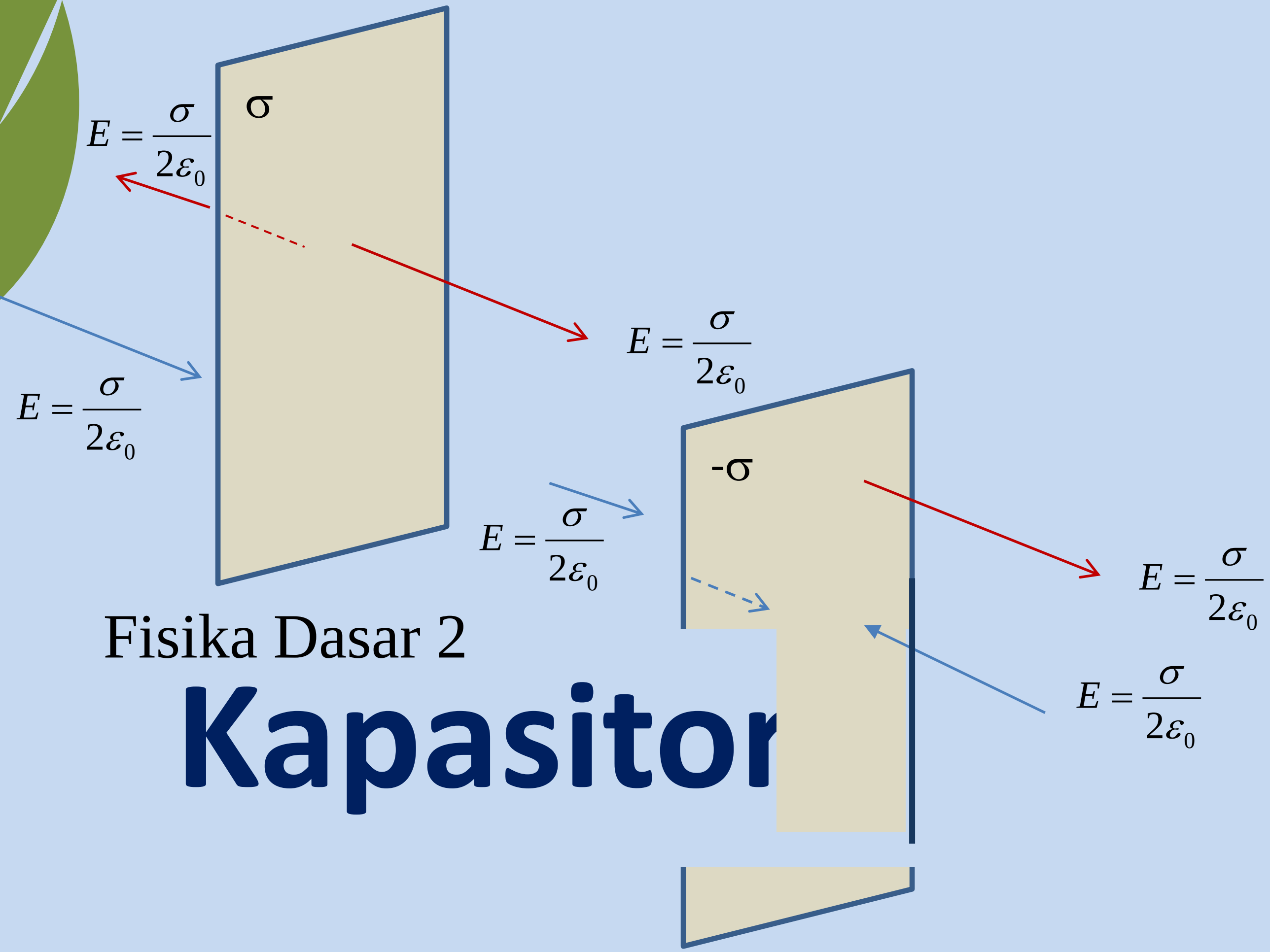

Fisika Dasar 2

Kapasitor

Kelompok Keilmuan Fisika Teoretik Energi Tinggi-FMIPA-ITB

Prof. Triyanta, Ph.D.

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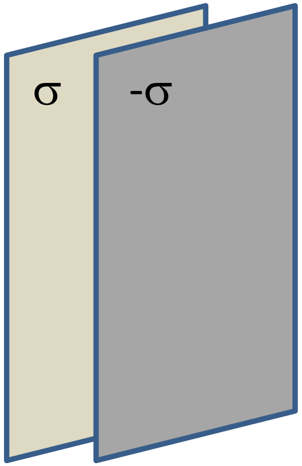
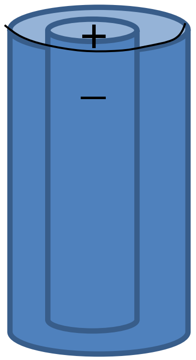
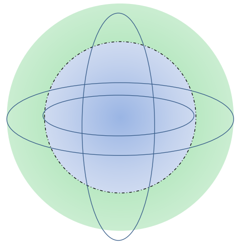
https://th.bing.com/th/id/OIP.wlkKPTZhAa8H22359bxyVAHaEG?w=320&h=180&c=7&r=0&o=5&dpr=1.5&pid=1.7

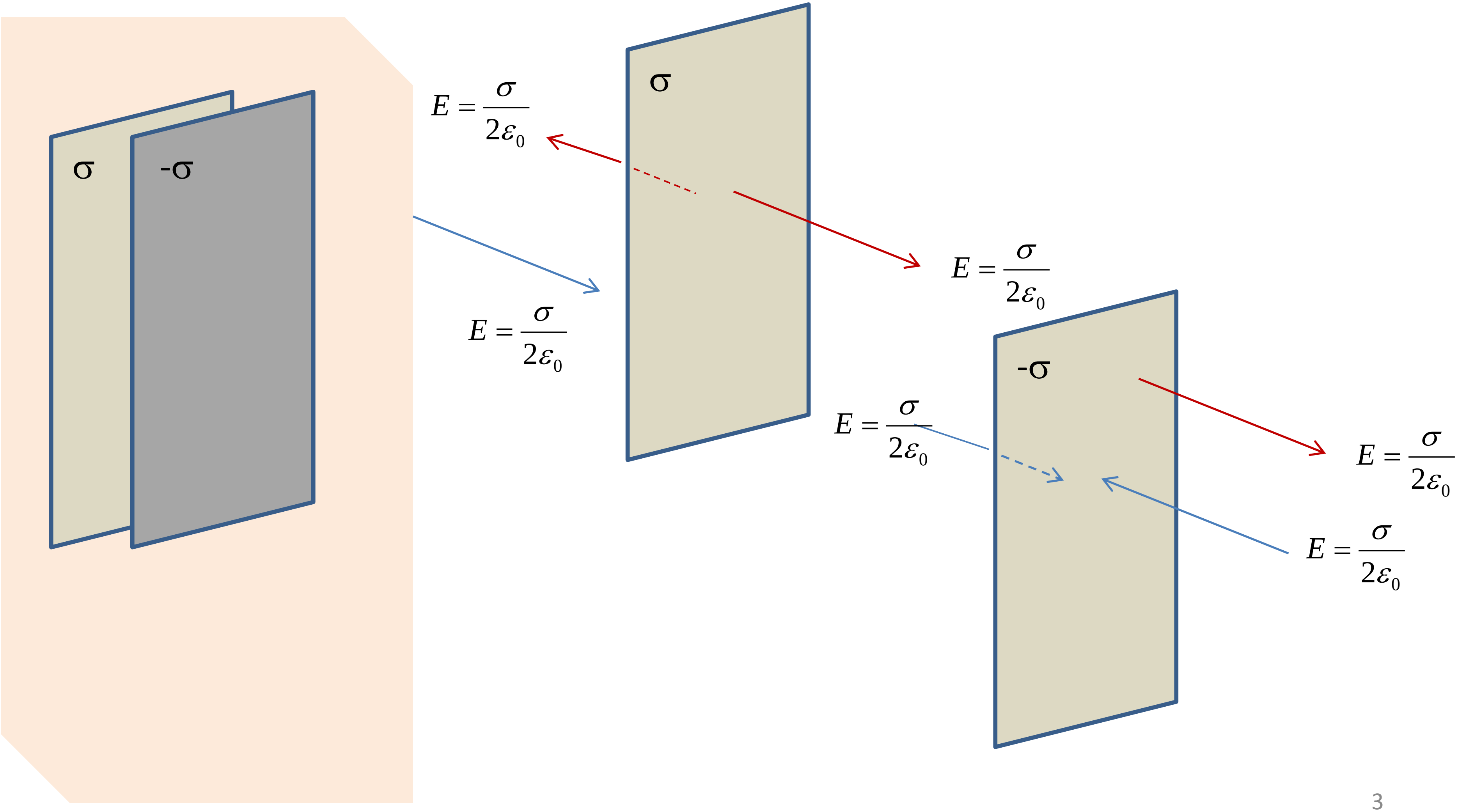
https://www.bing.com/images/search?q=Variable+Capacitor&FORM=R5FD6

