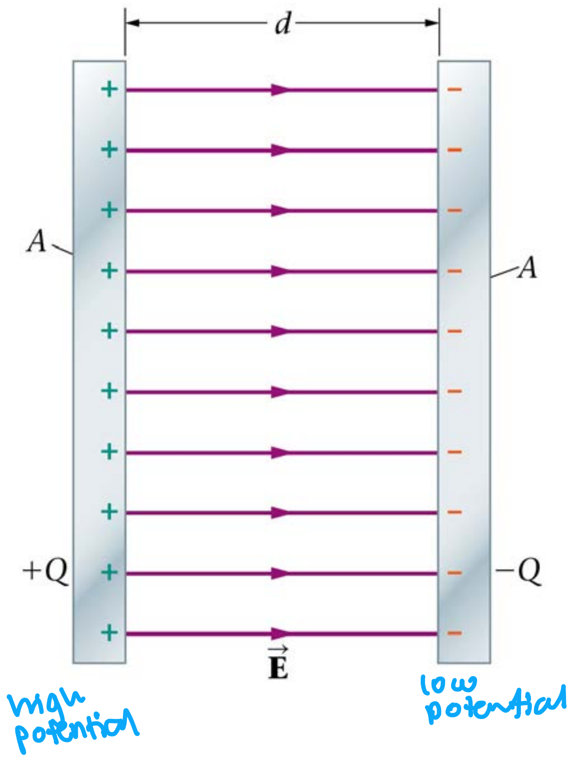
$$1\ \text{farad} = 1\ \text{F} = 1\ \text{coulomb per volt} = 1\ \text{C/V}.$$

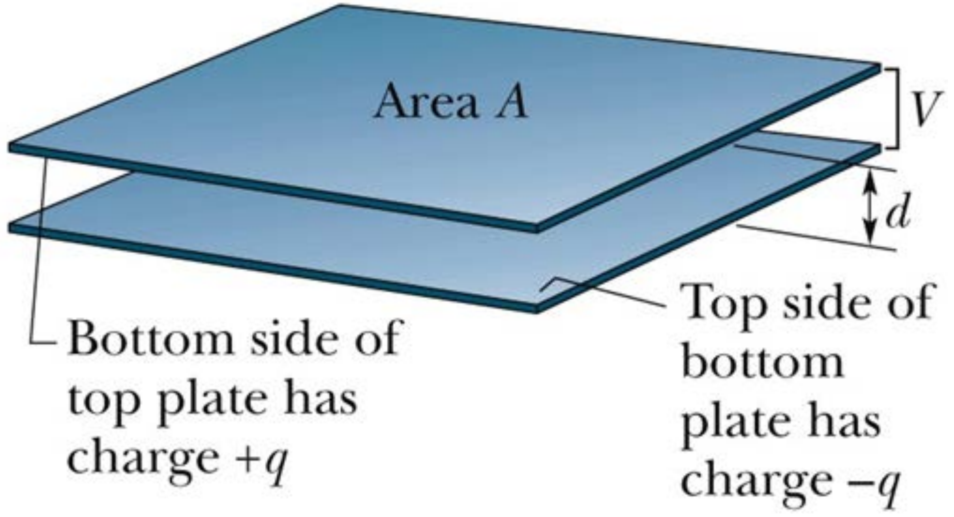
Where :

- C: is the capacitance and it's always a positive quantity
- Q: is the charge on each plate
- V: is the potential difference between the two plates

Parallel Plate Capacitor

A parallel-plate capacitor, made up of two plates of area *A* separated by a distance *d*. The charges on the facing plate surfaces have the same magnitude *q* but opposite signs





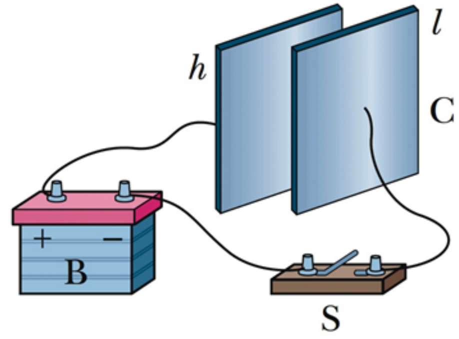
(a)

Charging a Capacitor

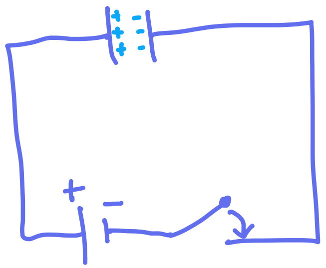
When a circuit with a battery, an open switch, and an uncharged capacitor is completed by closing the switch, conduction electrons shift, leaving the capacitor plates with opposite charges.

ohms law : resistor

capacitor symbol



(*a*)

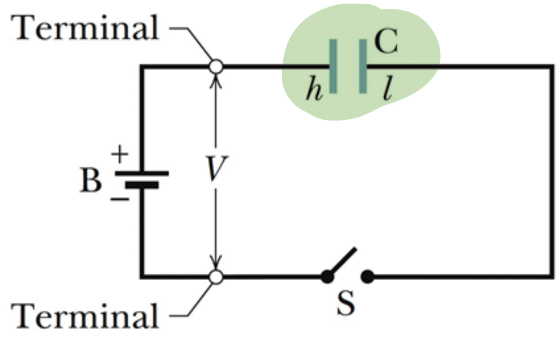


charge $q = CV$ → p.d (volts) V

coulombs

capacitance farad

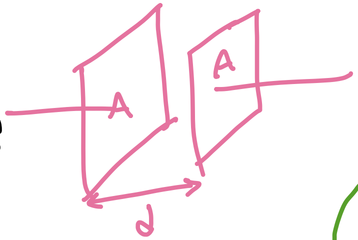
→ capacitor (fixed)



(*b*)

Fig. (*a*), a battery B, a switch S, an uncharged capacitor C, and interconnecting wires form a circuit. The same circuit is shown in the schematic diagram of Fig. (*b*), in which the symbols for a battery, a switch, and a capacitor represent those devices. The battery maintains potential difference *V* between its terminals. The terminal of higher potential is labeled + and is often called the positive terminal; the terminal of lower potential is labeled − and is often called the negative terminal.

Gauss' Law for Calculating Capacitance



A: Area of plate (m^2)
d: distance between the plate (m)

angle: 180° between $\vec{E}$ & motion

$\vec{E}\cdot d\vec{s} = E \times ds \times \cos 180$
$-Eds$

motion

$1cm^2 = 10^{-4} m^2$
$1mm = 10^{-3} m$
$1cm = 10^{-2} m$

$\theta = 0$
$\theta = 180$

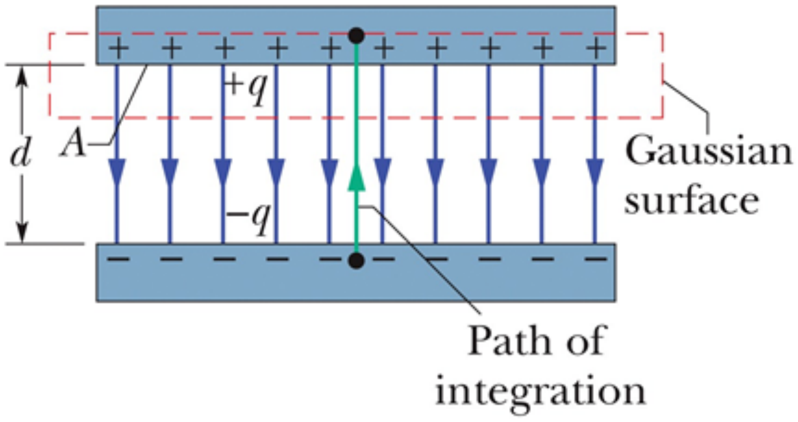
To relate the electric field $\vec{E}$ between the plates of a capacitor to the charge q on either plate, we shall use Gauss' law:

$$\varepsilon_0 \oint \vec{E} \cdot d\vec{A} = q.$$

A Gaussian surface encloses the charge on the positive plate. The integration is taken along a path extending directly from the negative plate to the positive plate. We obtain :

$$q = \varepsilon_0 EA$$

We use Gauss' law to relate q and E. Then we integrate the E to get the potential difference.



