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E2. Previous Unit Exams 2

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Abstract
Previous unit exams of course materials for Elementary Physics II (PHY 204), taught by Gerhard Müller at the University of Rhode Island. Documents will be updated periodically as more entries become presentable.
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The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the voltage $V_3$ across capacitor $C_3$.
(c) Find the charge $Q_2$ on capacitor $C_2$.

\[ C_3 = 3 \, \mu F \]
\[ C_1 = 1 \, \mu F \]
\[ C_2 = 2 \, \mu F \]
The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the voltage $V_3$ across capacitor $C_3$.
(c) Find the charge $Q_2$ on capacitor $C_2$.

Solution:

(a) $C_{12} = C_1 + C_2 = 3 \mu F$, \quad $C_{eq} = \left( \frac{1}{C_{12}} + \frac{1}{C_3} \right)^{-1} = 1.5 \mu F$.

(b) $Q_3 = Q_{12} = Q_{eq} = C_{eq}(8V) = 12 \mu C$
\[ \Rightarrow V_3 = \frac{Q_3}{C_3} = \frac{12 \mu C}{3 \mu F} = 4 V. \]

(c) $Q_2 = V_2 C_2 = 8 \mu C$. 
Consider the electrical circuit shown.

(a) Find the equivalent resistance $R_{eq}$.
(b) Find the current $I_3$ through resistor $R_3$. 

\[ \begin{align*} 
12V & \quad \quad \quad R_2 = 2\Omega \\
R_3 = 3\Omega & \quad \quad \quad R_6 = 6\Omega 
\end{align*} \]
Consider the electrical circuit shown.

(a) Find the equivalent resistance $R_{eq}$.

(b) Find the current $I_3$ through resistor $R_3$.

Solution:

(a) $R_{36} = \left( \frac{1}{R_3} + \frac{1}{R_6} \right)^{-1} = 2\Omega$, $R_{eq} = R_2 + R_{36} = 4\Omega$.

(b) $I_2 = I_{36} = \frac{12V}{R_{eq}} = 3A$

\[ \Rightarrow V_3 = V_{36} = I_{36}R_{36} = 6V \quad \Rightarrow I_3 = \frac{V_3}{R_3} = 2A. \]
This $RC$ circuit has been running for a long time.

(a) Find the current $I_2$ through the resistor $R_2$.
(b) Find the voltage $V_C$ across the capacitor.

\[ R_1 = 2\Omega \]
\[ C = 7\text{nF} \]
\[ R_2 = 4\Omega \]
This $RC$ circuit has been running for a long time.

(a) Find the current $I_2$ through the resistor $R_2$.
(b) Find the voltage $V_C$ across the capacitor.

Solution:

(a) $I_C = 0$, $I_2 = \frac{\mathcal{E}}{R_1 + R_2} = \frac{12\text{V}}{6\Omega} = 2\text{A}$.

(b) $V_C = V_2 = I_2 R_2 = (2\text{A})(4\Omega) = 8\text{V}$. 
Consider a charged particle moving in a uniform magnetic field as shown. The velocity is in the $y$-direction and the magnetic field in the $yz$-plane at $30^\circ$ from the $y$-direction.

(a) Find the direction of the magnetic force acting on the particle.

(b) Find the magnitude of the magnetic force acting on the particle.
Consider a charged particle moving in a uniform magnetic field as shown. The velocity is in $y$-direction and the magnetic field in the $yz$-plane at $30^\circ$ from the $y$-direction.

(a) Find the direction of the magnetic force acting on the particle.
(b) Find the magnitude of the magnetic force acting on the particle.

Solution:

(a) Use the right-hand rule: positive $x$-direction (front, out of page).
(b) $F = qvB \sin 30^\circ = (5 \times 10^{-9} \text{C})(3 \text{m/s})(4 \times 10^{-3} \text{T})(0.5) = 3 \times 10^{-11} \text{N}$. 
The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the charge $Q_3$ on capacitor $C_3$.
(b) Find the charge $Q_2$ on capacitor $C_2$. 

\[ C_1 = 2 \mu F \]
\[ C_2 = 2 \mu F \]
\[ C_3 = 3 \mu F \]
The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the charge \( Q_3 \) on capacitor \( C_3 \).

(b) Find the charge \( Q_2 \) on capacitor \( C_2 \).

Solution:

(a) \( Q_3 = C_3(12V) = (3\mu F)(12V) = 36\mu C \).

(b) \( Q_2 = Q_{12} = C_{12}(12V) = (1\mu F)(12V) = 12\mu C \).
Consider the two-loop circuit shown.

(a) Find the current $I_1$.
(b) Find the current $I_2$. 
Consider the two-loop circuit shown.

(a) Find the current $I_1$.

(b) Find the current $I_2$.

Solution:

(a) 
\[-(2\Omega)(I_1) + 10V - (2\Omega)(I_1) - 2V = 0 \quad \Rightarrow \quad I_1 = \frac{8V}{4\Omega} = 2A.\]

(b) 
\[-(2\Omega)(I_2) + 10V - (2\Omega)(I_2) - (3\Omega)(I_2) = 0 \quad \Rightarrow \quad I_2 = \frac{10V}{7\Omega} = 1.43A.\]
In this $RC$ circuit the switch S is initially open as shown.

(a) Find the current $I$ right after the switch has been closed.
(b) Find the current $I$ a very long time later.
In this $RC$ circuit the switch $S$ is initially open as shown.

(a) Find the current $I$ right after the switch has been closed.
(b) Find the current $I$ a very long time later.

Solution:

(a) No current through $2\Omega$-resistor: $I = \frac{12\text{V}}{4\Omega} = 3\text{A}$.

(b) No current through capacitor: $I = \frac{12\text{V}}{6\Omega} = 2\text{A}$. 

A current loop in the form of a right triangle is placed in a uniform magnetic field of magnitude $B = 30 \text{ mT}$ as shown. The current in the loop is $I = 0.4 \text{ A}$ in the direction indicated.

(a) Find magnitude and direction of the force $\vec{F}_1$ on side 1 of the triangle.

(b) Find magnitude and direction of the force $\vec{F}_2$ on side 2 of the triangle.
A current loop in the form of a right triangle is placed in a uniform magnetic field of magnitude $B = 30\text{mT}$ as shown. The current in the loop is $I = 0.4\text{A}$ in the direction indicated.

(a) Find magnitude and direction of the force $\vec{F}_1$ on side 1 of the triangle.

(b) Find magnitude and direction of the force $\vec{F}_2$ on side 2 of the triangle.

Solution:

(a) $\vec{F}_1 = I\vec{L} \times \vec{B} = 0$ (angle between $\vec{L}$ and $\vec{B}$ is $180^\circ$).

(b) $F_2 = ILB = (0.4\text{A})(0.2\text{m})(30 \times 10^{-3}\text{T}) = 2.4 \times 10^{-3}\text{N}$.
   Direction of $\vec{F}_2$: $\otimes$ (into plane).
Consider the configuration of two point charges as shown.

(a) Find the energy $U_3$ stored on capacitor $C_3$.
(b) Find the voltage $V_4$ across capacitor $C_4$.
(c) Find the voltage $V_2$ across capacitor $C_2$.
(d) Find the charge $Q_1$ on capacitor $C_1$. 

\[ C_1 = 2 \mu F \quad C_2 = 2 \mu F \]

\[ C_3 = 3 \mu F \]

\[ C_4 = 5 \mu F \]

\[ 6V \]
Consider the configuration of two point charges as shown.

(a) Find the energy $U_3$ stored on capacitor $C_3$.
(b) Find the voltage $V_4$ across capacitor $C_4$.
(c) Find the voltage $V_2$ across capacitor $C_2$.
(d) Find the charge $Q_1$ on capacitor $C_1$.

Solution:

(a) $U_3 = \frac{1}{2}(3 \mu F)(6V)^2 = 54 \mu J$.
(b) $V_4 = 6V$.
(c) $V_2 = \frac{1}{2}6V = 3V$.
(d) $Q_1 = (2 \mu F)(3V) = 6 \mu C$. 
Consider the electric circuit shown.

(a) Find the current $I$ when the switch $S$ is open.
(b) Find the power $P_3$ dissipated in resistor $R_3$ when the switch is open.
(c) Find the current $I$ when the switch $S$ is closed.
(d) Find the power $P_3$ dissipated in resistor $R_3$ when the switch is closed.
Consider the electric circuit shown.

(a) Find the current $I$ when the switch $S$ is open.
(b) Find the power $P_3$ dissipated in resistor $R_3$ when the switch is open.
(c) Find the current $I$ when the switch $S$ is closed.
(d) Find the power $P_3$ dissipated in resistor $R_3$ when the switch is closed.

Solution:

(a) $I = \frac{24\text{V}}{8\Omega} = 3\text{A}$.
(b) $P_3 = (3\text{A})^2(4\Omega) = 36\text{W}$.
(c) $I = \frac{24\text{V}}{6\Omega} = 4\text{A}$.
(d) $P_3 = (2\text{A})^2(4\Omega) = 16\text{W}$. 
Consider the two-loop circuit shown.

(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the potential difference $V_a - V_b$. 
Consider the two-loop circuit shown.

