I. Before coming to lab

Read this handout and the supplemental. Also read the handout on Digital Electronics found on the course website.

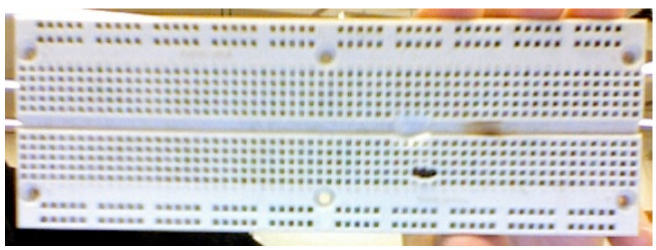
II. Learning Objectives

Using transistors and resistors, you'll build some simple logic circuits and then test your work. You'll also demonstrate the ability to perform binary addition using the circuits you've constructed.

III. Materials

Breadboard

Instead of using lots of alligator clips to connect circuit elements together, you'll be building your circuits on a breadboard. A breadboard is a piece of plastic with lots of little holes. If you stick a wire into one of the holes, it "grabs" the wire and makes an electrical contact with it. More information on the breadboard and how it works can be found in the supplemental.

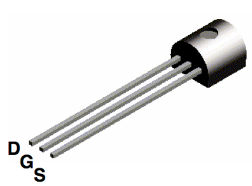


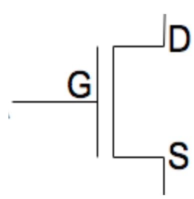
Power supply

This DC power supply maintains a 5-volt difference across its leads. The black terminal is ground, and the red terminal is +5.0 V. You'll need to connect the power supply to whichever breadboard you are working with. The top rail of the breadboard is usually at +5 V and the bottom rail is at ground.

Transitors

The type of transistor we will be using in this lab is known as the field-effect transistor, or FET. It is an electronic component with three terminals: the gate (G), source (S), and drain (D).





The transistor casing is flat on one side and rounded on the other, so that the three terminals can be distinguished. The gate is always the middle pin, but you'll need to know how the drain and source are oriented in order to put the transistor into your circuit correctly.

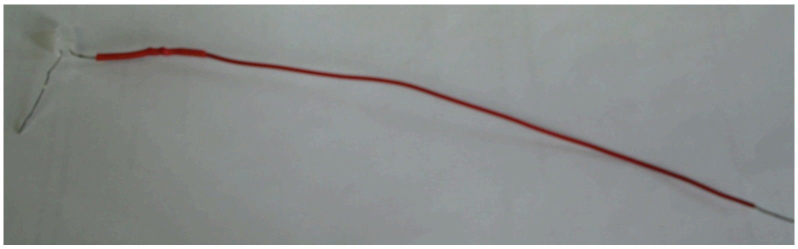
Resistors

You will have a selection of resistors that are needed for the different components to work properly, like the pull-up resistor used with transistors, for example.

Loose wires

You'll have a selection of short wires that are stripped at both ends, which you can use to make extra connections on your breadboard.

Digital logic probe



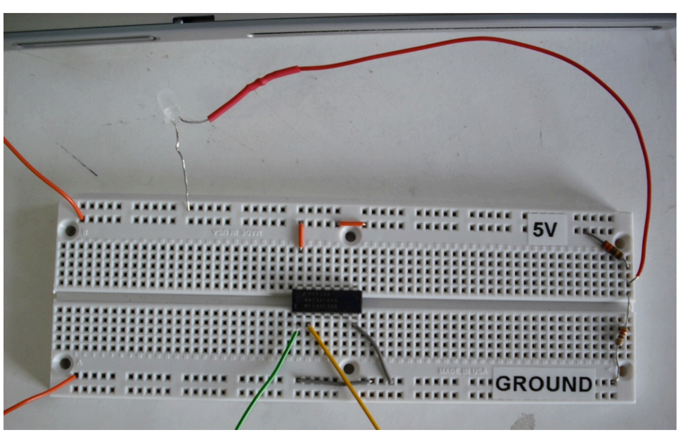
This is a device consisting of two LEDs (light-emitting diodes) in a single plastic dome on a long wire. It is used to probe the digital voltage in a circuit. The long leg should be plugged into the far right of your breadboard <u>between two resistors.</u> The other end (the leg of the LED itself) is the terminal you'll use to probe your circuit.

If you plug the LED end into a place on your breadboard that is at **high voltage (+5 V), the LED lights up red.** If you plug it into a place that is **at ground, the LED lights up green**. Red is generally used to refer to the high voltage in a circuit, while the ground or COM port is 0 volts.

Multimeter Voltage and Resistance Probe

A multimeter is an important tool to measure electronic components and circuits. The ground or COM port (black) and high voltage (red) port have electrodes already connected for you. We will need to perform two types of measurements: Voltages (turn dial to “V”) and ohmic resistances of resistors (turn dial to "Ω"). Make sure to start with a large range and decrease the range stepwise to get a better resolved value. A “1” on the display typically indicates that your range is too small.

