**P21.1** $I = \dfrac{\Delta Q}{\Delta t}$ $\Delta Q = I\Delta t = \left(30.0\times10^{-6}\text{ A}\right)(40.0\text{ s}) = 1.20\times10^{-3}\text{ C}$

$$N = \frac{Q}{e} = \frac{1.20\times10^{-3}\text{ C}}{1.60\times10^{-19}\text{ C/electron}} = \boxed{7.50\times10^{15}\text{ electrons}}$$

**P21.6** $I = \dfrac{\Delta V}{R} = \dfrac{120\text{ V}}{240\ \Omega} = 0.500\text{ A} = \boxed{500\text{ mA}}$

**P21.7** $\Delta V = IR$

and $R = \dfrac{\rho\ell}{A}$: $A = (0.600\text{ mm})^2\left(\dfrac{1.00\text{ m}}{1\,000\text{ mm}}\right)^2 = 6.00\times10^{-7}\text{ m}^2$

$\Delta V = \dfrac{I\rho\ell}{A}$: $I = \dfrac{\Delta VA}{\rho\ell} = \dfrac{(0.900\text{ V})\left(6.00\times10^{-7}\text{ m}^2\right)}{\left(5.60\times10^{-8}\ \Omega\cdot\text{m}\right)(1.50\text{ m})}$

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

**P21.8** (a) Given $M = \rho_d V = \rho_d A\ell$ where $\rho_d \equiv$ mass density,

we obtain: $A = \dfrac{M}{\rho_d\ell}$. Taking $\rho_r \equiv$ resistivity, $R = \dfrac{\rho_r\ell}{A} = \dfrac{\rho_r\ell}{M/\rho_d\ell} = \dfrac{\rho_r\rho_d\ell^2}{M}$.

Thus, $\ell = \sqrt{\dfrac{MR}{\rho_r\rho_d}} = \sqrt{\dfrac{\left(1.00\times10^{-3}\right)(0.500)}{\left(1.70\times10^{-8}\right)\left(8.92\times10^3\right)}}$ $\ell = \boxed{1.82\text{ m}}$.

(b) $V = \dfrac{M}{\rho_d}$, or $\pi r^2\ell = \dfrac{M}{\rho_d}$.

Thus, $r = \sqrt{\dfrac{M}{\pi\rho_d\ell}} = \sqrt{\dfrac{1.00\times10^{-3}}{\pi\left(8.92\times10^3\right)(1.82)}}$ $r = 1.40\times10^{-4}\text{ m}$.

The diameter is twice this distance: diameter $= \boxed{280\ \mu\text{m}}$.

**P21.14** $I = \dfrac{\mathcal{P}}{\Delta V} = \dfrac{600\text{ W}}{120\text{ V}} = \boxed{5.00\text{ A}}$

and $R = \dfrac{\Delta V}{I} = \dfrac{120\text{ V}}{5.00\text{ A}} = \boxed{24.0\ \Omega}$.

*P21.18 The energy taken in by electric transmission for the fluorescent lamp is

$$\mathcal{P}\Delta t = 11\ \text{J/s}(100\ \text{h})\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 3.96\times10^{6}\ \text{J}$$

$$\text{cost} = 3.96\times10^{6}\ \text{J}\left(\frac{\$0.08}{\text{kWh}}\right)\left(\frac{\text{k}}{1\,000}\right)\left(\frac{\text{W}\cdot\text{s}}{\text{J}}\right)\left(\frac{\text{h}}{3\,600\ \text{s}}\right) = \$0.088$$

For the incandescent bulb,

$$\mathcal{P}\Delta t = 40\ \text{W}(100\ \text{h})\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 1.44\times10^{7}\ \text{J}$$

$$\text{cost} = 1.44\times10^{7}\ \text{J}\left(\frac{\$0.08}{3.6\times10^{6}\ \text{J}}\right) = \$0.32$$

$$\text{saving} = \$0.32 - \$0.088 = \boxed{\$0.232}$$

P21.20 The total clock power is

$$\left(270\times10^{6}\ \text{clocks}\right)\left(2.50\ \frac{\text{J/s}}{\text{clock}}\right)\left(\frac{3\,600\ \text{s}}{1\ \text{h}}\right) = 2.43\times10^{12}\ \text{J/h}.$$