(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the potential difference $V_a - V_b$.

Solution:

(a) $I_1 = \frac{8V + 10V}{7\Omega} = 2.57A$.
(b) $I_2 = \frac{8V - 6V}{9\Omega} = 0.22A$.
(c) $V_a - V_b = 8V - 6V = 2V$. 
The circuit of capacitors is at equilibrium.

(a) Find the charge $Q_1$ on capacitor 1 and the charge $Q_2$ on capacitor 2.
(b) Find the voltage $V_1$ across capacitor 1 and the voltage $V_2$ across capacitor 2.
(c) Find the charge $Q_3$ and the energy $U_3$ on capacitor 3.

\[ C_3 = 5 \mu F \]

\[ C_1 = 6 \mu F \quad C_2 = 12 \mu F \]

\[ 12V \]
The circuit of capacitors is at equilibrium.

(a) Find the charge $Q_1$ on capacitor 1 and the charge $Q_2$ on capacitor 2.
(b) Find the voltage $V_1$ across capacitor 1 and the voltage $V_2$ across capacitor 2.
(c) Find the charge $Q_3$ and the energy $U_3$ on capacitor 3.

**Solution:**

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

$Q_1 = Q_2 = Q_{12} = (4 \mu F)(12V) = 48 \mu C$.

(b) $V_1 = \frac{Q_1}{C_1} = \frac{48 \mu C}{6 \mu F} = 8V$

$V_2 = \frac{Q_2}{C_2} = \frac{48 \mu C}{12 \mu F} = 4V$.

(c) $Q_3 = (5 \mu F)(12V) = 60 \mu C$

$U_3 = \frac{1}{2}(5 \mu F)(12V)^2 = 360 \mu J$. 
Consider the electric circuit shown. Find the current $I_1$ through resistor 1 and the voltage $V_1$ across it.

(a) when the switch $S$ is open,
(b) when the switch $S$ is closed.
(c) Find the equivalent resistance $R_{eq}$ of the circuit and the total power $P$ dissipated in it when the switch $S$ is closed.

\[
\begin{align*}
R_1 &= 4\Omega \\
R_2 &= 2\Omega \\
R_3 &= 4\Omega \\
12\text{V}
\end{align*}
\]
Consider the electric circuit shown. Find the current $I_1$ through resistor 1 and the voltage $V_1$ across it

(a) when the switch $S$ is open,
(b) when the switch $S$ is closed.
(c) Find the equivalent resistance $R_{eq}$ of the circuit and the total power $P$ dissipated in it when the switch $S$ is closed.

Solution:

(a) $I_1 = \frac{12V}{4\Omega + 2\Omega} = 2A$, \hspace{1cm} $V_1 = (4\Omega)(2A) = 8V$.

(b) $I_1 = \frac{1}{2} \frac{12V}{2\Omega + 2\Omega} = 1.5A$, \hspace{1cm} $V_1 = (4\Omega)(1.5A) = 6V$.

(c) $R_{eq} = \left( \frac{1}{4\Omega} + \frac{1}{4\Omega} \right)^{-1} + 2\Omega = 4\Omega$,

$P = \frac{(12V)^2}{4\Omega} = 36W$. 

Consider the electric circuit shown. Find the currents $I_1$, $I_2$, and $I_3$
(a) with the switch $S$ open,
(b) with the switch $S$ closed.
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, and $I_3$

(a) with the switch $S$ open,
(b) with the switch $S$ closed.

Solution:

(a) $I_1 = \frac{8V - 12V}{4\Omega} = -1A,$
$I_2 = -I_1 = +1A.$
$I_3 = 0.$

(b) $I_1 = \frac{8V - 12V}{4\Omega} = -1A,$
$I_3 = \frac{6V - 12V}{2\Omega} = -3A.$
$I_2 = -I_1 - I_3 = +4A.$
Both capacitor circuits are at equilibrium.
(a) In the circuit on the left, the voltage across capacitor 1 is $V_1 = 8V$. Find the charge $Q_1$ on capacitor 1, the charge $Q_2$ on capacitor 2, and the voltage $V_2$ across capacitor 2. Find the emf $\mathcal{E}_A$ supplied by the battery.
(b) In the circuit on the right, the charge on capacitor 3 is $Q_3 = 6\mu C$. Find the voltage $V_3$ across capacitor 3, the voltage $V_4$ across capacitor 4, and the charge $Q_4$ on capacitor 4. Find the emf $\mathcal{E}_B$ supplied by the battery.

![Diagram with capacitors and emfs]
Both capacitor circuits are at equilibrium.

(a) In the circuit on the left, the voltage across capacitor 1 is $V_1 = 8\, \text{V}$. Find the charge $Q_1$ on capacitor 1, the charge $Q_2$ on capacitor 2, and the voltage $V_2$ across capacitor 2. Find the emf $\mathcal{E}_A$ supplied by the battery.

(b) In the circuit on the right, the charge on capacitor 3 is $Q_3 = 6\, \mu\text{C}$. Find the voltage $V_3$ across capacitor 3, the voltage $V_4$ across capacitor 4, and the charge $Q_4$ on capacitor 4. Find the emf $\mathcal{E}_B$ supplied by the battery.

Solution:

(a) $Q_1 = (1\, \mu\text{F})(8\, \text{V}) = 8\, \mu\text{C}$, $Q_2 = Q_1 = 8\, \mu\text{C}$,

$V_2 = \frac{8\, \mu\text{C}}{2\, \mu\text{F}} = 4\, \text{V}$, $\mathcal{E}_A = 8\, \text{V} + 4\, \text{V} = 12\, \text{V}$.

(b) $V_3 = \frac{6\, \mu\text{C}}{3\, \mu\text{F}} = 2\, \text{V}$, $V_4 = V_3 = 2\, \text{V}$,

$Q_4 = (2\, \text{V})(4\, \mu\text{F}) = 8\, \mu\text{C}$, $\mathcal{E}_B = V_3 = V_4 = 2\, \text{V}$.
Consider the resistor circuit shown.
(a) Find the equivalent resistance $R_{eq}$.
(b) Find the power $P$ supplied by the battery.
(c) Find the current $I_4$ through the $4\Omega$-resistor.
(d) Find the voltage $V_2$ across the $2\Omega$-resistor.
Consider the resistor circuit shown.
(a) Find the equivalent resistance $R_{eq}$.
(b) Find the power $P$ supplied by the battery.
(c) Find the current $I_4$ through the $4\Omega$-resistor.
(d) Find the voltage $V_2$ across the $2\Omega$-resistor.

Solution:

(a) $R_{eq} = 8\Omega$.

(b) $P = \frac{(24\text{V})^2}{8\Omega} = 72\text{W}$.

(c) $I_4 = \frac{1}{2} \frac{24\text{V}}{8\Omega} = 1.5\text{A}$.

(d) $V_2 = (1.5\text{A})(2\Omega) = 3\text{V}$.
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, $I_3$, and $I_4$. 

\[
\begin{align*}
&\text{1V} & & \text{3V} & & \text{5V} \\
&\text{2V} & & \text{1V} \\
&\text{1Ω} & & \text{1Ω} & & \text{1Ω} & & \text{1Ω}
\end{align*}
\]
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, $I_3$, and $I_4$.

**Solution:** Use loops along quadrants in assumed current directions. Start at center.

\[
egin{align*}
+3V - I_1(1\Omega) - 1V &= 0 \Rightarrow I_1 = 2A. \\
+3V - I_2(1\Omega) + 2V &= 0 \Rightarrow I_2 = 5A. \\
-2V - I_3(1\Omega) + 5V &= 0 \Rightarrow I_3 = 3A. \\
+1V - I_4(1\Omega) + 5V &= 0 \Rightarrow I_4 = 6A.
\]

Both capacitor circuits are at equilibrium.
(a) Find the charge $Q_1$ on capacitor 1.
(b) Find the voltage $V_3$ across capacitor 3.
(c) Find the charge $Q_2$ on capacitor 2.
(d) Find the energy $U_4$ stored on capacitor 4.
Both capacitor circuits are at equilibrium.
(a) Find the charge $Q_1$ on capacitor 1.
(b) Find the voltage $V_3$ across capacitor 3.
(c) Find the charge $Q_2$ on capacitor 2.
(d) Find the energy $U_4$ stored on capacitor 4.

Solution:

(a) $C_{13} = \left( \frac{1}{C_1} + \frac{1}{C_3} \right)^{-1} = 0.75\,\text{pF}$,

$Q_1 = Q_3 = Q_{13} = (24\,\text{V})(0.75\,\text{pF}) = 18\,\text{pC}$.

(b) $V_3 = \frac{Q_3}{C_3} = \frac{18\,\text{pC}}{3\,\text{pF}} = 6\,\text{V}$.

(c) $Q_2 = (24\,\text{V})(2\,\text{pF}) = 48\,\text{pC}$.

