Lab 2

Transistor Logic Gates

Updated: January 15, 2020

2.1 Introduction

Logic gates are built using transistors which act like switches. In the first part of this lab, you will build AND and OR gate circuits using pushbutton switches. Then, you will use transistors to construct a single gate and verify its operation.

2.2 Objectives

After completing this lab, you should be able to:

- Describe how logic gates are based on switches
- Describe how transistors behave like controllable switches
- Develop a circuit on a breadboard using standard electrical components
- Verify operation of the circuit

2.3 Background

In this lab, we will be studying how logic gates are built. We will be building simple Binary Junction Transistor (BJT) gates from the logic family of Resistor-Transistor Logic (RTL). These gates were invented over 40 years ago, and have the virtues of being robust (work over a wide range of conditions), easy to understand, and easy to build. BJTs come in two basic varieties, PNP and NPN, which are named for how the doped semiconducting regions conduct the current - either N for negative charge carriers or P for positive charge carriers. Since there are two junctions in the layering of three regions, we have a binary junction transistor. We will be working exclusively with NPN for this lab.

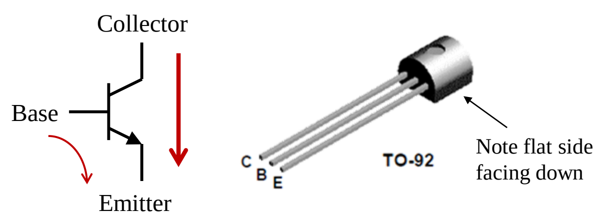


Figure 2.1: NPN Binary Junction Transistor (BJT) Operation

BJTs are current controlled devices. That means a small amount of current between the base and emitter will control a large amount of current between the collector and emitter. The current flows are marked on the transistors by red arrows (see Figure 2.1). (Remember that electrons flow opposite of the conventional current designation!) Current flowing between base and emitter causes a larger current to flow between collector and emitter. The direction of flow depends on the type of transistor (negative charge must go from N to P), and is controlled by the voltage difference between base and emitter. The voltage of the P region must be around 0.7 V greater than the N region. In our case, we are just interested in the extremes (called "saturation"), where the transistor is all the way off (no current anywhere) or all the way on (maximum current flow). Since BJTs have very small voltage drops and internal resistance, we will need external resistors to ensure that we don't draw too much current and burn the transistor up (jokingly called "letting the magic smoke out" due to the nasty smell that is produced when you burn one up).

2.4 Lab Equipment

For this lab, we will be using the blue IDL-800 Digital Lab station (see Figure 2.2). This unit has various basic electrical components (including switches and

LEDs) that will be useful for testing our circuits and a breadboard for constructing circuits (used in the second part of this lab).

2.4.1 IDL-800 Fixed Components

The components that are permanently attached to the IDL-800 are connected within the unit. You need to understand these connections, so you can use these components correctly.

Slide Switches

The slide switches connect their output to either the 5 V power supply or ground (i.e. 1 or 0, as labeled on the unit). See Figure 2.3.

LEDs

Similar to the switches, the LEDs are connected through a power limiting resistor to ground. (It's actually more complicated than this, but this is effectively what is going on.) See Figure 2.4.

2.4.2 Breadboards

Circuits are often tested in the prototype stage by building them on a "breadboard." One form of a breadboard that is often used is a white plastic device with holes arranged in various patterns so that certain groups of holes are connected as shown in. These hole groupings constitute nodes since all holes in a group are connected together. These holes permit insertion of component leads so that the necessary connections may be made in the construction of a circuit. Hole groupings across the top and near the bottom of the breadboard form "busses" that may be used for power supply and ground connections in your circuit. It should be noted that all of the hole groupings are horizontal except for the groupings at the very bottom of the breadboard which are vertical. See Figure 2.5.

In constructing circuits, *do not* insert components with large-diameter leads into the breadboard. An example of such a component is a 1 W resistor. Also *do not* insert wires with twisted or bent ends. Inserting such components can spread the connectors in the hole and create a loose connection when smaller components are subsequently inserted.

2.5 Materials

You will need:

- four (4) of either the 2N3904 or 2N2222 transistors (don't mix types)
- two (2) pushbuttons
- three (3) resistors around 200-600 Ω
- breadboard
- wires

(continued below)

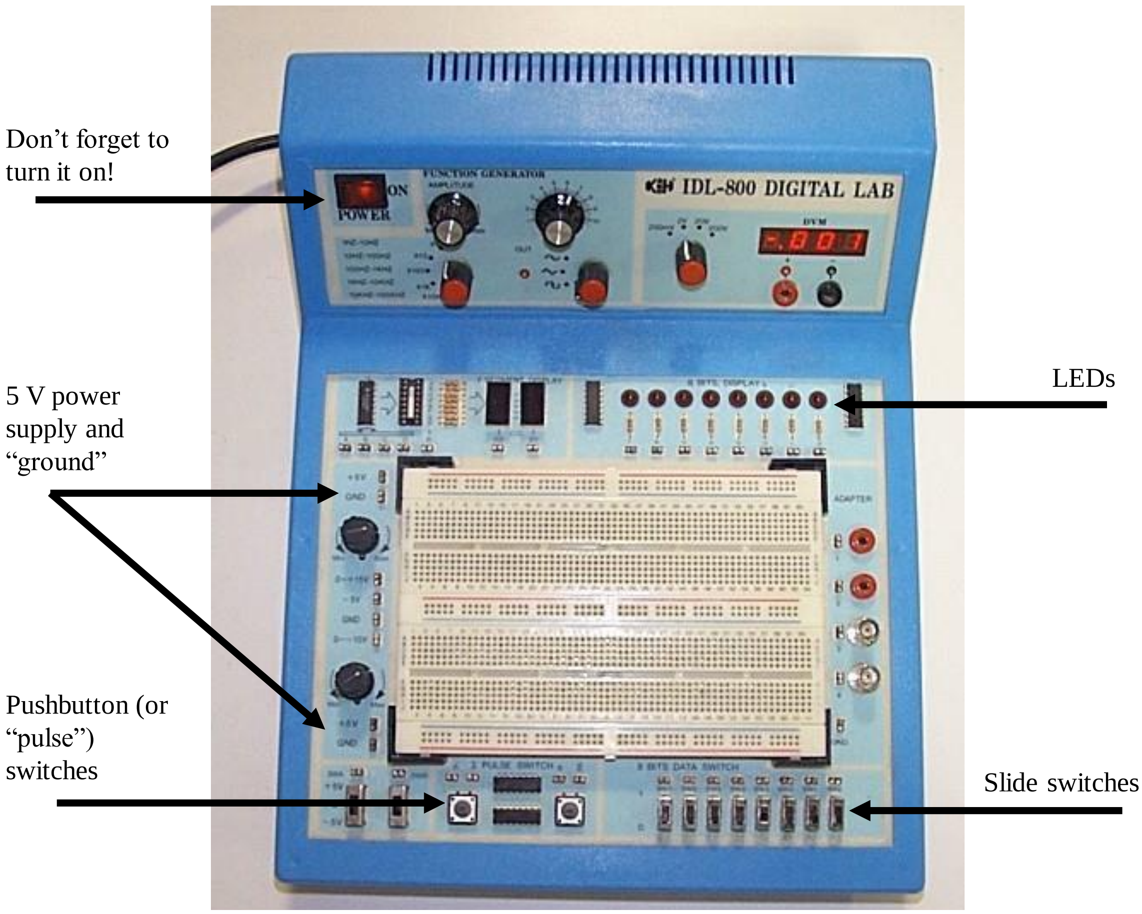


Figure 2.2: IDL-800 Digital Lab station

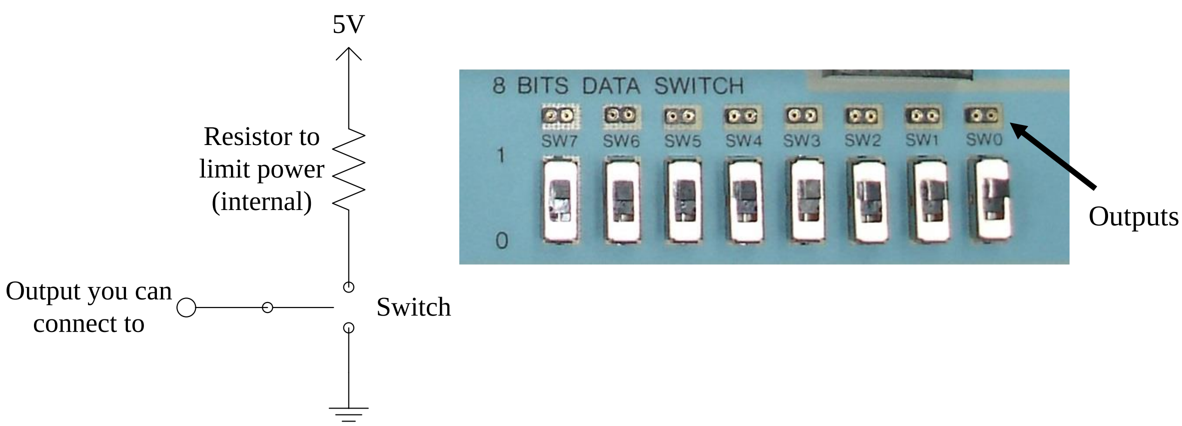


Figure 2.3: Slide switch schematic and physical layout

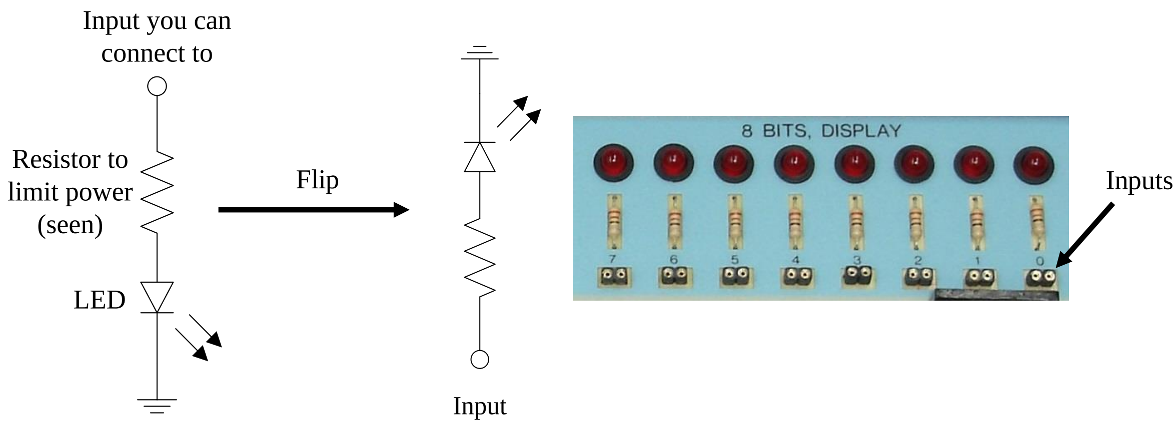


Figure 2.4: LED schematic and physical layout

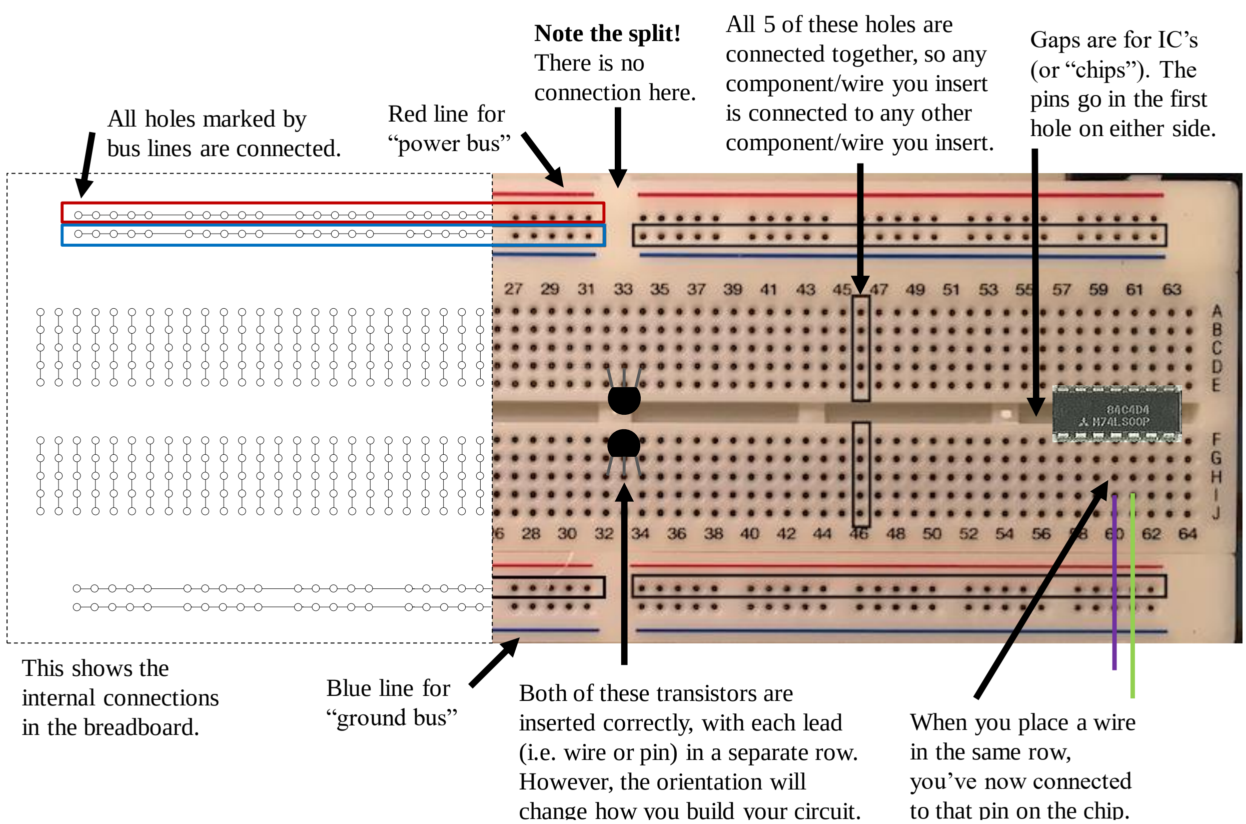


Figure 2.5: Breadboard hole and connection pattern

2.6 Experiment

2.6.1 Pushbutton Gates

As a test to verify correct operation of the IDL-800, connect one pushbutton between the 5V supply bus and one of the LED inputs as shown in Figure 2.6. Pressing the button should make the LED light up.

Remember: Wires and components should insert into the breadboard and input/output terminals on the IDL-800 with a small amount of force. Always use clean, straight wires.

Add a second pushbutton in line (or in "series") with your current wiring as shown in Figure 2.7. This is now an And gate, where the two buttons are acting as the two inputs and the LED displays the output (5V = 1 = On, Gnd = 0 = Off).