From $e = \frac{W_{\text{out}}}{Q_{\text{in}}}$, the power input to the generating plants must be:

$$\frac{Q_{\text{in}}}{\Delta t} = \frac{W_{\text{out}}/\Delta t}{e} = \frac{2.43\times10^{12}\ \text{J/h}}{0.250} = 9.72\times10^{12}\ \text{J/h}$$

and the rate of coal consumption is

$$\text{Rate} = \left(9.72\times10^{12}\ \text{J/h}\right)\left(\frac{1.00\ \text{kg coal}}{33.0\times10^{6}\ \text{J}}\right) = 2.95\times10^{5}\ \text{kg coal/h} = \boxed{295\ \text{metric ton/h}}.$$

**P21.21** You pay the electric company for energy transferred in the amount $E = \mathcal{P}\Delta t$

(a) $$\mathcal{P}\Delta t = 40\text{ W}(2\text{ weeks})\left(\frac{7\text{ d}}{1\text{ week}}\right)\left(\frac{86\,400\text{ s}}{1\text{ d}}\right)\left(\frac{1\text{ J}}{1\text{ W}\cdot\text{s}}\right) = 48.4\text{ MJ}$$

$$\mathcal{P}\Delta t = 40\text{ W}(2\text{ weeks})\left(\frac{7\text{ d}}{1\text{ week}}\right)\left(\frac{24\text{ h}}{1\text{ d}}\right)\left(\frac{\text{k}}{1\,000}\right) = 13.4\text{ kWh}$$

$$\mathcal{P}\Delta t = 40\text{ W}(2\text{ weeks})\left(\frac{7\text{ d}}{1\text{ week}}\right)\left(\frac{24\text{ h}}{1\text{ d}}\right)\left(\frac{\text{k}}{1\,000}\right)\left(\frac{0.12\text{ \$}}{\text{kWh}}\right) = \boxed{\$1.61}$$

(b) $$\mathcal{P}\Delta t = 970\text{ W}(3\text{ min})\left(\frac{1\text{ h}}{60\text{ min}}\right)\left(\frac{\text{k}}{1\,000}\right)\left(\frac{0.12\text{ \$}}{\text{kWh}}\right) = \boxed{\$0.005\,82} = 0.582¢$$

(c) $$\mathcal{P}\Delta t = 5\,200\text{ W}(40\text{ min})\left(\frac{1\text{ h}}{60\text{ min}}\right)\left(\frac{\text{k}}{1\,000}\right)\left(\frac{0.12\text{ \$}}{\text{kWh}}\right) = \boxed{\$0.416}$$

**P21.24** Consider a 400-W blow dryer used for ten minutes daily for a year. The energy transferred to the dryer is

$$\mathcal{P}\Delta t = (400\text{ J/s})(600\text{ s/d})(365\text{ d}) \approx 9\times10^{7}\text{ J}\left(\frac{1\text{ kWh}}{3.6\times10^{6}\text{ J}}\right) \approx 20\text{ kWh}.$$

We suppose that electrically transmitted energy costs on the order of ten cents per kilowatt-hour. Then the cost of using the dryer for a year is on the order of

$$\text{Cost} \approx (20\text{ kWh})(\$0.10/\text{kWh}) = \$2\,\boxed{\sim\$1}.$$

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

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

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

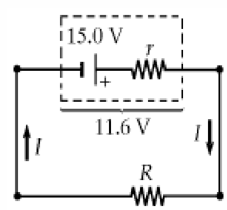


FIG. P21.25

(b) $$\Delta V = IR$$

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

and $$I = 1.72\text{ A}$$

$$\mathcal{E} = IR + Ir$$

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

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

P21.27 (a) $R_p = \frac{1}{(1/7.00\ \Omega)+(1/10.0\ \Omega)} = 4.12\ \Omega$

$R_s = R_1 + R_2 + R_3 = 4.00 + 4.12 + 9.00 = \boxed{17.1\ \Omega}$

(b) $\Delta V = IR$

$34.0\ \text{V} = I(17.1\ \Omega)$

$I = \boxed{1.99\ \text{A}}$ for $4.00\ \Omega$, $9.00\ \Omega$ resistors.

Applying $\Delta V = IR$, $(1.99\ \text{A})(4.12\ \Omega) = 8.18\ \text{V}$

$8.18\ \text{V} = I(7.00\ \Omega)$

so $I = \boxed{1.17\ \text{A}}$ for $7.00\ \Omega$ resistor

$8.18\ \text{V} = I(10.0\ \Omega)$

so $I = \boxed{0.818\ \text{A}}$ for $10.0\ \Omega$ resistor.