(d) $U_4 = \frac{1}{2}C_4V_4^2 = \frac{1}{2}(4\,\text{pF})(24\,\text{V})^2 = 1152\,\text{pJ}$.
Consider the resistor circuit shown.
(a) Find the current $I_L$ on the left.
(b) Find the current $I_R$ on the right.
(c) Find the equivalent resistance $R_{eq}$ of all four resistors.
(d) Find the power $P_2$ dissipated in resistor 2.
Consider the resistor circuit shown.
(a) Find the current $I_L$ on the left.
(b) Find the current $I_R$ on the right.
(c) Find the equivalent resistance $R_{eq}$ of all four resistors.
(d) Find the power $P_2$ dissipated in resistor 2.

Solution:

(a) $I_L = \frac{24\, \text{V}}{1\, \Omega + 3\, \Omega} = 6\, \text{A}$.

(b) $I_R = \frac{24\, \text{V}}{4\, \Omega} = 6\, \text{A}$.

(c) $R_{eq} = \left( \frac{1}{1\, \Omega + 3\, \Omega} + \frac{1}{2\, \Omega} + \frac{1}{4\, \Omega} \right)^{-1} = 1\, \Omega$.

(d) $P_2 = \frac{(24\, \text{V})^2}{2\, \Omega} = 288\, \text{W}$. 
Consider the electric circuit shown.
(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the current $I_3$.
(d) Find the potential difference $V_a - V_b$. 
Consider the electric circuit shown.

(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the current $I_3$.
(d) Find the potential difference $V_a - V_b$.

Solution:

(a) $12V + 3V - I_1(10\Omega) = 0 \implies I_1 = \frac{15V}{10\Omega} = 1.5A$.

(b) $-6V + 12V - I_2(5\Omega) = 0 \implies I_2 = \frac{6V}{5\Omega} = 1.2A$.

(c) $I_3 = I_1 + I_2 = 2.7A$.

(d) $V_a - V_b = -6V + 12V = 6V$. 
Find the equivalent capacitances $C_{eq}$ of the two capacitor circuits.

![Diagram of capacitor circuits](image-url)
Find the equivalent capacitances $C_{eq}$ of the two capacitor circuits.

Solution:

- $C_{eq} = 3nF + \left( \frac{1}{3nF} + \frac{1}{3nF} + \frac{1}{3nF} \right)^{-1} = 4nF$.

- $C_{eq} = \left( \frac{1}{2\mu F} + \frac{1}{2\mu F + 2\mu F} + \frac{1}{2\mu F} \right)^{-1} = \frac{4}{5} \mu F$. 
Consider a parallel-plate capacitor of capacitance $C = 6\text{pF}$ with plates separated a distance $d = 1\text{mm}$ and a potential difference $V = V_+ - V_- = 3\text{V}$ between them.

(a) Find the magnitude $E$ of the electric field between the plates.
(b) Find the amount $Q$ of charge on each plate.
(c) Find the energy $U$ stored on the capacitor.
(d) Find the area $A$ of each plate.
Consider a parallel-plate capacitor of capacitance $C = 6\text{pF}$ with plates separated a distance $d = 1\text{mm}$ and a potential difference $V = V_+ - V_- = 3\text{V}$ between them.

(a) Find the magnitude $E$ of the electric field between the plates.
(b) Find the amount $Q$ of charge on each plate.
(c) Find the energy $U$ stored on the capacitor.
(d) Find the area $A$ of each plate.

Solution:

(a) $E = \frac{V}{d} = \frac{3\text{V}}{1\text{mm}} = 3000\text{V/m}$.

(b) $Q = CV = (6\text{pF})(3\text{V}) = 18\text{pC}$.

(c) $U = \frac{1}{2}QV = 0.5(18\text{pC})(3\text{V}) = 27\text{pJ}$.

(d) $A = \frac{Cd}{\varepsilon_0} = \frac{(6\text{pF})(1\text{mm})}{8.85 \times 10^{-12}\text{C}^2\text{N}^{-1}\text{m}^{-2}} = 6.78 \times 10^{-4}\text{m}^2$. 

Consider the electric circuit shown. Find the currents $I_1$, $I_2$, $I_3$, and $I_4$. 

[Diagram of the circuit with labels $I_1$, $I_2$, $I_3$, and $I_4$, and resistors and voltage sources.]
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, $I_3$, and $I_4$

Solution:

- $I_1 = \frac{12V}{2\Omega + 4\Omega} = 2A.$
- $I_2 = \frac{12V}{2\Omega} = 6A.$
- $I_3 = I_4 = I_1 + I_2 = 8A.$
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, and $I_3$. 
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, and $I_3$

Solution:

- $12V + 6V - (8\Omega)I_1 = 0 \quad \Rightarrow \quad I_1 = \frac{9}{4}A = 2.25A$.

- $6V - 3V - (4\Omega)I_2 = 0 \quad \Rightarrow \quad I_2 = \frac{3}{4}A = 0.75A$.

- $I_3 = I_1 + I_2 = 3.00A$. 
Consider the capacitor circuit shown at equilibrium.
(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the total energy $U$ stored in the four capacitors.
(c) Find the voltage $V_*$ across the capacitor marked by an asterisk.
Consider the capacitor circuit shown at equilibrium.
(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the total energy $U$ stored in the four capacitors.
(c) Find the voltage $V_*$ across the capacitor marked by an asterisk.

Solution:

\[ C_{eq} = \left( \frac{1}{5nF + 1nF} + \frac{1}{6nF} + \frac{1}{6nF} \right)^{-1} = 2nF \]

\[ U = \frac{1}{2} (2nF)(10V)^2 = 100nJ \]

\[ V_* = \frac{10}{3} V = 3.33V \]

\[ C_{eq} = \left( \frac{1}{4nF + 5nF} + \frac{1}{9nF} + \frac{1}{9nF} \right)^{-1} = 3nF \]

\[ U = \frac{1}{2} (3nF)(20V)^2 = 600nJ \]

\[ V_* = \frac{20}{3} V = 6.67V \]
Consider the resistor circuit shown.
(a) Find the equivalent resistance $R_{eq}$.
(b) Find the current $I$ flowing through the battery.
(c) Find the voltage $V_*$ across the resistor marked by an asterisk.
Consider the resistor circuit shown.
(a) Find the equivalent resistance $R_{eq}$.
(b) Find the current $I$ flowing through the battery.
(c) Find the voltage $V_*$ across the resistor marked by an asterisk.

Solution:

$$R_{eq} = \left( \frac{1}{8\Omega} + \frac{1}{8\Omega} \right)^{-1} + 3\Omega + 3\Omega = 10\Omega$$

$$I = \frac{20V}{10\Omega} = 2A$$

$$V_* = (1A)(8\Omega) = 8V$$

$$R_{eq} = \left( \frac{1}{6\Omega} + \frac{1}{6\Omega} \right)^{-1} + 1\Omega + 1\Omega = 5\Omega$$

$$I = \frac{20V}{5\Omega} = 4A$$

$$V_* = (2A)(6\Omega) = 12V$$
Consider the $RC$ circuit shown. The switch has been closed for a long time.

(a) Find the current $I_B$ flowing through the battery.

(b) Find the voltage $V_C$ across the capacitor.

(c) Find the charge $Q$ on the capacitor.

(d) Find the current $I_3$ flowing through the $3\Omega$-resistor right after the switch has been opened.
Consider the $RC$ circuit shown. The switch has been closed for a long time.

(a) Find the current $I_B$ flowing through the battery.
(b) Find the voltage $V_C$ across the capacitor.
(c) Find the charge $Q$ on the capacitor.
(d) Find the current $I_3$ flowing through the $3\Omega$-resistor right after the switch has been opened.

![Circuit Diagram]

**Solution:**

$I_B = \frac{12V}{2\Omega + 4\Omega} = 2A$

$V_C = (2A)(2\Omega) = 4V$

$Q = (4V)(10nF) = 40nC$

$I_3 = \frac{4V}{2\Omega + 3\Omega} = 0.8A$

$I_B = \frac{12V}{3\Omega + 1\Omega + 4\Omega} = 1.5A$

$V_C = (1.5A)(3\Omega + 1\Omega) = 6V$

$Q = (6V)(10nF) = 60nC$

$I_3 = \frac{6V}{3\Omega + 1\Omega} = 1.5A$
Both capacitor circuits, charged up by batteries as shown, are now at equilibrium. The charge on capacitor $C_1 = 6\,\text{pF}$ is $Q_1 = 18\,\text{pC}$ and charge on capacitor $C_4 = 8\,\text{pF}$ is $Q_4 = 16\,\text{pC}$.

(a) Find the voltage $V_2$ across capacitor $C_2 = 4\,\text{pF}$.
(b) Find the emf $\varepsilon_A$ supplied by the battery.
(c) Find the charge $Q_3$ on capacitor $C_3 = 3\,\text{pF}$.
(d) Find the emf $\varepsilon_B$ supplied by the battery.
Both capacitor circuits, charged up by batteries as shown, are now at equilibrium. The charge on capacitor $C_1 = 6\,\text{pF}$ is $Q_1 = 18\,\text{pC}$ and charge on capacitor $C_4 = 8\,\text{pF}$ is $Q_4 = 16\,\text{pC}$.

(a) Find the voltage $V_2$ across capacitor $C_2 = 4\,\text{pF}$.
(b) Find the emf $\varepsilon_A$ supplied by the battery.
(c) Find the charge $Q_3$ on capacitor $C_3 = 3\,\text{pF}$.
(d) Find the emf $\varepsilon_B$ supplied by the battery.

Solution:

(a) $Q_2 = Q_1 = 18\,\text{pC}$, $V_2 = \frac{Q_2}{C_2} = 4.5\,\text{V}$.
(b) $\varepsilon_A = V_1 + V_2 = 3\,\text{V} + 4.5\,\text{V} = 7.5\,\text{V}$.
(c) $V_3 = V_4 = \frac{Q_4}{C_4} = 2\,\text{V}$.
(d) $\varepsilon_B = V_3 = V_4 = 2\,\text{V}$. 

\[\begin{array}{c}
\varepsilon_A \\
\text{C}_1 \\
\text{C}_2 \\
\varepsilon_B \\
\text{C}_3 \\
\text{C}_4
\end{array}\]
Consider the resistor circuit shown with $R_1 = 2\,\Omega \, [3\,\Omega]$, $R_2 = 3\,\Omega \, [2\,\Omega]$, and $R_3 = 1\,\Omega$.

(a) Find the current $I_2$ through resistor $R_2$.
(b) Find the voltage $V_3$ across resistor $R_3$.
(c) Find the power $P_1$ dissipated in resistor $R_1$.
(d) Find the equivalent resistance $R_{eq}$. 

\[ 12V \]
Consider the resistor circuit shown with $R_1 = 2\,\Omega \, [3\,\Omega]$, $R_2 = 3\,\Omega \, [2\,\Omega]$, and $R_3 = 1\,\Omega$.

(a) Find the current $I_2$ through resistor $R_2$.
(b) Find the voltage $V_3$ across resistor $R_3$.
(c) Find the power $P_1$ dissipated in resistor $R_1$.
(d) Find the equivalent resistance $R_{eq}$.

Solution:

(a) $I_2 = \frac{12V}{3\,\Omega + 1\,\Omega} = 3A \quad \left[ \frac{12V}{2\,\Omega + 1\,\Omega} = 4A \right]$.  

(b) $V_3 = (3A)(1\,\Omega) = 3V \quad \left[ (4A)(1\,\Omega) = 4V \right]$.  

(c) $P_1 = \frac{(12V)^2}{2\,\Omega} = 72W \quad \left[ \frac{(12V)^2}{3\,\Omega} = 48W \right]$.  

(d) $R_{eq} = \left( \frac{1}{2\,\Omega} + \frac{1}{3\,\Omega + 1\,\Omega} \right)^{-1} = \frac{4}{3} \,\Omega \quad \left[ \left( \frac{1}{3\,\Omega} + \frac{1}{2\,\Omega + 1\,\Omega} \right)^{-1} = \frac{3}{2} \,\Omega \right]$. 
Consider the electric circuit shown. Find the currents $I_1$, $I_2$, $I_3$, $I_4$ when ...

(a) only switch $S_A$ is closed,  
(b) only switch $S_B$ is closed,  
(c) switches $S_A$ and $S_B$ are closed. 

(a) only switch $S_C$ is closed,  
(b) only switch $S_B$ is closed,  
(c) switches $S_B$ and $S_C$ are closed.
Consider the electric circuit shown. Find the currents $I_1, I_2, I_3, I_4$ when ...

(a) only switch $S_A$ is closed,  
(b) only switch $S_B$ is closed,  
(c) switches $S_A$ and $S_B$ are closed.

(a) only switch $S_C$ is closed,  
(b) only switch $S_B$ is closed,  
(c) switches $S_B$ and $S_C$ are closed.

![Electric circuit diagram]

**Solution:**

(a) $I_1 = 0.6 \text{A}$, $I_2 = -0.6 \text{A}$, $I_3 = 0$, $I_4 = 0$.
(b) $I_1 = 0$, $I_2 = 0.2 \text{A}$, $I_3 = -0.2 \text{A}$, $I_4 = 0$.
(c) $I_1 = 0.6 \text{A}$, $I_2 = -0.4 \text{A}$, $I_3 = -0.2 \text{A}$, $I_4 = 0$.

(a) $I_1 = 0$, $I_2 = 0$, $I_3 = -0.4 \text{A}$, $I_4 = 0.4 \text{A}$.
(b) $I_1 = 0$, $I_2 = 0.2 \text{A}$, $I_3 = -0.2 \text{A}$, $I_4 = 0$.
(c) $I_1 = 0$, $I_2 = 0.2 \text{A}$, $I_3 = -0.6 \text{A}$, $I_4 = 0.4 \text{A}$.
Both capacitor circuits, charged up by batteries as shown, are now at equilibrium. Each of the six capacitors has a 2pF capacitance.

(a) Find the equivalent capacitance of the circuit on the left.
(b) Find the voltages $V_1$, $V_2$, $V_3$ across capacitors $C_1$, $C_2$, $C_3$, respectively.
(c) Find the equivalent capacitance of the circuit on the right.
(d) Find the charges $Q_4$, $Q_5$, $Q_6$ on capacitors $C_4$, $C_5$, $C_6$, respectively.
Both capacitor circuits, charged up by batteries as shown, are now at equilibrium. Each of the six capacitors has a 2pF capacitance.

(a) Find the equivalent capacitance of the circuit on the left.
(b) Find the voltages $V_1$, $V_2$, $V_3$ across capacitors $C_1$, $C_2$, $C_3$, respectively.
(c) Find the equivalent capacitance of the circuit on the right.
(d) Find the charges $Q_4$, $Q_5$, $Q_6$ on capacitors $C_4$, $C_5$, $C_6$, respectively.

Solution:

(a) $C_{eq} = 2pF + \left( \frac{1}{2pF} + \frac{1}{2pF} \right)^{-1} = 3pF$.

(b) $V_1 = 12V$, $V_2 = V_3 = 6V$

(c) $C_{eq} = \left( \frac{1}{2pF + 2pF} + \frac{1}{2pF} \right)^{-1} = \frac{4}{3}pF$.

(d) $Q_{45} = Q_6 = C_{eq}(12V) = 16pC \Rightarrow Q_4 = Q_5 = 8pC$. 
Consider the resistor circuit shown with $R_1 = 5\, \Omega$, $R_2 = 1\, \Omega$, and $R_3 = 3\, \Omega$.
(a) Find the equivalent resistance $R_{eq}$.
(b) Find the currents $I_1$, $I_2$, $I_3$ through resistors $R_1$, $R_2$, $R_3$, respectively.
(c) Find the voltages $V_1$, $V_2$, $V_3$ across resistors $R_1$, $R_2$, $R_3$, respectively.
Consider the resistor circuit shown with $R_1 = 5\Omega$, $R_2 = 1\Omega$, and $R_3 = 3\Omega$. 

(a) Find the equivalent resistance $R_{eq}$.
(b) Find the currents $I_1$, $I_2$, $I_3$ through resistors $R_1$, $R_2$, $R_3$, respectively.
(c) Find the voltages $V_1$, $V_2$, $V_3$ across resistors $R_1$, $R_2$, $R_3$, respectively.

Solution:

(a) $R_{eq} = \left( \frac{1}{1\Omega + 3\Omega} + \frac{1}{5\Omega} \right)^{-1} = \frac{20}{9} \Omega = 2.22\Omega$.
(b) $I_1 = \frac{12V}{5\Omega} = 2.4A$, $I_2 = I_3 = \frac{12V}{1\Omega + 3\Omega} = 3A$.
(c) $V_1 = R_1 I_1 = 12V$, $V_2 = R_2 I_2 = 3V$, $V_3 = R_3 I_3 = 9V$. 
Consider the two-loop circuit shown.
(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the potential difference $V_a - V_b$. 

![Circuit Diagram]

- 4V
- 2V
- 5Ω
- 6V
- 3Ω
- $I_1$
- $I_2$
Consider the two-loop circuit shown.
(a) Find the current $I_1$.
(b) Find the current $I_2$.
(c) Find the potential difference $V_a - V_b$.

**Solution:**

(a) $I_1 = \frac{6\text{V} - 4\text{V}}{5\Omega} = 0.4\text{A}$.

(b) $I_2 = \frac{6\text{V} + 2\text{V}}{3\Omega} = 2.67\text{A}$.

(c) $V_a - V_b = 6\text{V} + 2\text{V} = 8\text{V}$. 
Both capacitor circuits are at equilibrium.
(a) Find the charge $Q_1$ on capacitor 1.
(b) Find the energy $U_3$ stored on capacitor 3.
(c) Find the charge $Q_2$ on capacitor 2.
(d) Find the voltage $V_4$ across capacitor 4.
Both capacitor circuits are at equilibrium.
(a) Find the charge $Q_1$ on capacitor 1.
(b) Find the energy $U_3$ stored on capacitor 3.
(c) Find the charge $Q_2$ on capacitor 2.
(d) Find the voltage $V_4$ across capacitor 4.