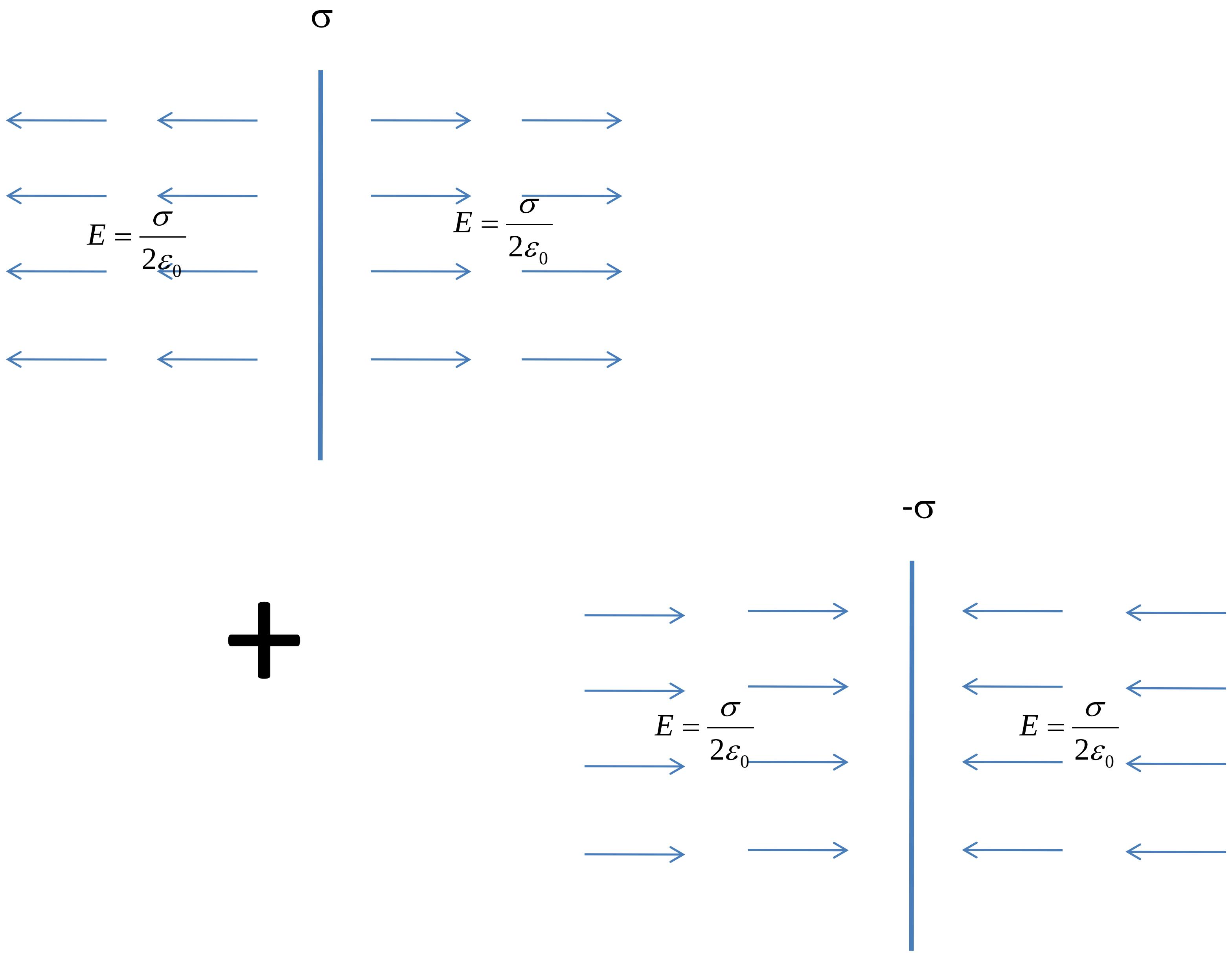


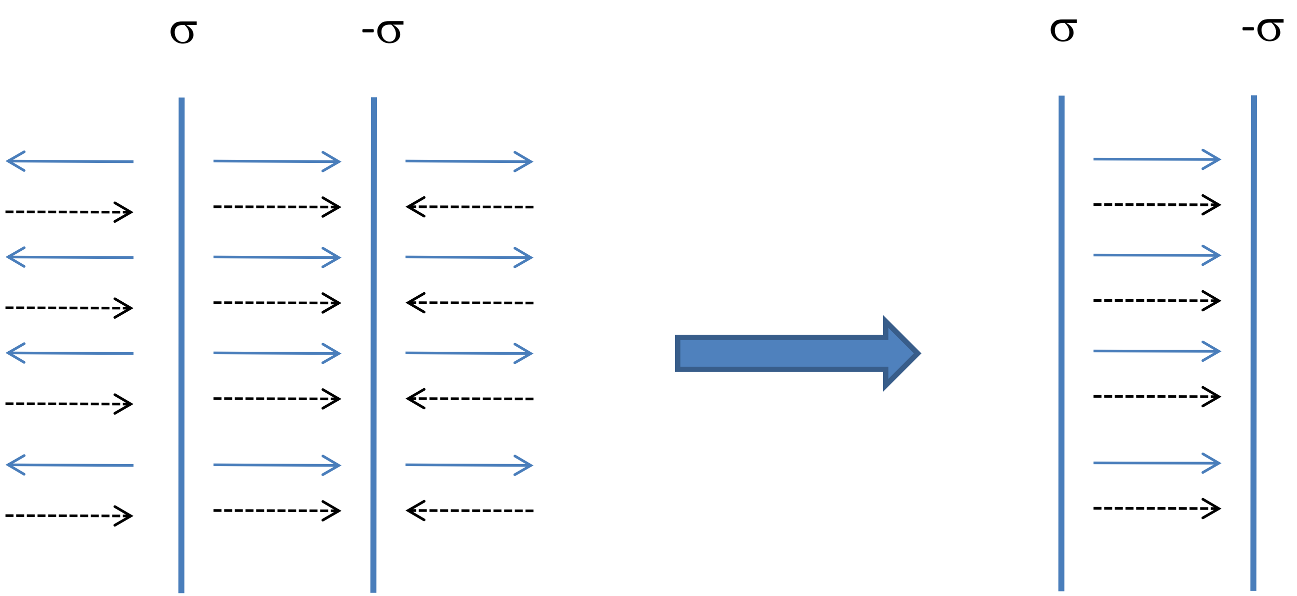


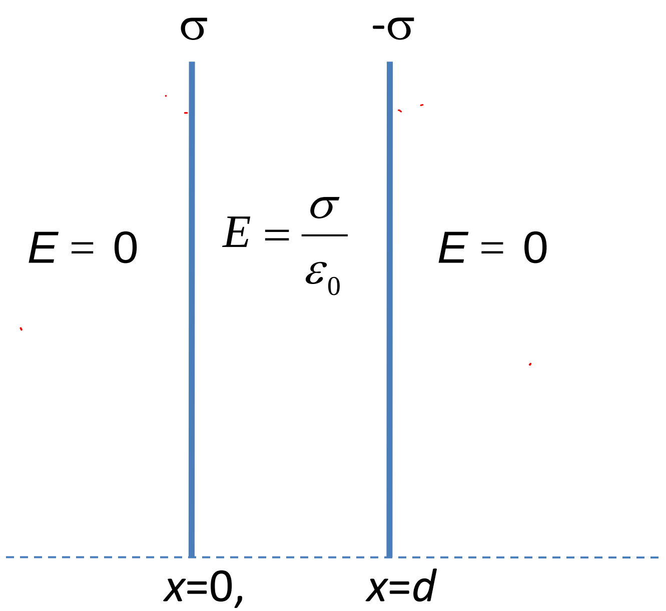


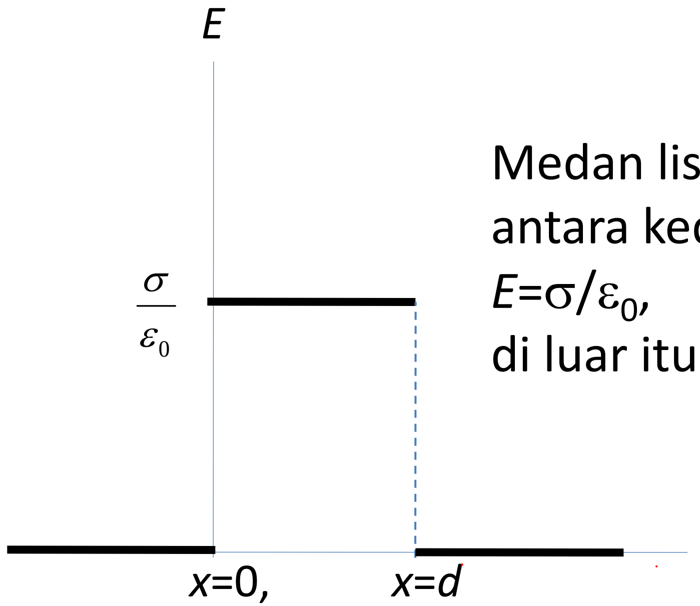
Dua keping sejajar dengan distribusi muatan homogen sama besar berbeda jenis




σ
$E = \frac{\sigma}{2\varepsilon_0}$
$E = \frac{\sigma}{2\varepsilon_0}$
+
-σ
$E = \frac{\sigma}{2\varepsilon_0}$
$E = \frac{\sigma}{2\varepsilon_0}$







Medan listrik di antara kedua pelat $E=\sigma/\varepsilon_0$, di luar itu nol.

$$x < 0 \qquad V(x) = -\int E dx + c_1 = c_1$$

$$0 < x < d \qquad V(x) = -\int E dx + c_2 = -\frac{\sigma}{\varepsilon_0} x + c_2$$

$$x > d \qquad V(x) = -\int E dx + c_3 = c_3$$

Pilih konstanta integrasi sehingga fungsi *V*(*x*) kontinu

x=0

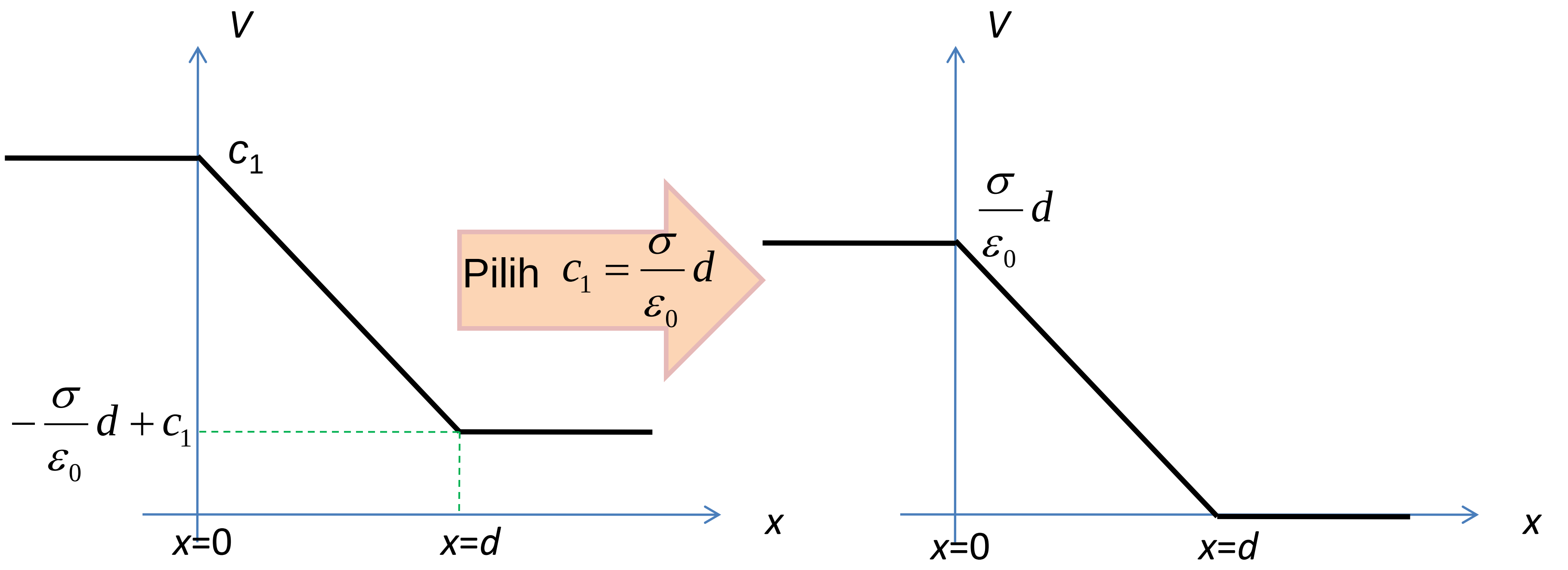
$$\left.\begin{array}{l} V(0) = c_1 \\ V(0) = c_2 \end{array}\right\} c_1 = c_2$$

