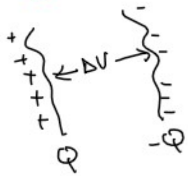
——o——o—— END of CH 23 ——o——

CH 24

CAPACITANCE
CAPACITORS
DIELECTRIC (yalıtkan)

capacitance $\equiv C \equiv \dfrac{Q}{\Delta V}$



$\left[F = \dfrac{C}{V}\right]$; $\left[C = FV\right]$

$\left[\text{Farad} = \dfrac{\text{Coulomb}}{\text{Volt}}\right]$

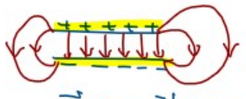
1 Farad is a HUGE cap. value

[1nF ; 1μF 1mF

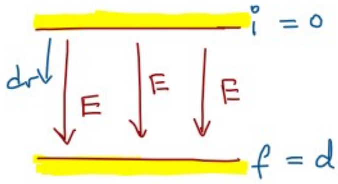
uniform $\vec{E}$ field two parallel plate

$\sqrt{\text{Area}} \gg$ distance, d

1cm ≫ 1mm



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



d → 0 Volt ↓ ⇒ −Ed Volt ; Ed volt ↓ 0 volts

E is constant

$-\int \vec{E}\cdot d\vec{r} = \Delta V$

$-\int E\,dr = -E\int dr = -E\left(r_f - r_i\right) = -Ed = \Delta V = V_f - V_i$

E = const. ; $\int dr = \Delta r$

$C = \dfrac{Q}{\Delta V} = \dfrac{Q}{Ed}$; Ch 22 E field of a ∞ large metal surface

$= \dfrac{Q}{\frac{\sigma}{\varepsilon_0} d} = \dfrac{Q}{\frac{Q}{A\varepsilon_0} d}$

$E = \dfrac{\sigma}{\varepsilon_0}$; $\sigma = \dfrac{Q}{\text{Area}} = \dfrac{Q}{A}$

$$\boxed{C = \varepsilon_0 \frac{A}{d} \quad \text{parallel plate capacitor}}$$

$\varepsilon_0 = 8.85 \times 10^{-12}\ \dfrac{C^2}{Nm^2} = 8.85 \times 10^{-12}\ \dfrac{F}{m}$

$C = \left(\sim 10^{-11}\right)\dfrac{A}{d}$

1) C is small number

2) C is purely geometrical

$\frac{A}{d}$		C
⇒ 10^8	⇒	10^{-3}F = 1mF
⇒ 10^5	⇒	10^{-6}F = 1μF
⇒ 10^2	⇒	10^{-9}F = 1nF

$C = \dfrac{Q}{\Delta V} = \varepsilon_0 \dfrac{A}{d}$ {This does not have any Q, V}

$\left[C = \varepsilon_0 \dfrac{A}{d}\ ;\ \Rightarrow \varepsilon_0 = 8.85\times10^{-12}\ \dfrac{F}{m}\right]$

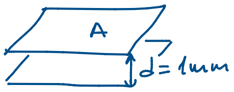
C = the ability to store (hold) charge +Q, −Q per potential difference.

$$\left[C = \varepsilon_0 \frac{A}{d} \;;\; \Rightarrow \varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m} \right]$$

C = the ability to store (hold) charge $+Q, -Q$ per potential difference.

$$\left[F = \frac{C^2}{Nm^2} \frac{m^2}{m} = \frac{C^2}{Nm} = \text{Farad} \right]$$

ex) parallel plate capacitor with $d = 1mm$
what would be the area of capacitor if $C = 1F$?



$A = ?$

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

$$1F = (8.85 \times 10^{-12}) \frac{A}{10^{-3}} \Rightarrow A = \frac{10^9}{8.85} \approx 10^8 m^2$$

$100{,}000{,}000 \, m^2$ = 30 times of campus size

Akdeniz Ü. campus $3{,}5 \times 10^6 \, m^2$

x) parallel plate capacitor $A = 2m^2$ $d = 5mm$ $\Delta V = 10kV$ $Q = ?$

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

$$C = 8.85 \times 10^{-12} \frac{2}{0.05} = 3.5 \times 10^{-9} F = 3.5 \, nF$$

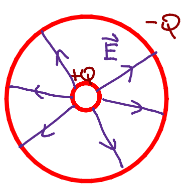
$$Q = C \Delta V = 3.5 \times 10^{-9} \times 10 \times 10^3 \, C$$
$$= 3.5 \times 10^{-5} C$$
$$\underline{Q = 35 \, \mu C}$$

b) $\vec{E}$ between the capacitor plate?

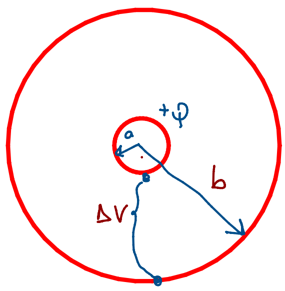
$$\Delta V = -Ed \qquad C = \frac{Q \rightarrow +}{\Delta V \rightarrow +} \qquad C \rightarrow +$$

$$E = \frac{\Delta V}{d} = \frac{10 \times 10^3 V}{5 \times 10^{-3} m} = \underline{2 \times 10^6 \, V/m}$$

SPHERICAL CAPACITORS



a = inner radius
b = outer radius



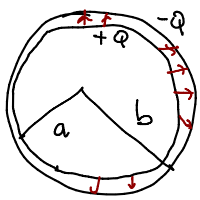
$$C = \frac{Q}{\Delta V} \qquad V(r_a) = \frac{kQ}{a} \qquad V(r_b) = \frac{kQ}{b} \Rightarrow \Delta V = \frac{kQ}{a} - \frac{kQ}{b} = kQ\left(\frac{b-a}{ab}\right)$$

$$C = \frac{Q}{kQ\left(\frac{b-a}{ab}\right)} = \frac{1}{k} \frac{ab}{b-a} = \boxed{4\pi\varepsilon_0 \frac{ab}{b-a} = C}$$

spherical cap.

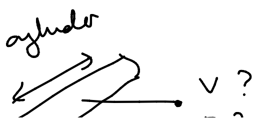
$$C \sim \varepsilon_0 \, [m]$$

$$\underset{\sim}{C \uparrow} \;;\; ab \uparrow \;;\; b-a \downarrow$$

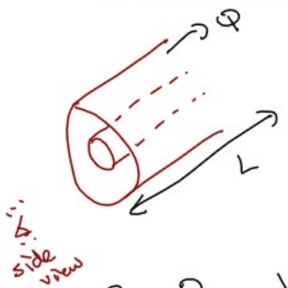


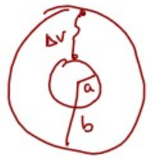
CYLINDIRICAL CAPACITOR

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

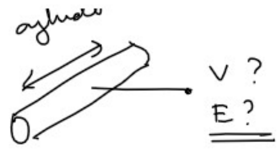


CYLINDIRICAL CAPACITOR



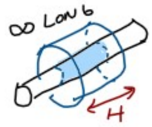


$C = \frac{Q}{\Delta V} \to ?$



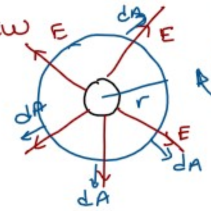
Ch22 Gauss Law

∞ LONG cylinder with charge density λ



$\oint \vec{E}\cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0} = \frac{\lambda H}{\varepsilon_0}$

TOP VIEW



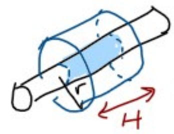
$\oint E\,dA\cos\theta$

$E\int dA + \int \vec{E}\cdot d\vec{A}$

side area

TOP BOTTO

$0 \quad \vec{E}\,d\vec{A}$



$2\pi r H = \text{side area}$

$E\,2\pi r H = \frac{\lambda H}{\varepsilon_0}\ ;\ E = \frac{\lambda}{2\pi\varepsilon_0 r}$

$C = \frac{Q}{\Delta V} = \frac{\lambda L}{\frac{\lambda}{2\pi\varepsilon_0}\ln\left(\frac{b}{a}\right)}$

$$\boxed{C = 2\pi\varepsilon_0 L \frac{1}{\ln\frac{b}{a}} = \frac{2\pi\varepsilon_0 L}{\ln b - \ln a}}$$

cylindrical cap.

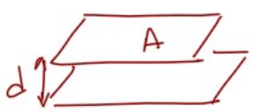
$C \sim \varepsilon_0\,[m]$ ✓

$C\uparrow;\ [\ln b - \ln a]\uparrow\ ;\ L\uparrow$

$\Delta V = -\int \vec{E}\cdot d\vec{r}$

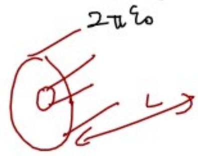
$= -\int \frac{\lambda}{2\pi\varepsilon_0}\frac{dr}{r} = \frac{\lambda}{2\pi\varepsilon_0}\left[\ln r\right]_{r_i = a}^{r_f = b}$

$\Delta V = \frac{\lambda}{2\pi\varepsilon_0}(\ln b - \ln a) = \frac{\lambda \ln\left(\frac{b}{a}\right)}{2\pi\varepsilon_0}$



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

$C = 4\pi\varepsilon_0 \frac{ab}{b-a}$



$C = 2\pi\varepsilon_0 L / \ln b/a$

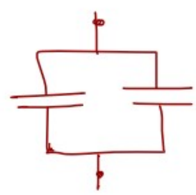
} Q, V ?!