Solution:
(a) $Q_1 = C_1 V_1 = (1\,\text{pF})(24\,\text{V}) = 24\,\text{pC}.$
(b) $U_3 = \frac{1}{2} C_3 V_3^2 = \frac{1}{2} (3\,\text{pF})(24\,\text{V})^2 = 864\,\text{pJ}.$
(c) $C_{24} = \left( \frac{1}{C_2} + \frac{1}{C_4} \right)^{-1} = \frac{4}{3}\,\text{pF},$

$Q_2 = Q_4 = Q_{24} = C_{24} V_{24} = \left( \frac{4}{3}\,\text{pF} \right) (24\,\text{V}) = 32\,\text{pC}.$
(d) $V_4 = \frac{Q_4}{C_4} = \frac{32\,\text{pC}}{4\,\text{pF}} = 8\,\text{V}.$
In the two resistor circuits shown find the equivalent resistances $R_{123}$ (left) and $R_{456}$ (right). Then find the currents $I_1, I_2, I_3$ through the individual resistors on the left, and the currents $I_4, I_5, I_6$ through the individual resistors on the right.
In the two resistor circuits shown find the equivalent resistances $R_{123}$ (left) and $R_{456}$ (right). Then find the currents $I_1, I_2, I_3$ through the individual resistors on the left. and the currents $I_4, I_5, I_6$ through the individual resistors on the right.

Solution:

- $R_{23} = 2\Omega + 2\Omega = 4\Omega, \quad R_{123} = \left(\frac{1}{2\Omega} + \frac{1}{4\Omega}\right)^{-1} = \frac{4}{3}\Omega$

- $R_{45} = \left(\frac{1}{2\Omega} + \frac{1}{2\Omega}\right)^{-1} = 1\Omega, \quad R_{456} = R_{45} + R_6 = 3\Omega$

- $I_1 = \frac{14V}{2\Omega} = 7A, \quad I_2 = I_3 = \frac{14V}{4\Omega} = 3.5A$

- $I_6 = I_{45} = \frac{14V}{3\Omega} = 4.67A, \quad I_4 = I_5 = \frac{1}{2}I_6 = 2.33A$
In the circuit shown find the currents $I_1$, $I_2$, and the potential difference $V_b - V_a$
(a) if the switch S is open,
(b) if the switch S is closed.
In the circuit shown find the currents $I_1, I_2$, and the potential difference $V_b - V_a$
(a) if the switch S is open,
(b) if the switch S is closed.

Solution:

(a) $I_1 = I_2 = \frac{12V}{5\Omega} = 2.4A$

$V_b - V_a = 8V - (2.4A)(2\Omega) = -4V + (2.4A)(3\Omega) = 3.2V.$

(b) $I_1 = \frac{8V}{2\Omega} = 4A, \quad I_2 = \frac{4V}{3\Omega} = 1.33A, \quad V_b - V_a = 0.$
Consider the capacitor circuit shown at equilibrium. (a) Find the equivalent capacitance $C_{eq}$. (b) Find the total energy $U$ stored in the three capacitors. (c) Find the voltage $V_\ast$ across the capacitor marked by an asterisk. (d) Find the voltage $V_1$ across the 1nF-capacitor.
Consider the capacitor circuit shown at equilibrium. (a) Find the equivalent capacitance $C_{eq}$. (b) Find the total energy $U$ stored in the three capacitors. (c) Find the voltage $V_*$ across the capacitor marked by an asterisk. (d) Find the voltage $V_1$ across the 1nF-capacitor.

![Circuit Diagram]

**Solution:**

(a) $C_{eq} = \left( \frac{1}{1nF + 2nF} + \frac{1}{3nF} \right)^{-1} = 1.5nF$

(b) $U = \frac{1}{2}(1.5nF)(6V)^2 = 27nJ$

(c) $V_* = \frac{1}{2}6V = 3V$

(d) $V_1 = 6V - 3V = 3V$

(a) $C_{eq} = \left( \frac{1}{3nF + 1nF} + \frac{1}{4nF} \right)^{-1} = 2nF$

(b) $U = \frac{1}{2}(2nF)(8V)^2 = 64nJ$

(c) $V_* = \frac{1}{2}8V = 4V$

(d) $V_1 = 8V - 4V = 4V$
Consider the resistor circuit shown. (a) Find the equivalent resistance $R_{eq}$. (b) Find the currents $I_1$ and $I_2$. (c) Find the power $P$ supplied by the battery.
Consider the resistor circuit shown. (a) Find the equivalent resistance $R_{eq}$. (b) Find the currents $I_1$ and $I_2$. (c) Find the power $P$ supplied by the battery.

Solution:

(a) $R_{eq} = \left( \frac{1}{4\Omega} + \frac{1}{4\Omega} \right)^{-1} + 3\Omega = 5\Omega$

(b) $I_1 = \frac{6V}{5\Omega} = 1.2\text{A}$, $I_2 = \frac{1}{2}I_1 = 0.6\text{A}$

(c) $P = (1.2\text{A})(6V) = 7.2\text{W}$

(a) $R_{eq} = \left( \frac{1}{2\Omega} + \frac{1}{2\Omega} \right)^{-1} + 3\Omega = 4\Omega$

(b) $I_1 = \frac{8V}{4\Omega} = 2\text{A}$, $I_2 = \frac{1}{2}I_1 = 1\text{A}$

(c) $P = (2\text{A})(8V) = 16\text{W}$
Consider the electric circuit shown. Find the currents $I_1, I_2, I_3$. 
Consider the electric circuit shown.
Find the currents $I_1, I_2, I_3$.

\[ 12V - I_2(2\Omega) - 3V = 0 \]
\[ \Rightarrow I_2 = \frac{9V}{2\Omega} = 4.5A \]
\[ 12V - I_3(3\Omega) + 3V = 0 \]
\[ \Rightarrow I_3 = \frac{15V}{3\Omega} = 5A. \]

$I_1 = I_2 + I_3 = 9.5A$

\[ 12V - I_2(2\Omega) + 3V = 0 \]
\[ \Rightarrow I_2 = \frac{15V}{2\Omega} = 7.5A. \]
\[ 12V - I_3(3\Omega) - 3V = 0 \]
\[ \Rightarrow I_3 = \frac{9V}{3\Omega} = 3A. \]

$I_1 = I_2 + I_3 = 10.5A$
The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the total energy $U$ stored in the three capacitors.
(c) Find the charge $Q_6$ on the capacitor on the left.
(d) Find the voltages $V_2$ and $V_4$ across the two capacitor on the right.
The circuit of capacitors connected to a battery is at equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the total energy $U$ stored in the three capacitors.
(c) Find the charge $Q_6$ on the capacitor on the left.
(d) Find the the voltages $V_2$ and $V_4$ across the two capacitor on the right.

Solution:

(a) $C_{eq} = \left( \frac{1}{2 \mu F + 4 \mu F} + \frac{1}{6 \mu F} \right)^{-1} = 3 \mu F$.
(b) $U = \frac{1}{2} (3 \mu F)(8V)^2 = 96 \mu J$.
(c) $Q_6 = (8V)(3 \mu F) = 24 \mu C$.
(d) $V_2 = V_4 = \frac{1}{2} (8V) = 4V$. 
Consider the electrical circuit shown.

(a) Find the current $I_1$ when the switch $S$ is open.
(b) Find the currents $I_1$ and $I_2$ when the switch $S$ is closed.
Consider the electrical circuit shown.

(a) Find the current $I_1$ when the switch $S$ is open.
(b) Find the currents $I_1$ and $I_2$ when the switch $S$ is closed.

Solution:

(a) $I_1 = \frac{6V - 4V}{4\Omega + 5\Omega + 3\Omega + 2\Omega} = 0.143\, \text{A}$.

(b) $I_1 = \frac{6V}{4\Omega + 5\Omega} = 0.667\, \text{A}$, \quad $I_2 = \frac{4V}{3\Omega + 2\Omega} = 0.8\, \text{A}$. 
This $RC$ circuit has been running for a long time with the switch open.

(a) Find the current $I$ while the switch is still open.
(b) Find the current $I$ right after the switch has been closed.
(c) Find the current $I$ a long time later.
(d) Find the charge $Q$ on the capacitor also a long time later.
This $RC$ circuit has been running for a long time with the switch open.

(a) Find the current $I$ while the switch is still open.
(b) Find the current $I$ right after the switch has been closed.
(c) Find the current $I$ a long time later.
(d) Find the charge $Q$ on the capacitor also a long time later.

Solution:

(a) $I = \frac{12V}{2\Omega + 4\Omega} = 2A$.
(b) $I = \frac{12V}{2\Omega} = 6A$.
(c) $I = \frac{12V}{2\Omega + 4\Omega} = 2A$.
(d) $Q = (8V)(7nF) = 56nC$. 
The capacitors (initially discharged) have been connected to the battery. The circuit is now at equilibrium. Find ...

(a) the voltage $V_2$ across capacitor $C_2$,  
(b) the energy $U_5$ on capacitor $C_5$,  
(c) the charge $Q_3$ on capacitor $C_3$,  
(d) the equivalent capacitance $C_{eq}$.

