3. Paul worked hard last night to construct the following circuit with parts I gave him. I bought him a rather cheap power supply with a rather large internal resistance (50 Ω).

\[ 12 \text{ V d.c.} \]
\[ \begin{array}{c}
\text{Switch} \\
R = 5.0 \, \text{kΩ} \\
C = 2.5 \, \text{μF}
\end{array} \]

(a) (11 points) At time \( t = 0 \), Paul flips the switch to position 1.

(i) In how many ms will the capacitor be 70% charged?

\[ V_c = V_0 \left(1 - e^{-t/RC}\right) \]
\[ V_0 = 12 \text{ V} \]
\[ \frac{V_c}{V_0} = 0.70 \Rightarrow e^{-t/RC} = 0.30 \]
\[ -\frac{t}{RC} = \ln 0.30 \Rightarrow t = -RC \ln 0.30 \]
\[ t = -\left(5.0 \times 10^3 \, \text{kΩ}\right) \left(2.5 \times 10^{-6} \, \text{F}\right) \ln 0.30 = 15 \text{ ms} \]

(ii) Using a cheap Radio Shack® voltmeter with an internal resistance of 100 kΩ, Paul measures the voltage across the resistor. Explain why there will be a systematic error in Paul’s measurement and predict the sign of the error.

Real voltages always dissipate some of the electrical driving force they are supplying, due to their non-zero internal resistance (50 Ω here).

\[ E_r = -\frac{R_{\text{source}}}{R_{\text{source}} + R_{\text{meter}}} \]
\[ I_{\text{always neglected}} \]

(equivalently, the non-infinite resistance of the voltmeter (here, a measly 100 kΩ) means that a non-negligible amount of current is diverted. Test 1--Page 3 of 8 through the meter.)

-1 minor error