➢The potential difference between the plates of a capacitor is related to the field by:

going from - to +

$$V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s},$$

$\Phi = \frac{q}{\varepsilon_0}$ (gauss law)

$\int \vec{E}\, d\vec{A} = \frac{q}{\varepsilon_0}$

$EA = \frac{q}{\varepsilon_0}$

$q = EA\varepsilon_0$

$\Delta V = V = V_f - V_i$

➢Letting V represent the difference $V = V_f - V_i$, we can then recast the above equation as :

$$V = \int_-^+ E\, ds = E\int_0^d ds = Ed.$$

slide above ✱

$\cos(180) = -1$

-ve cancel each other so we got $+Ed$

$\boxed{q = CV}$

$\cancel{E}A\varepsilon_0 = C\cancel{E}d$

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

➢ For this path, the vectors $\vec{E}$ and $d\vec{s}$ will have opposite directions ; so, the dot product will be (*-Eds).*

area ↑ capacitor ↑

d ↑ capacitance ↓

➢Now if we substitute $q=\varepsilon_0 EA$ *and* $V = Ed$ into $q = CV$, we get,

$$C = \frac{\varepsilon_0 A}{d} \quad \text{(parallel-plate capacitor)}.$$

parallel plate

$q = CV$

C F V

$V = Ed$

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

Example

- A parallel plate capacitor is constructed with plates of area (0.028 m^2) and separation (0.55 mm).
  - Find the magnitude of the charge on each plate of this capacitor when the potential difference between the plates is (20.1 V) .
  - What is the magnitude of the electric field between the plates of the capacitor.

A

d $\quad 0.55\,\cancel{mm} \times \frac{10^{-3}\,m}{1\,\cancel{mm}} = 5.5\times10^{-4}\,m$

V

Givens: $A = 0.028\,m^2$

$d = 5.5\times10^{-4}\,m$

$V = 20.1\,V$

Should know $\rightarrow \epsilon_0 = 8.85\times10^{-12}$

(a) $q = CV$

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

$\frac{8.85\times10^{-12}(0.028)}{(5.5\times10^{-4})}(20.1) = 9.05\times10^{-9}\,C$

(b) $E = \frac{V}{d} = \frac{20.1}{5.5\times10^{-4}} = 36545.45\,\frac{V}{m}$

Thu 29 Jan

Section 25.3 Capacitors in Parallel and In Series

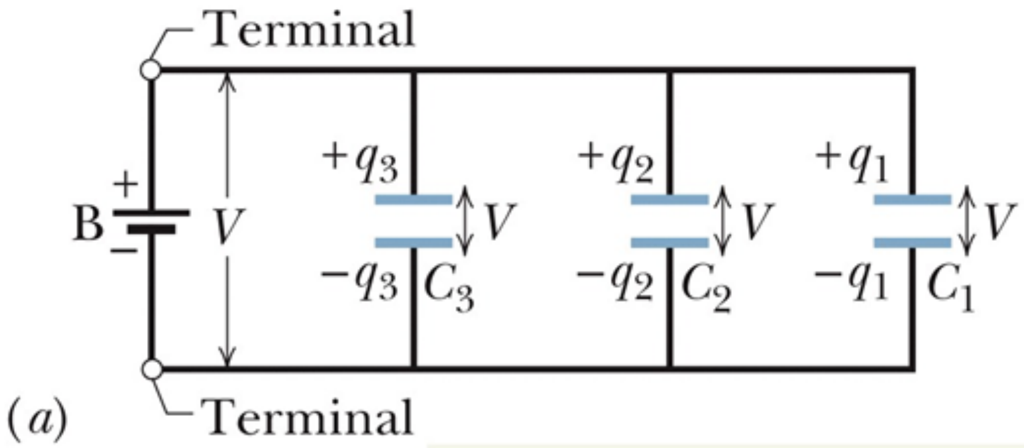
Net/Equivalent Capacitance for Capacitors in Parallel

When a potential difference *V* is applied across several capacitors connected in parallel, **that potential difference *V* is the same across each capacitor**. The total charge *q* stored on the capacitors is the sum of the charges stored on all the capacitors.

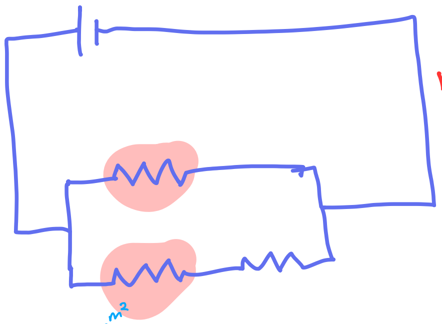
$$q_1 = C_1 V, \quad q_2 = C_2 V, \quad \text{and} \quad q_3 = C_3 V.$$

The total charge on the parallel combination is then:

$$q = q_1 + q_2 + q_3 = (C_1 + C_2 + C_3)V.$$



Parallel capacitors and their equivalent have the same *V* (“par-V”).



neither series nor parallel

$C = \frac{\varepsilon_0 A}{d}$ (m^2) (air / vaccum)

series: (same current / charge) — resistor, capacitor (q)

parallel: (same potential difference / voltage) — $V = Ed$ (V)

↳ same letters

$q = CV$

not everytime split it's parallel ✗ incorrect

letters won't be given
I must know them

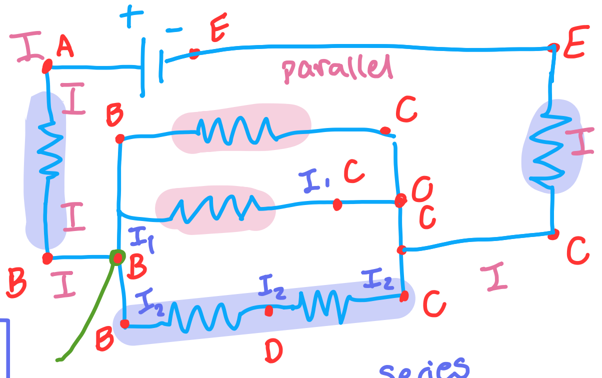
to ✗
and ✓

doesn't change leaves and enter same

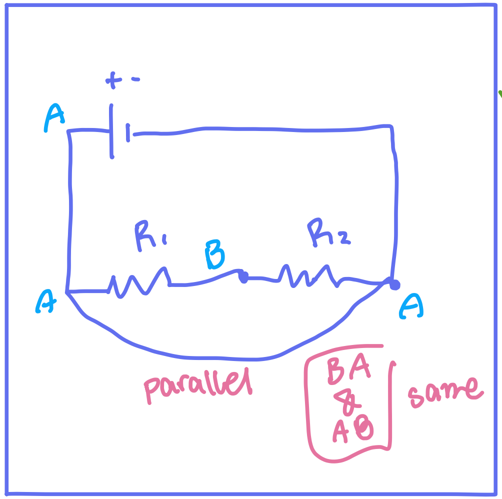
I: charges / time (current)

wire: letter don't change

anything else: change



junction: where theres split

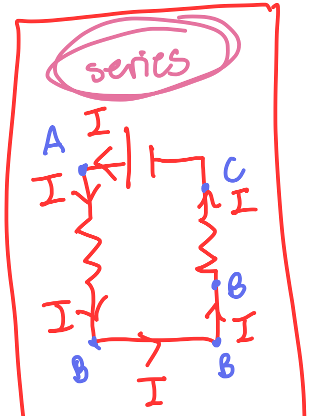


letter$_1$

letter$_2$ → to be parallel must have same

current passing through / into / in

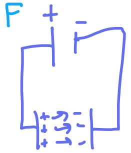
p.d across / between



$C = \dfrac{\varepsilon_0 A}{d}$ ($A \to m^2$, $d \to m$, $C \to F$)

