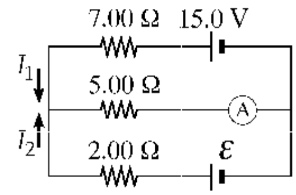
21.32 $+15.0-(7.00)I_1-(2.00)(5.00)=0$



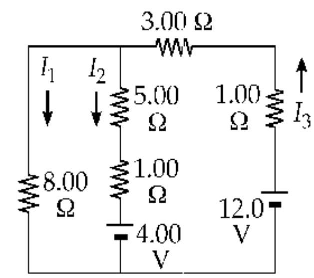
$5.00=7.00\,I_1$ so $\boxed{I_1=0.714\text{ A}}$

$I_3=I_1+I_2=2.00\text{ A}$

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

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

21.33 We name currents I_1, I_2, and I_3 as shown.



From Kirchhoff's current rule, $I_3=I_1+I_2$

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,

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

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

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

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

$I_1=\dfrac{14.7\text{ V}}{17.3\,\Omega}=0.846\text{ A}$ 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.

21.35 We use the results of Problem 33

(a) By the 4.00-V battery:

$$\Delta U = (\Delta V) I \Delta t = (4.00\ \text{V})(-0.462\ \text{A})120\ \text{s} = \boxed{-222\ \text{J}}$$

By the 12.0-V battery:

$$(12.0\ \text{V})(1.31\ \text{A})120\ \text{s} = \boxed{1.88\ \text{kJ}}$$

(b) By the 8.00-Ω resistor:

$$I^2 R \Delta t = (0.846\ \text{A})^2 (8.00\ \Omega)120\ \text{s} = \boxed{687\ \text{J}}$$

By the 5.00-Ω resistor:

$$(0.462\ \text{A})^2 (5.00\ \Omega)120\ \text{s} = \boxed{128\ \text{J}}$$

By the 1.00-Ω resistor:

$$(0.462\ \text{A})^2 (1.00\ \Omega)120\ \text{s} = \boxed{25.6\ \text{J}}$$

By the 3.00-Ω resistor:

$$(1.31\ \text{A})^2 (3.00\ \Omega)120\ \text{s} = \boxed{616\ \text{J}}$$

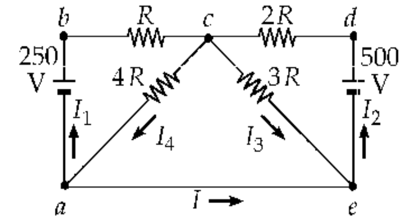
By the 1.00-Ω resistor:

$$(1.31\ \text{A})^2 (1.00\ \Omega)120\ \text{s} = \boxed{205\ \text{J}}$$

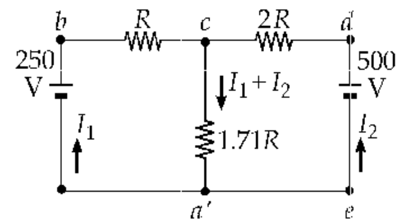
(c) $-222\ \text{J} + 1.88\ \text{kJ} = \boxed{1.66\ \text{kJ}}$ from chemical to electrical.

$687\ \text{J} + 128\ \text{J} + 25.6\ \text{J} + 616\ \text{J} + 205\ \text{J} = 1.66\ \text{kJ}$ from electrical to internal.

***21.36** 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.



(a)



(b)

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 $R = 1000\ \Omega$, 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), $$I_4 = \frac{V_c - V_a}{4R} = \frac{240 \text{ V}}{4000\ \Omega} = 60.0 \text{ mA}$$

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

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

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

21.38 (a) $I(t) = -I_0 e^{-t/RC}$

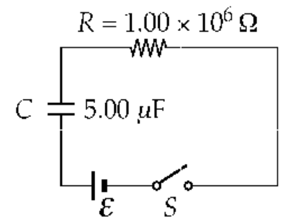
$$I_0 = \frac{Q}{RC} = \frac{5.10 \times 10^{-6} \text{ C}}{(1300\ \Omega)(2.00 \times 10^{-9} \text{ F})} = 1.96 \text{ A}$$

$$I(t) = -(1.96 \text{ A})\exp\left[\frac{-9.00 \times 10^{-6} \text{ s}}{(1300\ \Omega)(2.00 \times 10^{-9} \text{ F})}\right] = \boxed{-61.6 \text{ mA}}$$

(b) $$q(t) = Qe^{-t/RC} = (5.10\ \mu\text{C})\exp\left[\frac{-8.00 \times 10^{-6} \text{ s}}{(1300\ \Omega)(2.00 \times 10^{-9} \text{ F})}\right] = \boxed{0.235\ \mu\text{C}}$$

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

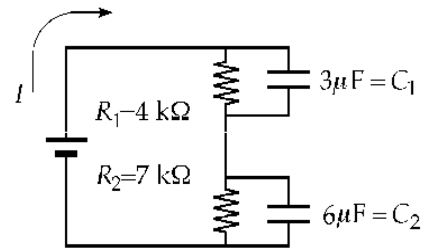
21.39 (a) $RC = (1.00\times 10^{6}\ \Omega)(5.00\times 10^{-6}\ \text{F}) = \boxed{5.00\ \text{s}}$



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

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

***21.46** (a) With the switch closed, current exists in a simple series circuit as shown. The capacitors carry no current. For R_2 we have



$$\mathcal{P} = I^2R_2 \qquad I = \sqrt{\frac{\mathcal{P}}{R_2}} = \sqrt{\frac{2.40\ \text{V}\cdot\text{A}}{7000\ \text{V/A}}} = 18.5\ \text{mA}$$

The potential difference across R_1 and C_1 is

$$\Delta V = IR_1 = (1.85\times 10^{-2}\ \text{A})(4000\ \text{V/A}) = 74.1\ \text{V}$$

The charge on C_1 is

$$Q = C_1\Delta V = (3.00\times 10^{-6}\ \text{C/V})(74.1\ \text{V}) = \boxed{222\ \mu\text{C}}$$

The potential difference across R_2 and C_2 is

$$\Delta V = IR_2 = (1.85\times 10^{-2}\ \text{A})(7000\ \Omega) = 130\ \text{V}$$

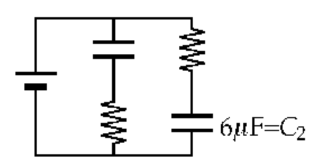
The charge on C_2 is

$$Q = C_2\Delta V = (6.00\times 10^{-6}\ \text{C/V})(130\ \text{V}) = 778\ \mu\text{C}$$

The battery emf is

$$IR_{eq} = I(R_1 + R_2) = 1.85\times 10^{-2}\ \text{A}(4000 + 7000)\ \text{V/A} = 204\ \text{V}$$

(b) In equilibrium after the switch has been opened, no current exists. The potential difference across each resistor is zero. The full 204 V appears across both capacitors. The new charge C_2 is



$$Q = C_2\Delta V = (6.00\times 10^{-6}\ \text{C/V})(204\ \text{V}) = 1222\ \mu\text{C}$$

for a change of $\quad 1222\ \mu\text{C} - 778\ \mu\text{C} = \boxed{444\ \mu\text{C}}$

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

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

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