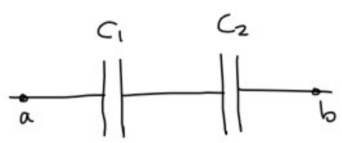
capacitors in series & parallel connections. ≡ CIRCUIT (devre)

capacitors are circuits elements

SERIES connection

Parallel





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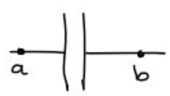


Ceq

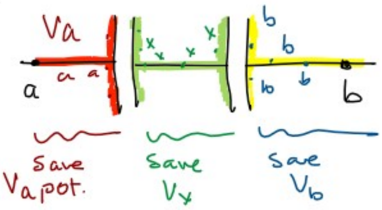
Vab

Ceq = equivalent capacity value. (eşdeğer)

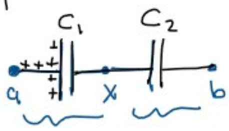
{METALS HAVE THE SAME POTENTIAL VALUE ON THE SURFACE}

{METALS HAVE THE SAME POTENTIAL VALUE ON THE SURFACE}

$\underbrace{}_{V_{ab}}$ Ceq

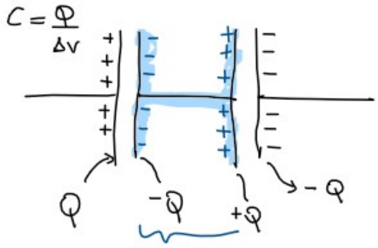


$\Rightarrow$



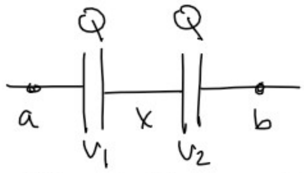
$\Rightarrow V_{ab} = V_{ax} + V_{xb}$

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



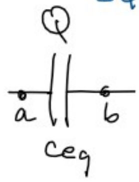
$\Sigma Q = 0$

series capacitors will ALWAYS have the same amount of charge Q



$V_{ax} + V_{xb} = V_{ab}$

$V_1 + V_2 = V_{ab}$ $\Rightarrow$

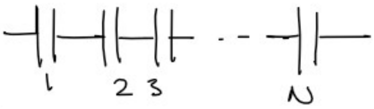


$$\frac{Q}{C_1} + \frac{Q}{C_2} = \frac{Q}{C_{eq}}$$

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

Cap. in series connection

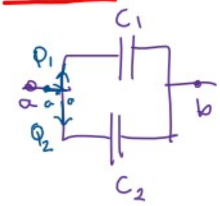
* *



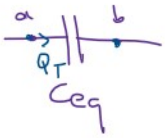
$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \frac{1}{C_N}}$$

SERIES CONNECTION

Capacitors in parallel connection



$\Rightarrow$



a a a a a a wire — same pot. on the surface.

* metals have equipotential surface.

$V_{ab} = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = V_{ab}$ $\Rightarrow \boxed{Q_1 + Q_2 = Q_T}$

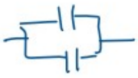
$C_{eq} = \frac{Q_T}{V_{ab}}$

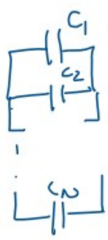
$Q_1 + Q_2 = Q_T$

$C_1 V_{ab} + C_2 V_{ab} = C_{eq} V_{ab}$

$V_{ab} = \frac{Q_T}{C_{eq}}$

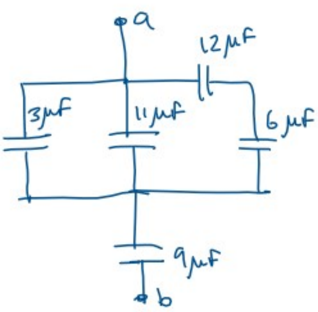
$\boxed{C_1 + C_2 = C_{eq}}$ parallel.



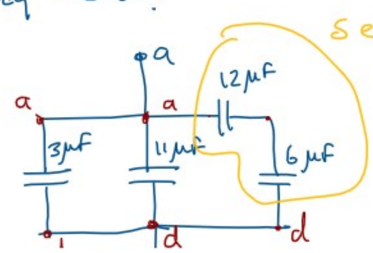


$$\boxed{C_{eq} = C_1 + C_2 + \dots + C_N}$$

parallel connection

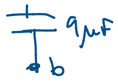


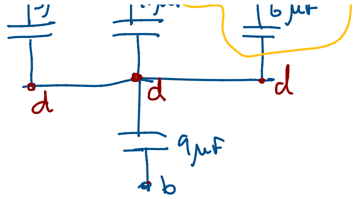
$C_{eq} = C_{ab} = ?$



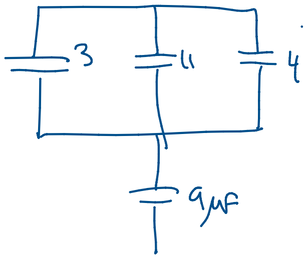
$$\left(\frac{1}{12} + \frac{1}{6}\right)^{-1} = \frac{6(12)}{6+12} = 4\mu F$$