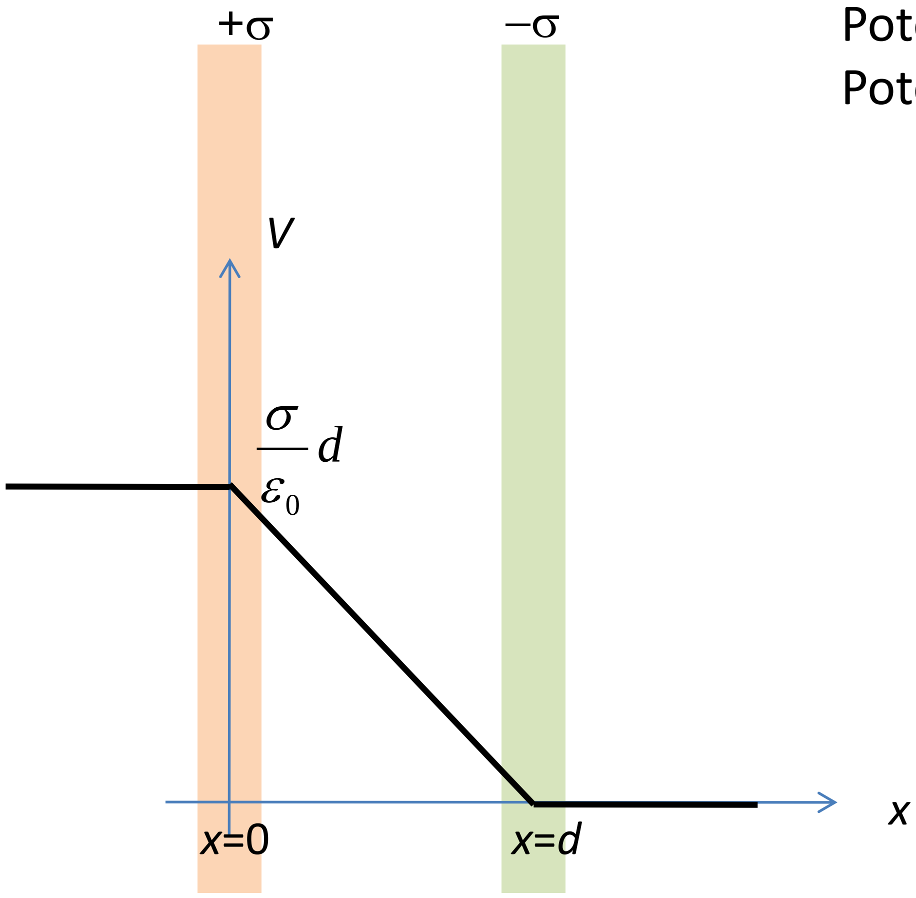
$$\left.\begin{array}{l} V(d) = -\frac{\sigma}{\varepsilon_0} d + c_2 \\ V(d) = c_3 \end{array}\right\} c_3 = -\frac{\sigma}{\varepsilon_0} d + c_2$$

$$x < 0 \qquad V(x) = c_1$$

$$0 < x < d \qquad V(x) = -\frac{\sigma}{\varepsilon_0} x + c_1$$

$$x > d \qquad V(x) = -\frac{\sigma}{\varepsilon_0} d + c_1$$





Potensial listrik di pelat(+): $V=\sigma d/\varepsilon_0$,
Potensial listrik di pelat(-) : $V=0$.

Beda potensial listrik antara kedua pelat $\Delta V=\sigma d/\varepsilon_0$

$$\Delta V = \frac{\sigma}{\varepsilon_0} d$$

Beda potensial antara kedua keping/pelat:

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

Q muatan keping
A luas satu keping

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

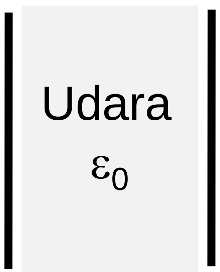
C: kapasitansi keping sejajar

Piranti keping sejajar dinamakan kapasitor. Kapasitor berfungsi sebagai penyimpan muatan. Muatan tersimpan tidak di ruang antara kedua keping tetapi di dalam keping

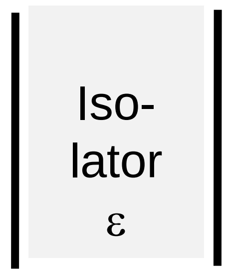
Untuk ΔV yang sama kapasitor mampu menampung muatan *Q* yang lebih besar bila kapasitansi (*C*) nya besar

C besar jika

- keping luas (*A* besar)
- jarak antar keping *d* kecil
- udara di antara kedua keping diganti dengan bahan dielektrik (isolator), ε_0 diganti dengan $\varepsilon=\varepsilon_0\varepsilon_r$.



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



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

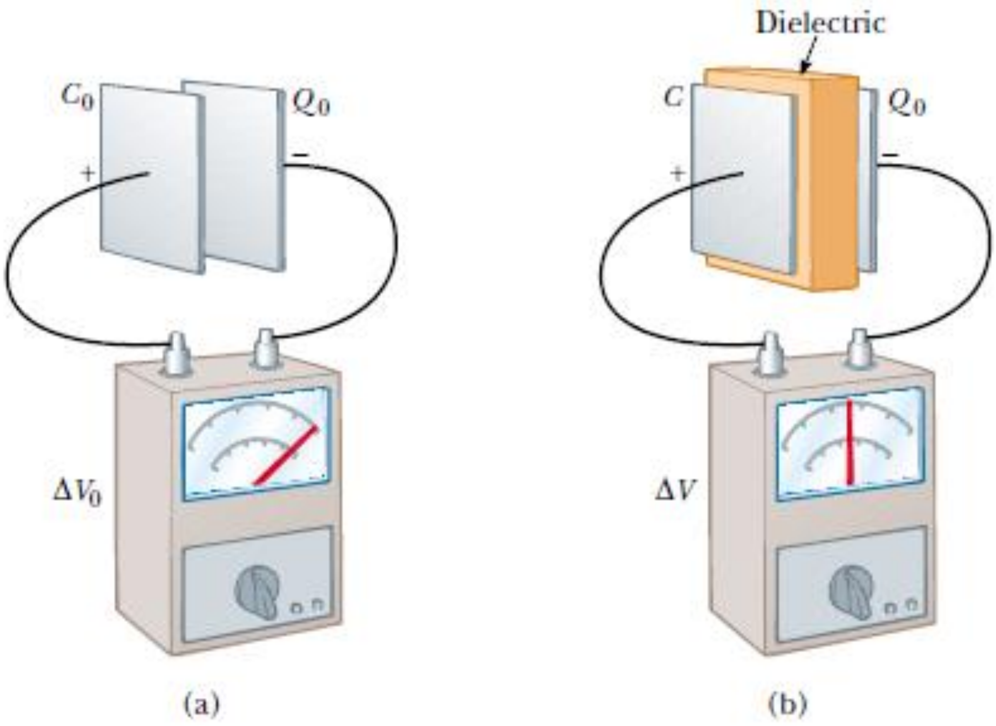
$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} = \varepsilon_r C_0 > C_0$$

ε_0=permitivitas listrik udara/vakum

ε =permitivitas listrik isolator/bahan dielektrik

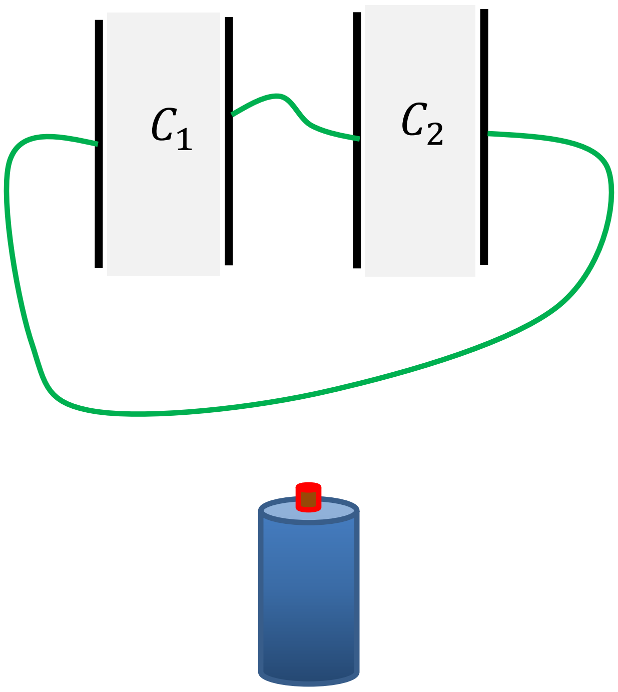
$\varepsilon_r = \kappa$=permitivitas relatif=konstanta dielektrik, $\varepsilon_r = \kappa > 1$

Material	Dielectric Constant κ
Air (dry)	1.000 59
Bakelite	4.9
Fused quartz	3.78
Neoprene rubber	6.7
Nylon	3.4
Paper	3.7
Polystyrene	2.56
Polyvinyl chloride	3.4
Porcelain	6
Pyrex glass	5.6
Silicone oil	2.5
Strontium titanate	233
Teflon	2.1
Vacuum	1.000 00
Water	80



