4.1. Under the scaling transformation, \(W \rightarrow W/\kappa, L \rightarrow L/\kappa, t_{ox} \rightarrow t_{ox}/\kappa, V_{ds} \rightarrow V_{ds}/\kappa, V_g \rightarrow V_g/\kappa\) and \(V_t \rightarrow V_t/\kappa\), Eq. (3.19) becomes

\[
I_{ds} \rightarrow \mu_{\text{eff}}(\kappa C_{ox}) \frac{W}{L} \left( \frac{V_g}{\kappa} - \frac{V_t}{\kappa} \right) \frac{V_{ds}}{\kappa} = \frac{I_{ds}}{\kappa},
\]

and Eq. (3.23) becomes

\[
I_{ds} \rightarrow \mu_{\text{eff}}(\kappa C_{ox}) \frac{W}{L} \frac{1}{2m} \left( \frac{V_g}{\kappa} - \frac{V_t}{\kappa} \right)^2 = \frac{I_{ds}}{\kappa}.
\]

Note that both \(m = 1 + 3t_{ox}/W_{dm}\) and \(\mu_{\text{eff}}\) which is a function of \(\kappa_{\text{eff}}\) given by Eq. (3.49) are nearly invariant under constant field scaling.

4.2. Under the same scaling rules as above, Eq. (3.36) becomes

\[
I_{ds} \rightarrow \mu_{\text{eff}}(\kappa C_{ox}) \frac{W}{L} \left( m - 1 \right) \left( \frac{kT}{q} \right)^2 e^{q(V_g - V_t)/mkT}.
\]

The \(\exp(-qV_{ds}/kT)\) term has been neglected since typically \(V_{ds} >> kT/q\). In subthreshold, \(V_g < V_t\) and \(\exp[\frac{q(V_g - V_t)}{mkT}] > \exp[\frac{q(V_g - V_t)}{mkT}]\) (note that \(\kappa > 1\)), therefore, the subthreshold current increases with scaling faster than \(\kappa I_{ds}\).

If the temperature also scales down by the same factor, i.e., \(T \rightarrow T/\kappa\), then \(I_{ds} \rightarrow I_{ds}/\kappa\) same as the drift current in Exercise 4.1.
5.2. For the following $RC$ circuit,

\[ V_{dd} = V(t) + RI(t) = V(t) + RC \frac{dV}{dt}. \]

If the voltage source is switched to $V_{dd}$ at $t = 0$, then

\[ V(t) = V_{dd} \left( 1 - e^{-t/RC} \right). \]

The energy dissipated in $R$ is

\[ E = \int_0^\infty R I^2 dt = \frac{V_{dd}^2}{R} \int_0^\infty e^{-2t/RC} dt = \frac{1}{2} CV_{dd}^2, \]

which is independent of $R$. The same amount of energy is stored in $C$.

If the voltage source is now switched to 0, one has

\[ V(t) + RC \frac{dV}{dt} = 0. \]

With the initial condition $V(t = 0) = V_{dd}$, the solution for $V(t)$ is

\[ V(t) = V_{dd} e^{-t/RC}. \]

The energy stored in $C$ is now all dissipated in $R$:

\[ E = \int_0^\infty R I^2 dt = \frac{V_{dd}^2}{R} \int_0^\infty e^{-2t/RC} dt = \frac{1}{2} CV_{dd}^2. \]
5.3. From Eq. (3.21) and the inversion charge expression above Eq. (3.54), the transit time is
\[ \tau_v = \frac{W L C_{ox} (V_g - V_t - mV_{ds} / 2)}{\mu_{eff} C_{ox} (W / L) (V_g - V_t - mV_{ds} / 2)V_{ds}} = \frac{L^2}{\mu_{eff} V_{ds}} \]
for a MOSFET device biased in the linear region.

From Eq. (3.23) and the inversion charge expression above Eq. (3.56), the transit time is
\[ \tau_v = \frac{(2 / 3)W L C_{ox} (V_g - V_t)}{\mu_{eff} C_{ox} (W / L) (V_g - V_t)^2 / 2m} = \frac{4ml^2}{3\mu_{eff} (V_g - V_t)} \]
for a long-channel MOSFET biased in saturation.

5.4. From Eq. (3.78) and the inversion charge expression in Problem 3.10, the transit time is
\[ \tau_v = \frac{Q_i}{I_{dsat}} = \frac{L}{\nu_{sat}} \frac{\sqrt{1 + 2\mu_{eff}(V_g - V_t) / (m\nu_{sat}L)} + 1 / 3}{\sqrt{1 + 2\mu_{eff}(V_g - V_t) / (m\nu_{sat}L)} - 1} \]
for a short-channel MOSFET biased in saturation. The limiting value of \( \tau_v \) is \( L/\nu_{sat} \) when the device becomes fully velocity saturated as \( L \to 0 \).