Problem 1

56. (*a*) To make an ammeter, a shunt resistor must be placed in parallel with the galvanometer. The voltage across the shunt resistor must be the voltage across the galvanometer. See Figure 26-28 for a circuit diagram.

$$V_{\text{shunt}} = V_G \rightarrow (I_{\text{full}} - I_G)R_{\text{shunt}} = I_G R_G \rightarrow$$

$$R_{\text{shunt}} = \frac{I_G R_G}{(I_{\text{full}} - I_G)} = \frac{(55\times10^{-6}\,\text{A})(32\,\Omega)}{(25\,\text{A} - 55\times10^{-6}\,\text{A})} = \boxed{7.0\times10^{-5}\,\Omega}$$

(*b*) To make a voltmeter, a resistor must be placed in series with the galvanometer, so that the desired full-scale voltage corresponds to the full scale current of the galvanometer. See Figure 26-29 for a circuit diagram.

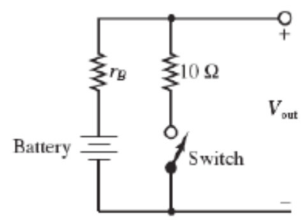
$$V_{\text{full scale}} = I_G(R_{\text{ser}} + R_G) \rightarrow R_{\text{ser}} = \frac{V_{\text{full scale}}}{I_G} - R_G = \frac{250\,\text{V}}{55\times10^{-6}\,\text{A}} - 30\,\Omega = \boxed{4.5\times10^{6}\,\Omega}$$

Problem 2

Solution:

Known quantities:

Schematic of the circuit shown in Figure P2.72; voltage at terminals switch open and closed for fresh battery; same voltages for the same battery after 1 year.



with

Figure P2.72

Find:

The internal resistance of the battery in each case.

Analysis:

a)

$$V_{out} = \left(\frac{10}{10 + r_B}\right)V_{oc}$$

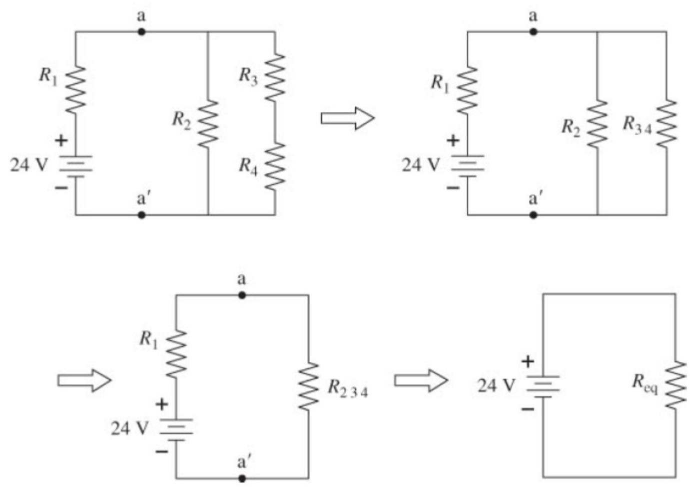
$$r_B = 10\left(\frac{V_{oc}}{V_{out}} - 1\right) = 10\left(\frac{2.28}{2.27} - 1\right) = 0.044\Omega$$

b)

$$r_B = 10\left(\frac{V_{oc}}{V_{out}} - 1\right) = 10\left(\frac{2.2}{0.31} - 1\right) = 60.97\Omega$$

problem 3

Model: The battery and the connecting wires are ideal.
Visualize:



The figure shows how to simplify the circuit in Figure P32.60 using the laws of series and parallel resistances. We have labeled the resistors as $R_1 = 6\ \Omega$, $R_2 = 15\ \Omega$, $R_3 = 6\ \Omega$, and $R_4 = 4\ \Omega$. Having reduced the circuit to a single equivalent resistance R_{eq}, we will reverse the procedure and "build up" the circuit using the loop law and the junction law to find the current and potential difference of each resistor.
Solve: R_3 and R_4 are combined to get $R_{34} = 10\ \Omega$, and then R_{34} and R_2 are combined to obtain R_{234}:

$$\frac{1}{R_{234}} = \frac{1}{R_2} + \frac{1}{R_{34}} = \frac{1}{15\ \Omega} + \frac{1}{10\ \Omega} \Rightarrow R_{234} = 6\ \Omega$$