(a) the voltage $V_4$ across capacitor $C_4$,  
(b) the energy $U_7$ on capacitor $C_7$,  
(c) the charge $Q_6$ on capacitor $C_6$,  
(d) the equivalent capacitance $C_{eq}$. 

\[ V_2 = 12 \text{V} \]
\[ C_5 = 5 \mu \text{F} \]
\[ C_6 = 6 \mu \text{F} \]
\[ C_3 = 3 \mu \text{F} \]
\[ C_2 = 2 \mu \text{F} \]

\[ C_4 = 4 \mu \text{F} \]
\[ C_3 = 3 \mu \text{F} \]
\[ C_6 = 6 \mu \text{F} \]
\[ C_7 = 7 \mu \text{F} \]
\[ 18 \text{V} \]
The capacitors (initially discharged) have been connected to the battery. The circuit is now at equilibrium. Find ...

(a) the voltage $V_2$ across capacitor $C_2$,
(b) the energy $U_5$ on capacitor $C_5$,
(c) the charge $Q_3$ on capacitor $C_3$,
(d) the equivalent capacitance $C_{eq}$.

(a) the voltage $V_4$ across capacitor $C_4$,
(b) the energy $U_7$ on capacitor $C_7$,
(c) the charge $Q_6$ on capacitor $C_6$,
(d) the equivalent capacitance $C_{eq}$.

Solution:

(a) $V_2 = 12V$.
(b) $U_5 = \frac{1}{2} (5\mu F)(12V)^2 = 360\mu J$.
(c) $C_{36} = 2\mu F$
   $\Rightarrow Q_3 = Q_{36} = (12V)(2\mu F) = 24\mu C$.
(d) $C_{eq} = C_5 + C_{36} + C_2 = 9\mu F$.

(a) $V_4 = 18V$.
(b) $U_7 = \frac{1}{2} (7\mu F)(18V)^2 = 1134\mu J$.
(c) $C_{36} = 2\mu F$
   $\Rightarrow Q_6 = Q_{36} = (18V)(2\mu F) = 36\mu C$.
(d) $C_{eq} = C_4 + C_{36} + C_7 = 13\mu F$. 
This resistor circuit is in a state of steady currents. Find ... 

(a) the voltage $V_2$ across resistor $R_2$, 
(b) the power $P_4$ dissipated in resistor $R_4$, 
(c) the current $I_3$ flowing through resistor $R_3$  
(d) the equivalent resistance $R_{eq}$.

(a) the voltage $V_3$ across resistor $R_3$, 
(b) the power $P_6$ dissipated in resistor $R_6$, 
(c) the current $I_4$ flowing through resistor $R_4$, 
(d) the equivalent resistance $R_{eq}$.
This resistor circuit is in a state of steady currents. Find ...

(a) the voltage $V_2$ across resistor $R_2$,
(b) the power $P_4$ dissipated in resistor $R_4$,
(c) the current $I_3$ flowing through resistor $R_3$
(d) the equivalent resistance $R_{eq}$.

(a) the voltage $V_3$ across resistor $R_3$,
(b) the power $P_6$ dissipated in resistor $R_6$,
(c) the current $I_4$ flowing through resistor $R_4$,
(d) the equivalent resistance $R_{eq}$.

Solution:

(a) $V_2 = 18V$.
(b) $P_4 = \frac{18V^2}{4\Omega} = 81W$.
(c) $I_3 = \frac{18V}{3\Omega + 1\Omega} = 4.5A$.
(d) $R_{eq} = \left(\frac{1}{4\Omega} + \frac{1}{1\Omega + 3\Omega} + \frac{1}{2\Omega}\right)^{-1} = 1\Omega$.

(a) $V_3 = 12V$
(b) $P_6 = \frac{12V^2}{6\Omega} = 24W$.
(c) $I_4 = \frac{12V}{2\Omega + 4\Omega} = 2A$.
(d) $R_{eq} = \left(\frac{1}{3\Omega} + \frac{1}{2\Omega + 4\Omega} + \frac{1}{6\Omega}\right)^{-1} = 1.5\Omega$.
This two-loop resistor circuit is in a state of steady currents. Find ...
(a) the current $I_1$,
(b) the current $I_2$,
(c) the potential difference $V_a - V_b$. 

\[ 7V \quad 11V \]
\[ 8\Omega \quad 6\Omega \]
This two-loop resistor circuit is in a state of steady currents. Find ...
(a) the current $I_1$,
(b) the current $I_2$,
(c) the potential difference $V_a - V_b$.

Solution:

(a) $I_1 = \frac{5V + 7V}{8\Omega} = +1.5A$.
(b) $I_2 = \frac{5V + 11V}{6\Omega} = +2.67A$.
(c) $V_a - V_b = -7V + 11V = +4V$.
The capacitors (initially discharged) have been connected to the battery. The circuit is now at equilibrium. Find ...

(a) the charge \( Q_4 \) on the 4pF-capacitor,
(b) the energy \( U_7 \) on the 7pF-capacitor,
(c) the voltage \( V_{10} \) across the upper 10pF-capacitor,
(d) the equivalent capacitance \( C_{eq} \).

(a) the charge \( Q_3 \) on the 3pF-capacitor,
(b) the energy \( U_5 \) on the 5pF-capacitor,
(c) the voltage \( V_8 \) across the lower 8pF-capacitor,
(d) the equivalent capacitance \( C_{eq} \).
The capacitors (initially discharged) have been connected to the battery. The circuit is now at equilibrium. Find ...

(a) the charge $Q_4$ on the 4pF-capacitor,
(b) the energy $U_7$ on the 7pF-capacitor,
(c) the voltage $V_{10}$ across the upper 10pF-capacitor,
(d) the equivalent capacitance $C_{eq}$.

(a) the charge $Q_3$ on the 3pF-capacitor,
(b) the energy $U_5$ on the 5pF-capacitor,
(c) the voltage $V_8$ across the lower 8pF-capacitor,
(d) the equivalent capacitance $C_{eq}$.

Solution:

(a) $Q_4 = (6V)(4pF) = 24pC$.
(b) $U_7 = \frac{1}{2} (7pF)(6V)^2 = 126pJ$.
(c) $V_{10} = \frac{1}{2} 6V = 3V$.
(d) $C_{eq} = 4pF + 7pF + 5pF = 16pF$.

(a) $Q_3 = (9V)(3pF) = 27pC$.
(b) $U_5 = \frac{1}{2} (5pF)(9V)^2 = 202.5pJ$.
(c) $V_8 = \frac{1}{2} 9V = 4.5V$.
(d) $C_{eq} = 3pF + 5pF + 4pF = 12pF$. 
Consider this circuit with two terminals, four resistors, and one switch.
(a) Find the equivalent resistance $R_{eq}^{(open)}$ when the switch is open.
(b) Find the equivalent resistance $R_{eq}^{(closed)}$ when the switch is closed.
Consider this circuit with two terminals, four resistors, and one switch.
(a) Find the equivalent resistance $R_{\text{eq}}^{(\text{open})}$ when the switch is open.
(b) Find the equivalent resistance $R_{\text{eq}}^{(\text{closed})}$ when the switch is closed.

Solution:

\[
R_{\text{eq}}^{(\text{open})} = \left( \frac{1}{1\Omega + 2\Omega} + \frac{1}{1\Omega + 2\Omega} \right)^{-1} = \frac{3}{2} \Omega.
\]

\[
R_{\text{eq}}^{(\text{open})} = \left( \frac{1}{1\Omega + 3\Omega} + \frac{1}{1\Omega + 3\Omega} \right)^{-1} = 2\Omega.
\]

\[
R_{\text{eq}}^{(\text{closed})} = \left( \frac{1}{1\Omega} + \frac{1}{2\Omega} \right)^{-1} + \left( \frac{1}{1\Omega} + \frac{1}{2\Omega} \right)^{-1} = \frac{4}{3} \Omega.
\]

\[
R_{\text{eq}}^{(\text{closed})} = \left( \frac{1}{1\Omega} + \frac{1}{3\Omega} \right)^{-1} + \left( \frac{1}{1\Omega} + \frac{1}{3\Omega} \right)^{-1} = \frac{3}{2} \Omega.
\]
Consider this circuit with two batteries, two resistors, and one switch.
(a) Find the current $I$ when the switch is open.
(b) Find the current $I$ when the switch is closed.
(c) Find the potential difference $V_a - V_b$ when the switch is open.
(d) Find the potential difference $V_a - V_b$ when the switch is closed.
Consider this circuit with two batteries, two resistors, and one switch.
(a) Find the current $I$ when the switch is open.
(b) Find the current $I$ when the switch is closed.
(c) Find the potential difference $V_a - V_b$ when the switch is open.
(d) Find the potential difference $V_a - V_b$ when the switch is closed.

Solution:
(a) $I = \frac{15\text{V}}{5\Omega} = 3\text{A}.$
(b) $I = \frac{15\text{V}}{5\Omega} + \frac{12\text{V}}{6\Omega} = 3\text{A} + 2\text{A} = 5\text{A}.$
(c) $V_a - V_b = 12\text{V}.$
(d) $V_a - V_b = 0.$

(a) $I = \frac{16\text{V}}{2\Omega} = 8\text{A}.$
(b) $I = \frac{16\text{V}}{2\Omega} + \frac{15\text{V}}{5\Omega} = 8\text{A} + 3\text{A} = 11\text{A}.$
(c) $V_a - V_b = 15\text{V}.$
(d) $V_a - V_b = 0.$
This circuit is at equilibrium.

