Problem 1

![Diagram of a circuit with capacitors and voltage labels]

**a)** Bitline BL = V_{DD} = 5V, Wordline = V_{DD} = 5V

Final voltage \( V_s = V_{DD} - V_{T_n} \), but \( V_{SB} = V_s \implies \)

\[
V_s = V_{DD} - V_{T_0} - \gamma (\sqrt{2} \phi_F) + V_s - \gamma (\sqrt{2} \phi_F)
\]

\[
= 5 - 1.0 - 0.3 (\sqrt{0.6} + V_s - \sqrt{0.6})
\]

Solve by iteration (or graphically) \( V_s = 3.62 \text{ V} \)

**b)** During a READ-1, \( V_s = 3.62 \text{ V} \) and \( BL = V_{DD}/2 \). Capacitors \( C_{BL} \) and \( C_s \) short together and share their charge.

\[
Q_{BL} = C_{BL} \frac{V_{DD}}{2} = (450 \text{ FF}) (2.5 \text{ V})
\]

\[
Q_s = C_s V_s = (50 \text{ FF}) (3.62 \text{ V})
\]

\[
V_{BL} (\text{final}) = \frac{Q_{tot}}{C_{tot}} = \frac{Q_{BL} + Q_s}{C_{BL} + C_s} = \frac{(450 \text{ FF})(2.5 \text{ V}) + (50 \text{ FF})(3.62 \text{ V})}{500 \text{ FF}}
\]

\[
V_{BL} (\text{final}) = 2.61 \text{ V}
\]

Note using 10.1 in K+L p. 420, \( V_{BL} (\text{final}) = \frac{V_{DD} + \Delta V}{2} = 2.5V + \frac{50 \text{ FF} 2.5V}{500 \text{ FF}} \)

\[
= 2.75 \text{ V} \text{ is incorrect!}
\]

The book equation assumed \( V_s = V_{DD} \).
Problem 2

To change the state of the cell for \( V_C \leq 0.5 \) \( V_D \), the voltage at node 1 must be \( V_{DD} \) (if it were \( 0V \), then the cell wouldn’t change state).

For \( M_1, M_2 \), \( W/L = 4/4 \) must size \( M_5, M_6 \) assuming \( (W/L)_S = (W/L)_B \).

For \( M_3, M_4 \), \( W/L = 2/4 \).

Suppose node 1 is initially at \( V_{DD} \). To switch the SRAM state, node 4 voltage must go below the \( M_6, M_2 \) inverter switching threshold:

Voltage @ node 1 = \( V_{TH} = V_{TO,n} + \frac{1}{\sqrt{K_R}} \left( V_{DD} - V_{TO,pl} \right) \)

\[
K_R = \frac{K_n}{K_p} = \frac{K_n'(W/L)_2}{K_p(W/L)_6} = \frac{2(4/4)}{(W/L)_6} = 2 \left( \frac{W}{L} \right)_6
\]

If node 1 initially at \( V_{DD} \), node 2 is initially \( 0V \). Assuming \( V_{TH} \approx V_{DD}/2 \), then \( M_5 \) and \( M_3 \) are in linear region and \( M_1 \) is cut off.

\[
I_{DS,M_3} = I_{DS,M_5} \Rightarrow \frac{K_n'(W/L)_3 \left[ 2(V_{DD} - V_{T,n3})(V_1 - V_C) - (V_1 - V_C)^2 \right]}{2} = \frac{K_p'(W/L)_6 \left[ 2(-V_{DD} - V_{T,p3})(V_1 - V_{DD}) - (V_1 - V_{DD})^2 \right]}{2}
\]
Assume $V_{PD} = 5\, V$, $V_{TO,P} = -0.7\, V$

For $V_{Tn3}$: $V_{SB} = 0.5\, V \Rightarrow V_{Tn3} = V_{TO} + r\left(\sqrt{2\phi_F} + V_{SB} - \sqrt{2\phi_F}\right)$

$$= 0.7\, V + 0.4\left(\sqrt{0.6} + 0.5 - \sqrt{0.6}\right) = 0.810\, V$$

Let $X = \frac{W}{L}$, $V_1 = V_{TH} = \frac{0.7 + \sqrt{X/2}}{1 + \sqrt{X/2}} (5 - 0.7) = 0.7 + \sqrt{X/2} (4.3)$

Plug $V_1(x)$ into the current equations and solve numerically...

$\left(\frac{W}{L}\right)_6 = \left(\frac{W}{L}\right)_5 \approx 0.5$ \hspace{1cm} $V_{TH} = 1.9\, V$ \hspace{1cm} therefore linear assumption was good.