Use the HEF4007UB chip (or equivalent) that has discrete CMOS transistors.

A. Pre-laboratory work

1. The simplest latch shown below (as in Fig. 11.1(a)) is built by two cascaded inverters. Because of the transfer relation of the inverters, the resulting voltage at the output (V_X) is “stable” at either high or low. By stable, we mean that unless there is a voltage signal driving the latch to change states, the logic state will stay put basically forever. (The reason is that the probability of switching is \( \exp(V_{\text{supply}}/k_B T) \). Assume a supply voltage of 2V, at room temperature, this probably becomes negligibly small.)

![Circuit Diagram](image)

Draw the circuit diagram of a CMOS implementation of the “latch flip-flop.”

2. But, the memory needs to be programmable. Draw the circuit diagram of the CMOS implementations of
   a. A clocked SR flip-flop; and
   b. A D type flip-flop.
   Put down the truth table. Explain each entry.

3. Draw the complete circuit of a ring oscillator and observe its frequency, propagation delay from low to high, and from high to low. Start with three stages. Increase the number of stages if the circuit does not oscillate by itself.

![Ring Oscillator Circuit](image)

4. Draw the complete circuit of
   a. A two-input AND gate;
   b. A two-input NOR gate;
   c. A two-input XOR gate; and
   d. A two-input OR gate.

5. For a typical red light emitting diode (LED), what kind of semiconductor is it made of? (It is definitely not made of silicon, why?) What’s the typical semiconductor used for green, blue, and white LEDs?

B. What to do in the laboratory
6. Use a light emitting diode (LED) with a resistor as the “logic status sensor.” First, apply dc voltage (V=0) to the LED. Gradually increase the voltage setting, until the LED is lit up. What is the voltage that is necessary to light up the LED? From this voltage, estimate how much resistance you should have in series, in order to use the LED to sense the logic status, that is, either 5V or 0V. The LED and this resistance in series (as a unit) can be wired at the circuit node to provide a visual verification of the digitized output voltage.

7. Construct the SR flip-flop by the HEF4007UB chip and measure its characteristics, including (1) the truth table; (2) delay from high to low; and (3) delay from low to high. Use 5V as the supply voltage. Demonstrate that you can SET and RESET the memory status.

8. Construct the NOR logic gate by the HEF4007UB chip and measure its characteristics, including (1) the truth table; (2) delay from high to low; and (3) delay from low to high. Use 5V as the supply voltage.

9. Construct the XOR by the HEF4007UB chip and measure its characteristics, including (1) the truth table; (2) delay from high to low; and (3) delay from low to high. Use 5V as the supply voltage.

10. Construct a ring oscillator by several HEF4007UB and measure its characteristics, including (1) oscillation frequency; (2) delay from high to low; and (3) delay from low to high. Use 5V as the supply voltage.

C. Post-laboratory report questions, in addition to your report on data and your additional observation

1. What is the measured high frequency limit of your logic circuits? Discuss the possible physical origin and estimate the order of magnitude of the delay from these origins.

2. What the LED is made of? More specifically, what was the color of the LED that you used? What type of semiconductor one can use to generate that color? Search online and put down your best answer in a few sentences. Explain your answer. For example, explain why the red LED is made of that specific semiconductor.