- Find the charge $Q_7$ on capacitor $C_7$ [$Q_5$ on $C_5$].
- Find the energy $U_5$ on capacitor $C_5$ [$U_7$ on $C_7$].
- Find the voltages $V_2$, $V_4$ across capacitors $C_2$, $C_4$ [$V_3$, $V_6$ across $C_3$, $C_6$].
This circuit is at equilibrium.

- Find the charge $Q_7$ on capacitor $C_7$ [$Q_5$ on $C_5$].
- Find the energy $U_5$ on capacitor $C_5$ [$U_7$ on $C_7$].
- Find the voltages $V_2, V_4$ across capacitors $C_2, C_4$ [$V_3, V_6$ across $C_3, C_6$].

\[
\begin{align*}
C_2 &= 2 \mu F \\
C_4 &= 4 \mu F \\
C_7 &= 7 \mu F \\
C_5 &= 5 \mu F \\
C_3 &= 3 \mu F \\
C_6 &= 6 \mu F
\end{align*}
\]

Solution:

- $Q_7 = (24V)(7\mu F) = 168\mu C$  [$Q_5 = (24V)(5\mu F) = 120\mu C$]
- $U_5 = \frac{1}{2}(5\mu F)(24V)^2 = 1440\mu J$  [$U_7 = \frac{1}{2}(7\mu F)(24V)^2 = 2016\mu J$]
- $V_2 + V_4 = 24V, \quad V_2C_2 = V_4C_4 \quad \Rightarrow \quad V_2 = 16V, \quad V_4 = 8V$
- $[V_3 + V_6 = 24V, \quad V_3C_3 = V_6C_6 \quad \Rightarrow \quad V_3 = 16V, \quad V_6 = 8V]$
Consider the resistor circuit on the left. Find the currents $I_1, I_2, I_3, I_4$ and the potential difference $V_a - V_b, [V_c - V_d]$

(a) when the switch $S_w$ is open,

(b) when the switch $S_w$ is closed
Consider the resistor circuit on the left [right].

Find the currents $I_1$, $I_2$ [$I_3$, $I_4$] and the potential difference $V_a - V_b$ [$V_c - V_d$]

(a) when the switch $S_w$ [$S_y$] is open,

(b) when the switch $S_w$ [$S_y$] is closed

Solution:

(a) $I_1 = I_2 = \frac{3V + 6V}{5\Omega + 3\Omega} = 1.125A$, $V_a - V_b = 9V.$

$\left[ I_3 = I_4 = \frac{2V + 5V}{6\Omega + 4\Omega} = 0.7A, \quad V_c - V_d = 7V. \right]$ 

(b) $I_1 = \frac{3V}{5\Omega} = 0.6A$, $I_2 = \frac{6V}{3\Omega} = 2A$, $V_a - V_b = 9V.$

$\left[ I_3 = \frac{5V}{4\Omega} = 1.25A, \quad I_4 = \frac{2V}{6\Omega} = 0.333A, \quad V_c - V_d = 7V. \right]$
The switch S of this circuit has been open for a long time. The capacitor has capacitance $C = 6\,\text{pF}$ [$C = 4\,\text{pF}$]. Each resistor has resistance $R = 6\,\Omega$ [$R = 4\,\Omega$].

(a) Find the currents $I_1$, $I_2$, $I_3$ right after the switch has been closed.

(b) Find the currents $I_1$, $I_2$, $I_3$ a long time later.
The switch $S$ of this circuit has been open for a long time. The capacitor has capacitance $C = 6\text{pF}$ [$C = 4\text{pF}$]. Each resistor has resistance $R = 6\Omega$ [$R = 4\Omega$].

(a) Find the currents $I_1, I_2, I_3$ right after the switch has been closed.

(b) Find the currents $I_1, I_2, I_3$ a long time later

**Solution:**

(a) no voltage across capacitor: $R_{eq} = 9\Omega$  [$R_{eq} = 6\Omega$]

\[
I_3 = I_1 + I_2 = \frac{36\text{V}}{9\Omega} = 4A, \quad I_1 = I_2 = 2A \quad \left[I_3 = I_1 + I_2 = \frac{36\text{V}}{6\Omega} = 6A, \quad I_1 = I_2 = 3A \right].
\]

(b) no current through capacitor: $R_{eq} = 12\Omega$  [$R_{eq} = 8\Omega$]

\[
I_1 = I_3 = \frac{36\text{V}}{12\Omega} = 3A, \quad I_2 = 0, \quad \left[I_1 = I_3 = \frac{36\text{V}}{8\Omega} = 4.5A, \quad I_2 = 0 \right].
\]
The circuit shown has reached equilibrium. The specifications are $E = 12\text{V}$, $C_1 = C_2 = C_3 = 5\text{nF}$.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charge $Q_2$ on capacitor $C_2$.
(c) Find the voltage $V_3$ across capacitor $C_3$.
(d) Find the total energy $U$ stored in the capacitors.
The circuit shown has reached equilibrium. The specifications are $E = 12\text{V}$ $[18\text{V}]$, $C_1 = C_2 = C_3 = 5\text{nF}$ $[4\text{nF}]$

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charge $Q_2$ on capacitor $C_2$.
(c) Find the voltage $V_3$ across capacitor $C_3$.
(d) Find the total energy $U$ stored in the capacitors.

Solution:

(a) $C_{12} = C_1 + C_2 = 10\text{nF}$ $[8\text{nF}]$.

$C_{eq} = \left( \frac{1}{C_{12}} + \frac{1}{C_3} \right)^{-1} = \frac{10}{3} \text{nF} \left[ \frac{8}{3} \text{nF} \right]$.

(b) $Q_3 = Q_{12} = E C_{eq} = 40\text{nC}$ $[48\text{nC}]$, $Q_1 = Q_2 = \frac{1}{2} Q_{12} = 20\text{nC}$ $[24\text{nC}]$.

(c) $V_3 = \frac{Q_3}{C_3} = 8\text{V}$ $[12\text{V}]$, $V_1 = V_2 = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = 4\text{V}$ $[6\text{V}]$.

(d) $U = \frac{1}{2} C_{eq} E^2 = 240\text{nJ}$ $[432\text{nJ}]$. 
The circuit shown is in a steady state. The specifications are $E = 12\text{V}$ [18V], $R_1 = R_2 = R_3 = 5\Omega$ [4Ω].

(a) Find the equivalent resistance $R_{eq}$.
(b) Find the currents $I_1$ through resistor $R_1$.
(c) Find the voltage $V_3$ across resistor $R_3$.
(d) Find the power $P$ produced by the battery.
The circuit shown is in a steady state. The specifications are $E = 12\,V [18\,V]$, $R_1 = R_2 = R_3 = 5\,\Omega [4\,\Omega]$.

(a) Find the equivalent resistance $R_{eq}$.
(b) Find the currents $I_1$ through resistor $R_1$.
(c) Find the voltage $V_3$ across resistor $R_3$.
(d) Find the power $P$ produced by the battery.

Solution:

(a) $R_{12} = \left( \frac{1}{R_1} + \frac{1}{R_3} \right)^{-1} = 2.5\,\Omega [2.0\,\Omega]$, $R_{eq} = R_{12} + R_3 = 7.5\,\Omega [6.0\,\Omega]$.

(b) $I_3 = I_{12} = \frac{E}{R_{eq}} = 1.6\,A [3.0\,A]$, $I_1 = I_2 = \frac{1}{2} I_{12} = 0.8\,A [1.5\,A]$.

(c) $V_3 = R_3 I_3 = 8\,V [12\,V]$, $V_1 = V_2 = R_1 I_1 = R_2 I_2 = 4\,V [6\,V]$.

(d) $P = \frac{E^2}{R_{eq}} = R_{eq} I_3^2 = 19.2\,W [54.0\,W]$. 
This circuit is in a steady state with the switch $S$ either open or closed.

(a) Find the currents $I_1$ and $I_2$ when the switch is open.

(b) Find the currents $I_1$ and $I_2$ when the switch is closed.

(c) Find the voltages $V_a - V_b$ and $V_b - V_c$ when the switch is open.

(d) Find the voltages $V_a - V_b$ and $V_b - V_c$ when the switch is closed.
This circuit is in a steady state with the switch $S$ either open or closed.

(a) Find the currents $I_1$ and $I_2$ when the switch is open.

(b) Find the currents $I_1$ and $I_2$ when the switch is closed.

(c) Find the voltages $V_a - V_b$ and $V_b - V_c$ when the switch is open.

(d) Find the voltages $V_a - V_b$ and $V_b - V_c$ when the switch is closed.

Solution:

(a) $I_1 = I_2 = \frac{6V + 8V - 3V - 2V}{3\Omega + 4\Omega} = \frac{9}{7}A = 1.29A$.

(b) $I_1 = \frac{8V - 3V}{4\Omega} = \frac{5}{4}A = 1.25A$, $I_2 = \frac{6V - 2V}{3\Omega} = \frac{4}{3}A = 1.33A$.

(c) $V_a - V_b = 8V - (1.29A)(4\Omega) = 2.84V$, $V_b - V_c = 6V - (1.29A)(3\Omega) = 2.13V$.

(d) $V_a - V_b = 3V$, $V_b - V_c = 2V$. 