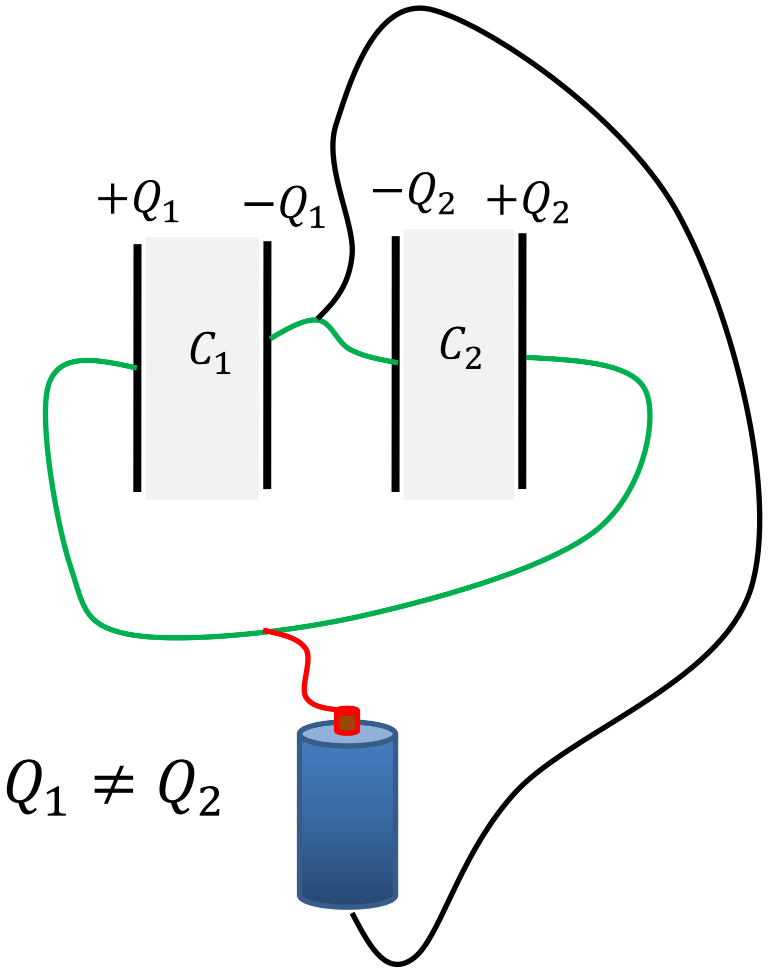
Kapasitor yang telah diisi diukur beda potensialnya:
(a) kasus kapasitor berisi udara
(b) kasus kapasitor diisi bahan dielektrik

Rangkaian kapasitor

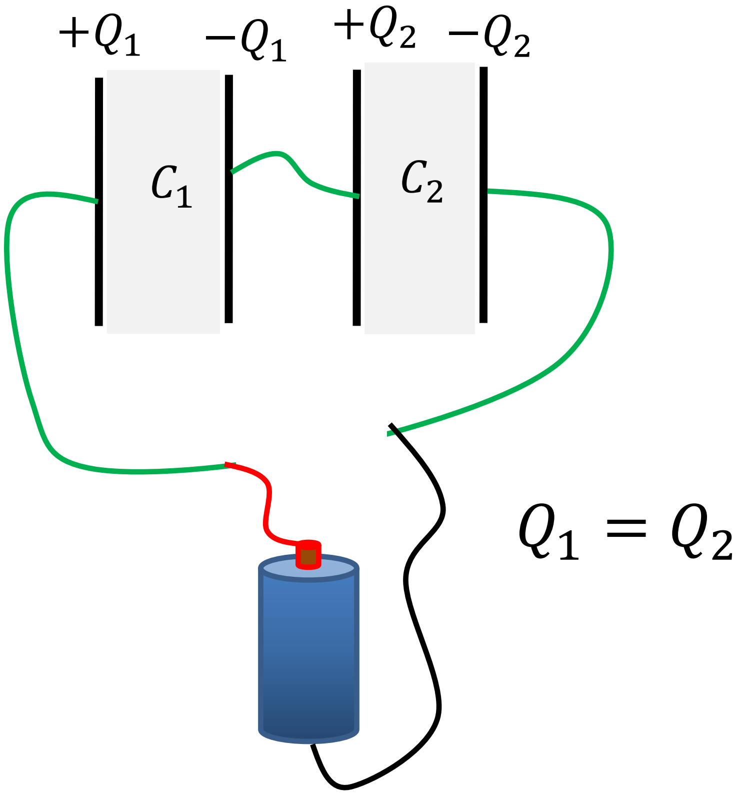


Menghubungkan dua kapasitor dan baterai dengan kawat/konduktor:

Berapa kemungkinan rangkaian yang berbeda?

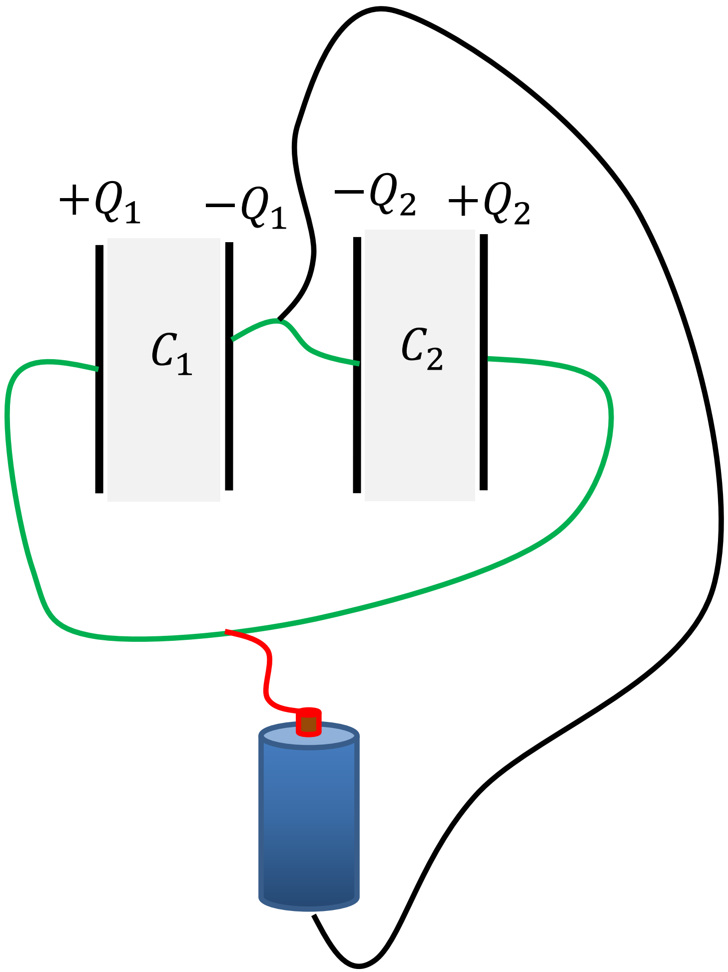


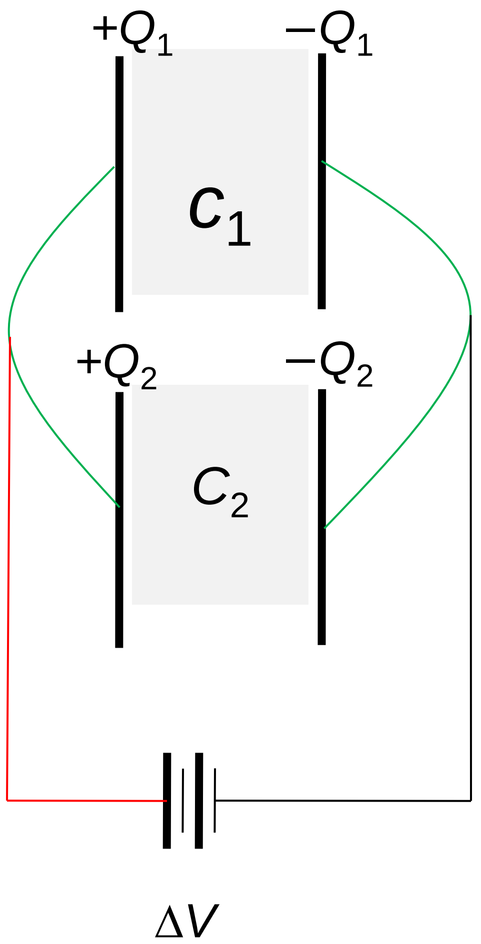
Kapasitor terangkai paralel



Kapasitor terangkai seri

Rangkaian paralel kapasitor

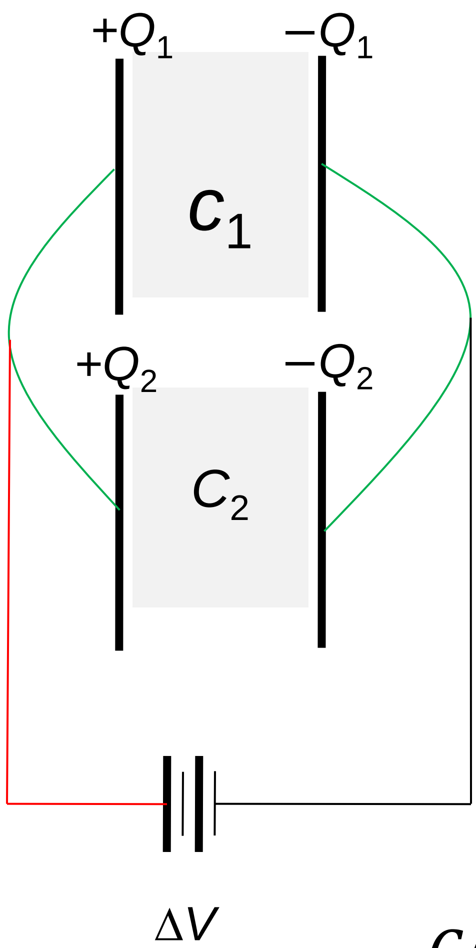




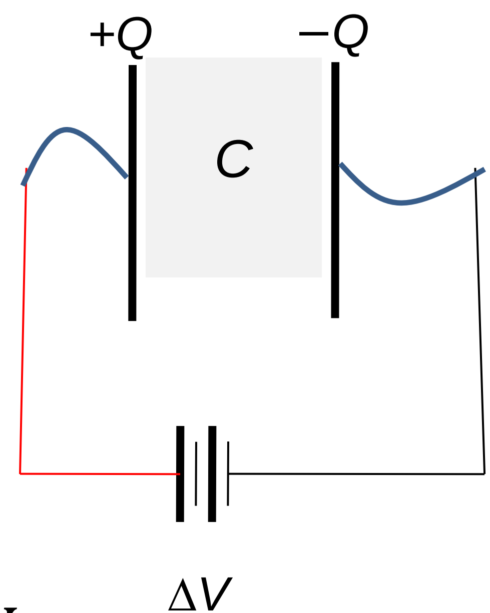
Beda potensial antar keping untuk kedua kapasitor sama

