Problem 5.7

With $V_{DS} = 5$ V the transistor operates in the saturation region for which we have $i_d = K(V_{GS} - V_{TO})^2(1 + \lambda V_{DS})$.

Solving for $K$ and substituting values we obtain $K = 31.25$ $\mu$A/V$^2$.
However we have $K = (W/L)(KP/2)$. Solving for $W/L$ and substituting values we obtain $W/L = 1.25$. Thus for $L = 2 \mu$m, we need $W = 2.5 \mu$m.

Repeating the calculations with $\lambda = 0.05$, we obtain $K = 25$, $W/L = 1$ and $W = 2 \mu$m.

Problem 5.13

For a device operating in the triode region with $\lambda = 0$, we have

$$i_d = K[2(V_{GS} - V_{TO})V_{DS} - V_{DS}^2]$$

Assuming that $V_{DS} << V_{GS} - V_{TO}$ this becomes

$$i_d = K(2V_{GS} - V_{TO})V_{DS}$$

Then the resistance between drain and source is given by

$$r_d = V_{DS}/i_d = \frac{1}{K(2V_{GS} - V_{TO})}$$

With the device in cutoff (i.e., $V_{GS} \leq V_{TO}$), the drain current is zero and $r_d$ is infinite.

Evaluating we have:

<table>
<thead>
<tr>
<th>$V_{GS}$ (V)</th>
<th>$r_d$ (k$\Omega$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>$\infty$</td>
</tr>
<tr>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>2.0</td>
<td>2</td>
</tr>
</tbody>
</table>

Problem 5.24

Many resistor values will work. In general we want to pick values such that

$$R_D = \frac{V_{DD}}{4}$$

$$V_{DSQ} = \frac{V_{DD}}{2}$$

$$R_S = \frac{V_{DD}}{4}$$

Thus we select $R_D = R_S = 3$ k$\Omega$. Then we have $K = (KP/2)(W/L) = 0.2$ mA/V$^2$ and $V_{GSQ} = \frac{I_{DSQ}/K + V_{TO}}{2} = 3.236$ V. Next we compute

$$V_O = V_{GSQ} + R_S^2/DQ = 6.236 V = \frac{V_{DD}}{2}/(1 + R_1/R_2).$$

Solving we find that we need $R_1/R_2 = 0.924$. Using nominal 5% tolerance values we could select $R_1 = 910$ k$\Omega$ and $R_2 = 1$ M$\Omega$. 

Problem 5.25

For a source follower we do not need a drain resistor. Thus we design for

\[ V_{DSQ} = V_{DD}/2 = 6 \text{ V} \]
\[ R_S I_{DSQ} = 6 \text{ V} \]

Thus we select \( R_S = 6.2 \text{ k}\Omega \) which is a standard 5\% tolerance value. Then we have \( K = (K_F/2)(W/L) = 0.2 \text{ mA/V}^2 \) and \( V_{GSQ} = \sqrt{I_{DQ}/K + V_{to}} = 3.236 \text{ V} \). Next we compute \( V_G = V_{GSQ} + R_S I_{DQ} = 9.236 \text{ V} = V_{DD}/(1 + R_1/R_2) \). Solving we find that we need \( R_1/R_2 = 0.2996 \). Using nominal 5\% tolerance values we could select \( R_1 = 300 \text{ k}\Omega \) and \( R_2 = 1 \text{ M}\Omega \).
5 CCD

A CCD is created with square pixels measuring 7 µm × 7 µm and contains an oxide layer that is 250 nm thick with an $\epsilon = 3.8\epsilon_0$. The oxide layer has a maximum potential of 1 volt.

5.1 What is the capacitance per unit area?

$$C_{ox} = \frac{\epsilon}{t} = \frac{3.8\epsilon_0}{t} = 1.4 \text{ Farads/m}^2,$$

where $t$ is the thickness.

5.2 What is the full well capacity?

The capacitance of a pixel is

$$C = C_{ox}A = \frac{3.8\epsilon_0}{t} \times \left(7 \times 10^{-6} \text{ m}\right)^2 = 6.6 \times 10^{-15} \text{ Farads.}$$

The charge is

$$Q = CV = \frac{3.8\epsilon_0}{t} \times \left(7 \times 10^{-6} \text{ m}\right)^2 \times 1 \text{ Volt} = 6.6 \times 10^{-15} \text{ Coulombs.}$$

The number of electrons is

$$N = \frac{Q}{q_e} = \frac{3.8\epsilon_0}{1.6 \times 10^{-19} \text{ Coulombs}} \times \left(7 \times 10^{-6} \text{ m}\right)^2 \times 1 \text{ Volt} = 4.1 \times 10^4.$$

5.3 Chip Size

If you utilized these pixels to build a square, 1-megapixel CCD camera, what would its dimensions be?

One million pixels is 1000 × 1000, so there must be 1000 pixels in each direction.

$$Height = Width = 1000 \times 7 \times 10^{-6} \text{ m} = 7 \text{ mm.}$$
<table>
<thead>
<tr>
<th>Input 1 (V)</th>
<th>Input 2 (V)</th>
<th>Vout (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

6 Logic Gate

6.1 Truth table

Note: the last entry in the table is not 0 volts. This is acceptable as long as any circuit that utilizes $V_{out}$ factors this in.

6.2 Current

When $V_{out}$ is high, there is no current traveling through $R_1$. When $V_{out}$ is low, the current through $R_1$ is

$$I_{R1} = \frac{V_1 - V_{out}}{R_1} = 0.4 \text{ mA}$$

6.3 No Connection

If $V_1$ and $V_2$ do not have a power source attached, $V_{out}$ will be 5 volts. This would be the case in the absence of $R_2$ and $R_3$. 