Using the same two pushbuttons, design a circuit that operates like an Or gate. (Think: How does an Or gate operate?) Print the Circuit Demonstration Page at the end of this document and demonstrate your working "Or gate" to your instructor.

2.6.2 Inverter

Now we will build an inverter, which is also called a **Not** gate, using an NPN transistor and a slide switch as the input. See Figure 2.8. Normally, current-limiting resistors are required when building transistor circuits; however, the IDL-800 has resistors built into its switches and LEDs. Thus, we only need one additional resistor on the power supply (between +5 V and the collector) of the transistor. Pay careful attention to the orientation of the transistor and its pins (base, emitter, collector). Note the location of the flat side in Figure 2.8. You may also refer back to Figure 2.1 if needed. How does this circuit work? Use arrows or highlighting to draw the flow of current through the circuit on the Circuit Demo Page. Test the operation of your circuit and show it and your diagram to the lab instructor.

2.6.3 Nor Gate

Now, we will build a **Nor** gate. See Figure 2.9. Notice that the transistors are in parallel (i.e. connected to the same points on each end). This is one basic configuration. Components in series (end-to-end) is the other. These two basic configurations, parallel and series, are used to make almost every gate type, just as you observed with the pushbuttons earlier. How does it work? Draw the current paths on the given circuit. Test the operation of your circuit and show both to the lab instructor.

2.6.4 Final Gate

Keep your **Nor** gate. Build two more inverters, and connect one to each input (between the switch and the transistor of the Nor gate). Make a logic table of this new gate. What logic operation does it implement? How does it work? As before, draw the current paths and show both to the lab instructor.

2.7 Summary

Big ideas:

- Gates are made up of switches (on/off). How you connect them determines the type of gate.
- Transistors are "voltage-controlled switches," so we can hook gates together.

