SOLUTIONS CHAPTER 16

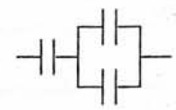
8. There are eight different combinations that use all three capacitors in the circuit. These combinations and their equivalent capacitances are:

All three capacitors in series - $C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)^{-1}$

All three capacitors in parallel - $C_{eq} = C_1 + C_2 + C_3$

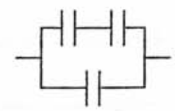
One capacitor in series with a parallel combination of the other two:

$$C_{eq} = \left(\frac{1}{C_1 + C_2} + \frac{1}{C_3}\right)^{-1},\ C_{eq} = \left(\frac{1}{C_3 + C_1} + \frac{1}{C_2}\right)^{-1},\ C_{eq} = \left(\frac{1}{C_2 + C_3} + \frac{1}{C_1}\right)^{-1}$$



One capacitor in parallel with a series combination of the other two:

$$C_{eq} = \left(\frac{1}{C_1 + C_2}\right)^{-1} + C_3,\ C_{eq} = \left(\frac{1}{C_3 + C_1}\right)^{-1} + C_2,\ C_{eq} = \left(\frac{1}{C_2 + C_3}\right)^{-1} + C_1$$



12. The energy stored in a capacitor is $W = \frac{1}{2}C(\Delta V)^2$.

(a) If the potential difference is doubled while all other factors remain constant, the stored energy is quadrupled.

(b) Assuming a parallel plate capacitor, the capacitance is $C = \kappa \epsilon_0 A/d$ and the energy stored becomes $W = \frac{\kappa \epsilon_0 A(\Delta V)^2}{2d}$. Thus, if the plate separation is doubled while the potential difference is held constant, the stored energy will be cut in half.

16.5 $E = \frac{|\Delta V|}{d} = \frac{25\,000\ \text{J/C}}{1.5 \times 10^{-2}\ \text{m}} = \boxed{1.7 \times 10^6\ \text{N/C}}$

16.8 (a) $|\Delta V| = Ed = (5.90 \times 10^3\ \text{V/m})(1.00 \times 10^{-2}\ \text{m}) = \boxed{59.0\ \text{V}}$

(b) $\frac{1}{2}m_e v^2 - 0 = \Delta KE = W = -\Delta PE_e = |q(\Delta V)|$,

so $v = \sqrt{\frac{2|q(\Delta V)|}{m_e}} = \sqrt{\frac{2(1.60 \times 10^{-19}\ \text{C})(59.0\ \text{J/C})}{9.11 \times 10^{-31}\ \text{kg}}} = \boxed{4.55 \times 10^6\ \text{m/s}}$

16.12 Calling q_3 the charge at the corner opposite *P*,

$$V = V_1 + V_2 + V_3 = k_e\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{\sqrt{r_1^2 + r_2^2}}\right)$$

$$= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(\frac{8.00\times10^{-6}\ \text{C}}{0.200\ \text{m}} - \frac{8.00\times10^{-6}\ \text{C}}{0.350\ \text{m}} + \frac{12.0\times10^{-6}\ \text{C}}{\sqrt{(0.200)^2+(0.350)^2}\ \text{m}}\right)$$

$$= \boxed{4.22\times10^5\ \text{V}}$$

16.19 From conservation of energy, $(KE + PE_e)_f = (KE + PE_e)_i$, which gives

$$0 + \frac{k_e Qq}{r_f} = \frac{1}{2}m_\alpha v_i^2 + 0 \quad \text{or} \quad r_f = \frac{2k_e Qq}{m_\alpha v_i^2} = \frac{2k_e(79e)(2e)}{m_\alpha v_i^2}$$

$$r_f = \frac{2\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(158)\left(1.60\times10^{-19}\ \text{C}\right)^2}{\left(6.64\times10^{-27}\ \text{kg}\right)\left(2.00\times10^7\ \text{m/s}\right)^2} = \boxed{2.74\times10^{-14}\ \text{m}}$$

16.25 (a) $E = \frac{\Delta V}{d} = \frac{20.0\ \text{V}}{1.80\times10^{-3}\ \text{m}} = 1.11\times10^4\ \text{V/m} = \boxed{11.1\ \text{kV/m}}$ directed toward the negative plate

(b) $C = \frac{\epsilon_0 A}{d} = \frac{\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(7.60\times10^{-4}\ \text{m}^2\right)}{1.80\times10^{-3}\ \text{m}}$

$= 3.74\times10^{-12}\ \text{F} = \boxed{3.74\ \text{pF}}$

(c) $Q = C(\Delta V) = \left(3.74\times10^{-12}\ \text{F}\right)(20.0\ \text{V}) = 7.47\times10^{-11}\ \text{C} = \boxed{74.7\ \text{pC}}$ on one plate and $\boxed{-74.7\ \text{pC}}$ on the other plate.

16.31 (a) Using the rules for combining capacitors in series and in parallel, the circuit is reduced in steps as shown below. The equivalent capacitor is shown to be a $\boxed{2.00\ \mu\text{F}}$ capacitor.