$$Q_1 = C_1 \Delta V$$

$$Q_2 = C_2 \Delta V$$



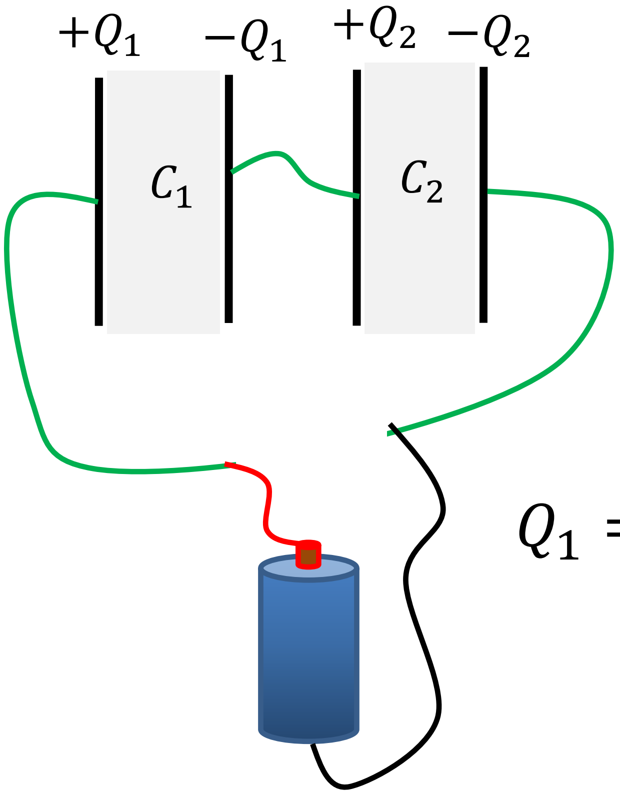
$$Q = C\Delta V$$
$$Q = Q_1 + Q_2$$

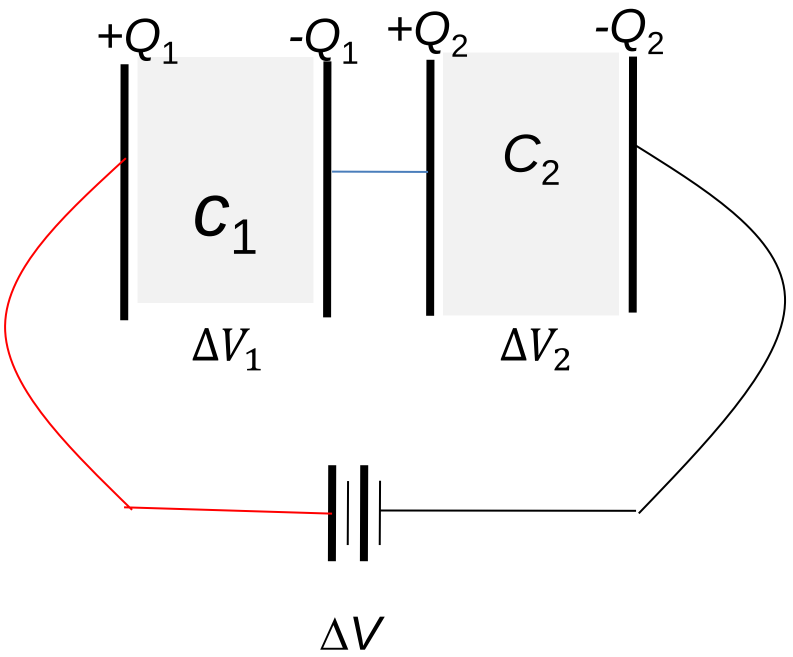


$$Q = Q_1 + Q_2$$
$$C\Delta V = C_1 \Delta V + C_2 \Delta V$$

$$C = C_1 + C_2$$

Rangkaian seri kapasitor



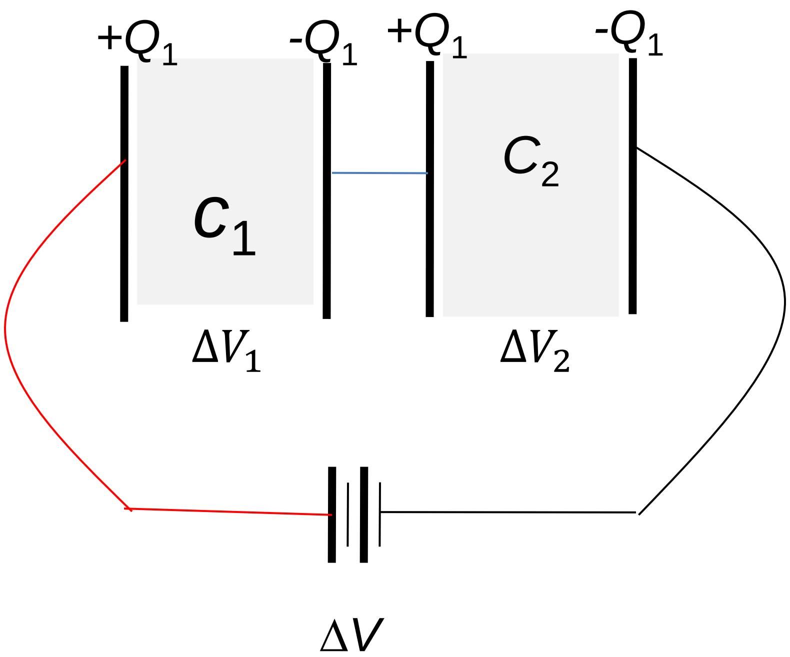


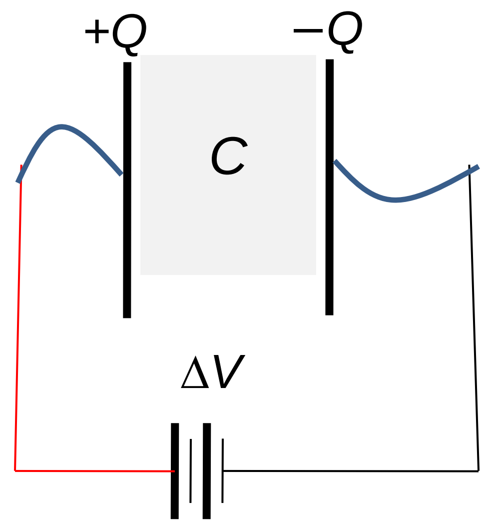
$$Q_1 = Q_2$$

$$Q_1 = C_1 \Delta V_1, \qquad Q_2 = C_2 \Delta V_2 = Q_1$$

$$\Delta V = \Delta V_1 + \Delta V_2$$

$$Q = C\Delta V$$
$$Q = Q_1$$





$$Q_1 = C_1\Delta V_1, \qquad Q_2 = C_2\Delta V_2 = Q_1$$

$$\Delta V = \Delta V_1 + \Delta V_2$$

$$Q = C\Delta V = C(\Delta V_1 + \Delta V_2)$$
$$Q = C\left(\frac{Q_1}{C_1} + \frac{Q_2}{C_2}\right) = C\left(\frac{Q}{C_1} + \frac{Q}{C_2}\right)$$
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Rangkaian n kapasitor paralel

$$C = C_1 + C_2 + \cdots + C_n$$

Rangkaian n kapasitor seri

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

Energi yang tersimpan dalam kapasitor

Misalkan *q* adalah muatan pada kapasitor pada suatu saat ketika kapasitor sedang diisi.
Beda potensial antara kedua keping kapasitor pada saat itu adalah $\Delta V = q/C$.
Usaha yang dilakukan untuk memindahkan sejumlah kecil muatan *dq* dari pelat (-) ke pelat (+) adalah

$$dW = \Delta V dq = \frac{q}{C} dq$$

Usaha total yang diperlukan untuk mengisi kapasitor dari $q=0$ sampai $q=Q$ adalah

$$W = \int_{q=0}^{q=Q} dW = \int_{q=0}^{q=Q} \frac{q}{C} dq = \frac{Q^2}{2C}$$

Usaha yang dilakukan untuk mengisi kapasitor muncul sebagai energi potensial listrik yang tersimpan dalam kapasitor.

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

Formula di atas berlaku untuk semua jenis kapasitor.

Untuk kapasitor keping sejajar

$$U = \frac{1}{2}C(\Delta V)^2 = \frac{1}{2}\frac{\varepsilon_0 A}{d}(Ed)^2 = \frac{1}{2}\varepsilon_0 AE^2 d$$

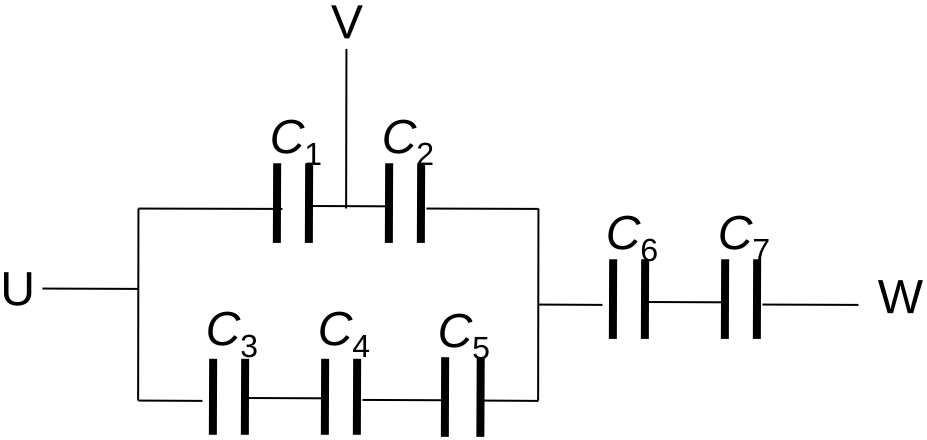
Energi yang tersimpan per satuan volume kapasitor

$$u = \frac{U}{Ad} == \frac{1}{2}\varepsilon_0 E^2$$

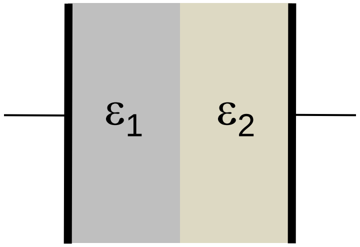
Soal-Soal

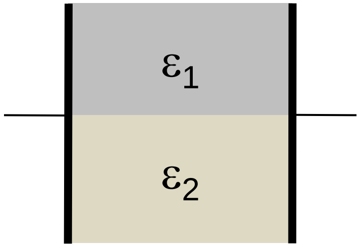
Untuk rangkaian 7 kapasitor identik di samping, tentukanlah kapasitansi antara

a) U dan V
b) U dan W
c) V dan W



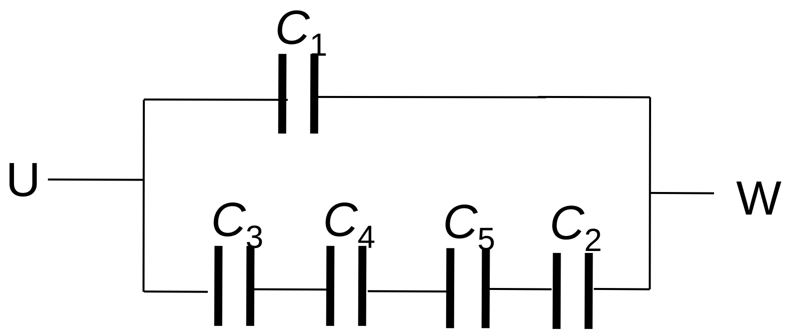
Tentukanlah kapasitansi dari setiap kapasitor di bawah yang masing-masing terisi dua bahan dielektrik yang berbeda sbb:





Jawab

Kapasitansi antara U dan V
sama dengan kapasitansi
rangkaian di samping:

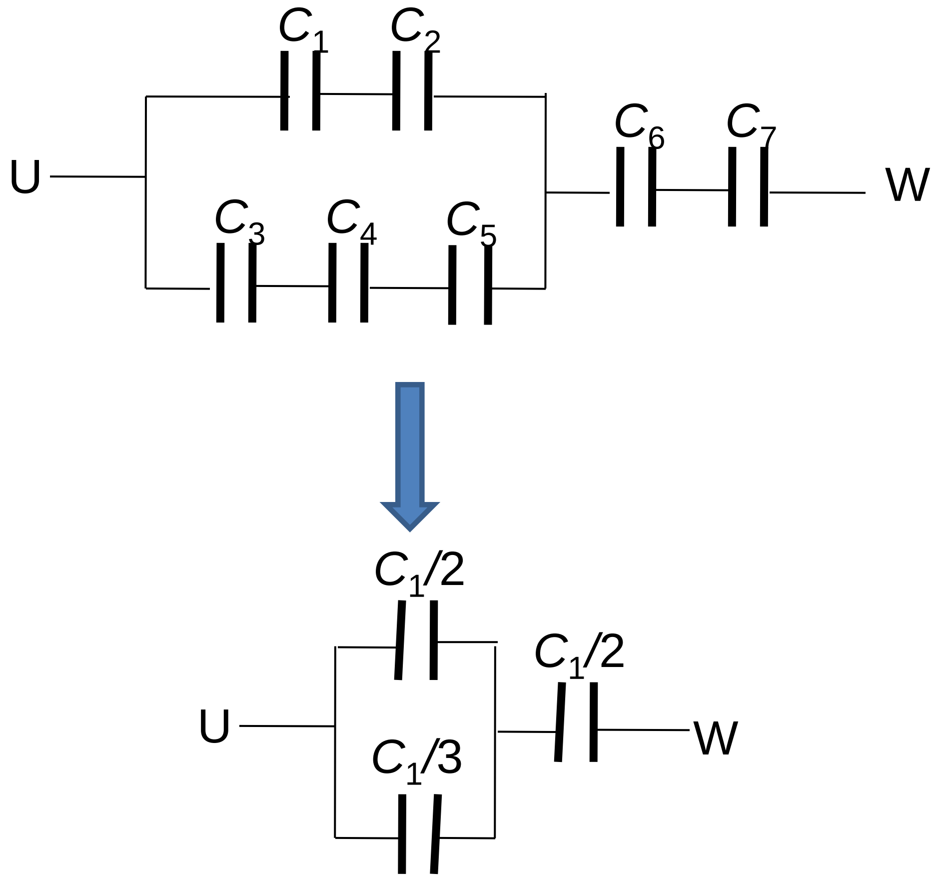


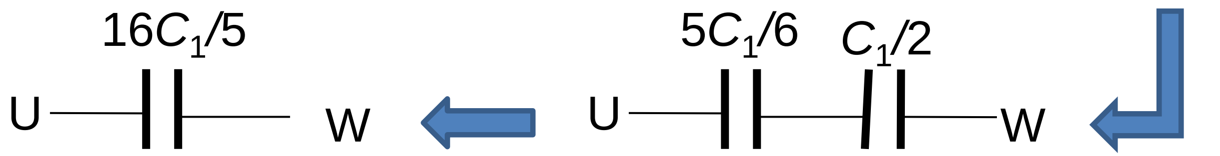
$$C = C_1 + \frac{1}{\frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5}} = C_1 + \frac{1}{\frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1}}$$

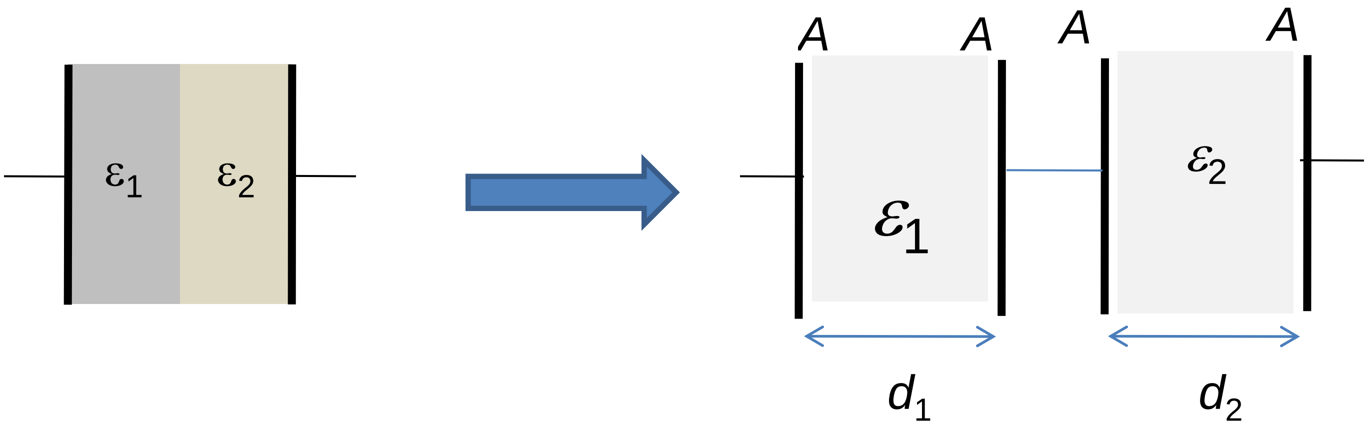
$$= C_1 + \frac{1}{\frac{4}{C_1}} = \frac{5}{4} C_1$$

Kapasitansi antara U dan W sama dengan kapasitansi dari rangkaian di samping. Perhitungan kapasitansi dapat dilihat dari proses penyederhanaan rangkaian. Hasilnya (lihat gambar):

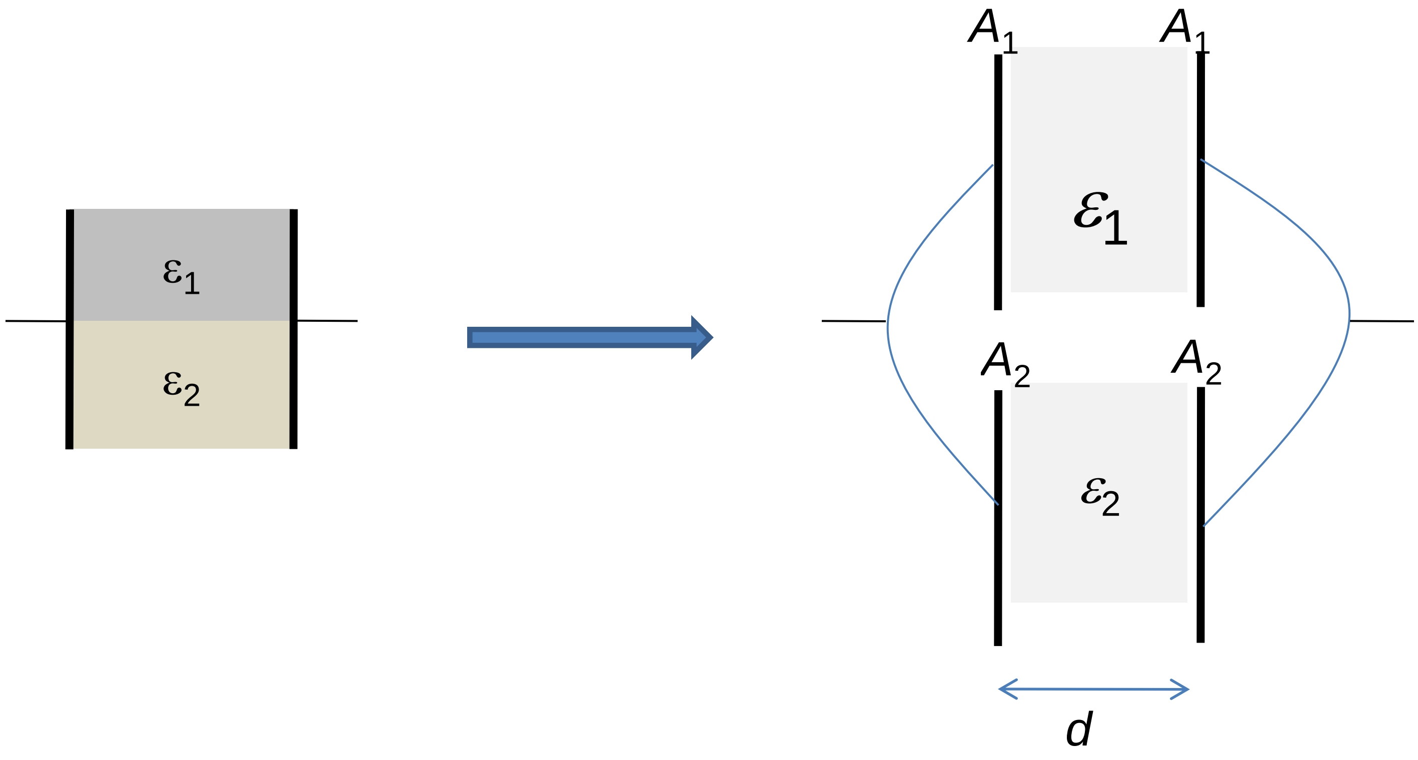
$$C = \frac{16}{5} C_1$$





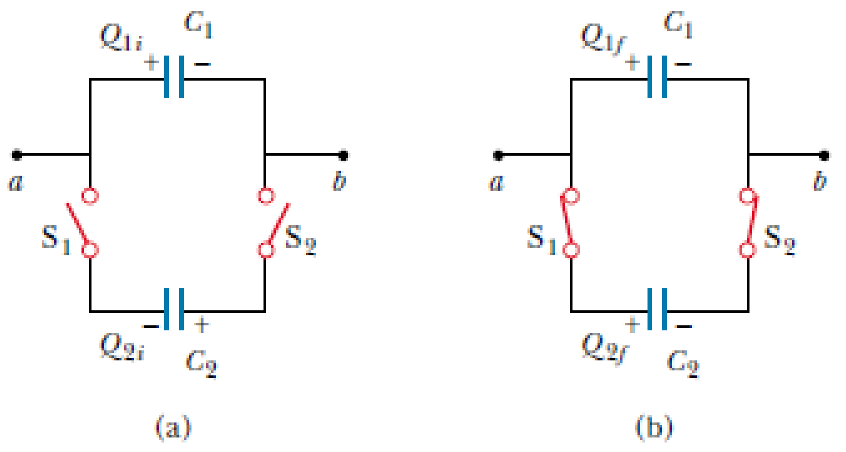


$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d_1}{\varepsilon_1 A} + \frac{d_2}{\varepsilon_2 A}, \qquad d = d_1 + d_2$$



$$C = C_1 + C_2 = \frac{\varepsilon_1 A_1}{d} + \frac{\varepsilon_2 A_2}{d}, \qquad A = A_1 + A_2$$