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

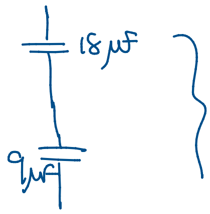




$$\frac{c_1c_2}{c_1+c_2} = c_{eq}$$

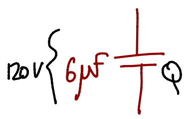


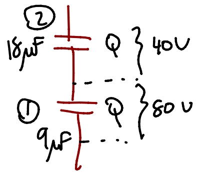
$3+11+4 = 18\mu F$

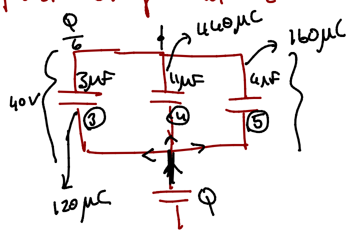


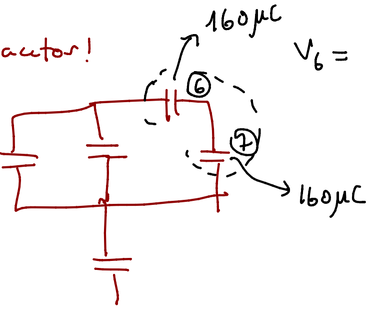
$$\frac{18(9)}{18+9} = 6\mu F = C_{ab}$$

If $V_{ab} = 120\,V$ $\Rightarrow$ find charges at each capacitor!









$$V_6 = \frac{160\mu C}{12\mu F} = \frac{40}{3}\,V$$

$$V_7 = \frac{160}{6} = \frac{80}{3}$$

$Q = CV$

$= 6(120)$

$= 720\mu C$

$$V_1 = \frac{720}{9} = 80V$$

$$V_2 = \frac{720}{18} = 40V$$

$Q_3 = (40V)\,3\mu F$

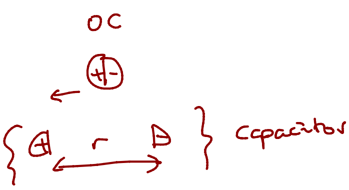
$= 120\mu C$

$Q_4 = (40V)\,11\mu F$

$= 440\mu C$

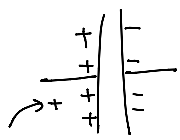
$Q_5 = (40V)\,4 = 160\mu C$

capacitors store charge
" " energy



Energy of a capacitor

$$W = -\Delta U = -\Delta(qV) = -q\Delta V = \int \vec F\cdot d\vec r = q\int \vec E\cdot d\vec r$$



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

$$\cancel{U \stackrel{?}{=} q\Delta V \stackrel{?}{=} (c\Delta V)\Delta V \stackrel{?}{=} c(\Delta V)^2}$$

$Vc = q \Rightarrow dV\,c = dq$

$dV = \frac{dq}{c}$

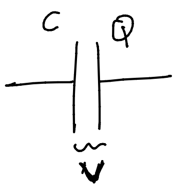
$U = qV$ $\Rightarrow$ $\int q\,dV$

related

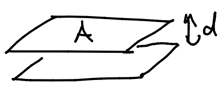
$$\int q\frac{dq}{c} = \frac{1}{c}\int q\,dq = \frac{q^2}{2C} \equiv U$$

$Q = CV$

$$\boxed{U = \frac{Q^2}{2C} = \frac{CV^2}{2} = \frac{QV}{2}}$$



$V \equiv \Delta V$



$$\text{Energy density of a capacitor} = \frac{\text{Energy}}{\text{volume}} = \frac{C\frac{V^2}{2}}{Ad} = \frac{\left(\varepsilon_0\frac{A}{d}\right)\frac{V^2}{2}}{Ad} = \varepsilon_0\frac{V^2}{2d^2}$$

Energy density of a capacitor $= \dfrac{\text{Energy}}{\text{volume}} = \dfrac{C\frac{V^2}{2}}{Ad} = \dfrac{\left(\varepsilon_0 \frac{A}{d}\right)\frac{V^2}{2}}{Ad} = \varepsilon_0 \dfrac{V^2}{2d^2}$

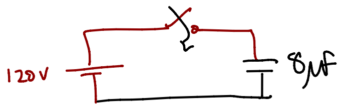
$\Delta V = -\int \vec{E}\cdot d\vec{r}$ $\quad d \updownarrow \underline{\downarrow\downarrow\downarrow E} \} \Delta V$ $= \varepsilon_0 \dfrac{E^2 d^2}{2d^2} = \dfrac{\varepsilon_0 \left(\frac{\sigma}{\varepsilon_0}\right)^2}{2} = \underline{\underline{\dfrac{\sigma^2}{2\varepsilon_0}}} = \left[\dfrac{J}{m^3}\right]$

$V = \Delta V = +Ed$

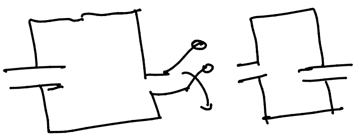
energy density of a parallel plate capacitor

$\sigma = \dfrac{Q}{A}$ = charge density

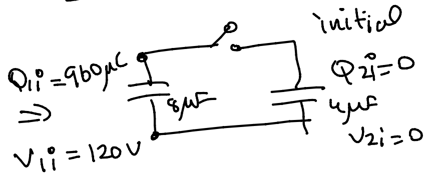
ex) $C_1 = 8\mu F$ is charged by 120V battery. ; battery is disconnected
C_1 is connected an uncharged $C_2 = 4\mu F$ capacitor.
what's the final charge distribution of C_1 & C_2?
" " final voltage " ?
Discuss the total energy before and after charge C_2.