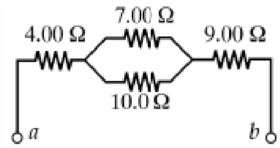


FIG. P21.27

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:

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

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 $25.0\ \text{V}$, 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 $1.93\ \text{A}$ 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 $\Delta V_{ab}$, 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 $ab$,

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

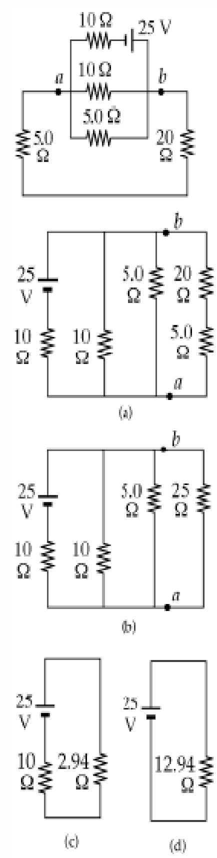


FIG. P21.29

**P21.30** (a) Since all the current in the circuit must pass through the series $100\ \Omega$ resistor, $\mathcal{P} = I^2R$

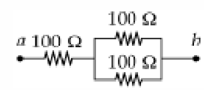


FIG. P21.30

$$\mathcal{P}_{\max} = RI_{\max}^2$$

so $$I_{\max} = \sqrt{\frac{\mathcal{P}}{R}} = \sqrt{\frac{25.0\ \text{W}}{100\ \Omega}} = 0.500\ \text{A}$$

$$R_{eq} = 100\ \Omega + \left(\frac{1}{100} + \frac{1}{100}\right)^{-1}\ \Omega = 150\ \Omega$$

$$\Delta V_{\max} = R_{eq} I_{\max} = \boxed{75.0\ \text{V}}$$

(b) $$\mathcal{P} = I\Delta V = (0.500\ \text{A})(75.0\ \text{V}) = \boxed{37.5\ \text{W}}\ \text{total power}$$

$$\mathcal{P}_1 = \boxed{25.0\ \text{W}}$$

$$\mathcal{P}_2 = \mathcal{P}_3 = RI^2 = (100\ \Omega)(0.250\ \text{A})^2 = \boxed{6.25\ \text{W}}$$

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

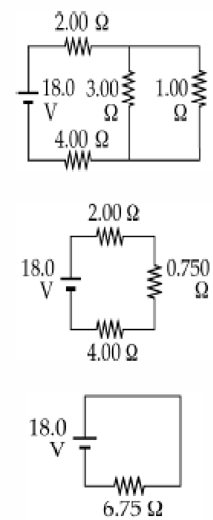


FIG. P21.31

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

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

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

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

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

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

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

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

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

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

**P21.34** $$+15.0 - (7.00)I_1 - (2.00)(5.00) = 0$$

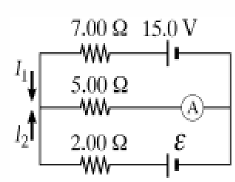


FIG. P21.34

$$5.00 = 7.00I_1 \quad \text{so} \quad \boxed{I_1 = 0.714\ \text{A}}$$

$$I_1 + I_2 - 2.00\ \text{A} = 0$$

$$0.714 + I_2 = 2.00 \quad \text{so} \quad \boxed{I_2 = 1.29\ \text{A}}$$

$$+\mathcal{E} - 2.00(1.29) - 5.00(2.00) = 0 \quad \boxed{\mathcal{E} = 12.6\ \text{V}}$$

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

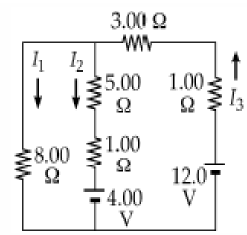


FIG. P21.35

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

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

$$12.0 \text{ V} - (4.00)I_3 - (6.00)I_2 - 4.00 \text{ V} = 0$$
$$8.00 = (4.00)I_3 + (6.00)I_2$$

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

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

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 $8 = 4I_1 + 13.3I_1 - 6.67$

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

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.

**P21.39** Label the currents in the branches as shown in the first figure. Reduce the circuit by combining the two parallel resistors as shown in the second figure.

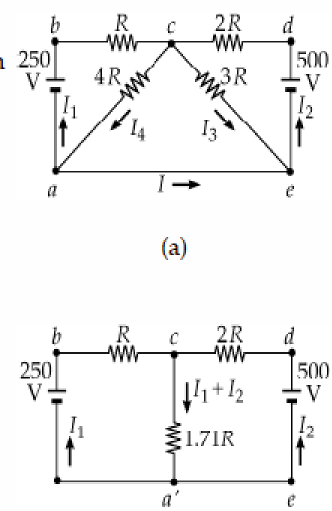


FIG. P21.39

Apply Kirchhoff's loop rule to both loops in Figure (b) to obtain:

$$(2.71R)I_1 + (1.71R)I_2 = 250$$

and

$$(1.71R)I_1 + (3.71R)I_2 = 500.$$

With $R = 1\,000 \ \Omega$, simultaneous solution of these equations yields:

$$I_1 = 10.0 \text{ mA}$$

and

$$I_2 = 130.0 \text{ mA}.$$

From Figure (b), $V_c - V_a = (I_1 + I_2)(1.71R) = 240 \text{ V}$.