2.8 Deliverables

Use the provided LaTeX template to create a report and submit it to Canvas. Include the following items/questions:

- Logic/truth table for the Final gate
- What logic operation does it implement?
- Complete the Circuit Demonstration Page and include it. You can include the full two pages or divide it into parts and include each image separately. If you do full pages, it's fine if they shrink a little, but make sure they are readable.

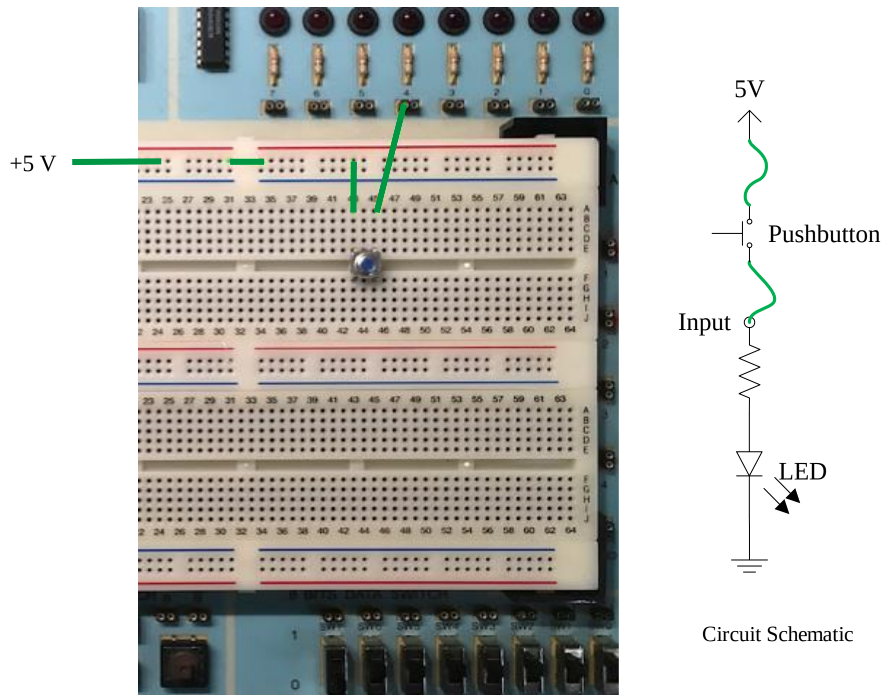


Figure 2.6: Single pushbutton test circuit

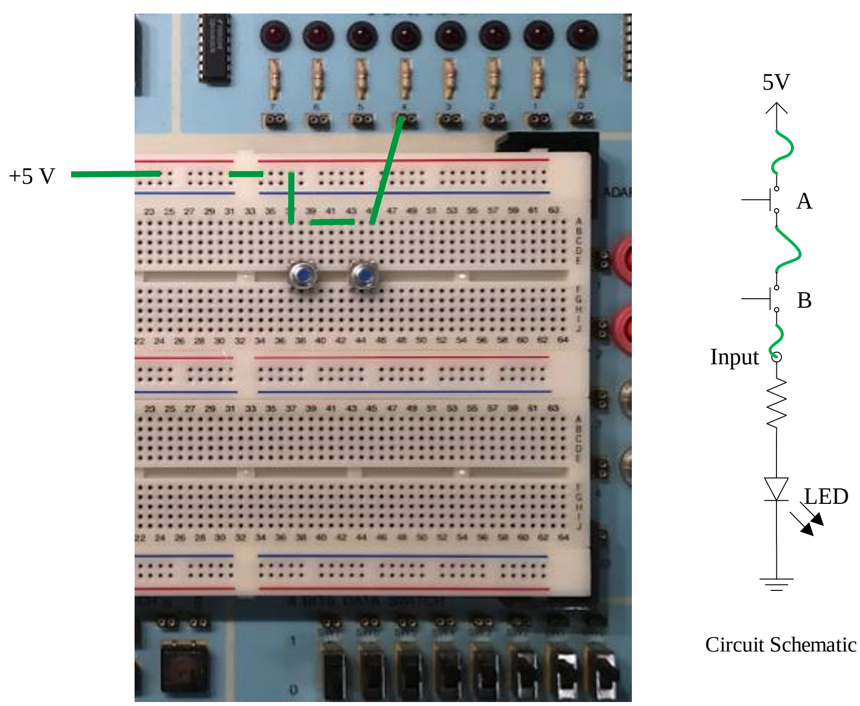


Figure 2.7: Two pushbutton And gate circuit

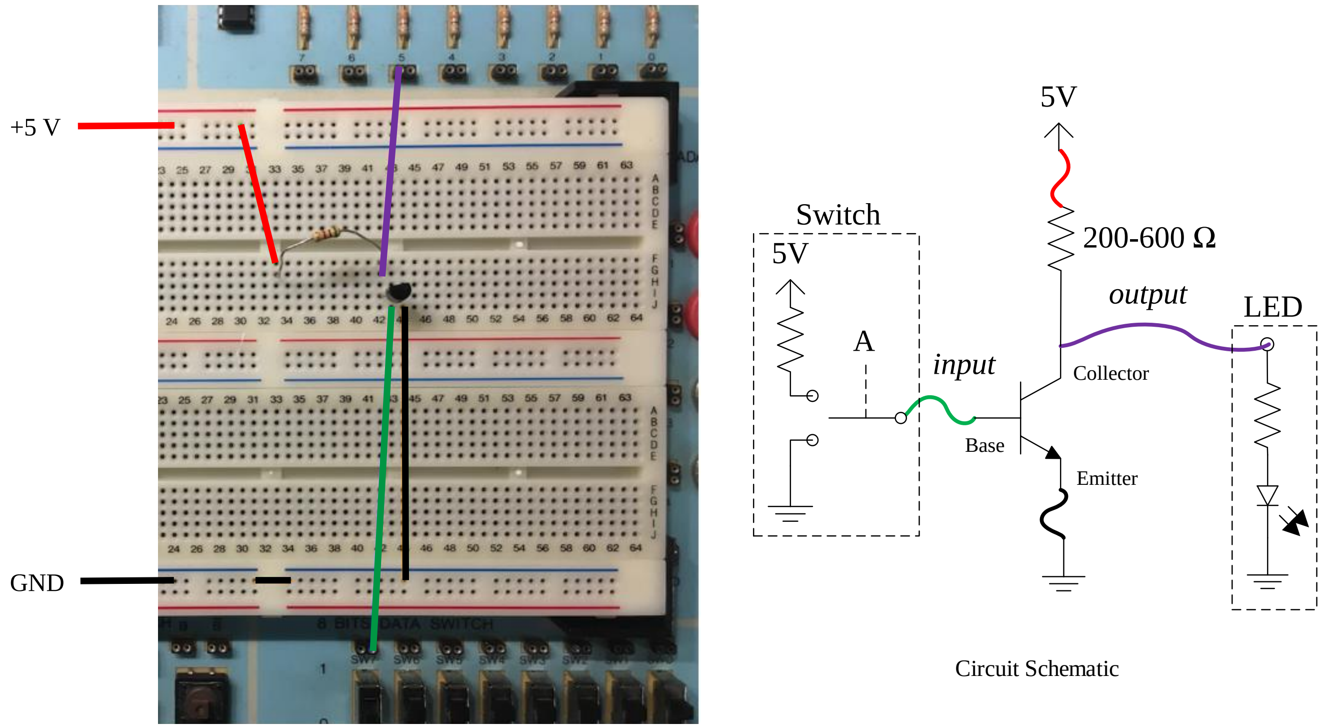


Figure 2.8: Inverter or Not Gate

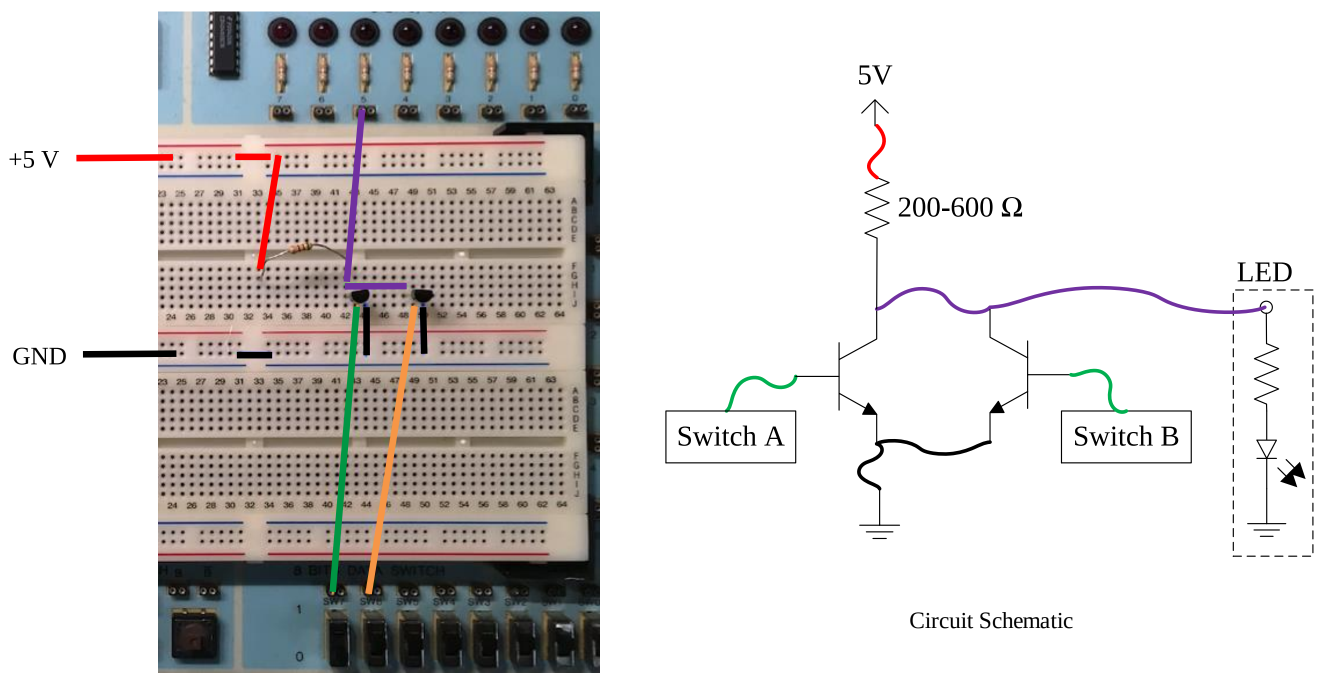


Figure 2.9: Nor Gate

Circuit Demonstration Page

Student names: ____________________ ____________________

____

Instructor Initials

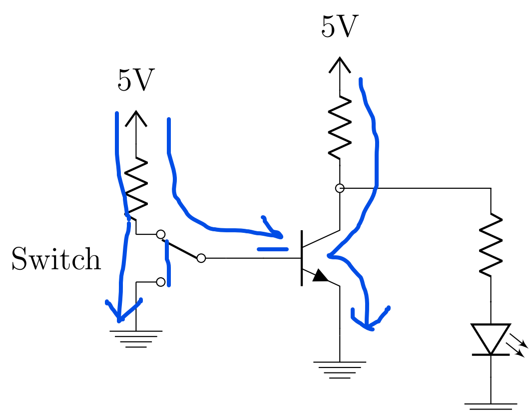
Pushbutton “Or Gate” __________ Transistor Not gate __________

Transistor Nor gate __________ Transistor unknown gate __________

Diagrams

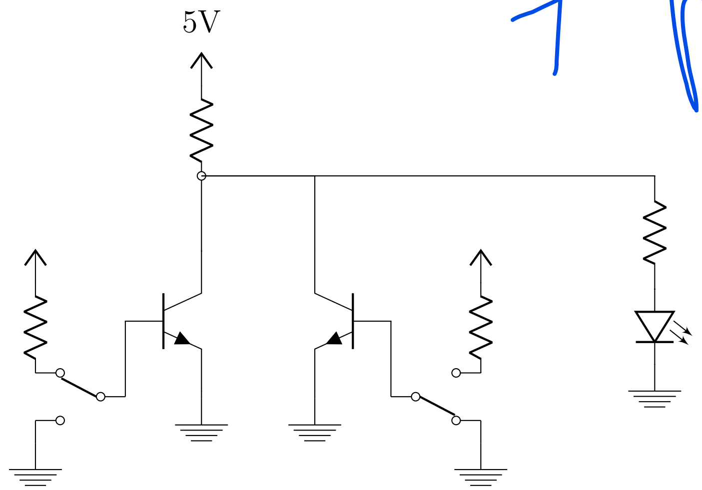
On each of the circuits below, draw the current paths and note whether each switch, transistor, and LED is ON or OFF.

Inverter:



label this

NOR:



and turn in

Final gate: