1. (a) By inspection, the period is \( T = 3 \text{ ms} \).

(b) The DC/average voltage may be found as follows, since the voltage is constant during certain intervals of time:

\[
V_{DC} = \frac{1}{T} \int_0^T V(t)dt
\]

\[
= \frac{1}{3 \text{ ms}} [(1 \text{ V})(1 \text{ ms}) + (2 \text{ V})(1 \text{ ms}) + (0 \text{ V})(1 \text{ ms})]
\]

\[
= 1 \text{ V}
\]

(c) The RMS voltage may be found as follows, since the voltage is constant during certain intervals of time:

\[
V_{rms} = \sqrt{\frac{1}{T} \int_0^T V(t)^2dt}
\]

\[
= \sqrt{\frac{1}{3 \text{ ms}} [(1 \text{ V})^2(1 \text{ ms}) + (2 \text{ V})^2(1 \text{ ms}) + (0 \text{ V})^2(1 \text{ ms})]}
\]

\[
= \sqrt{\frac{5 \text{ V}^2}{3}}
\]

\[
= \sqrt{\frac{5}{3}} \text{ V}
\]

2. (a) 

\[5e^{j\pi} \leftrightarrow 5 \cos(\omega t + \frac{\pi}{2})\]

(b) 

\[3 + 4j = (3^2 + 4^2)^{\frac{1}{2}}e^{j \tan^{-1}(\frac{4}{3})}
\]

\[\leftrightarrow 5 \cos(\omega t + \tan^{-1}(\frac{4}{3}))\]

(c) 

\[3 \cos(\omega t) + 4 \sin(\omega t) \leftrightarrow 3e^{j0} + 4e^{-j\frac{\pi}{2}}
\]

\[= 3 - 4j\]

(d) 

\[\sqrt{2} \sin(\omega t - 45^\circ) = \sqrt{2} \cos(\omega t - \frac{3\pi}{4})
\]

\[\leftrightarrow \sqrt{2}e^{-j\frac{3\pi}{4}}\]
3. The internal resistance $R$ of a practical current source is in **parallel** with the source.

For a well-designed circuit with a practical current source, this internal resistance $R$ should be much **larger** than the load resistance.

A circuit element that requires an external power supply is called **passive**.

We **cannot** find the Thevenin equivalent of a circuit containing diodes.

The input resistance of an ammeter is **very small**.

An oscilloscope can easily **not be used** to measure magnetic field strength.

4. (a) The internal resistance of a practical battery model is in **series** with the voltage source. A realistic model of a practical voltmeter has an internal resistance in parallel with an ideal voltmeter. The circuit diagram is given in Figure 1.

\[ V = (10 \, \text{V}) \frac{(R_L \parallel R_2)}{R_1 + (R_L \parallel R_2)} \]

\[ = \frac{10}{\frac{R_1}{R_L + R_2} + \frac{R_1 R_2}{R_L + R_2}} \, \text{V} \]

\[ = \frac{10 R_L R_2}{R_1 R_L + R_1 R_2 + R_L R_2} \, \text{V} \]

(b) The measured voltage can be found by reducing the parallel combination of $R_L$ and $R_2$ into an equivalent resistance, and then applying the voltage divider formula.

(c) Ideally, you would want $R_1 <<< R_L$ so the load experiences a voltage drop that is close to the open-circuit voltage.

(d) Ideally, you would want $R_2 >> R_L$ so the voltmeter does not perturb the original circuit too much.
Figure 2: Frequency response $H(\omega)$. The asymptotic approximation is in black and the actual plot is in blue.

5. (a) A current of $I_{in}$ flows through the capacitor and the resistance $R_2$. To find the current $I_{out}$, we can use the current divider formula, where $Z_L$ is the impedance of the inductor.

$$I_{out} = I_{in} \frac{Z_L}{Z_L + R_1}$$
$$= I_{in} \frac{j\omega L}{j\omega L + R_1}$$

(b) The frequency response function is:

$$H(\omega) = \frac{j\omega L}{R_1 + j\omega L}$$
$$= \frac{j\omega L}{j\omega L \cdot R_1 + 1}$$
$$= \frac{j\omega 10^{-4}}{j\omega 10^{-4} + 1}$$

The voltage gain is given in Figure 2.

(c) This is a **high-pass** filter.

6. Assign ground as the node at the bottom of the circuit.

   (a) KCL at node $a$, using the sum of the currents **into** the node:

$$1 + \frac{0 - V_a}{1} + \frac{V_b - V_a}{1} = 0$$
This can be rewritten as:

\[ 2V_a - V_b = 1 \]

(b) KCL at node b, using the sum of the currents into the node:

\[-I + \frac{0 - V_b}{1} + \frac{V_a - V_b}{1} = 0\]

This can be rewritten as:

\[-V_a + 2V_b = -I\]

(c) The extra equation that is required is the relationship between the node voltages and the voltage source (recall that we had to introduce an extra unknown \( I \) to account for the current through the voltage source).

\[ V_b - 0 = 10 \text{ V} \]
\[ V_b = 10 \text{ V} \]

Now we can use the equation from Part (a) to solve for \( V_a \):

\[ V_a = \frac{V_b + 1}{2} \text{ V} \]
\[ V_a = \frac{11}{2} \text{ V} \]

7. (a) Pulling out the capacitor allows the Thevenin equivalent circuit to be found. The first step is finding \( V_{oc} \), or the open-circuit voltage across the terminals after the capacitor is removed (using the sign convention for \( v_c(t) \)). Noticing that no current flows through \( R_3 \) when the capacitor is removed, the expression for \( V_{oc} \) may be obtained by applying the voltage divider formula:

\[ V_{oc} = v_s \frac{R_2}{R_1 + R_2} \]
\[ = v_s \frac{2 \text{ k}\Omega}{4 \text{ k}\Omega} \]
\[ = \frac{1}{2} v_s \]

Since \( V_{oc} = v_T(t) \), then the Thevenin voltage is:

\[ v_T(t) = \begin{cases} -2 \text{ V} & t \leq 0 \\ 3 \text{ V} & t > 0 \end{cases} \]

The Thevenin resistance may be found by finding the short circuit current and then finding \( \frac{V}{I} \). For this problem, it will be easier to find the equivalent resistance looking into the terminals with all of the sources zeroed out.

\[ R_T = R_3 + \frac{R_1 R_2}{R_1 + R_2} \]
\[ = 3000 \text{ }\Omega + \frac{2000^2 \text{ }\Omega^2}{4000 \text{ }\Omega} \]
\[ = 4 \text{ k}\Omega \]
(b) The time constant for the Thevenin equivalent circuit is
\[
\tau = R_T C \\
= (6000)(2.5 \times 10^{-6}) \text{ sec} \\
= 15 \text{ ms}.
\]
The steady state voltage for \( v_c \) is equal to \( v_T \) for \( t > 0 \). The initial voltage across the capacitor is \( v_T \) for \( t \leq 0 \), assuming that the system had sufficient time to equilibrate. This information, along with the time constant, gives the expression for the voltage across the capacitor for \( t > 0 \):
\[
v_C(t) = 5 + (-8)e^{-\frac{t}{\tau}} \\
= 5 - 8e^{-\frac{t}{15}}.
\]
We expect that the solution will reach the steady state in approximately 3 time constants. The graph is given in Figure 3.

![Figure 3: \( v_C(t) \) for Problem 7.](image)

8. There are only four possible resistances that may be constructed from two resistors:
\[
\begin{align*}
R_1 \\
R_2 \\
R_1 + R_2 \\
\frac{R_1R_2}{R_1 + R_2}
\end{align*}
\]
The series combination means that \( R_1 + R_2 = 18 \, \Omega \) since it is the greatest resistance possible. Plugging in the other two choices for combinations of \( R_1 \) and \( R_2 \) leaves the following:

\[
\begin{align*}
R_1 &= 6 \, \Omega \\
R_2 &= 12 \, \Omega
\end{align*}
\]