① $\frac{I}{A} = \frac{e^2 n \Delta t}{m} E = \sigma E$

for alum: $M = 0.027$ kg/mole
$\rho = 2.7 \times 10^3$ kg/m^3
$\sigma = 3.6 \times 10^7$

$$n = \left(3 \frac{e^-}{atom}\right)\left(6.02\times10^{23}\frac{atoms}{mole}\right)\left(\frac{1\ mole}{0.027\ kg}\right)\left(2.7\times10^3\ \frac{kg}{m^3}\right) = 1.8\times10^{29}\frac{e^-}{m^3}$$

$$\Delta t = \frac{\sigma m}{e^2 n} = \frac{(3.6\times10^7)(9.1\times10^{-31})}{(1.6\times10^{-19}C)^2(1.8\times10^{29}e^-/m^3)}$$

$$= 7.1\times10^{-15}\ s$$

assume a typical thermal speed of 10^6 m/s

$$d = v\Delta t = 7.1\times10^{-9}\ m$$

atomic density ~ 6×10^{28} atoms/m^3 ⇒ atomic spacing $= (6\times10^{28})^{-1/3}$
$= 2.5\times10^{-10}$ m

$$d = \frac{7.1\times10^{-9}\ m}{2.5\times10^{-10}\ m} \cong 28\ \text{atoms}$$

② (a) The 12-V battery is more successful pushing current counterclockwise than the 8-V battery is pushing current clockwise. So the current flows from B to A.

(b) The 12-V battery is doing positive work on the flowing charges. The flowing charges do work on the 8-V battery, so the 8-V battery is doing negative work.

(c) Current flows from B to A, so $V_B > V_A$.

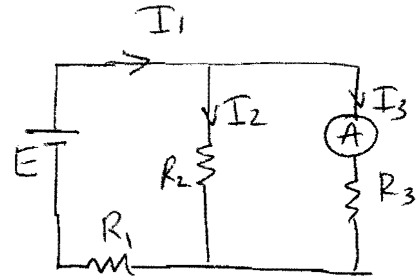
③ Assume current flows counterclockwise. Applying the loop rule starting from Q:

$$+150\ V - I(2.0\ \Omega) - 50\ V - I(3.0\ \Omega) = 0$$

$$I = \frac{150\ V - 50\ V}{5\ \Omega} = 20\ A$$

$$V_Q = V_P - 50\ V - I(3.0\ \Omega) = -10\ V$$

④ (a)



Junction rule: $I_1 = I_2 + I_3$

Loop rule: $E - I_2 R_2 - I_1 R_1 = 0$

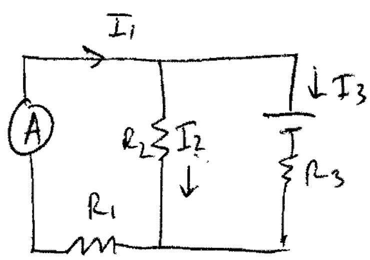
$- I_3 R_3 + I_2 R_2 = 0$

$$E - I_2 R_2 - I_1 R_1 = 0$$
$$E - I_2 R_2 - (I_2 + I_3) R_1 = 0$$
$$E - I_2 (R_2 + R_1) - I_3 R_1 = 0$$
$$E - I_3 \left(\frac{R_3}{R_2}\right)(R_2 + R_1) - I_3 R_1 = 0$$

$$I_3 = \frac{E}{\frac{R_3}{R_2}(R_2 + R_1) + R_1} = \frac{R_2 E}{R_3 R_2 + R_3 R_1 + R_2 R_1}$$

$$= \frac{(4\,\Omega)(5\,V)}{(6)(4) + (6)(2) + (4)(2)} = 0.45\,A$$

(b)



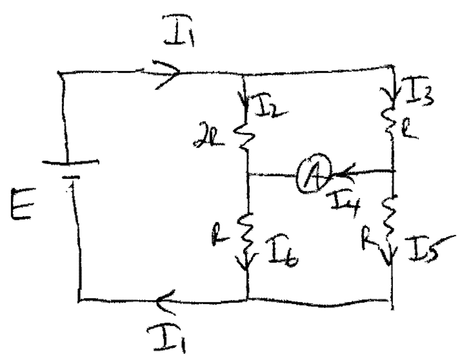
$$I_1 = I_2 + I_3$$
$$- I_2 R_2 - I_1 R_1 = 0$$
$$- E - I_3 R_3 + I_2 R_2 = 0$$

$$- E - (I_1 - I_2) R_3 + I_2 R_2 = 0$$

$$- E - \left(I_1 + I_1 \frac{R_1}{R_2}\right) R_3 - I_1 \cancel{R_2} \frac{R_1}{\cancel{R_2}} = 0$$

$$I_1 = \frac{- E R_2}{R_2 R_3 + R_3 R_1 + R_2 R_1} = -0.45\,A$$

⑤



Junctions:

$I_1 = I_2 + I_3$ — J1

$I_3 = I_4 + I_5$ — J2

$I_2 + I_4 = I_6$ — J3

$I_5 + I_6 = I_1$ — J4

Loops:

$\mathcal{E} - I_2 (2R) - I_6 R = 0$ — L1

$- I_3 R + I_2 (2R) = 0$ — L2

$- I_5 R + I_6 R = 0$ — L3

Solve for I_4

L_3: $I_5 = I_6$

L_2: $I_3 = 2I_2$

J_4: $I_1 = 2I_6 \Rightarrow I_6 = \frac{1}{2}I_1$

J_1: $I_1 = 3I_2 \Rightarrow I_2 = \frac{1}{3}I_1$

L_1: $\mathcal{E} - \frac{1}{3}I_1(2R) - \frac{1}{2}I_1 R = 0$

$$\mathcal{E} - \frac{7}{6}I_1 R = 0 \qquad \Rightarrow I_1 = \frac{6\mathcal{E}}{7R}$$

J_3: $I_4 = I_6 - I_2 = \frac{1}{2}I_1 - \frac{1}{3}I_1 = \frac{1}{6}I_1$

$$I_4 = \frac{1}{6}\cdot\frac{6\mathcal{E}}{7R}$$

$$\boxed{I_4 = \frac{\mathcal{E}}{7R}}$$

check $I_1 = \frac{6\mathcal{E}}{7R}$, $I_2 = \frac{2\mathcal{E}}{7R}$, $I_3 = \frac{4\mathcal{E}}{7R}$

$I_6 = \frac{3\mathcal{E}}{7R}$, $I_5 = \frac{3\mathcal{E}}{7R}$

all add up ok