1a. Construct the following circuit shown in Figure 1. Assume resistor R3 is 2000 ohms and $V_{dd}$ is 5 volts. If the voltage across the LED is 2 volts, what is the current, $I_{dd} =$

Note: Use red wires for $V_{dd}$ or positive power. Use black wires for ground.

1b. Replace the resistor in Figure 1 with a value for R3 of 330 Ohms.

What is the color code for 330 Ohms =

What is the current, $I_{dd} =$ ? Is the LED brighter or dimmer than part 1? and why?

2. Now, construct an addition circuit in Figure 2. (Do not remove the circuit in Figure 1, that is you safety check if power is properly going to the circuit).

2a. Fill in the following table. Note: Avoid connecting a NMOS gate directly to $V_{dd}$ but instead connect the gate to the resistor, $R_2$ which connects $V_{dd}$.

<table>
<thead>
<tr>
<th>$V_a$</th>
<th>M1 on/off</th>
<th>LED on/off</th>
<th>$V_f$ (Volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Volts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 Volts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why does the $V_f$ behave has a NOT gate and the LED as a buffer?

When does this Figure 2 consume current, $I_{dd}$, when $V_a$ is on or off?

When does Wakerly Figure 3-12 on page 89 consume current?

Argue under which conditions would you use one design over the other? (hint: number of wires, cost, availability)

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**Figure 1: LED circuit**

**Figure 2: NMOS NOT**

**Figure 3: Mystery Circuit**
3. Construct the circuit in Figure 3 and fill in the following table:

<table>
<thead>
<tr>
<th>$V_a$</th>
<th>$V_b$</th>
<th>$V_c$</th>
<th>M1 on/Off</th>
<th>M2 on/off</th>
<th>M3 on/off</th>
<th>LED on/off</th>
<th>$V_f$ (Volts)</th>
</tr>
</thead>
</table>

When M1 is off, what type of logic is M2 and M3 in relation to $V_f$?

When M2 and M3 are off, What type of logic is M1 in relation to $V_f$?

What is the Boolean expression of this circuit, $f(a, b, c) =$

Compare this circuit with Wakerly Figure 3-20 (AOI) and Figure 3-22 (OAI) on pages 94 and 95. Draw the logic diagram of this circuit in the form of Figure 3-21 or Figure 3-23:

4. Determine which Figure 4, 5, or 6 is the XOR? Then draw the XOR circuit using the least number of NMOS transistors and resistors. (Hint: use the knowledge of problem 3). Build the circuit to verify your design.

Figure 4: XOR1  
Figure 5: XOR2  
Figure 6: XOR2