Next, R_{234} and R_1 are combined to obtain

$$R_{eq} = R_{234} + R_1 = 6\ \Omega + 6\ \Omega = 12\ \Omega$$

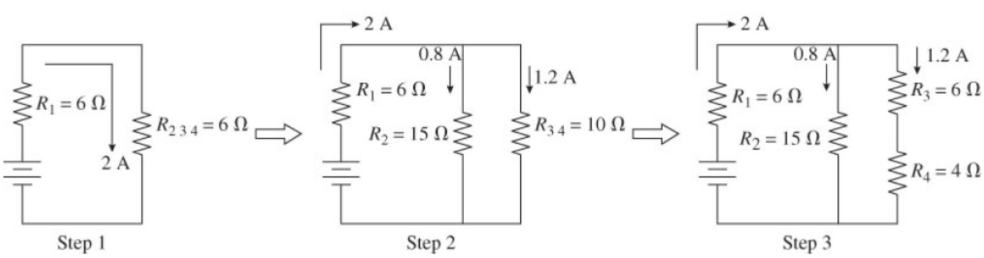
From the final circuit,

$$I = \frac{\mathcal{E}}{R_{eq}} = \frac{24\ \text{V}}{12\ \Omega} = 2\ \text{A}$$

Thus, the current through the battery and R_1 is $I_{R1} = 2$ A and the potential difference across R_1 is

$$I(R_1) = (2\ \text{A})(6\ \Omega) = 12\ \text{V}$$

As we rebuild the circuit, we note that series resistors *must* have the same current I and that parallel resistors *must* have the same potential difference ΔV.



In Step 1 of the above figure, $R_{eq} = 12\ \Omega$ is returned to $R_1 = 6\ \Omega$ and $R_{234} = 6\ \Omega$ in series. Both resistors must have the same 2.0 A current as R_{eq}. We then use Ohm's law to find

$$\Delta V_{R1} = (2\ \text{A})(6\ \Omega) = 12\ \text{V} \qquad \Delta V_{R234} = (2\ \text{A})(6\ \Omega) = 12\ \text{V}$$

As a check, 12 V + 12 V = 24 V, which was ΔV of the R_{eq} resistor. In Step 2, the resistance R_{234} is returned to R_2 and R_{34} in parallel. Both resistors must have the same $\Delta V = 12$ V as the resistor R_{234}. Then from Ohm's law,

$$I_{R2} = \frac{12\ \text{V}}{15\ \Omega} = 0.80\ \text{A} \qquad I_{R34} = \frac{12\ \text{V}}{10\ \Omega} = 1.2\ \text{A}$$

As a check, $I_{R2} + I_{R34} = 2.0$ A, which was the current I of the R_{234} resistor. In Step 3, R_{34} is returned to R_3 and R_4 in series. Both resistors must have the same 1.2 A as the R_{34} resistor. We then use Ohm's law to find

$$(\Delta V)_{R3} = (1.2\ \text{A})(6\ \Omega) = 7.2\ \text{V} \qquad (\Delta V)_{R4} = (1.2\ \text{A})\ (4\ \Omega) = 4.8\ \text{V}$$

As a check, 7.2 V + 4.8 V = 12 V, which was ΔV of the resistor R_{34}.

Resistor	Potential difference (V)	Current (A)
6 Ω left	12	2
15 Ω	12	0.80
6 Ω right	7.2	1.2
4 Ω	4.8	1.2

Problem 4

Model: Assume ideal connecting wires.

Visualize: Please refer to Figure in the problem. Because the ammeter we have shows a full-scale deflection with a current of 500 μA = 0.500 mA, we must not allow a current more than 0.500 mA to pass through the ammeter. Since we wish to measure a maximum current of 50 mA, we must split the current in such a way that 0.500 mA flows through the ammeter and 49.500 mA flows through the resistor R.

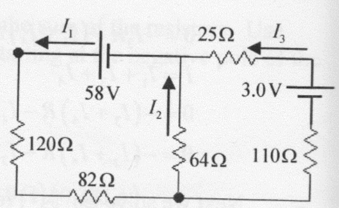
Solve: **(a)** The potential difference across the ammeter and the resistor is the same. Thus,

$$V_R = V_{\text{ammeter}} \Rightarrow (49.500 \times 10^{-3}\ \text{A})R = (0.500 \times 10^{-3}\ \text{A})(50.0\ \Omega) \Rightarrow R = 0.505\ \Omega$$

(b) Effective resistance is $\dfrac{1}{R_{eq}} = \dfrac{1}{0.505\ \Omega} + \dfrac{1}{50.0\ \Omega} \Rightarrow R_{eq} = 0.500\ \Omega$

Problem 5

32. There are three currents involved, and so there must be three independent equations to determine those three currents. One comes from Kirchhoff's junction rule applied to the junction of the three branches at the top center of the circuit.



$$I_1 = I_2 + I_3$$

Another equation comes from Kirchhoff's loop rule applied to the left loop, starting at the negative terminal of the battery and progressing counterclockwise.

$$58\,\text{V} - I_1(120\Omega) - I_1(82\Omega) - I_2(64\Omega) = 0 \ \rightarrow\ 58 = 202I_1 + 64I_2$$

The final equation comes from Kirchhoff's loop rule applied to the right loop, starting at the negative terminal of the battery and progressing counterclockwise.

$$3.0\,\text{V} - I_3(25\Omega) + I_2(64\Omega) - I_3(110\Omega) = 0 \ \rightarrow\ 3 = -64I_2 + 135I_3$$

Substitute $I_1 = I_2 + I_3$ into the left loop equation, so that there are two equations with two unknowns.

$$58 = 202(I_2 + I_3) + 64I_2 = 266I_2 + 202I_3$$

Solve the right loop equation for I_2 and substitute into the left loop equation, resulting in an equation with only one unknown, which can be solved.

$$3 = -64I_2 + 135I_3 \ \rightarrow\ I_2 = \frac{135I_3 - 3}{64}\ ;\ 58 = 266I_2 + 202I_3 = 266\left(\frac{135I_3 - 3}{64}\right) + 202I_3 \ \rightarrow$$

$$I_3 = 0.09235\,\text{A}\ ;\ I_2 = \frac{135I_3 - 3}{64} = 0.1479\,\text{A}\ ;\ I_1 = I_2 + I_3 = 0.24025\,\text{A}$$

The current in each resistor is as follows:

$$\boxed{120\Omega\text{: }0.24\,\text{A} \quad 82\Omega\text{: }0.24\,\text{A} \quad 64\Omega\text{: }0.15\,\text{A} \quad 25\Omega\text{: }0.092\,\text{A} \quad 110\Omega\text{: }0.092\,\text{A}}$$

Problem 6

33. Because there are no resistors in the bottom branch, it is possible to write Kirchhoff loop equations that only have one current term, making them easier to solve. To find the current through R_1, go around the outer loop counterclockwise, starting at the lower left corner.

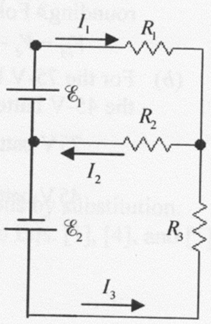
$$V_3 - I_1R_1 + V_1 = 0 \rightarrow I_1 = \frac{V_3 + V_1}{R_1} = \frac{6.0\,\text{V} + 9.0\,\text{V}}{22\,\Omega} = \boxed{0.68\,\text{A, left}}$$

To find the current through R_2, go around the lower loop counterclockwise, starting at the lower left corner.

$$V_3 - I_2R_2 = 0 \rightarrow I_2 = \frac{V_3}{R_2} = \frac{6.0\,\text{V}}{18\,\Omega} = \boxed{0.33\,\text{A, left}}$$

Problem 7

34. (a) There are three currents involved, and so there must be three independent equations to determine those three currents. One comes from Kirchhoff's junction rule applied to the junction of the three branches on the right of the circuit.



$$I_2 = I_1 + I_3 \rightarrow I_1 = I_2 - I_3$$

Another equation comes from Kirchhoff's loop rule applied to the top loop, starting at the negative terminal of the battery and progressing clockwise.

$$\mathcal{E}_1 - I_1R_1 - I_2R_2 = 0 \rightarrow 9 = 25I_1 + 48I_2$$

The final equation comes from Kirchhoff's loop rule applied to the bottom loop, starting at the negative terminal of the battery and progressing counterclockwise.

$$\mathcal{E}_2 - I_3R_3 - I_2R_2 = 0 \ \rightarrow \ 12 = 35I_3 + 48I_2$$

Substitute $I_1 = I_2 - I_3$ into the top loop equation, so that there are two equations with two unknowns.

$$9 = 25I_1 + 48I_2 = 25(I_2 - I_3) + 48I_2 = 73I_2 - 25I_3 \ ; \ 12 = 35I_3 + 48I_2$$

Solve the bottom loop equation for I_2 and substitute into the top loop equation, resulting in an equation with only one unknown, which can be solved.

$$12 = 35I_3 + 48I_2 \ \rightarrow \ I_2 = \frac{12 - 35I_3}{48}$$

$$9 = 73I_2 - 25I_3 = 73\left(\frac{12 - 35I_3}{48}\right) - 25I_3 \ \rightarrow \ 432 = 876 - 2555I_3 - 1200I_3 \ \rightarrow$$

$$I_3 = \frac{444}{3755} = 0.1182\ \text{A} \approx \boxed{0.12\ \text{A}\ ,\ \text{up}} \ ; \ I_2 = \frac{12 - 35I_3}{48} = 0.1638\ \text{A} \approx \boxed{0.16\ \text{A}\ ,\ \text{left}}$$

$$I_1 = I_2 - I_3 = 0.0456\ \text{A} \approx \boxed{0.046\ \text{A}\ ,\ \text{right}}$$

(*b*) We can include the internal resistances simply by adding 1.0Ω to R_1 and R_3. So let $R_1 = 26\Omega$ and let $R_3 = 36\Omega$. Now re-work the problem exactly as in part (*a*).

$$I_2 = I_1 + I_3 \ \rightarrow \ I_1 = I_2 - I_3$$

$$\mathcal{E}_1 - I_1R_1 - I_2R_2 = 0 \ \rightarrow \ 9 = 26I_1 + 48I_2$$

$$\mathcal{E}_2 - I_3R_3 - I_2R_2 = 0 \ \rightarrow \ 12 = 36I_3 + 48I_2$$

$$9 = 26I_1 + 48I_2 = 26(I_2 - I_3) + 48I_2 = 74I_2 - 26I_3 \ ; \ 12 = 36I_3 + 48I_2$$

$$12 = 36I_3 + 48I_2 \ \rightarrow \ I_2 = \frac{12 - 36I_3}{48} = \frac{1 - 3I_3}{4}$$

$$9 = 74I_2 - 26I_3 = 74\left(\frac{1 - 3I_3}{4}\right) - 26I_3 \ \rightarrow \ 36 = 74 - 222I_3 - 104I_3 \ \rightarrow$$

$$I_3 = \frac{38}{326} = 0.1166\ \text{A} \approx \boxed{0.12\ \text{A}\ ,\ \text{up}} \ ; \ I_2 = \frac{1 - 3I_3}{4} = 0.1626\ \text{A} \approx \boxed{0.16\ \text{A, left}}$$

$$I_1 = I_2 - I_3 = \boxed{0.046\ \text{A}\ ,\ \text{right}}$$

The currents are unchanged to 2 significant figures by the inclusion of the internal resistances.