Thus, from Figure (a), $I_4 = \dfrac{V_c - V_a}{4R} = \dfrac{240 \text{ V}}{4\,000 \ \Omega} = 60.0 \text{ mA}$.

Finally, applying Kirchhoff's point rule at point $a$ in Figure (a) gives:

$$I_4 - I_1 - I = 0$$
$$I = I_4 - I_1 = 60.0 \text{ mA} - 10.0 \text{ mA} = +50.0 \text{ mA}$$

or $I = \boxed{50.0 \text{ mA from point } a \text{ to point } e}$.

**P21.40** Using Kirchhoff's rules,

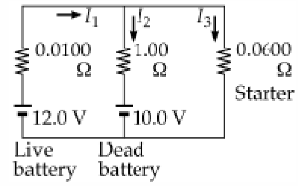


FIG. P21.40

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

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.

**P21.41** (a) $RC=\left(1.00\times10^{6}\ \Omega\right)\left(5.00\times10^{-6}\text{ F}\right)=\boxed{5.00\text{ s}}$

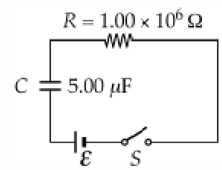


FIG. P21.41

(b) $Q=C\mathcal{E}=\left(5.00\times10^{-6}\text{ C}\right)(30.0\text{ V})=\boxed{150\ \mu\text{C}}$

(c) $I(t)=\dfrac{\mathcal{E}}{R}e^{-t/RC}=\left(\dfrac{30.0}{1.00\times10^{6}}\right)\exp\left[\dfrac{-10.0}{\left(1.00\times10^{6}\right)\left(5.00\times10^{-6}\right)}\right]=\boxed{4.06\ \mu\text{A}}$

**P21.42** (a) $I(t)=-I_0e^{-t/RC}$

$$I_0=\frac{Q}{RC}=\frac{5.10\times10^{-6}\text{ C}}{(1\,300\ \Omega)\left(2.00\times10^{-9}\text{ F}\right)}=1.96\text{ A}$$

$$I(t)=-(1.96\text{ A})\exp\left[\frac{-9.00\times10^{-6}\text{ s}}{(1\,300\ \Omega)\left(2.00\times10^{-9}\text{ F}\right)}\right]=\boxed{-61.6\text{ mA}}$$

(b) $q(t)=Qe^{-t/RC}=(5.10\ \mu\text{C})\exp\left[\dfrac{-8.00\times10^{-6}\text{ s}}{(1\,300\ \Omega)\left(2.00\times10^{-9}\text{ F}\right)}\right]=\boxed{0.235\ \mu\text{C}}$

(c) The magnitude of the maximum current is $I_0=\boxed{1.96\text{ A}}$.

**P21.43** (a) $\tau = RC = (1.50 \times 10^5\ \Omega)(10.0 \times 10^{-6}\ \text{F}) = \boxed{1.50\ \text{s}}$

(b) $\tau = (1.00 \times 10^5\ \Omega)(10.0 \times 10^{-6}\ \text{F}) = \boxed{1.00\ \text{s}}$

(c) The battery carries current $\dfrac{10.0\ \text{V}}{50.0 \times 10^3\ \Omega} = 200\ \mu\text{A}$.

The 100 kΩ carries current of magnitude $I = I_0 e^{-t/RC} = \left(\dfrac{10.0\ \text{V}}{100 \times 10^3\ \Omega}\right) e^{-t/1.00\ \text{s}}$.

So the switch carries downward current $\boxed{200\ \mu\text{A} + (100\ \mu\text{A})e^{-t/1.00\ \text{s}}}$.