Two capacitors C_1 and C_2 (where $C_1 > C_2$) are charged to the same initial potential difference ΔV_i, but with opposite polarity. The charged capacitors are removed from the battery, and their plates are connected as shown in Figure 26.12a. The switches S_1 and S_2 are then closed, as shown in Figure 26.12b. (a) Find the final potential difference ΔV_f between a and b after the switches are closed.



$$Q_{1i} = C_1\,\Delta V_i \qquad \text{and} \qquad Q_{2i} = -\,C_2\,\Delta V_i$$

$$Q = Q_{1i} + Q_{2i} = (C_1 - C_2)\,\Delta V_i$$

$$Q = Q_{1f} + Q_{2f} \qquad Q_{1f} = C_1\,\Delta V_f \qquad \text{and} \qquad Q_{2f} = C_2\,\Delta V_f$$

$$\frac{Q_{1f}}{Q_{2f}} = \frac{C_1\,\Delta V_f}{C_2\,\Delta V_f} = \frac{C_1}{C_2}$$

$$Q_{1f} = \frac{C_1}{C_2}\,Q_{2f} \qquad Q_{1f} = \frac{C_1}{C_2}\,Q_{2f} = \frac{C_1}{C_2}\,Q\left(\frac{C_2}{C_1 + C_2}\right) = Q\left(\frac{C_1}{C_1 + C_2}\right)$$

$$Q = Q_{1f} + Q_{2f} = \frac{C_1}{C_2}\,Q_{2f} + Q_{2f} = Q_{2f}\left(1 \;\cdot\; C_1 \right)$$

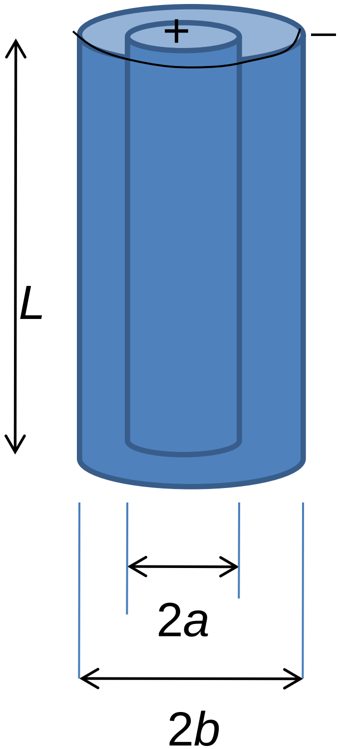
$$Q_{2f} = Q\left(\frac{C_2}{C_1 + C_2}\right)$$

$$\Delta V_{2f} = \frac{Q_{2f}}{C_2} = \frac{Q\left(\frac{C_2}{C_1 + C_2}\right)}{C_2} = \frac{Q}{C_1 + C_2}$$

$$\Delta V_{1f} = \frac{Q_{1f}}{C_1} = \frac{Q\left(\frac{C_1}{C_1 + C_2}\right)}{C_1} = \frac{Q}{C_1 + C_2}$$

$$\Delta V_f = \left(\frac{C_1 - C_2}{C_1 + C_2}\right)\Delta V_i$$

Kapasitor Silinder



Menurut hukum Gauss

Medan listrik oleh muatan +*Q* pada permukaan logam silinder dalam:

$r<a \quad E=0$
$r>a \quad E=Q/2\pi\varepsilon_0 rL$ arah: radial keluar

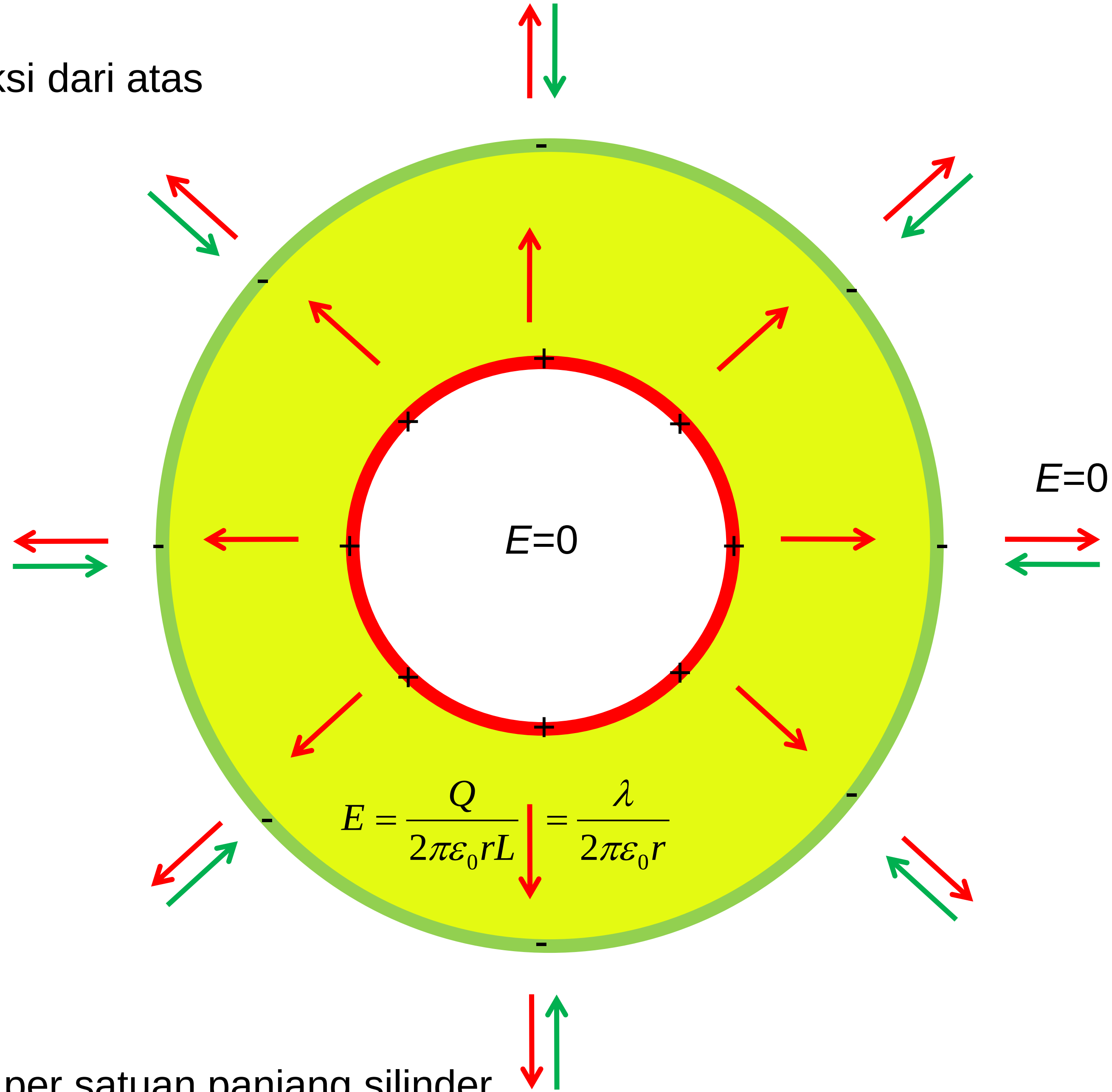
Medan listrik oleh muatan -*Q* pada permukaan logam silinder luar:

$r<b \quad E=0$
$r>b \quad E=Q/2\pi\varepsilon_0 rL$ arah: radial masuk

Maka medan listrik oleh kedua silinder sama dengan superpisisi kedua medan:

$r<a \quad E=0$
$a<r<b \quad E=Q/2\pi\varepsilon_0 rL$ arah: radial keluar
$r>b \quad E=0$

Proyeksi dari atas



$$E = \frac{Q}{2\pi\varepsilon_0 rL} = \frac{\lambda}{2\pi\varepsilon_0 r}$$

λ: muatan per satuan panjang silinder

Beda potensial antara kedua silinder:

$$V(b)-V(a)=-\int_{r=a}^{b}Edr=-\frac{Q}{2\pi\varepsilon_0 L}\ln\frac{b}{a}$$

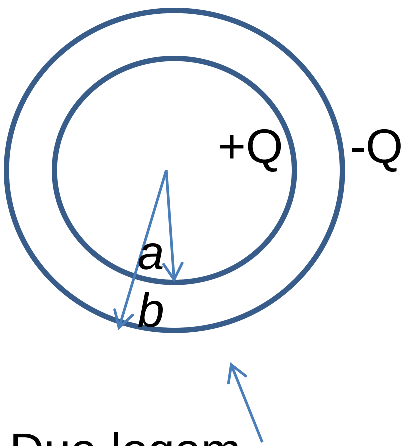
Beda potensial ΔV didefinisikan sebagai potensial pada silinder bermuastan +*Q* minus potensial silinder bermuatan –*Q*:

$$\Delta V=V(+)-V(-)=V(a)-V(b)=\frac{Q}{2\pi\varepsilon_0 L}\ln\frac{b}{a}$$

Kapasitansi kapasitor silinder:

$$C=\frac{Q}{\Delta V}=\frac{2\pi\varepsilon_0 L}{\ln\frac{b}{a}}$$

Kapasitor Bola/Sferis



Dua logam masing-masing berbentuk bola berongga berkulit tipis

Menurut hukum Gauss

Medan listrik oleh muatan +*Q* pada permukaan logam bola dalam:

$r<a \quad E=0$

$r>a \quad E=Q/4\pi\varepsilon_0 r^2$ arah: radial keluar

Medan listrik oleh muatan -*Q* pada permukaan logam bola luar:

$r<b \quad E=0$

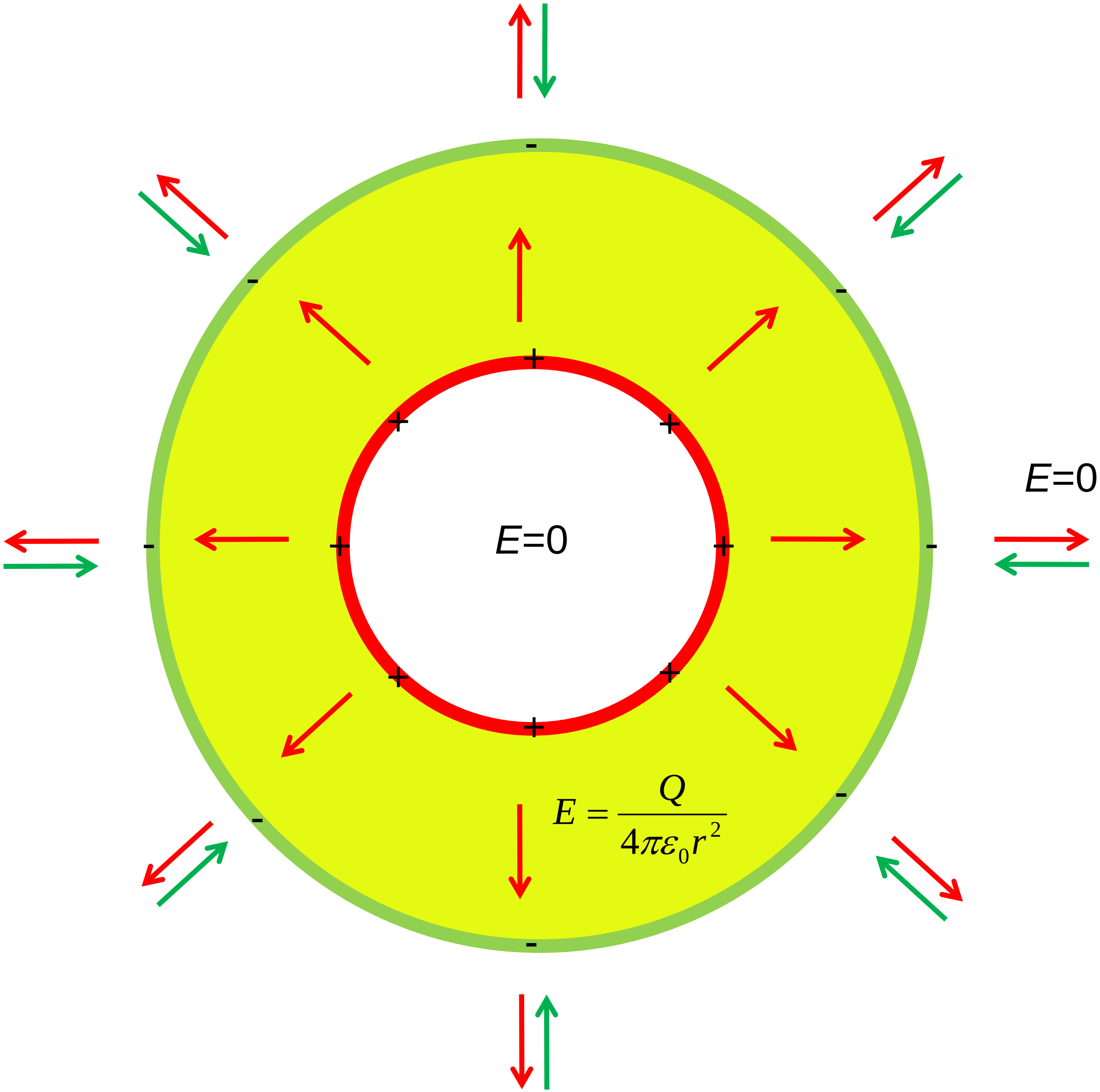
$r>b \quad E=Q/4\pi\varepsilon_0 r^2$ arah: radial masuk

Maka medan listrik oleh kedua bola sama dengan superpisisi kedua medan:

$r<a \quad E=0$

$a<r<b \quad E=Q/4\pi\varepsilon_0 r^2$ arah: radial keluar

$r>b \quad E=0$


E=0
E=0
$E = \frac{Q}{4\pi\varepsilon_0 r^2}$

Beda potensial antara kedua bola:

$$V(b) - V(a) = -\int_{r=a}^{b} E dr = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{b} - \frac{1}{a}\right) = \frac{Q}{4\pi\varepsilon_0}\frac{a-b}{ab}$$

Beda potensial ΔV didefinisikan sebagai potensial pada bola bermuatan +*Q* minus potensial bola bermuatan –*Q*:

$$\Delta V = V(+) - V(-) = V(a) - V(b) = \frac{Q}{4\pi\varepsilon_0}\frac{b-a}{ab}$$

Kapasitansi kapasitor bola:

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

Bola konduktor terisolasi

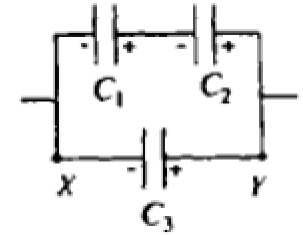
Bila bola luar berjari-jari sangat besar (tak hingga) atau dengan kata lain bola tersebut berada di tak hingga maka kapasitor ini ekivalen dengan sebuah bola sendirian (terisolasi)

Bola terisolasi mempunyai kapasitansi yang sama dengan kapasitansi kapasitor bola dengan mengambil limit $b \rightarrow \infty$:

$$C = \lim_{b\to\infty} \frac{4\pi\varepsilon_0 ab}{b-a} = \lim_{b\to\infty} \frac{4\pi\varepsilon_0 ab}{b} = \lim_{b\to\infty} \frac{4\pi\varepsilon_0 a}{1} = 4\pi\varepsilon_0 a$$

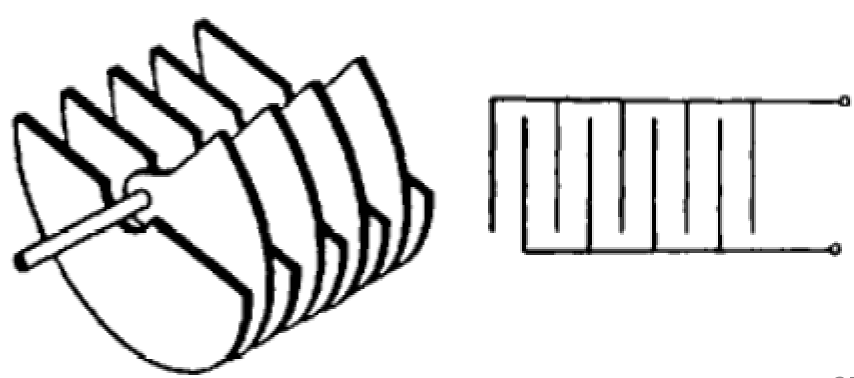
A parallel plate capacitor of plate area 0.04 m^2 and plate separation 0.25 mm is charged to 24 V. Determine the charge on a plate and the electric field between the plates.

Three capacitors $C_1 = 3\ \mu F$, $C_2 = 5\ \mu F$, and $C_3 = 8\ \mu F$ are each charged by a 24-V battery and then connected as shown here. Determine the final charge on each capacitor and the potential difference between points X and Y.



Capacitors $C_1 = C_0$ and $C_2 = 2C_0$ are given charges $4q$ and q, respectively. They are then connected in series, with the positive plate of one capacitor connected to the negative plate of the other. What is the final charge on C_2?

SP 23.5 Tuning capacitors of the type used in radios have overlapping plates, and the capacitance is changed by varying the amount of overlap, as illustrated here. If each plate has area A and the spacing between the plates is d, what is the capacitance of the unit?



$$C = \frac{\epsilon_0 A}{d} = \frac{(8.55 \times 10^{-12}\ \text{F/m})(0.04\ \text{m}^2)}{(0.25 \times 10^{-3}\ \text{m})} = 1.42 \times 10^{-9}\ \text{F}$$

$$Q = CV = (1.42 \times 10^{-9}\ \text{F})(24\ \text{V}) = 3.4 \times 10^{-8}\ \text{C} \qquad E = \frac{\rho}{\epsilon_0} = \frac{Q}{A\epsilon_0} = 9.6 \times 10^{4}\ \text{V/m}$$

Let Q_1', Q_2', Q_3' = final charges, and V = final potential difference.

$$Q_2 + Q_3 = Q_2' + Q_3' = \frac{C_1 C_2}{C_1 + C_2} V + C_3 V \qquad Q_2 = C_2 V_0 = (5)(24) = 120\ \mu\text{C}$$

$$Q_3 = C_3 V_0 = (8)(24) = 192\ \mu\text{C} \qquad Q_2 + Q_3 = Q_2' + Q_3' = 312\ \mu\text{C}$$

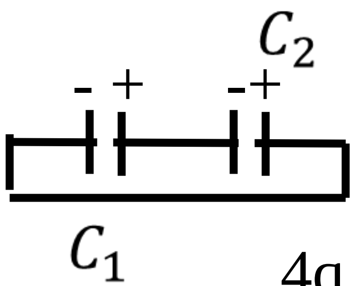
$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} + C_3 = 9.9\ \mu\text{F}, \qquad Q_2' + Q_3' = C_{eq} V_{XY},\ \text{so}\ V_{XY} = 31.6\ \text{V}$$

$$Q_3' = C_3 V_{XY} = 253\ \mu\text{C}, \qquad Q_2 = Q_1 = C_{12} V_{XY} = \frac{(3)(5)}{(3+5)}(31.6) = 59\ \mu\text{C}$$

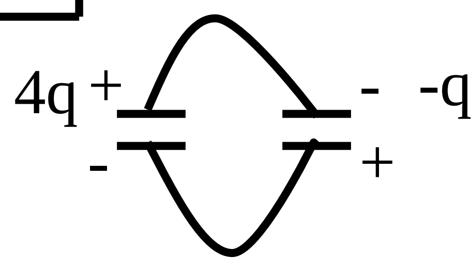
Capacitors $C_1 = C_0$ and $C_2 = 2C_0$ are given charges $4q$ and q, respectively. They are then connected in series, with the positive plate of one capacitor connected to the negative plate of the other. What is the final charge on C_2?

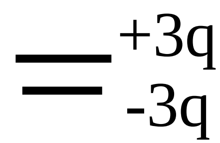
One has two capacitors in parallel with charge $3q$:

$$V = \frac{Q}{C} = \frac{3q}{C_0 + 2C_0} = \frac{q}{C_0}, \quad \text{so } Q_2 = C_2 V = 2C_0\left(\frac{q}{C_0}\right) - 2q$$



$$V_{10} = \frac{4q}{C_0}, V_{20} = \frac{q}{2C_0}$$





This is equivalent to eight capacitors in parallel, so

$$C = 8C_1 = 8\frac{\epsilon_0 A}{d}$$