Q21.21 Suppose $\mathcal{E} = 12\text{ V}$ and each lamp has $R = 2\ \Omega$. Before the switch is closed the current is $\frac{12\text{ V}}{6\ \Omega} = 2\text{ A}$. The potential difference across each lamp is $(2\text{ A})(2\ \Omega) = 4\text{ V}$. The power of each lamp is $(2\text{ A})(4\text{ V}) = 8\text{ W}$, totaling 24 W for the circuit. Closing the switch makes the switch and the wires connected to it a zero-resistance branch. All of the current through A and B will go through the switch and (b) lamp C goes out, with zero voltage across it. With less total resistance, the (c) current in the battery $\frac{12\text{ V}}{4\ \Omega} = 3\text{ A}$ becomes larger than before and (a) lamps A and B get brighter. (d) The voltage across each of A and B is $(3\text{ A})(2\ \Omega) = 6\text{ V}$, larger than before. Each converts power $(3\text{ A})(6\text{ V}) = 18\text{ W}$, totaling 36 W, which is (e) an increase.

P21.3 $$Q(t) = \int_0^t I dt = I_0\tau\left(1 - e^{-t/\tau}\right)$$

(a) $$Q(\tau) = I_0\tau\left(1 - e^{-1}\right) = \boxed{(0.632)I_0\tau}$$

(b) $$Q(10\tau) = I_0\tau\left(1 - e^{-10}\right) = \boxed{(0.999\ 95)I_0\tau}$$

(c) $$Q(\infty) = I_0\tau\left(1 - e^{-\infty}\right) = \boxed{I_0\tau}$$

P21.7 $\Delta V = IR$

and $R = \frac{\rho\ell}{A}$: $$A = (0.600\text{ mm})^2\left(\frac{1.00\text{ m}}{1\ 000\text{ mm}}\right)^2 = 6.00 \times 10^{-7}\text{ m}^2$$

$\Delta V = \frac{I\rho\ell}{A}$: $$I = \frac{\Delta V A}{\rho\ell} = \frac{(0.900\text{ V})\left(6.00 \times 10^{-7}\text{ m}^2\right)}{\left(5.60 \times 10^{-8}\ \Omega\cdot\text{m}\right)(1.50\text{ m})}$$

$$I = \boxed{6.43\text{ A}}$$

P21.19 At operating temperature,

(a) $$\mathcal{P} = I\Delta V = (1.53\text{ A})(120\text{ V}) = \boxed{184\text{ W}}$$

(b) Use the change in resistance to find the final operating temperature of the toaster.

$$R = R_0(1 + \alpha\,\Delta T) \qquad \frac{120}{1.53} = \frac{120}{1.80}\left[1 + \left(0.400 \times 10^{-3}\right)\Delta T\right]$$

$\Delta T = 441°\text{C}$ $\qquad\qquad T = 20.0°\text{C} + 441°\text{C} = \boxed{461°\text{C}}$

P21.23 (a) $P = I\Delta V$

so $I = \frac{P}{\Delta V} = \frac{8.00 \times 10^3\ \text{W}}{12.0\ \text{V}} = \boxed{667\ \text{A}}$.

(b) $\Delta t = \frac{\Delta U}{P} = \frac{2.00 \times 10^7\ \text{J}}{8.00 \times 10^3\ \text{W}} = 2.50 \times 10^3\ \text{s}$

and $\Delta x = v\Delta t = (20.0\ \text{m/s})(2.50 \times 10^3\ \text{s}) = \boxed{50.0\ \text{km}}$.

P21.28 We assume that the metal wand makes low-resistance contact with the person's hand and that the resistance through the person's body is negligible compared to the resistance R_{shoes} of the shoe soles. The equivalent resistance seen by the power supply is $1.00\ \text{M}\Omega + R_{\text{shoes}}$. The current through both resistors is $\frac{50.0\ \text{V}}{1.00\ \text{M}\Omega + R_{\text{shoes}}}$. The voltmeter displays

$$\Delta V = I(1.00\ \text{M}\Omega) = \frac{50.0\ \text{V}(1.00\ \text{M}\Omega)}{1.00\ \text{M}\Omega + R_{\text{shoes}}} = \Delta V .$$

(a) We solve to obtain $\quad 50.0\ \text{V}(1.00\ \text{M}\Omega) = \Delta V(1.00\ \text{M}\Omega) + \Delta V(R_{\text{shoes}})$

$$R_{\text{shoes}} = \frac{1.00\ \text{M}\Omega(50.0 - \Delta V)}{\Delta V}.$$

(b) With $R_{\text{shoes}} \to 0$, the current through the person's body is

$\frac{50.0\ \text{V}}{1.00\ \text{M}\Omega} = 50.0\ \mu\text{A}$ $\qquad \boxed{\text{The current will never exceed } 50\ \mu\text{A}}$.