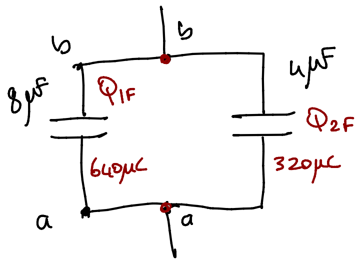


$Q = (8\mu F)(120V) = 960\,\mu C$ total charge
$U = \dfrac{QV}{2} = \dfrac{(960)(120)}{2} = 57600\,J$ } initial



$\Rightarrow$





* total charge will be conserved. *

$\boxed{Q_{1F} + Q_{2F} = Q_T = 960\,\mu C}$

$V_{ab} = V_{1F} = V_{2F} \Rightarrow Q_{1F} = V_{ab} C_1$
$Q_{2F} = V_{ab} C_2$

$V_{ab} C_1 + V_{ab} C_2 = 960\mu C \Rightarrow V_{ab} = \dfrac{960\mu C}{C_1 + C_2} = \dfrac{960\mu C}{12\mu F}$

$Q_{1F} = V_{ab} C_1 = 80(8) = 640\,\mu C$ $\qquad \underline{\underline{V_{ab} = 80V}}$

$Q_{2F} = V_{ab} C_2 = 80(4) = 320\,\mu C$

	initial	final
V_1	120V	80V
V_2	0V	80V
Q_1	960μC	640μC
Q_2	0	320μC
U_1	57600	25600
U_2	0	12800
	57600 J	38400 J

$U_{1F} = \dfrac{Q_{1F} V_{ab}}{2} = \dfrac{640\,(80)}{2} = 25600\,J$

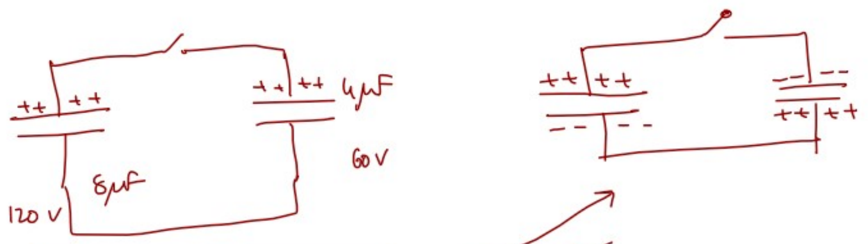
$U_{2F} = \dfrac{Q_{2F} V_{ab}}{2} = \dfrac{320\,(80)}{2} = 12800\,J$

$+$

$\underline{\underline{\text{Final}}}$ $\quad$ 38400 J

$\Rightarrow$ energy is NOT conserved ?!

$\dfrac{576 - 384}{576}$ = % 33 is LOST



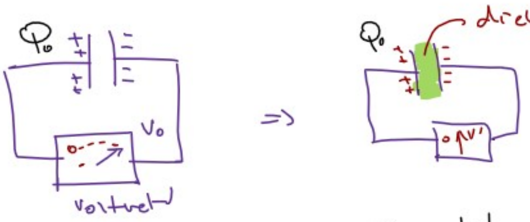
$$\boxed{Q_{1i} + Q_{2i} = Q_{1F} + Q_{2F}}$$

960 +120

960 −120

DIELECTRICS (yalıtkan)

Dielectric used to increase the capacity of capacitors



$Q_0 = C_0 V_0$ $\Rightarrow$ $Q_0 = V'C'$

$V' < V_0$

$C' > C_0$

$$\boxed{C' = K C_0}$$

↳ kappa (dielectric const.)

$K > 1$

	K
vacuum	→ 1.00000 ...
air	→ 1.0006
teflon	→ 2.1
glass	→ 5 −10
glycerin	→ 42.5
strontium titanate	→ 310

(I)

$C' = C_0 K$

$V' = V_0 \frac{1}{K}$

$Q_0 = Q'$

$$\boxed{V_0 = K V'}$$

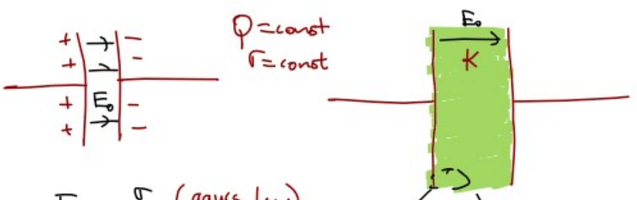
C_0	$KC_0 = C'$
V_0	$\frac{V_0}{K}$
Q_0	Q_0

$Q = CV$

(II)

C_0	$KC_0 = C'$
V_0	$V_0 = V'$
Q_0	$KQ_0 = Q'$

what's happening to $\vec{E}$ inside of a capacitor when dielectric mat. is filled?

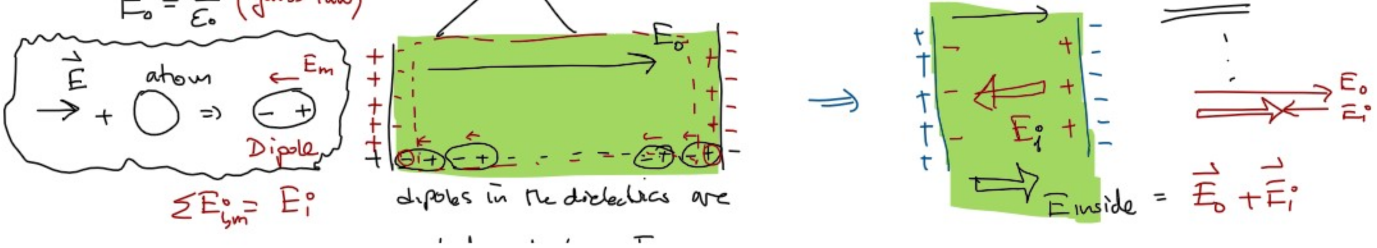


$\vec{E}' = \vec{E}_0 + \vec{E}_i$

$E' < E_0$

$E' = \frac{E_0}{K}$

$E_0 = \frac{\sigma}{\varepsilon_0}$ (gauss law)



$\sum E_{i,in} = E_i$

dipoles in the dielectrics are

$E_{inside} = \vec{E}_0 + \vec{E}_i$

Dipole + (− +)(− +) ... (− +)(− +) −

$\sum E_{i,m}^{\circ} = E_i^{\circ}$

dipoles in the dielectrics are induced by E_0

$\Longrightarrow E_{inside} = \vec{E}_0 + \vec{E}_i$

$E_{inside} < E_0$

$V_0 > V' = \frac{V_0}{K}$

$\Delta V = -\int \vec{E} \cdot d\vec{r}$

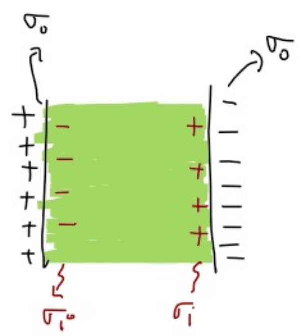
$\downarrow$

$\frac{V_0}{K} \Rightarrow \frac{E_0}{K}$

$\vec{E}_{inside} = \vec{E}' = \vec{E}_0 + \vec{E}_i^{\circ} \qquad E_i^{\circ} = |\vec{E}_i|$

$E' = E_0 - E_i^{\circ} = \underline{\underline{\frac{E_0}{K}}}$

$E_0 - E_i^{\circ} = \frac{E_0}{K} \Rightarrow E_i^{\circ} = \left(\frac{K-1}{K}\right) E_0 \Rightarrow \frac{\sigma_i^{\circ}}{\varepsilon_0} = \frac{K-1}{K} \frac{\sigma_0}{\varepsilon_0}$



$*\ \boxed{\sigma_i^{\circ} = \frac{K-1}{K} \sigma_0}$; $K = 1.5 \Rightarrow \sigma_i^{\circ} = \frac{0.5}{1.5} \sigma_0 \Longrightarrow$

$\boxed{\sigma_i^{\circ} < \sigma_0}$

$\sigma_i^{\circ} \simeq (33\%) \sigma_0$

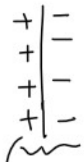
$\left[\sigma = \frac{\text{charge}}{\text{area}} = \frac{Q}{A}\right]$

$\boxed{Q_i^{\circ} < Q_0}$

$\boxed{Q_i^{\circ} = \frac{K-1}{K} Q_0} \rightarrow Q_i^{\circ} \simeq Q_0$

$K \gg 1 \qquad \frac{299}{300} \simeq 1 = \frac{K-1}{K}$

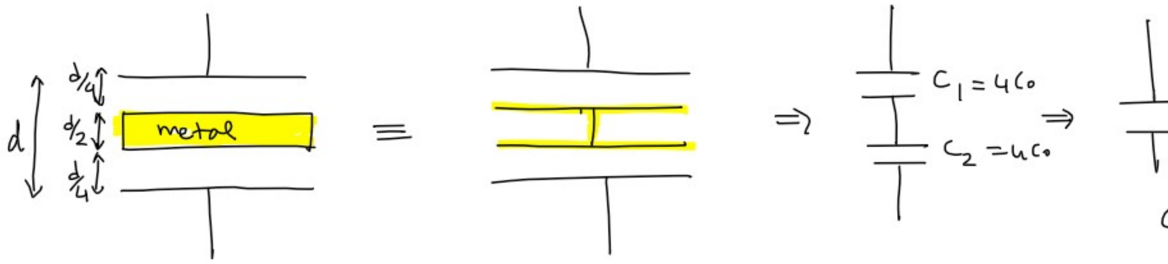
$K \to \infty$ material behaves like <u>metal</u>