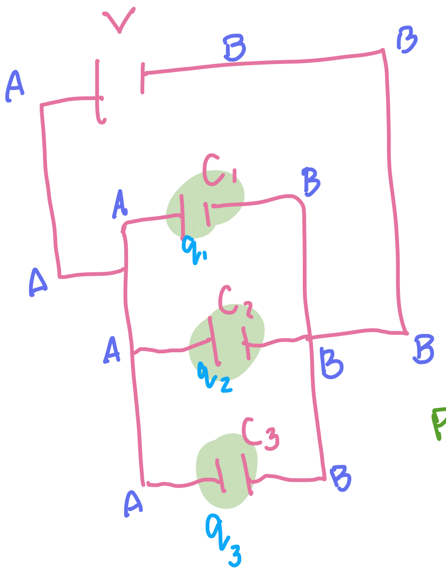
(air / vaccum

plate capacitor



$V = Ed$

$q = CV$ ($q \to C$, $C \to F$, $V \to V$)



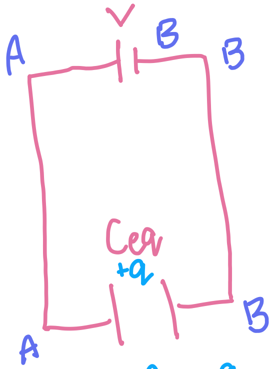
Farad prob wrong

pico, nano } more accurate

$$\left.\begin{aligned} q_1 &= C_1 V_{AB} \\ q_2 &= C_2 V_{AB} \\ q_3 &= C_3 V_{AB} \end{aligned}\right\} \text{But } V_{AB} = V$$

parallel

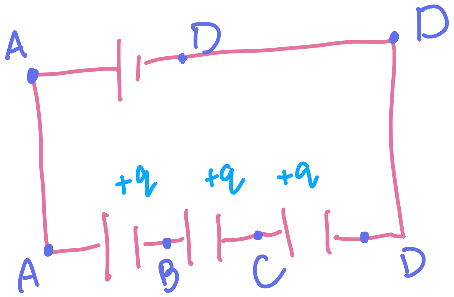
$$q = C_{eq} V_{AB}$$

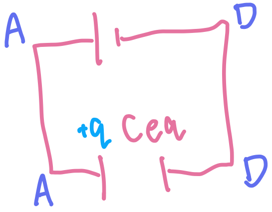


$$q = q_1 + q_2 + q_3$$

$$C_{eq}\cancel{V_{AB}} = C_1\cancel{V_{AB}} + C_2\cancel{V_{AB}} + C_3\cancel{V_{AB}}$$

$$\boxed{C_{eq} = C_1 + C_2 + C_3}$$ parallel





$$V_{AD} = V_{AB} + V_{BC} + V_{CD}$$

$$\frac{\cancel{q}}{C_{eq}} = \frac{\cancel{q}}{C_1} + \frac{\cancel{q}}{C_2} + \frac{\cancel{q}}{C_3}$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$C_{eq}^{-1} = C_1^{-1} + C_2^{-1} + C_3^{-1}$$

The equivalent capacitance, with the same total charge *q* and applied potential difference *V* as the combination, is then

$$C_{\text{eq}} = \tfrac{q}{V} = C_1 + C_2 + C_3,$$

a result that we can easily extend to any number n of capacitors, as

$$C_{\text{eq}} = \sum_{j=1}^{n} C_j \quad (n \text{ capacitors in parallel}).$$

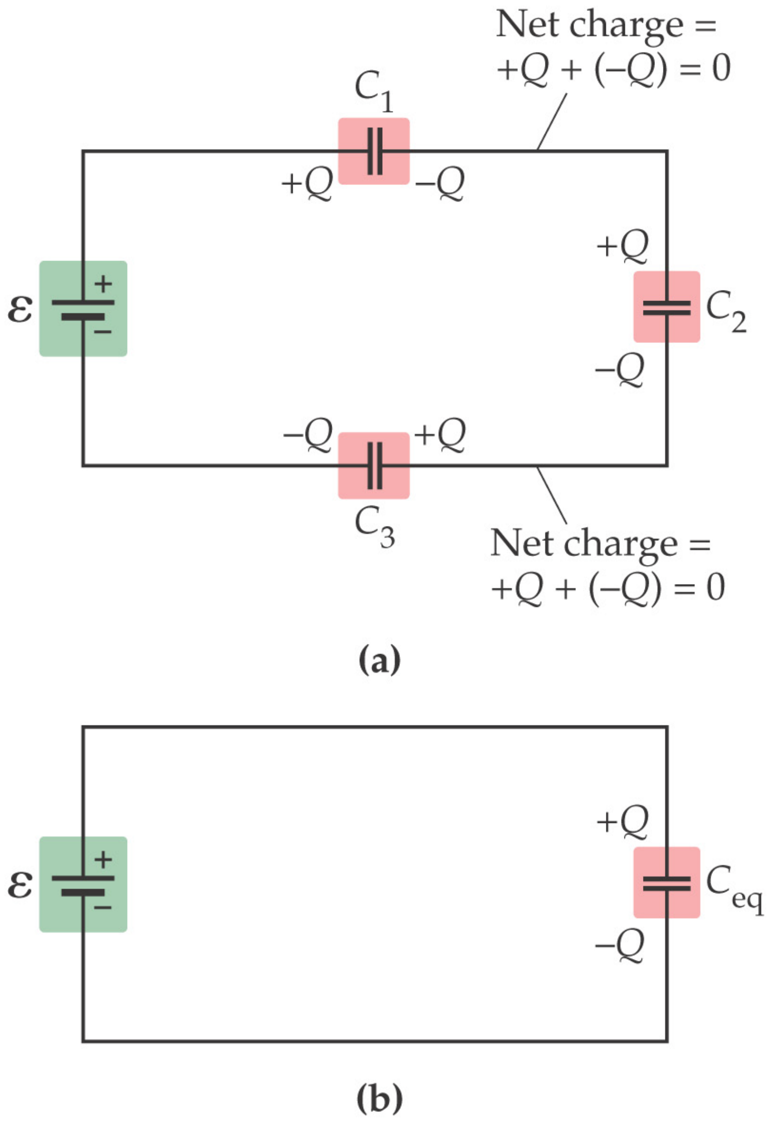
Net/Equivalent Capacitance for Capacitors in Series

When a potential difference V is applied across several capacitors connected in series, **the capacitors have <u>same</u> <u>charge *q*</u>**. The sum of the potential differences across all the capacitors is equal to the applied potential difference V.

$$V_1 = \frac{q}{C_1}, \quad V_2 = \frac{q}{C_2}, \quad \text{and} \quad V_3 = \frac{q}{C_3}.$$

The total potential difference V due to the battery is the sum:

$$V = V_1 + V_2 + V_3 = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right).$$



The equivalent capacitance is then:

$$C_{\mathrm{eq}} = \frac{q}{V} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}},$$

or

$$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

$$\frac{1}{C_{\mathrm{eq}}} = \sum_{j=1}^{n} \frac{1}{C_j} \quad (n \text{ capacitors in series}).$$

$m = \times 10^{-3}$
$\mu = \times 10^{-6}$
$n = \times 10^{-9}$
$p = \times 10^{-12}$

$C_{eq} = \frac{q}{V}$

Steps: must work backwards
① letters/label C_1, C_2
② Go from back, check relation → series: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$; parallel: $C_{eq} = C_1 + C_2$
③ Merge them (letters) C_{eq_1} with next C
④ Repeat....

technique in solving: backwards

Example

charge in capacitor

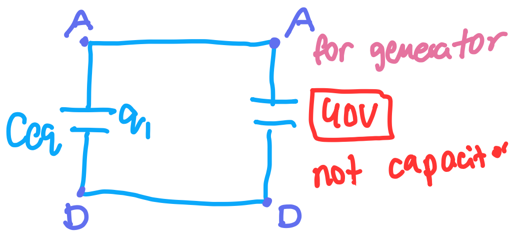
Find the equivalent capacitance of the shown circuit

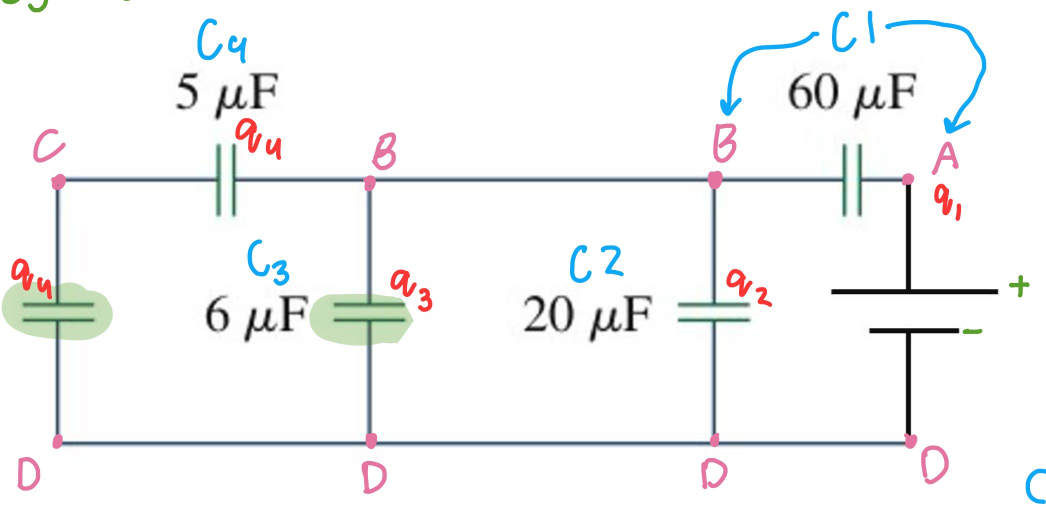
ⓐ C_{eq}? $20\mu F$

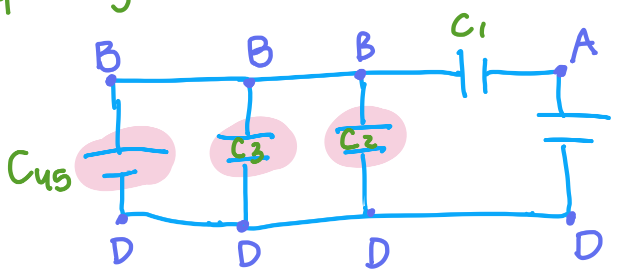
C_4 & C_5 : series

$\frac{1}{C_{45}} = \frac{1}{C_4} + \frac{1}{C_5} = \frac{1}{20} + \frac{1}{5} = \frac{1}{4}$ $\quad C_{45} = 4\mu F$

ⓑ q C_1?



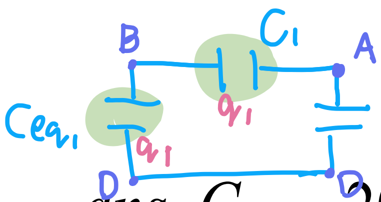




C_2, C_3, C_{45} in parallel

$C_{eq_1} = 4 + 6 + 20 = 30\mu F$

$q_1 = C_{eq} \times V_{AD} = 20\mu F \times 40V = 800\mu C$ $= 8 \times 10^{-4} C$



$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_{eq_1}}$
$= \frac{1}{60} + \frac{1}{30}$

ⓒ V C_1

$V_{C_1} = \frac{q_1}{V_1} = \frac{8 \times 10^{-4}}{60 \times 10^{-6}} V$

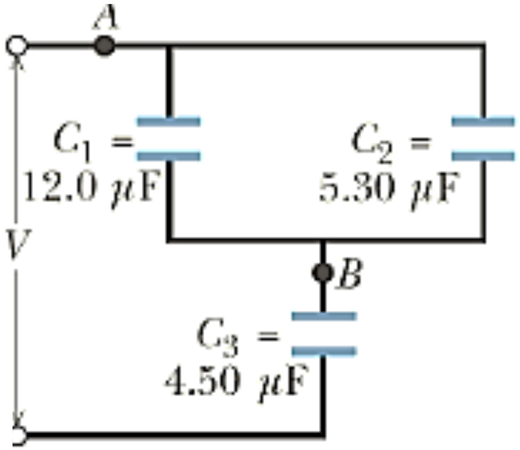
$ans.\ C_{eq} = 20\mu F$ $\quad C_{eq} = 20\mu F$

Extra Practice

(a) Find the equivalent capacitance for the combination of capacitances shown in Fig. 25.3.3a, across which potential difference V is applied. Assume

$C_1 = 12.0\ \mu\text{F}, \quad C_2 = 5.30\ \mu\text{F}, \quad \text{and } C_3 = 4.50\ \mu\text{F}.$

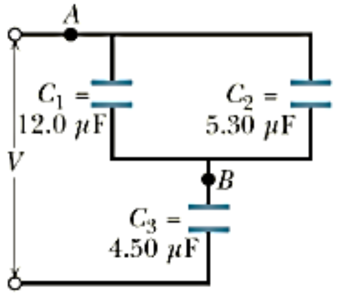
(b) The potential difference applied to the input terminals in Fig. 25.3.3a is $V = 12.5\ \text{V}$. What is the charge on C_1?



(a)

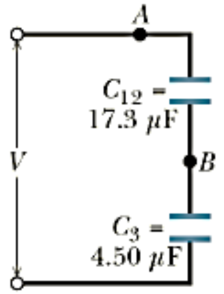
Solution:

We first reduce the circuit to a single capacitor.



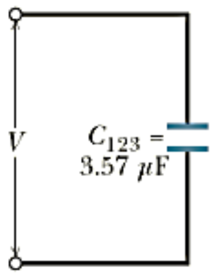
(a)

The equivalent of parallel capacitors is larger.



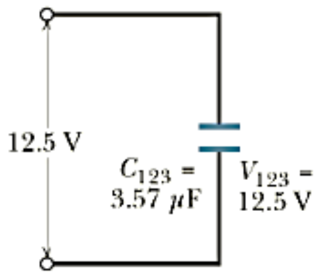
(b)

The equivalent of series capacitors is smaller.



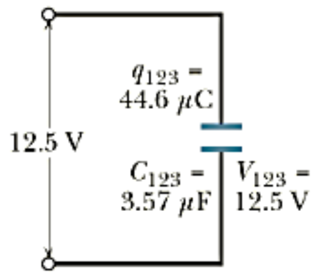
(c)

Next, we work backwards to the desired capacitor.



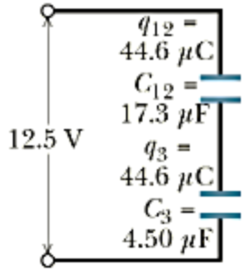
(d)

Applying $q = CV$ yields the charge.



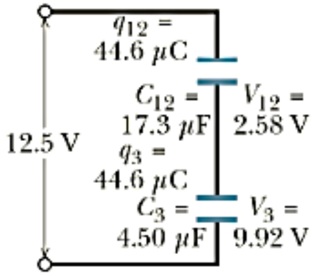
(e)

Series capacitors and their equivalent have the same q ("seri-q").



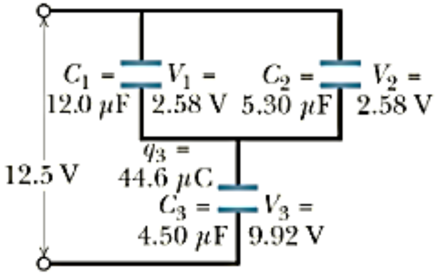
(f)

Applying $V = q/C$ yields the potential difference.



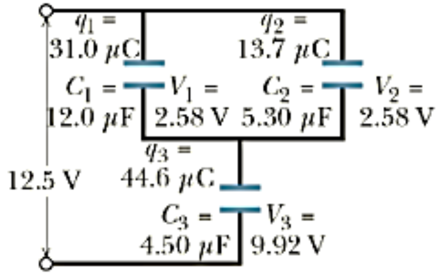
(g)

Parallel capacitors and their equivalent have the same V ("par-V").

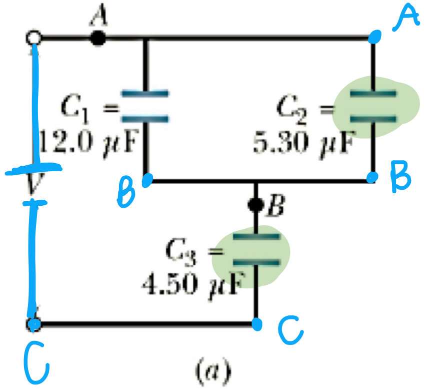


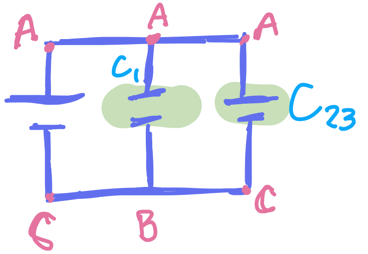
(h)

Applying $q = CV$ yields the charge.

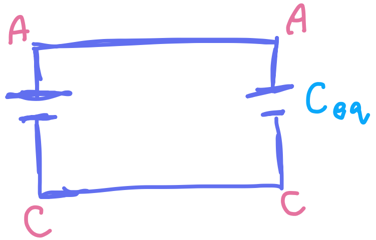


(i)

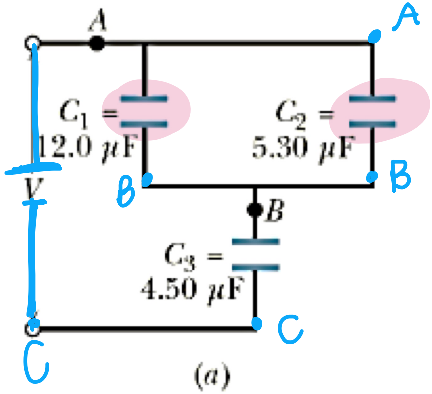




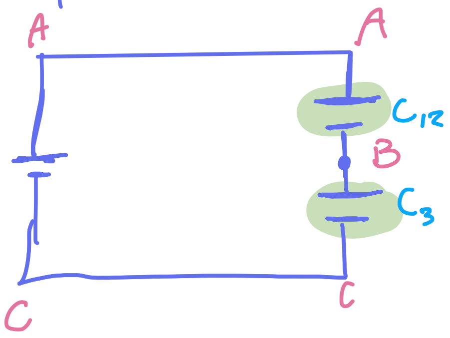
$C_2\ C_3$ series $= \frac{1}{C_2} + \frac{1}{C_3} = 0.411\ \mu F = C_{23}$



$C_1\ C_{23}$ series $= \frac{1}{C_{23}} + \frac{1}{C_1} = 2.516\ \mu F = C_{eq}$



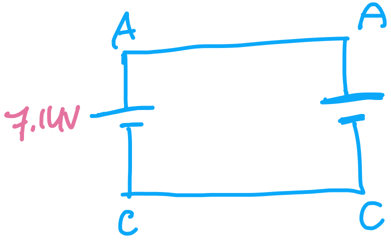
C_1 & C_2 Parallel : $C_{12} = C_1 + C_2 = 12 + 5.3 = 17.3\ \mu F$



C_{12} & C_3 series

$\frac{1}{C_{eq}} = \frac{1}{C_{12}} + \frac{1}{C_3} = \frac{1}{17.3} + \frac{1}{4.5}$

$C_{eq} = \left(\frac{1}{17.3} + \frac{1}{4.5}\right)^{-1} = 3.57\ \mu F$

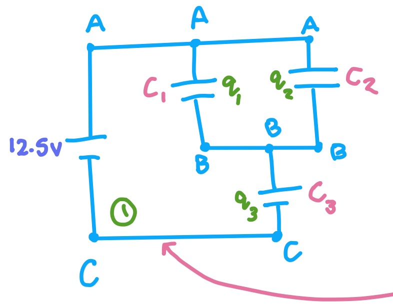


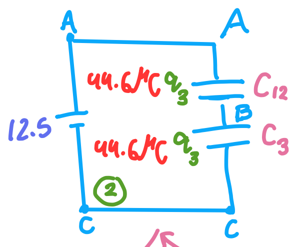
$C_{eq} = 3.57\ \mu F$

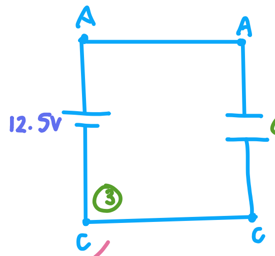
V_{AB} have

V_{AC} have

Wed 4 Feb







$q_3 = C_{eq} V_{AC}$

$(3.57)(12.5) = 44.6\ \mu C$

$V_{BC} = \frac{q_3}{C_3} = \frac{44.6\ \cancel{\mu} C}{4.5\ \cancel{\mu} F} = 9.91V$

Two ways:

① $V_{AB} = V_{C12} = \frac{q_3}{C_{12}} = \frac{44.6\ \mu C}{17.3\ \mu F} = 2.6V$

② $V_{AB} = V_{AC} - V_{BC} = 12.5 - 9.91 = \boxed{2.59}$

$C_{12} = 17.3\ \mu F$

$C_{eq} = 3.57\ \mu F$

$q_1 = C_1 V_{AB} = (12\ \mu F) 2.6 = 31.2\ \mu C$

$q_2 = C_2 V_{AB} = (5.3)(2.6) = 13.4\ \mu C$

$\boxed{OR}$

$q_2 = q_3 - q_1 = 44.6 - 31.2 = 13.4\ \mu C$

Tips:

- Write equation

Tue 10 Feb

Capacitors:

$U = qV$ Potential difference

energy stored in capacitor

very imp

① $U = \boxed{\frac{1}{2}} qV$

② $q = CV$

③ $U = \frac{1}{2} CV \cdot V = \frac{1}{2} CV^2$

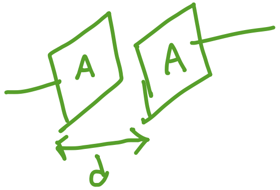
④ $U = \frac{1}{2} q \times \frac{q}{C} = \frac{q^2}{2C}$

Way of thinking of energy:

Jood is 6
can I compare him with 12 yr old?
No there's no factor that's constant

Recap

F
$C = \frac{\epsilon_0 A}{d}$
m^2
$1/m$



Section 25.4 Energy Stored in an Electric Field

The **electric potential energy** *U* of a charged capacitor,

$$U = \frac{q^2}{2C} \quad \text{(potential energy)}.$$

and

$$U = \tfrac{1}{2}CV^2 \quad \text{(potential energy)}.$$

and

$$U = \frac{1}{2}QV$$

is equal to the work required to charge the capacitor. This energy can be associated with the capacitor's electric field

Energy Stored in an Electric Field

The potential energy of a charged capacitor may be viewed as being stored in the electric field between its plates.

Every electric field, in a capacitor or from any other source, has an associated stored energy. In vacuum, the **energy density** *u* (potential energy per unit volume) in a field of magnitude *E* is

$$u = \frac{U}{\boxed{\text{volume}}} \quad U \to J, \quad \text{volume} \to m^3$$

careful it's not potential difference

$$u = \tfrac{1}{2}\varepsilon_0 E^2 \quad \text{(energy density)}.$$

$u \to \boxed{\frac{J}{m^3}}$

$E \to$ electric field

Example

- A parallel plate capacitor is fully charged by a 300 V battery. If the area of each plate is 35 cm^2 and the gap between them is 1.77 mm. What is the charge carried by the capacitor and the energy stored in it?

$V = 300V$

$A = 35cm^2 = 35\times10^{-4} m^2$

$d = 1.77\ mm = 1.77\times10^{-3} m$

$q = CV$

$\epsilon_0 = 8.85\times10^{-12}$

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

$q = \frac{\epsilon_0 A}{d}(V) = 0.00000000525\ C$

$U = \frac{q^2}{2C} = \frac{(0.00000000525)^2}{2(1.75\times10^{-11})} = \boxed{0.0000007875\ J}$

$7.9\times10^{-7} J$

Example

IMP

doctor says ab analysis

- A parallel plate capacitor of plate area 82 cm^2 carries a charge of 55 nC when charged at 220 volt. What is the plate separation (d) of this capacitor and the energy stored in it?

Tip
use question givens

$A = 82\,cm^2 = 82\times10^{-4}\,m^2$
$q = 55\,nC = 55\times10^{-9}\,C$
$V = 220\,V$
$d = ?$

$q = CV$

$55\times10^{-9} = \frac{\epsilon_0 A}{d}(220)$

$d = \frac{(8.85\times10^{-12})(82\times10^{-4})(220)}{55\times10^{-9}}$

$= 0.00029028 = \boxed{2.9\times10^{-4}\,m}$

$U = \frac{1}{2} q V$

$= \frac{1}{2}(55\times10^{-9})(220)$

$\boxed{= 6.05\times10^{-6}\,J}$

m $\times 10^{-3}$

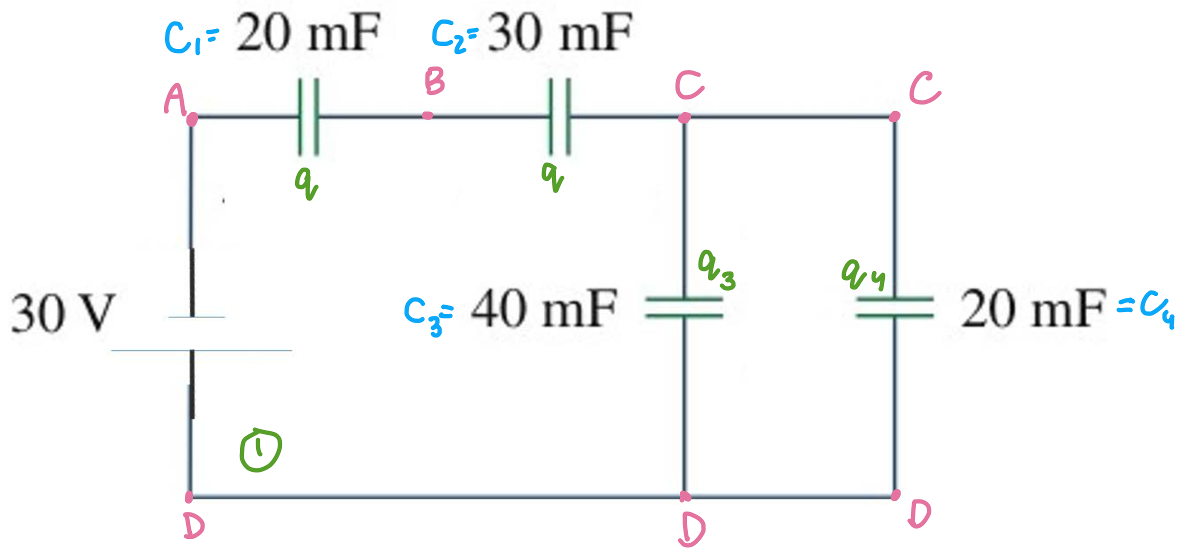
Example

For the circuit shown, find the voltage, charge and energy stored for each capacitor.

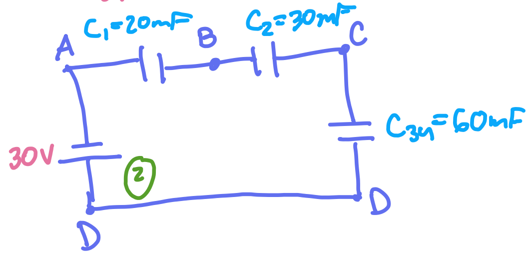
ⓐ V

ⓑ q

ⓒ energy?

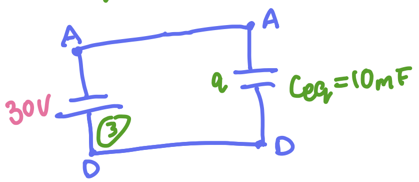


C_3 & C_4 parallel:
$C_{34} = 40+20 = 60mF$



C_1, C_2, C_{34}
are in series

$C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_{34}}\right)^{-1} = 10mF$



C_{12} & C_{34} series $= C_{eq} = 10mF$

Thu 5 Feb

Same question continued

Example

- Two capacitors, $C_1 = C$, $C_2 = 2C$, are connected to a battery.
- Which capacitor will store more energy when they are connected to the battery in series? Explain

q is the same

$U = \frac{1}{2} qV$ don't have voltage for all capacitors

$U = \frac{1}{2} CV^2$ eliminated (I'm stupid)

$U = \frac{q^2}{2C}$ ✓ because q doesn't change in series

$U_1 = \frac{q^2}{2C_1} = \frac{q^2}{2C}$ greater

$U_2 = \frac{q^2}{2C_2} = \frac{q^2}{2(2C)} = \frac{q^2}{4C}$

$\boxed{U_1 > U_2}$

- Which capacitor stores more energy when they are connected in parallel? Explain.