P21.31 $R_p = \left(\frac{1}{3.00} + \frac{1}{1.00}\right)^{-1} = 0.750\ \Omega$

$R_s = (2.00 + 0.750 + 4.00)\ \Omega = 6.75\ \Omega$

$I_{\text{battery}} = \frac{\Delta V}{R_s} = \frac{18.0\ \text{V}}{6.75\ \Omega} = 2.67\ \text{A}$

$\text{P} = I^2 R$: $\quad \text{P}_2 = (2.67\ \text{A})^2 (2.00\ \Omega)$

$\text{P}_2 = \boxed{14.2\ \text{W}}$ in $2.00\ \Omega$

$\text{P}_4 = (2.67\ \text{A})^2 (4.00\ \text{A}) = \boxed{28.4\ \text{W}}$ in $4.00\ \Omega$

$\Delta V_2 = (2.67\ \text{A})(2.00\ \Omega) = 5.33\ \text{V},$

$\Delta V_4 = (2.67\ \text{A})(4.00\ \Omega) = 10.67\ \text{V}$

$\Delta V_p = 18.0\ \text{V} - \Delta V_2 - \Delta V_4 = 2.00\ \text{V}\left(= \Delta V_3 = \Delta V_1\right)$

$\text{P}_3 = \frac{(\Delta V_3)^2}{R_3} = \frac{(2.00\ \text{V})^2}{3.00\ \Omega} = \boxed{1.33\ \text{W}}$ in $3.00\ \Omega$

$\text{P}_1 = \frac{(\Delta V_1)}{R_1} = \frac{(2.00\ \text{V})^2}{1.00\ \Omega} = \boxed{4.00\ \text{W}}$ in $1.00\ \Omega$

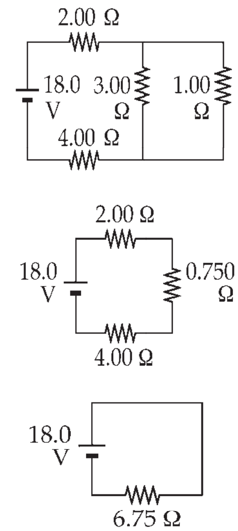

FIG. P21.31

P21.35 We name currents I_1, I_2, and I_3 as shown.

From Kirchhoff's current rule, $I_3 - I_1 - I_2 = 0$.

Applying Kirchhoff's voltage rule to the loop containing I_2 and I_3,

$12.0\ \text{V} - (4.00)I_3 - (6.00)I_2 - 4.00\ \text{V} = 0$

$8.00 = (4.00)I_3 + (6.00)I_2$

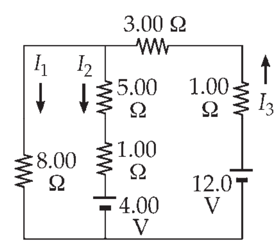

FIG. P21.35

Applying Kirchhoff's voltage rule to the loop containing I_1 and I_2,

$-(6.00)I_2 - 4.00\ \text{V} + (8.00)I_1 = 0$

$(8.00)I_1 = 4.00 + (6.00)I_2.$

Solving the above linear system, we proceed to the pair of simultaneous equations:

$$\begin{cases} 8 = 4I_1 + 4I_2 + 6I_2 \\ 8I_1 = 4 + 6I_2 \end{cases} \quad \text{or} \quad \begin{cases} 8 = 4I_1 + 10I_2 \\ I_2 = 1.33I_1 - 0.667 \end{cases}$$

and to the single equation $8 = 4I_1 + 13.3I_1 - 6.67$

$I_1 = \frac{14.7\ \text{V}}{17.3\ \Omega} = 0.846\ \text{A}$. Then $I_2 = 1.33(0.846\ \text{A}) - 0.667$

and $I_3 = I_1 + I_2$ give $\boxed{I_1 = 846\ \text{mA},\ I_2 = 462\ \text{mA},\ I_3 = 1.31\ \text{A}}$.