Problem 8

36. (*a*) Since there are three currents to determine, there must be three independent equations to determine those three currents. One comes from Kirchhoff's junction rule applied to the junction near the negative terminal of the middle battery.

$$I_1 = I_2 + I_3$$

Another equation comes from Kirchhoff's loop rule applied to the top loop, starting at the negative terminal of the middle battery, and progressing counterclockwise. We add series resistances.

$$12.0\,\text{V} - I_2(12\,\Omega) + 12.0\,\text{V} - I_1(35\,\Omega) = 0 \rightarrow 24 = 35I_1 + 12I_2$$

The final equation comes from Kirchhoff's loop rule applied to the bottom loop, starting at the negative terminal of the middle battery, and progressing clockwise.

$$12.0\,\text{V} - I_2(12\,\Omega) - 6.0\,\text{V} + I_3(34\,\Omega) = 0 \rightarrow 6 = 12I_2 - 34I_3$$

Substitute $I_1 = I_2 + I_3$ into the top loop equation, so that there are two equations with two unknowns.

$$24 = 35I_1 + 12I_2 = 35(I_2 + I_3) + 12I_2 = 47I_2 + 35I_3$$

Solve the bottom loop equation for I_2 and substitute into the top loop equation, resulting in an equation with only one unknown, which can be solved for I_3.

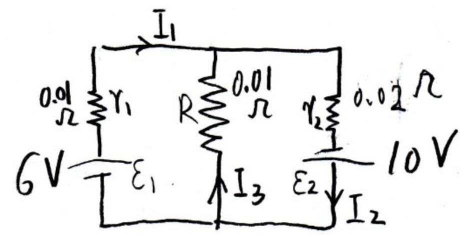
$$6 = 12I_2 - 34I_3 \rightarrow I_2 = \frac{6 + 34I_3}{12} \;;\; 24 = 47I_2 + 35I_3 = 47\left(\frac{6 + 34I_3}{12}\right) + 35I_3 \rightarrow$$

$$I_3 = \boxed{2.97\,\text{mA}} \;;\; I_2 = \frac{6 + 34I_3}{12} = \boxed{0.508\,\text{A}} \;;\; I_1 = I_2 + I_3 = \boxed{0.511\,\text{A}}$$

(*b*) The terminal voltage of the 6.0-V battery is $6.0\,\text{V} - I_3 r = 6.0\,\text{V} - (2.97\times10^{-3}\,\text{A})(1.0\,\Omega)$

$$= 5.997\,\text{V} \approx \boxed{6.0\,\text{V}}$$

Problem 9



(a) $\quad I_2 = I_1 + I_3 \qquad (1)$

left loop cw $\quad 6 - 0.01 I_1 + 0.01 I_3 = 0 \qquad (2)$

right loop cw $\quad -0.01 I_3 - 0.02 I_2 + 10 = 0 \qquad (3)$

From (2) $\quad I_1 = I_3 + 600 \qquad (4)$

From (3) $\quad I_2 = 500 - 0.5 I_3 \qquad (5)$

Substitute (4) (5) into (1)

$$500 - 0.5 I_3 = 2I_3 + 600$$

$$I_3 = -40 \ (A)$$

$$I_1 = 560 \ (A)$$

$$I_2 = 520 \ (A)$$

(b) $\quad \Delta V_R = 40 \ (A) \times (0.01 \ \Omega) = 0.4 V$

(c)

$P_R = I_3^2 R = (40)^2 \times 0.01 = 16 \ (W)$

$P_{r_1} = I_1^2 r_1 = (560)^2 \times 0.01 = 3136 \ (W)$

$P_{r_2} = I_2^2 r_2 = (520)^2 \times 0.02 = 5408 \ (W)$

Batteries are discharging.

$$P_1 = \varepsilon_1 I_1 = 6 \times (560) = 3360\ (W)$$

$$P_2 = \varepsilon_2 I_2 = 10 \times 520 = 5200\ (W)$$

Note $P_1 + P_2 = P_R + P_{r_1} + P_{r_2} = 8560\ (W)$

Energy conservation. Batteries discharging power equals to Joule heating power.