($Q_0 \cong Q_i^{\circ} \Rightarrow$ metal property)

$\left\{ C' = K C_0 \begin{array}{l} \rightarrow V_0 = \text{const} \quad Q' = K Q_0 \\ \rightarrow Q_0 = \text{const} \quad V' = \frac{V_0}{K} \end{array} \right\}$

END of chapter

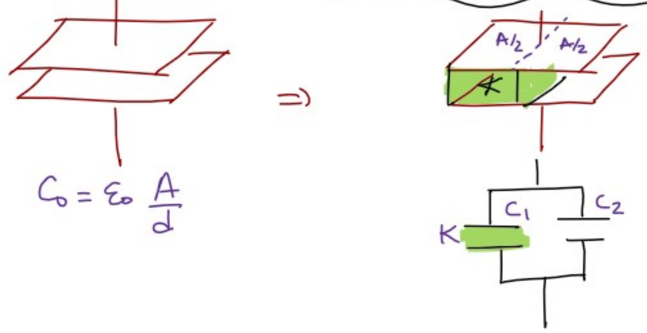


$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$

$C_{eq} = \frac{16 C_0^2}{4C_0 + 4C_0} = 2C$

$C_0 = \varepsilon_0 \frac{A}{d}$; $C_1 = \varepsilon_0 \frac{A}{d/4} = 4 \varepsilon_0 \frac{A}{d} = 4C_0 = C_2$

ex)



$C_0 = \varepsilon_0 \frac{A}{d}$

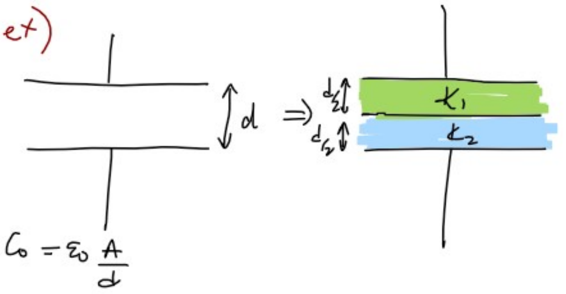
$C_{eq} = ?$

$C_{eq} = C_1 + C_2$

$= \varepsilon_0 \frac{A/2}{d} K + \varepsilon_0 \frac{A/2}{d}$

$$C_{eq} = \frac{\varepsilon_0 A}{2d}(K+1) = \frac{C_0}{2}(K+1)$$

ex)



$C_{eq} = ?$

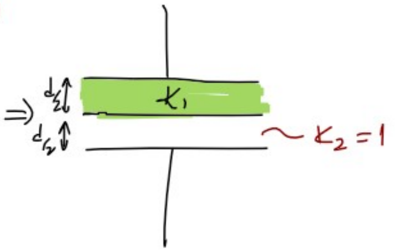
$C_1 = K_1 \varepsilon_0 \frac{A}{d/2} = 2K_1 C_0$

$C_2 = K_2 \varepsilon_0 \frac{A}{d/2} = 2K_2 C_0$

$C_0 = \varepsilon_0 \frac{A}{d}$

$$\frac{C_1 C_2}{C_1 + C_2} = C_{eq} = \frac{4K_1 K_2 C_0^2}{2C_0(K_1+K_2)} = \frac{2C_0 K_1 K_2}{K_1+K_2}$$

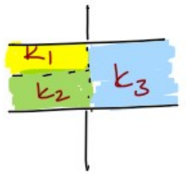
ex)



$\sim K_2 = 1$

$$C_{eq} = \frac{2C_0 K_1 (1)}{(K_1+1)}$$

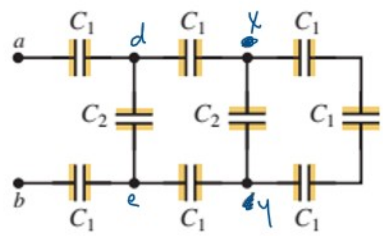
ex)

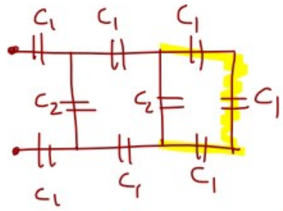


$\Rightarrow C_{eq} = ?$ (do it yourself)

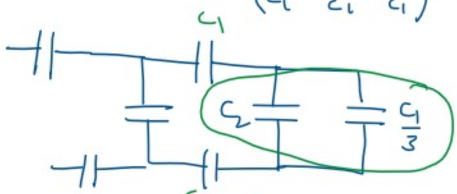
24.63 •• In Fig. P24.63, each capacitance C_1 is 6.9 μF, and each capacitance C_2 is 4.6 μF. (a) Compute the equivalent capacitance of the network between points a and b. (b) Compute the charge on each of the three capacitors nearest a and b when $V_{ab} = 420$ V. (c) With 420 V across a and b, compute V_{xy}.