All currents are in the directions indicated by the arrows in the circuit diagram.

P21.41 (a) $RC = (1.00 \times 10^6\ \Omega)(5.00 \times 10^{-6}\ \text{F}) = \boxed{5.00\ \text{s}}$

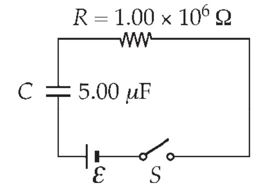

FIG. P21.41

(b) $Q = C\mathcal{E} = (5.00 \times 10^{-6}\ \text{C})(30.0\ \text{V}) = \boxed{150\ \mu\text{C}}$

(c) $I(t) = \dfrac{\mathcal{E}}{R} e^{-t/RC} = \left(\dfrac{30.0}{1.00 \times 10^6}\right) \exp\left[\dfrac{-10.0}{(1.00 \times 10^6)(5.00 \times 10^{-6})}\right] = \boxed{4.06\ \mu\text{A}}$

P21.12 (a) n is $\boxed{\text{unaffected}}$

(b) $|J| = \dfrac{I}{A} \propto I$

so it $\boxed{\text{doubles}}$.

continued on next page

(c) $J = nev_d$

so v_d $\boxed{\text{doubles}}$.

(d) $\tau = \frac{m\sigma}{nq^2}$ is $\boxed{\text{unchanged}}$ as long as σ does not change due to a temperature change in the conductor.

P21.25 (a) $P = \frac{(\Delta V)^2}{R}$

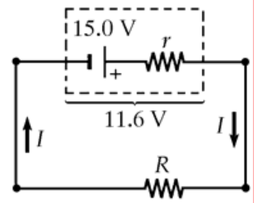

FIG. P21.25

becomes $20.0\text{ W} = \frac{(11.6\text{ V})^2}{R}$

so $R = \boxed{6.73\ \Omega}$.

(b) $\Delta V = IR$

so $11.6\text{ V} = I(6.73\ \Omega)$

and $I = 1.72\text{ A}$

$\mathcal{E} = IR + Ir$

so $15.0\text{ V} = 11.6\text{ V} + (1.72\text{ A})r$

$r = \boxed{1.97\ \Omega}$.

P21.29 If we turn the given diagram on its side, we find that it is the same as figure (a). The $20.0\ \Omega$ and $5.00\ \Omega$ resistors are in series, so the first reduction is shown in (b). In addition, since the $10.0\ \Omega$, $5.00\ \Omega$, and $25.0\ \Omega$ resistors are then in parallel, we can solve for their equivalent resistance as:

$$R_{eq} = \frac{1}{\left(\frac{1}{10.0\ \Omega} + \frac{1}{5.00\ \Omega} + \frac{1}{25.0\ \Omega}\right)} = 2.94\ \Omega\ .$$

This is shown in figure (c), which in turn reduces to the circuit shown in figure (d).

Next, we work backwards through the diagrams applying $I = \frac{\Delta V}{R}$ and $\Delta V = IR$ alternately to every resistor, real and equivalent. The $12.94\ \Omega$ resistor is connected across 25.0 V, so the current through the battery in every diagram is

$$I = \frac{\Delta V}{R} = \frac{25.0\ \text{V}}{12.94\ \Omega} = 1.93\ \text{A}\ .$$

In figure (c), this 1.93 A goes through the $2.94\ \Omega$ equivalent resistor to give a potential difference of:

$$\Delta V = IR = (1.93\ \text{A})(2.94\ \Omega) = 5.68\ \text{V}\ .$$

From figure (b), we see that this potential difference is the same across ΔV_{ab}, the $10\ \Omega$ resistor, and the $5.00\ \Omega$ resistor.

(b) Therefore, $\Delta V_{ab} = \boxed{5.68\ \text{V}}$.