$U = \frac{1}{2} CV^2$ = volt constant in parallel

$U_1 = \frac{1}{2} C_1 V^2 = \frac{1}{2} CV^2$

$U_1 < U_2$

$U_2 = \frac{1}{2} C_2 V^2 = \frac{1}{\cancel{2}} \cancel{2} CV^2 = CV^2$ greater

Section 25.5 Capacitor with a Dielectric

Definition of a Dielectric

insulator between 2 capacitors

If the space between the plates of a capacitor is completely filled with a **dielectric material**, which is an insulator, the capacitance C in vacuum (or, effectively, in air) is multiplied by the material's **dielectric constant** κ, (Greek kappa) which is a number greater than 1.

In a region completely filled by a dielectric material of dielectric constant κ, all electrostatic equations containing the permittivity constant ε_0 are to be modified by replacing ε_0 with $\boxed{\kappa\varepsilon_0.}$ KAPPA

capacitance even more with an dielectric constant

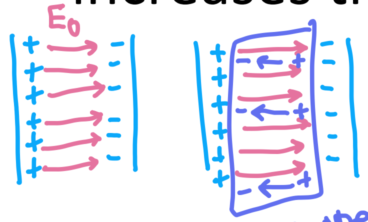
Figure 25.5.1 The simple electrostatic apparatus used by Faraday. An assembled apparatus (second from left) forms a spherical capacitor consisting of a central brass ball and a concentric brass shell. Faraday placed dielectric materials in the space between the ball and the shell.

Dielectric In a Parallel Plate Capacitor (same charge)

- If a dielectric is placed between the plates of a capacitor it gives a lower potential difference with **the same charge**, due to the polarization of the material. This increases the capacitance.

young & Freedman

will have opposing



$C = \frac{q}{V}$ V↓ C↑

$E_{net} = E - E_0$

adding dielectric creates another electric field inside

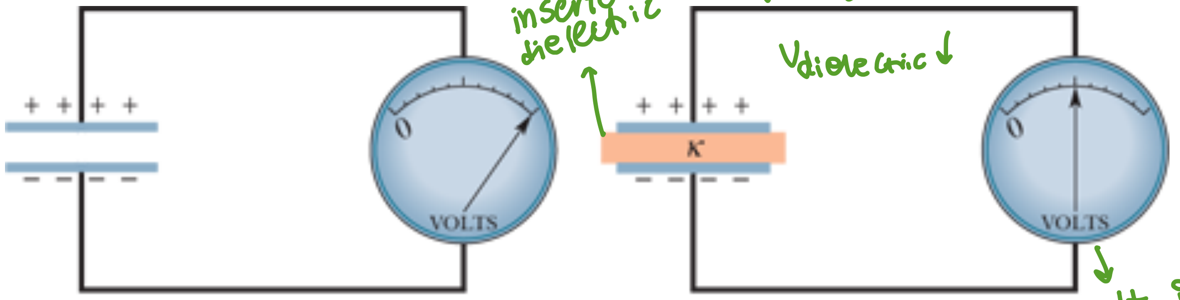
$E_{with\ dielectric}$ ↓

↓$V = Ed$

voltage also decrease

inserted dielectric

$V_{dielectric}$ ↓

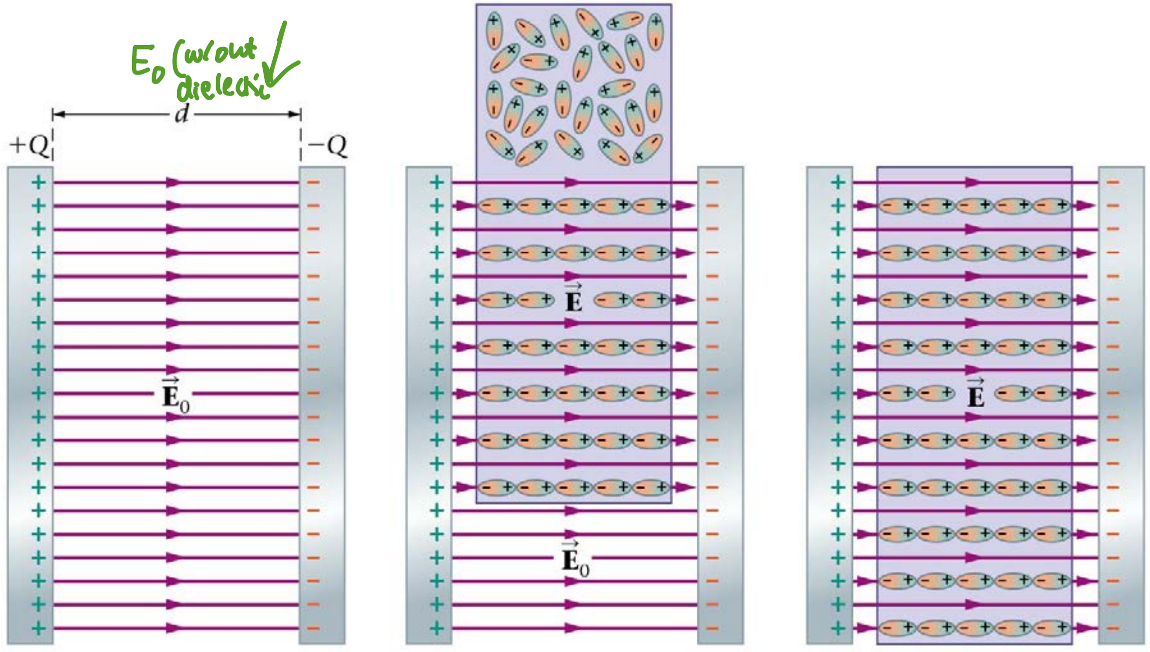


volt got less

q = a constant

Polarization

E_0 (w/out dielectric)



(a) Capacitor without dielectric

(b) Inserting a dielectric

(c) A dielectric reduces the electric field within a capacitor

Wed 11 Feb

- The polarization of the dielectric results in a lower electric field within it; the new field is given by dividing the original field by the dielectric constant κ:

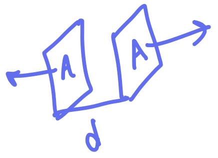
$$E = \frac{E_0}{\kappa}$$

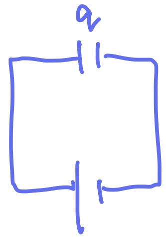
- Therefore, the capacitance becomes:

$$C = \frac{Q}{V} = \frac{Q}{(V_0/\kappa)} = \kappa \frac{Q}{V_0} = \kappa C_0$$

Ch25

capacitor





$q = CV$

C F V

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

C series : same charge (q)

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

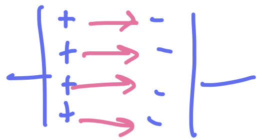
C parallel : same P.d "V"

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

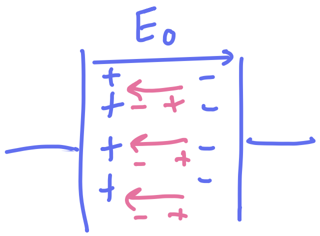
$V = Ed$

Dielectric :

1. q constant



dielectric



$E_{net} = E_0 - E$ $E_{net} = \frac{E_0}{K}$

$E_{net} \downarrow$

constant $q = CV$

$C\uparrow$ $V\downarrow$

$V = Ed$ $E\downarrow$ $V\downarrow$

$\epsilon_0 \equiv K\epsilon_0$

K: dielectric constant

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

- The dielectric constant is a property of the material; here are some examples:

TABLE 20-1 Dielectric Constants

Substance	Dielectric constant, κ
Water	80.4
Neoprene rubber	6.7
Pyrex glass	5.6
Mica	5.4
Paper	3.7
Mylar	3.1
Teflon	2.1
Air	1.00059
Vacuum	1

usually ← Teflon

given

- If the electric field in a dielectric becomes too large, it can tear the electrons off the atoms, thereby enabling the material to conduct. This is called **dielectric breakdown**; the field at which this happens is called the dielectric strength.

voltage too high insulators get e^- too charged they can start conducting

TABLE 20-2 Dielectric Strengths

don't forget the minus in previous chapters

$\left(\frac{N}{C}\right)$ $\left(\frac{V}{m}\right)$ electric field

Substance	Dielectric Strength (V / m)
Mica	100×10^6
Teflon	60×10^6
Paper	16×10^6
Pyrex glass	14×10^6
Neoprene rubber	12×10^6
Air	3.0×10^6

Example

- Determine (a) the capacitance and (b) the maximum potential difference that can be applied to a Teflon-filled parallel-plate capacitor having a plate area of 1.75 cm^2 and plate separation of 0.04 mm. (κ for Teflon = 2.1)

$d = 0.04 \times 10^{-3}$ m

$A = 1.75 \times 10^{-4}$ m^2

(a) $C = \frac{\epsilon_0 A}{d} = \frac{(8.85\times10^{-12})(2.1)(1.75\times10^{-4})}{0.04\times10^{-3}} = 8.13\times10^{-11}$ F

(b) Go to table: $60\times10^{6} \frac{V}{m}$

$V = Ed = (60\times10^{6})(0.04\times10^{-3}) = 2.4\times10^{3}$ V

Example

- A parallel-plate capacitor is constructed using a dielectric material whose dielectric constant is 3 and whose dielectric strength is 2× 10^8 N/C. The desired capacitance is 0.25 μF, and the capacitor must withstand a maximum potential difference of 4000 V. Find the minimum area of the capacitor plates.

$V = Ed \rightarrow d = \frac{V}{E} = \frac{4000}{2\times10^8} = 2\times10^{-5}$ m

$C = 0.25\times10^{-6}$ F

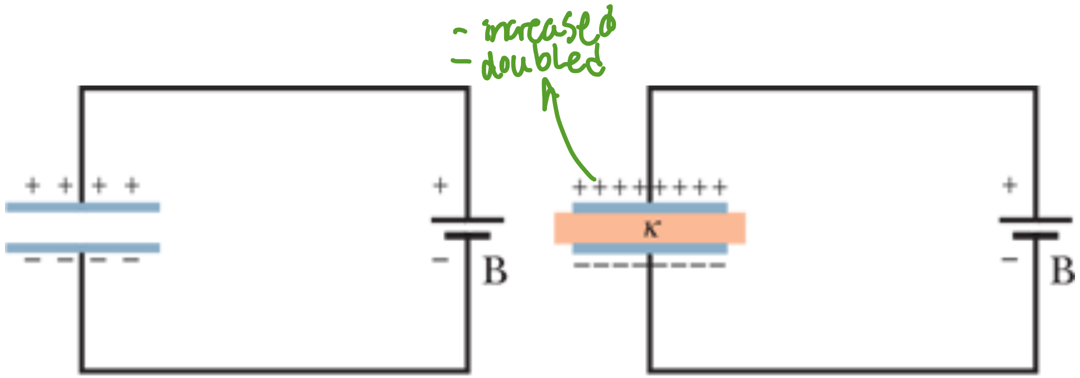
$V = 4000$ V

$K = 3$

$A = ?$

$C = \frac{K\epsilon_0 A}{d} \rightarrow \frac{C\cdot d}{K\epsilon_0} = \frac{K\epsilon_0 A}{K\epsilon_0} \rightarrow A = \frac{Cd}{K\epsilon_0} = \boxed{1.88\times10^{-1}\ m^2}$

Dielectric In a Parallel Plate Capacitor (same potential difference)



V = a constant

(a)

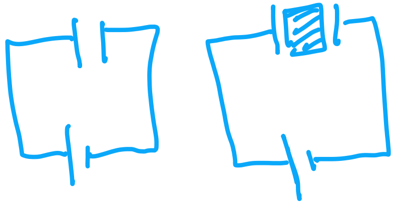
If the **potential difference** between the plates of a capacitor is maintained, as by the presence of battery B, the effect of a dielectric is to increase the charge on the plates.

q constant
$U=\frac{1}{2}CV^2$
$= 1.05\times10^{-9}$ J

$C=13.5\times10^{-12}$ F
$V=12.5$ V
$\kappa=6.50$

Extra Practice

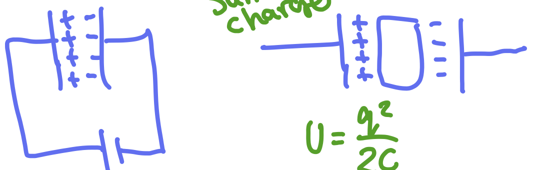
Plot to understand:



Same voltage: battery
$U=\frac{1}{2}CV^2$

A parallel-plate capacitor whose capacitance C is 13.5 pF is charged by a battery to a potential difference $V = 12.5$ V between its plates. The charging battery is now disconnected, and a porcelain slab ($\kappa = 6.50$) is slipped between the plates.

but if I said I charged it



same charge
$U=\frac{q^2}{2C}$

(a) What is the potential energy of the capacitor before the slab is inserted?

KEY IDEA

We can relate the potential energy U_i of the capacitor to the capacitance C and either the potential V (with Eq. 25.4.2) or the charge q (with Eq. 25.4.1):

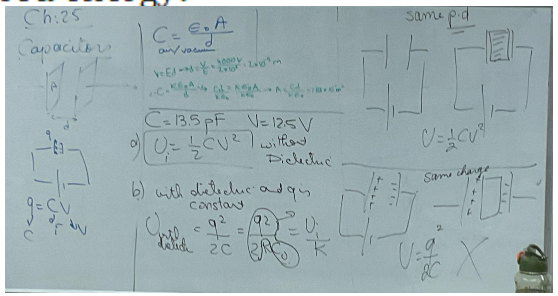
!! final exam !!

$$U_i = \tfrac{1}{2}CV^2 = \frac{q^2}{2C}.$$

Calculation: Because we are given the initial potential V $(= 12.5\ \text{V})$, we use Eq. 25.4.2 to find the initial stored energy:

$$U_i = \tfrac{1}{2}CV^2 = \tfrac{1}{2}(13.5\times10^{-12}\ \text{F})(12.5\ \text{V})^2$$
$$= 1.055\times10^{-9}\ \text{J} = 1055\ \text{pJ} \approx 1100\ \text{pJ}. \quad \text{(Answer)}$$

eqs in graphs



$U=\frac{q^2}{2\kappa C_0}=\frac{U_i}{\kappa}$
with dielectric

(b) What is the potential energy of the capacitor–slab device after the slab is inserted?

KEY IDEA

Because the battery has been disconnected, the charge on the capacitor cannot change when the dielectric is inserted. However, the potential *does* change.

Calculations: Thus, we must now use Eq. 25.4.1 to write the final potential energy U_f, but now that the slab is within the capacitor, the capacitance is κC. We then have

$$U_f = \frac{q^2}{2\kappa C} = \frac{U_i}{\kappa} = \frac{1055\ \text{pJ}}{6.50}$$
$$= 162\ \text{pJ} \approx 160\ \text{pJ}. \qquad \text{(Answer)}$$

When the slab is introduced, the potential energy decreases by a factor of κ.