The circuit shown has reached equilibrium. The specifications are $\mathcal{E} = 12\text{V}$ [14V], $C_1 = C_2 = C_3 = 7\text{nF}$ [5nF]

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charges $Q_1, Q_2, Q_3$ on capacitors 1, 2, 3, respectively.
(c) Find the voltages $V_1, V_2, V_3$ across capacitors 1, 2, 3, respectively.
The circuit shown has reached equilibrium. The specifications are $E = 12\text{V}$ [14V], $C_1 = C_2 = C_3 = 7\text{nF}$ [5nF]

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charges $Q_1, Q_2, Q_3$ on capacitors 1, 2, 3, respectively.
(c) Find the voltages $V_1, V_2, V_3$ across capacitors 1, 2, 3, respectively.

Solution:

(a) $C_{13} = \left( \frac{1}{C_1} + \frac{1}{C_3} \right)^{-1} = \frac{7}{2}\text{nF} \left[ \frac{5}{2}\text{nF} \right]$. 

$C_{eq} = C_{13} + C_2 = \frac{21}{2}\text{nF} \left[ \frac{15}{2}\text{nF} \right]$.

(b) $Q_1 = Q_3 = E C_{13} = 42\text{nC}$ [35nC], $Q_2 = E C_2 = 84\text{nC}$ [70nC].

(c) $V_1 = \frac{Q_1}{C_1} = 6\text{V}$ [7V], $V_2 = \frac{Q_2}{C_2} = 12\text{V}$ [14V], $V_3 = \frac{Q_3}{C_3} = 6\text{V}$ [7V].
The circuit shown is in a steady state. The specifications are \( E = 12\, \text{V} \) [14V], \( R_1 = R_2 = R_3 = 7\, \Omega \) [5Ω].

(a) Find the equivalent resistance \( R_{eq} \).
(b) Find the currents \( I_1, I_2, I_3 \) through resistors 1, 2, 3, respectively.
(c) Find the voltages \( V_1, V_2, V_3 \) across resistors 1, 2, 3, respectively.
The circuit shown is in a steady state.
The specifications are \( E = 12\text{V} \) [14V], \( R_1 = R_2 = R_3 = 7\Omega \) [5Ω].

(a) Find the equivalent resistance \( R_{eq} \).
(b) Find the currents \( I_1, I_2, I_3 \) through resistors 1, 2, 3, respectively.
(c) Find the voltages \( V_1, V_2, V_3 \) across resistors 1, 2, 3, respectively.

Solution:

(a) \( R_{13} = R_1 + R_3 = 14\Omega \) [10A], \( R_{eq} = \left( \frac{1}{R_{13}} + \frac{1}{R_2} \right)^{-1} = 4.67\Omega \) [3.33A].

(b) \( I_1 = I_3 = \frac{E}{R_{13}} = 0.857\text{A} \) [1.40A], \( I_2 = \frac{E}{R_2} = 1.71\text{A} \) [2.80A].

(c) \( V_1 = R_1 I_1 = 6\text{V} \) [7V], \( V_2 = R_2 I_2 = 12\text{V} \) [14V], \( V_3 = R_3 I_3 = 6\text{V} \) [7V].
This circuit is in a steady state with the switch $S$ either open or closed. The specifications are $E_1 = 4V [3V]$, $E_2 = 6V [7V]$, $E_3 = 10V [9V]$, $R = 7\Omega [11\Omega]$.

(a) Find the currents $I_1$ and $I_2$ when the switch is open.
(b) Find the currents $I_1$ and $I_2$ when the switch is closed.
(c) Find the voltages $V_b - V_a$ when the switch is open.
(d) Find the voltages $V_b - V_a$ when the switch is closed.
This circuit is in a steady state with the switch \( S \) either open or closed. The specifications are \( \varepsilon_1 = 4V \) [3V], \( \varepsilon_2 = 6V \) [7V], \( \varepsilon_3 = 10V \) [9V], \( R = 7\Omega \) [11\( \Omega \)].

(a) Find the currents \( I_1 \) and \( I_2 \) when the switch is open.
(b) Find the currents \( I_1 \) and \( I_2 \) when the switch is closed.
(c) Find the voltages \( V_b - V_a \) when the switch is open.
(d) Find the voltages \( V_b - V_a \) when the switch is closed.

Solution:

(a) \( I_1 = I_2 = \frac{10V - 4V}{7\Omega + 7\Omega} = 0.429A \)
\[
I_1 = I_2 = \frac{9V - 3V}{11\Omega + 11\Omega} = 0.273A
\]

(b) \( I_1 = \frac{6V - 4V}{7\Omega} = 0.286A \), \( I_2 = \frac{10V - 6V}{7\Omega} = 0.571A \)
\[
I_1 = \frac{7V - 3V}{11\Omega} = 0.364A \), \( I_2 = \frac{9V - 7V}{11\Omega} = 0.182A
\]

(c) \( V_b - V_a = (0.429A)(7\Omega) + 4V = 10V - (0.429A)(7\Omega) = 7V \)
\[
[V_b - V_a = (0.273A)(11\Omega) + 3V = 9V - (0.273A)(11\Omega) = 6V]
\]

(d) \( V_b - V_a = 6V \) \[V_b - V_a = 7V\]
The circuit shown has reached equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charges $Q_1$, $Q_2$, $Q_3$, $Q_4$ on the four capacitors.
(c) Find the voltages $V_1$, $V_2$, $V_3$, $V_4$ across the four capacitors.

\[ C_1 = 2\text{pF} \]
\[ C_2 = 1\text{pF} \]
\[ C_3 = 1\text{pF} \]
\[ C_4 = 1\text{pF} \]

\[ 6\text{V} \]
The circuit shown has reached equilibrium.

(a) Find the equivalent capacitance $C_{eq}$.
(b) Find the charges $Q_1, Q_2, Q_3, Q_4$ on the four capacitors.
(c) Find the voltages $V_1, V_2, V_3, V_4$ across the four capacitors.

Solution:

(a) $C_{34} = C_3 + C_4 = 2\ \text{pF}$, $C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_{34}} + \frac{1}{C_2}\right)^{-1} = \frac{1}{2} \text{pF}$.

(b) $Q_1 = Q_2 = Q_{34} = C_{eq}(6\ \text{V}) = 3\ \text{pC}$, $Q_3 = Q_4 = \frac{1}{2}Q_{34} = 1.5\ \text{pC}$.

(c) $V_1 = \frac{Q_1}{C_1} = 1.5\ \text{V}$, $V_2 = \frac{Q_2}{C_2} = 3\ \text{V}$, $V_3 = \frac{Q_3}{C_3} = 1.5\ \text{V}$, $V_4 = \frac{Q_4}{C_4} = 1.5\ \text{V}$. 
The circuit shown is in a steady state with the switch S either open or closed.

(a) Find the equivalent resistance $R_{eq}$ when the switch is open.
(b) Find the currents $I_1$ and $I_2$ when the switch is open.
(c) Find the equivalent resistance $R_{eq}$ when the switch is closed.
(d) Find the currents $I_1$ and $I_2$ when the switch is closed.
The circuit shown is in a steady state with the switch S either open or closed.

(a) Find the equivalent resistance $R_{eq}$ when the switch is open.
(b) Find the currents $I_1$ and $I_2$ when the switch is open.
(c) Find the equivalent resistance $R_{eq}$ when the switch is closed.
(d) Find the currents $I_1$ and $I_2$ when the switch is closed.

Solution:

(a) $R_{eq} = 2\Omega + 3\Omega + 3\Omega + 2\Omega = 10\Omega$.
(b) $I_1 = 0, \quad I_2 = \frac{18V}{10\Omega} = 1.8A$.
(c) $R_{eq} = 2\Omega + \left(\frac{1}{3\Omega} + \frac{1}{3\Omega + 3\Omega}\right)^{-1} + 2\Omega = 6\Omega$.
(d) $I_1 = \frac{6V}{3\Omega} = 2A, \quad I_2 = \frac{6V}{3\Omega + 3\Omega} = 1A$. 
This circuit is in a steady state with the switch S either open or closed.

(a) Find the currents $I_1$ and $I_2$ when the switch is open.
(b) Find the voltage $V_a - V_b$ when the switch is open.
(c) Find the currents $I_1$ and $I_2$ when the switch is closed.
(d) Find the voltage $V_a - V_b$ when the switch is closed.
This circuit is in a steady state with the switch S either open or closed.

(a) Find the currents $I_1$ and $I_2$ when the switch is open.

(b) Find the voltage $V_a - V_b$ when the switch is open.

(c) Find the currents $I_1$ and $I_2$ when the switch is closed.

(d) Find the voltage $V_a - V_b$ when the switch is closed.

Solution:

(a) $I_1 = I_2 = \frac{4V + 6V}{1\Omega + 4\Omega} = 2A$.

(b) $V_a - V_b = -(1\Omega)(2A) + 4V = 2V$, $V_a - V_b = -6V + (4\Omega)(2A) = 2V$.

(c) $I_1 = \frac{6V - 2V}{4\Omega} = 1A$, $I_2 = \frac{4V + 2V}{1\Omega} = 6A$.

(d) $V_a - V_b = -2V$. 