**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.

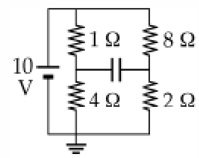


FIG. P21.45(a)

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

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

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

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

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

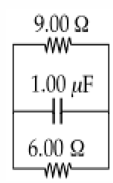


FIG. P21.45(b)

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

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

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

**P21.49** (a) $I = \frac{\Delta V}{R}$ so $\mathcal{P} = I\Delta V = \frac{(\Delta V)^2}{R}$

$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120\text{ V})^2}{25.0\text{ W}} = \boxed{576\ \Omega} \quad \text{and} \quad R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120\text{ V})^2}{100\text{ W}} = \boxed{144\ \Omega}$$

(b) $I = \frac{\mathcal{P}}{\Delta V} = \frac{25.0\text{ W}}{120\text{ V}} = 0.208\text{ A} = \frac{Q}{\Delta t} = \frac{1.00\text{ C}}{\Delta t}$

$$\Delta t = \frac{1.00\text{ C}}{0.208\text{ A}} = \boxed{4.80\text{ s}}$$

The bulb takes in charge at high potential and puts out the same amount of charge at low potential. The charge in itself is identical.

(c) $\mathcal{P} = 25.0\text{ W} = \frac{\Delta U}{\Delta t} = \frac{1.00\text{ J}}{\Delta t}$ $\Delta t = \frac{1.00\text{ J}}{25.0\text{ W}} = \boxed{0.040\,0\text{ s}}$

The bulb takes in energy by electrical transmission and puts out the same amount of energy by heat and light.

(d) $\Delta U = \mathcal{P}\Delta t = (25.0\ \text{J/s})(86\,400\ \text{s/d})(30.0\text{ d}) = 64.8 \times 10^8\text{ J}$

The electric company sells $\boxed{\text{energy}}$.

$$\text{Cost} = 64.8 \times 10^6\text{ J}\left(\frac{\$0.070\,0}{\text{kWh}}\right)\left(\frac{\text{k}}{1\,000}\right)\left(\frac{\text{W}\cdot\text{s}}{\text{J}}\right)\left(\frac{\text{h}}{3\,600\text{ s}}\right) = \boxed{\$1.26}$$

$$\text{Cost per joule} = \frac{\$0.070\,0}{\text{kWh}}\left(\frac{\text{kWh}}{3.60 \times 10^6\text{ J}}\right) = \boxed{\$1.94 \times 10^{-8}/\text{J}}$$

**P21.57** The current in the simple loop circuit will be $I = \frac{\mathcal{E}}{R+r}$.

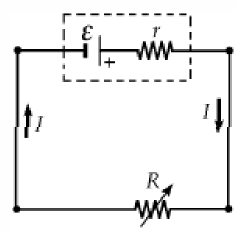


FIG. P21.57

(a) $\Delta V_{ter} = \mathcal{E} - Ir = \frac{\mathcal{E}R}{R+r}$ and $\Delta V_{ter} \to \mathcal{E}$ as $\boxed{R \to \infty}$.

(b) $I = \frac{\mathcal{E}}{R+r}$ and $I \to \frac{\mathcal{E}}{r}$ as $\boxed{R \to 0}$.

(c) $\mathcal{P} = I^2R = \mathcal{E}^2\frac{R}{(R+r)^2}$ $\frac{d\mathcal{P}}{dR} = \frac{-2\mathcal{E}^2R}{(R+r)^3} + \frac{\mathcal{E}^2}{(R+r)^2} = 0$

Then $2R = R + r$ and $\boxed{R = r}$.

**P21.59** (a) $q = C\Delta V\left(1 - e^{-t/RC}\right)$

$$q = \left(1.00\times10^{-6}\ \text{F}\right)(10.0\ \text{V})\left[1 - e^{-10.0/\left[\left(2.00\times10^{6}\right)\left(1.00\times10^{-6}\right)\right]}\right] = \boxed{9.93\ \mu\text{C}}$$

(b) $I = \dfrac{dq}{dt} = \left(\dfrac{\Delta V}{R}\right)e^{-t/RC}$

$$I = \left(\frac{10.0\ \text{V}}{2.00\times10^{6}\ \Omega}\right)e^{-5.00} = 3.37\times10^{-8}\ \text{A} = \boxed{33.7\ \text{nA}}$$

(c) $\dfrac{dU}{dt} = \dfrac{d}{dt}\left(\dfrac{1}{2}\dfrac{q^2}{C}\right) = \left(\dfrac{q}{C}\right)\dfrac{dq}{dt} = \left(\dfrac{q}{C}\right)I$

$$\frac{dU}{dt} = \left(\frac{9.93\times10^{-6}\ \text{C}}{1.00\times10^{-6}\ \text{C/V}}\right)\left(3.37\times10^{-8}\ \text{A}\right) = 3.34\times10^{-7}\ \text{W} = \boxed{334\ \text{nW}}$$

(d) $\mathcal{P}_{\text{battery}} = I\mathcal{E} = \left(3.37\times10^{-8}\ \text{A}\right)(10.0\ \text{V}) = 3.37\times10^{-7}\ \text{W} = \boxed{337\ \text{nW}}$