(a) Since the current through the $20.0\ \Omega$ resistor is also the current through the $25.0\ \Omega$ line *ab*,

$$I = \frac{\Delta V_{ab}}{R_{ab}} = \frac{5.68\ \text{V}}{25.0\ \Omega} = 0.227\ \text{A} = \boxed{227\ \text{mA}}\ .$$

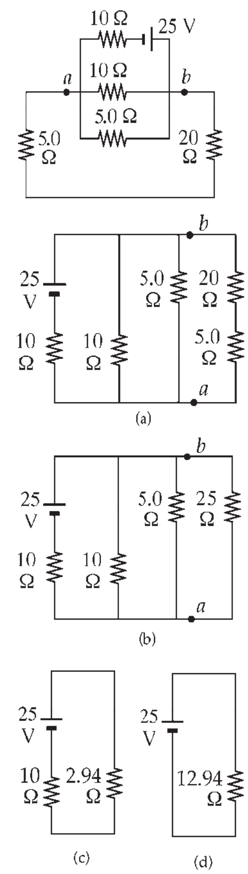

FIG. P21.29

P21.40 Using Kirchhoff's rules,

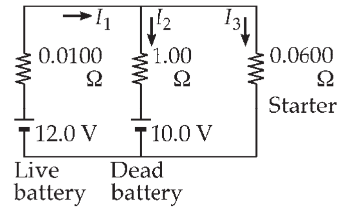

FIG. P21.40

$$12.0-(0.010\,0)I_1-(0.060\,0)I_3=0$$
$$10.0+(1.00)I_2-(0.060\,0)I_3=0$$

and $I_1-I_2-I_3=0$ or $I_1=I_2+I_3$

then $12.0-(0.010\,0)I_2-(0.070\,0)I_3=0$

and $I_2=0.06I_3-10$

Solving simultaneously, $12-(0.01)(0.06I_3-10)-0.07I_3=0$

$I_2=$ $\boxed{0.283\text{ A downward}}$ in the dead battery

and $I_3=$ $\boxed{171\text{ A downward}}$ in the starter.

The currents are forward in the live battery and in the starter, relative to normal starting operation. The current is backward in the dead battery, tending to charge it up.

P21.45 (a) Call the potential at the left junction V_L and at the right V_R. After a "long" time, the capacitor is fully charged.

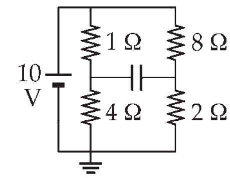

FIG. P21.45(a)

$V_L = 8.00\text{ V}$ because of voltage divider:

$$I_L = \frac{10.0\text{ V}}{5.00\ \Omega} = 2.00\text{ A}$$
$$V_L = 10.0\text{ V} - (2.00\text{ A})(1.00\ \Omega) = 8.00\text{ V}$$

Likewise, $$V_R = \left(\frac{2.00\ \Omega}{2.00\ \Omega + 8.00\ \Omega}\right)(10.0\text{ V}) = 2.00\text{ V}$$

or $$I_R = \frac{10.0\text{ V}}{10.0\ \Omega} = 1.00\text{ A}$$

$$V_R = (10.0\text{ V}) - (8.00\ \Omega)(1.00\text{ A}) = 2.00\text{ V}.$$

Therefore, $$\Delta V = V_L - V_R = 8.00 - 2.00 = \boxed{6.00\text{ V}}.$$

(b) Redraw the circuit $$R = \frac{1}{(1/9.00\ \Omega) + (1/6.00\ \Omega)} = 3.60\ \Omega$$

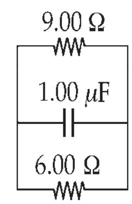

FIG. P21.45(b)

$$RC = 3.60 \times 10^{-6}\text{ s}$$

and $$e^{-t/RC} = \frac{1}{10}$$

so $$t = RC \ln 10 = \boxed{8.29\ \mu\text{s}}.$$

P21.47 $J = \sigma E$ so $$\sigma = \frac{J}{E} = \frac{6.00 \times 10^{-13}\text{ A/m}^2}{100\text{ V/m}} = \boxed{6.00 \times 10^{-15}\ (\Omega \cdot \text{m})^{-1}}$$

P21.48 (a) $$\mathcal{P} = \Delta V I = (300 \times 10^3\text{ J/C})(1.00 \times 10^3\text{ C/s}) = \boxed{3.00 \times 10^8\text{ W}}$$

A large electric generating station, fed by a trainload of coal each day, converts energy faster.

(b) $$I = \frac{\mathcal{P}}{A} = \frac{\mathcal{P}}{\pi r^2}$$

$$\mathcal{P} = I(\pi r^2) = (1\,370\text{ W/m}^2)\left[\pi(6.37 \times 10^6\text{ m})^2\right] = \boxed{1.75 \times 10^{17}\text{ W}}$$

Terrestrial solar power is immense compared to lightning and compared to all human energy conversions.