Figure **P24.63**



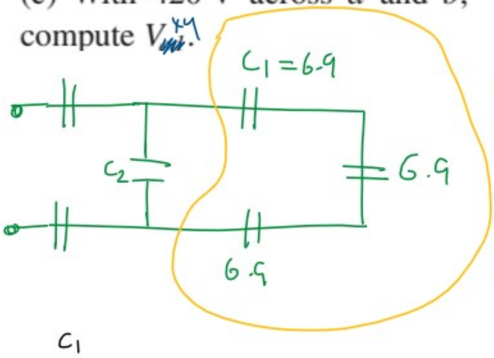


$$\left(\frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1}\right)^{-1} = \frac{C_1}{3} = \frac{6.9}{3} = 2.3$$



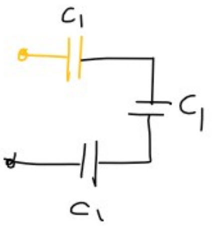
$6.9 = C$

$C_2 + \frac{C_1}{3} = 4.6 + 2.3 = 6.9$

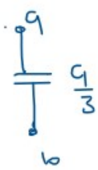


$C_1 = 6.9$

$\frac{C_1}{3}$



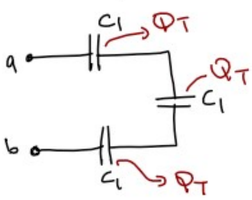
$$\Rightarrow \frac{C_1}{3} = C_{eq} = \frac{6.9}{3} = \underline{\underline{2.3 \mu F}} \Rightarrow$$



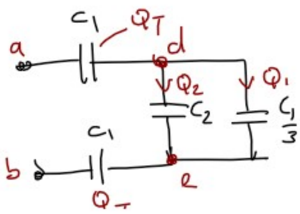
$\frac{9}{3} = 2.3 \mu F$

$Q = (2.3)\mu F\ (420\ V)$

$Q_T = 966 \mu C$

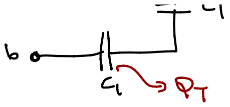


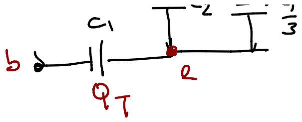
$\Rightarrow$



$Q_2 + Q_1 = 966 \mu C$

$$V_{de} = \frac{Q_2}{C_2} = \frac{Q_1}{C_1} \Rightarrow \frac{Q_2}{4.6} = \frac{Q_1}{2.3}$$





$Q_2 + Q_1 = 966\,\mu C$

$$V_{de} = \frac{Q_2}{C_2} = \frac{Q_1}{C_1/3} \Rightarrow \frac{Q_2}{4.6} = \frac{Q_1}{2.3}$$

$$Q_2 = 2Q_1$$

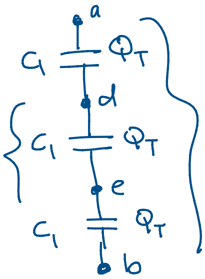
$$\Rightarrow 3Q_1 = 966\,\mu C$$

$$Q_1 = 322\,\mu C$$

$$Q_2 = 644\,\mu C$$

$V_{ab} = 420\,V$

2nd way:



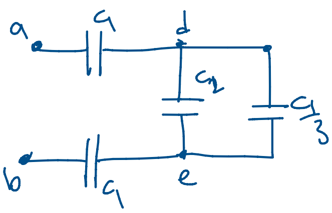
$V_{ab} = 420\,V$

$$140\,V = V_{de} = \frac{V_{ab}}{3}$$

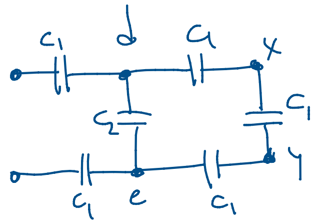
$$V_{de} = \frac{Q_T}{C_1} = \frac{966\,\mu C}{6.9\,\mu F} = 140\,V$$

$$V_{de} = \frac{Q_2}{C_2} = \frac{Q_2}{4.6\,\mu F} = 140 \Rightarrow Q_2 = 644\,\mu C$$

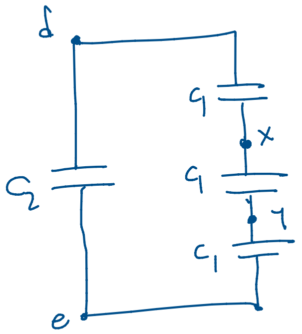
$$V_{de} = \frac{Q_1}{C_1/3} \Rightarrow (140\,V)(2.3\,\mu F) \Rightarrow Q_1 = 322\,\mu C$$



$\Rightarrow$



$140 = V_{de}$



$$\frac{V_{de}}{3} = \frac{140}{3}\,V = 46.7\,V$$