1) Label all source and component values with a voltage drop measurement (+,-) and a current flow measurement (arrow): By the passive sign convention, the current flow measurement arrow must point toward the minus sign of the voltage drop measurement. The passive sign convention ensures that sign errors are eliminated from Ohm's law and power calculations. Note that we may add as many measurements of voltage or current to the circuit diagram as we like. Note also that measurement directions may differ from physical directions of voltage drops or current flows. So we are free to choose the direction of voltage (or current) measurement where it is not already specified for resistors. Indeed, we are unable to determine physical directions of voltage drops or current flows until we solve the circuit!

Our circuit diagram is rather busy now.
2) A symbolic name of a source or resistor may be treated as a known numerical quantity in calculations. Our task is to solve for all currents and voltages for resistors, and sometimes we must solve for currents in voltage sources or voltage drops across current sources. Since we have a dependent source that depends on $i_{g1}$ in our example circuit, we must find $i_{g1}$.

**KCL**

3) **Color all the nodes in the circuit.** That is, draw bubbles around segments of wires or wires connected directly to each other. Kirchhoff’s current law says that the current flowing into each node equals the current flowing out of each node. It follows that the current measured into each node equals the current measured out of each node. We show only current measurements, (and $v_3$ that is needed for the dependent current source).

4) **If currents for voltage sources are not needed (shown in red above), expand adjacent nodes across those voltage sources.** The voltage sources will disappear from the KCL equations. Here, $i_{g1}$ is needed for the dependent voltage source, so we retain the nodes next to the $v_{g1}$ source.
By Kirchhoff's current law, the current flowing out of any node is the same as the total current flowing into all the other nodes combined. That is, the current may be partitioned into two regions with zero net current flow in and out and connected to each other. It follows that we have some redundancy in the current summation equations. Here, we find that we may eliminate any one of the following equations. (Green terms in equations are variables to be solved for.)

\[ 0 A = i_1 + i_{g1} \quad \text{(top left node)} \]  \hspace{1cm} (1)
\[ i_{g1} + i_s = i_2 \quad \text{(top right node)} \]  \hspace{1cm} (2)
\[ i_1 + i_2 + \beta v_3 = i_s + \beta v_3 + i_3 + i_4 \quad \text{(middle node, drop this equation)} \]  \hspace{1cm} (3)
\[ i_3 + i_4 = 0A \quad \text{(bottom right node)} \]  \hspace{1cm} (4)

We will ignore (3).

**KVL**

5) **Draw \( v \)-loops for each mesh (inner) loop.**

6) **If voltages for current sources are not needed (shown in red above), combine voltage loops adjacent to the current source, bypassing the current source. If a current source is on the outside edge of the circuit and its voltage is not needed, no loop passing through it is needed. Also, any adjacent loop that would be combined with that loop is not needed.** In our example circuit, we are left with two voltage loops.
Write a voltage loop equation for each remaining loop: sum of voltage drops around loop equals zero. Choose a direction (either is okay) and a starting point (any starting point in the loop is okay) for each loop. Decide whether the sign of the voltage drop corresponds to where the loop enters a component or where the loop leaves a component and maintain that convention all the way around the loop. Each loop may have a different direction, starting point, and sign choice, if desired.

\[ -v_1 + v_g1 + v_2 = 0 \text{ V} \quad \text{(v-loop}_1) \]
\[ -\alpha_i + v_g2 + v_3 - v_4 = 0 \text{ V} \quad \text{(v-loop}_2) \]

7) **Write an Ohm's law equation for each resistor:** You may choose to use only a voltage or a current variable for each resistor later on—using $iR$ for a resistor voltage or $v/R$ for a resistor current—to eliminate half of the variables at the outset.

\[ v_1 = i_1 R_1 \]  
\[ v_2 = i_2 R_2 \]  
\[ v_3 = i_3 R_3 \]  
\[ v_4 = i_4 R_4 \]

8) **Verify that there are $n$ equations in $n$ unknowns:** You need as many independent equations as unknowns. Be on the lookout for subsets of equations that may be solved. That is, sometimes part of a circuit may be solved by itself without adding further equations. In our example, we have 9 equations, and we have 9 unknowns: $i_{g1}, i_1, i_2, i_3, i_4, v_1, v_2, v_3$ and $v_4$.

9) **Use Ohm's law equations to replace $v$'s with $i$-$R$'s, eliminating about half of the equations.**

In our example, we substitute into equations (5) and (6).

\[ -i_1 R_1 + v_g1 + i_3 R_2 = 0 \text{ V} \quad \text{(v-loop}_1) \]
\[ -\alpha_i + v_g2 + i_3 R_3 - i_4 R_4 = 0 \text{ V} \quad \text{(v-loop}_2) \]

We have now used the Ohm's law equations and are left with equations (1), (2), (4), (11), and (12).
10) **Solve for the unknowns.** In our example, we will use the simplest of the remaining equations to eliminate variables.

\[ i_1 = -i_{g1} \quad \text{(from (1))} \quad (13) \]
\[ i_2 = i_{g1} + i_s \quad \text{(from (2))} \quad (14) \]
\[ i_4 = -i_3 \quad \text{(from (4))} \quad (15) \]

Now substitute for \( i_1, i_2, \) and \( i_4 \) in (11) and (12).

\[ -i_{g1}R_1 + v_{g1} + (i_{g1} + i_s)R_2 = 0 \quad \text{V-loop}_1 \quad (16) \]
\[ -\alpha i_{g1} + v_{g2} + i_3R_3 - -i_3R_4 = 0 \quad \text{V-loop}_2 \quad (17) \]

We collect terms multiplying variables, and we put constants on the right side of the equations.

\[ i_{g1}(R_1 + R_2) = -v_{g1} - i_sR_2 \quad \text{(v-loop}_1 \quad (18) \]
\[ i_{g1}(-\alpha) + i_3(R_3 + R_4) = -v_{g2} \quad \text{(v-loop}_2 \quad (19) \]

Here, (18) may be solved for \( i_{g1} \) directly.

\[ i_{g1} = \frac{-v_{g1} + i_sR_2}{R_1 + R_2} \quad \text{(v-loop}_1 \quad (20) \]

We find \( i_3 \) by substituting (20) into (19).

\[ -\frac{v_{g1} + i_sR_2}{R_1 + R_2}(-\alpha) + i_3(R_3 + R_4) = -v_{g2} \quad \text{(v-loop}_2 \quad (21) \]

Some algebra yields \( i_3 \).

\[ i_3(R_3 + R_4) = -v_{g2} + \frac{v_{g1} + i_sR_2}{R_1 + R_2}(-\alpha) \quad \text{(v-loop}_2 \quad (22) \]

or

\[ i_3 = -\frac{v_{g2} + \frac{v_{g1} + i_sR_2}{R_1 + R_2}(-\alpha)}{R_3 + R_4} \quad \text{(v-loop}_2 \quad (19) \]