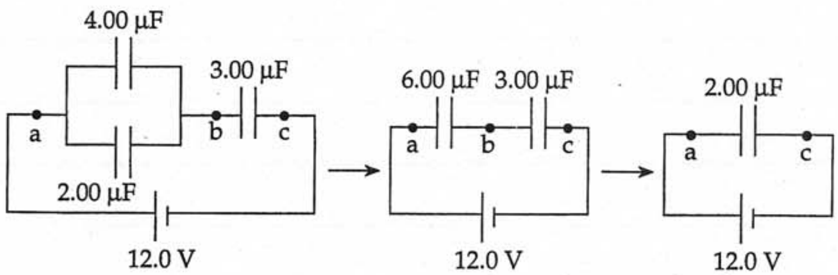


Figure 1 **Figure 2** **Figure 3**

(b) From Figure 3: $Q_{ac}=C_{ac}(\Delta V)_{ac}=(2.00\ \mu\text{F})(12.0\ \text{V})=24.0\ \mu\text{C}$

From Figure 2: $Q_{ab}=Q_{bc}=Q_{ac}=24.0\ \mu\text{C}$

Thus, the charge on the $3.00\ \mu\text{F}$ capacitor is $Q_3=\boxed{24.0\ \mu\text{C}}$

Continuing to use Figure 2, $(\Delta V)_{ab}=\dfrac{Q_{ab}}{C_{ab}}=\dfrac{24.0\ \mu\text{C}}{6.00\ \mu\text{F}}=4.00\ \text{V}$,

and $(\Delta V)_3=(\Delta V)_{bc}=\dfrac{Q_{bc}}{C_{bc}}=\dfrac{24.0\ \mu\text{C}}{3.00\ \mu\text{F}}=\boxed{8.00\ \text{V}}$

From Figure 1, $(\Delta V)_4=(\Delta V)_2=(\Delta V)_{ab}=\boxed{4.00\ \text{V}}$

and $Q_4=C_4(\Delta V)_4=(4.00\ \mu\text{F})(4.00\ \text{V})=\boxed{16.0\ \mu\text{C}}$

$Q_2=C_2(\Delta V)_2=(2.00\ \mu\text{F})(4.00\ \text{V})=\boxed{8.00\ \mu\text{C}}$

16.35

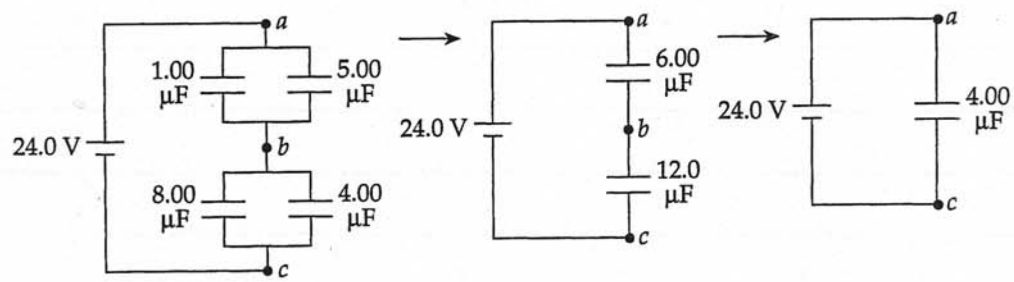


Figure 1 **Figure 2** **Figure 3**

The circuit may be reduced in steps as shown above.

Using the Figure 3, $Q_{ac} = (4.00\ \mu\text{F})(24.0\ \text{V}) = 96.0\ \mu\text{C}$.

Then, in Figure 2, $(\Delta V)_{ab} = \dfrac{Q_{ac}}{C_{ab}} = \dfrac{96.0\ \mu\text{C}}{6.00\ \mu\text{F}} = 16.0\ \text{V}$,

and $(\Delta V)_{bc} = (\Delta V)_{ac} - (\Delta V)_{ab} = 24.0\ \text{V} - 16.0\ \text{V} = 8.00\ \text{V}$.

Finally, using Figure 1, $Q_1 = C_1(\Delta V)_{ab} = (1.00\ \mu\text{F})(16.0\ \text{V}) = \boxed{16.0\ \mu\text{C}}$,

$Q_5 = (5.00\ \mu\text{F})(\Delta V)_{ab} = \boxed{80.0\ \mu\text{C}}$, $Q_8 = (8.00\ \mu\text{F})(\Delta V)_{bc} = \boxed{64.0\ \mu\text{C}}$,

and $Q_4 = (4.00\ \mu\text{F})(\Delta V)_{bc} = \boxed{32.0\ \mu\text{C}}$

16.44 (a) When connected in parallel, the energy stored is

$$W = \frac{1}{2}C_1(\Delta V)^2 + \frac{1}{2}C_2(\Delta V)^2 = \frac{1}{2}(C_1 + C_2)(\Delta V)^2$$

$$= \frac{1}{2}\left[(25.0 + 5.00)\times 10^{-6}\ \text{F}\right](100\ \text{V})^2 = \boxed{0.150\ \text{J}}$$

(b) When connected in series, the equivalent capacitance is

$$C_{eq} = \left(\frac{1}{25.0} + \frac{1}{5.00}\right)^{-1}\ \mu\text{F} = 4.17\ \mu\text{F}$$

From $W = \frac{1}{2}C_{eq}(\Delta V)^2$, the potential difference required to store the same energy as in part (a) above is

$$\Delta V = \sqrt{\frac{2W}{C_{eq}}} = \sqrt{\frac{2(0.150\ \text{J})}{4.17\times 10^{-6}\ \text{F}}} = \boxed{268\ \text{V}}$$