XOR gate



On a breadboard you'll be given an XOR gate which is actually made out of an integrated circuit, or IC (the black chip in the middle of the breadboard). It would require quite a few transistors to make an XOR yourself, but the chip actually contains four separate implementations of XOR inside it. You'll only need to use one. The leads connected to the two leftmost pins on the bottom row are the inputs; the next pin over (3rd one on the bottom) is the output.

IV. Procedure

Tell us who you are! (Picture, names, and emails please)

A:

In part 1, you will test how the probes and the XOR gate work. In part 2, you will build basic logic gates using transistors and in part 3 you will build a half-adder.

Part 1a: Get to know your probes

Start by opening **Digital_Logic.cmbl**. Now, connect both inputs of the XOR gate to ground. Connect the red probe of the voltage probe to the output of the XOR (the 3rd pin on the bottom). **What voltage do you read on your Logger Pro screen for the XOR output when both inputs are connected to ground? Is this "high" or "low"?**

A:

Locate your LED logic probe and test it by plugging the LED end directly into the +5 V supply and then directly into ground. ***BE SURE THE LONG LEG OF THE PROBE IS BETWEEN THE TWO RESISTORS!*** **What color lights up when connected to the +5 V supply? Connected to ground?**

A:

Now take the LED probe and connect it to the output of the XOR gate. **Which color lights up? Does this agree with your voltage measurement (high or low)?**

A:

Choose a set of inputs that makes the output high. Connect the voltage probe but not the LED to the output and click the "Collect" button. Notice what happens to the voltage reading when you plug in the LED probe at the output. **How much does it change? Does this affect whether it is considered high or low?**
A:

Why do you think the voltage changes when you use the LED probe? (Hint: an ideal logic probe would draw almost zero current when making a measurement.)

A:

Part 1b: Verify the truth table of an XOR gate

Connect the voltage probe to the output of the XOR gate. While collecting data on Logger Pro, see what happens when you change the inputs from low to high, one at a time. Fill in the truth table for the XOR gate. **When you are done, paste a copy of the truth table below:**

A:

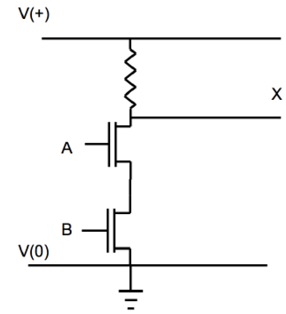
Part 2a: Build a NOT gate out of a transistor

Connect a transistor with a 100 Ω resistor to make a NOT gate. (Note: This resistor is referred to as a "pull-up" resistor.) When you think you have wired up the circuit correctly, try testing the output (X) for the two different values of the input (A). You can use either the voltmeter or the LED probe for this testing. **Fill in the NOT truth table in the Logger Pro file and paste it below:**

A:

When everything is working, talk to your TF and show him/her your circuit and how it responds to the two different inputs. Don't take out the NOT circuit you've built; you'll use it again later in the lab.

Part 2b: Build a NAND gate out of several transistors



Now, on another section of the breadboard, combine transistors and pull-up resistors to implement a NAND gate. The circuit diagram is to the right. Test it for all 4 possible input combinations, using either the logic probe or the voltmeter. Don't forget to **show your TF** how your NAND gate works. **Fill in the NAND truth table in the Logger Pro file and paste it below:**

A:

Part 2c: Combine NAND with NOT to form AND

Using the circuits you've already built, make an AND circuit and test it in the same way. **Draw a circuit diagram for the AND circuit; take a picture and paste it here:**

A:

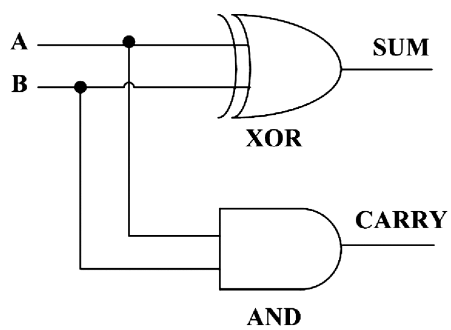
Fill in the truth table for AND in the Logger Pro file and paste it below:

A:

Talk to your TF and show him/her your AND gate. Clearly indicate where the inputs are and where the output is measured.

Part 3: Do Binary Addition (build a half-adder)

Recall that a half-adder has two inputs (A and B) and two outputs (S and C, for sum and carry).



Build a half adder from what you already have on the breadboard and verify it works as expected. **Show your TF. Draw out a truth table for 4 columns (A, B, Sum, Cary) and fill it out, then take a picture and paste it below.**

A:

Clean up

Before leaving, please disconnect everything on your original breadboard **except**:

- The short jumper wires that connect the rails together across the gap in the middle of the board
- The resistors forming a voltage divider at the far right of the board
- The XOR gate

If you can't remember what it was like at the start of the lab period, there is a picture of it on the Materials section for this lab.

V. Conclusion

What is the most important thing you learned in lab today?

A: