SUMMER INSTITUTE FOR ENGINEERING AND TECHNOLOGY EDUCATION

ELECTRICAL ENGINEERING - TEACHER MODULE 1

LOGIC GATES

CONCEPT

This unit will introduce you to logic gates and truth tables. Logic gates are the basic elements of all digital electronic devices.

OBJECTIVES

At the completion of this unit you will be able to do the following:

- Define a digital device.
- Define gate.
- Define truth table.
- Write the correct truth tables for AND and OR gates.
- Construct a simple logic circuit and determine its results.

SCIENCE PROCESS SKILLS

- Observing
- Measurement
- Communication
- Inferring
- Hypothesizing
- Design An Experiment
- Predicting
- Discerning Patterns
- Group Decision Making
- Communication

AAAS SCIENCE BENCHMARKS

- 1B Scientific Inquiry
- 3A Technology and Science
- 4E Energy Transformation
- 4G Forces of Nature
- 8C Energy Sources and Uses

SCIENCE EDUCATION CONTENT STANDARDS (NRC)

Grades 5-8:

- Transformations of Energy

Grades 9-12:

- Conservation of Energy
- Interactions of Energy and Matters
- Forces and Motion

STATE SCIENCE CURRICULUM FRAMEWORKS:

Grades 5-8: 1.1.9, 1.1.10, 2.1.9, 3.1.19, 3.1.20, 3.1.23, 3.1.24

Grades 9-12: 1.1.20, 1.1.23, 2.1.13, 2.1.14, 3.1.32, 3.1.33, 3.1.34, 3.1.39, 3.1.43, 3.1.44

WHAT IS A DIGITAL DEVICE?

A **digital device** can be defined as any device that operates on or manipulates **binary**, or two-state, information. Binary coding can be represented by any type of two state device, such as an **on** or **off** light, an **open** or **closed** switch, two different voltage levels, or the abstract symbols **0** (off) and **1** (on).

In digital electronics, we are especially interested in electronic digital devices that manipulate binary information that is in the form of voltage levels (+5 volts for the logic 1 state and GROUND potential for the logic 0 state). Through rather startling advances in the electronics industry, it is now possible to construct devices that will change state very quickly, in times as fast as 2 nanoseconds, or 0.000000002 seconds. Furthermore, a wide variety of such devices can be purchased in quantities of one for prices ranging from $ 0.14 to $ 1.50. Thus, two important considerations -- speed and low cost -- have combined to make digital electronics a powerful force for the improvement of society in the areas of communications, controls, and data-processing.

What is a Nanosecond?

Some Examples of scale:

- A nanosecond (ns) is a thousand times faster than a microsecond (μs). There are a thousand microseconds in a millisecond (ms), and there are a thousand milliseconds in a second (s).
- If your computer's CPU is running at 66 MHz, it is able to do part of an instruction every 15 nanoseconds.
- If you were to race your computer and you could calculate by hand in one second what it could do in a microsecond, it would take you 11 days, 13 hours, and 46 minutes to finish the calculations your computer could do in a second. (You know it doesn't take you over a week to multiply 5.5 and 2, but it may take a computer many steps to do the calculation and if those steps require input, output, or memory, the CPU spends most of it's time waiting.)

WHAT ARE GATES?

A **gate** is the simplest digital device that has one or more inputs and one output. The digital information appearing at the output depends upon the combination of digital information that appears at the inputs. Actually, the term "gate" has several meanings in the field of electronics. Here, we are concerned only with the gate as a digital device.

WHAT IS A TRUTH TABLE?

A **truth table** is a tabulation that shows the relationship of all output logic levels of a digital circuit to all possible combinations of input logic levels in such a way as to characterize the circuit functions completely. By input or output "logic levels" , we are referring to the logic 0 or logic 1.

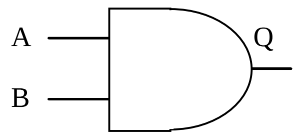
GATE SYMBOLS AND FUNCTION

The symbolic representation of gates has become standard throughout the digital electronics industry. We shall use these standard symbols in our discussions and in experiments provided with these modules.

AND

The behavior of a 2-input **AND** gate can be stated as follows. If input A is logic 1 and input B is logic 1, then output Q is logic 1; otherwise, output Q is logic 0. In

Figure 1, we show the symbol for this gate, as well as its truth table.

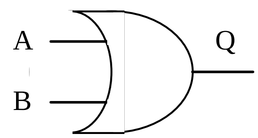


Inputs		Outputs
B	**A**	**Q**
0	0	0
0	1	0
1	0	0
1	1	1

Figure 1: A 2-input AND gate and its truth table.

OR

An **OR** gate is a binary circuit with two or more inputs and a single output, in which the output is logic 0 only when all inputs are logic 0, and the output is logic 1 if any one of the inputs is logic 1. The behavior of a 2-input OR gate can be stated as follows. If input A is logic 1 or input B is logic 1 , then output Q is logic 1; otherwise , output Q is logic 0. Included in this statement is the condition when both input A and input B are logic 1, in which case, output Q is also logic 1. The symbol and truth table for a 2-input OR gate are given in **Figure 2**.



Inputs		Outputs
B	**A**	**Q**
0	0	0
0	1	1
1	0	1
1	1	1

Figure 2: A 2-input OR gate and its truth table.

DIGITAL LOGIC ACTIVITIES

Purpose

The purpose of this experiment is to determine experimentally the truth table for the 2-input **AND** gate and the 2-input **OR** gate, and a two-level logic circuit.

MATERIALS

- 1-Experimental Logic Board
- 10-Short wires (6")
- 8-Long wires (12")
- 1-6-volt lantern battery. This will serve as the "5 volt " power source and ground.

EXAMPLE QUESTIONS

1. Circle one or more of the following terms that refer to an OFF condition in digital electronics:

   no yes false one zero true on

   ANSWER: no, false, zero
2. Draw the schematic symbol for a 2-input AND gate.
3. Draw the truth-table for an OR gate with two inputs.
4. How many milliseconds are in a second?

   ANSWER: 1000 ms in one second

MANAGEMENT SUGGESTIONS

Have the students examine each component separately. LED's should be tested separately before use. LED's work in only one direction. Make sure that, if an LED does not light, that the polarity is reversed.

SAFETY CAUTIONS

- Electricity always carries a potential for shock. Use caution when working with batteries.
- Electrical components sometimes get hot enough to cause burns.
- Components and wires have sharp points and, if handled improperly, can puncture the skin.

PROCEDURES

Please refer to **Figure 3** for the layout of the Experimental Logic Board. The board has hardwired ground connections so wires can be connected from one component to another. The components provided on the board are 6 switches (labeled *A-F*), 6 LED's (labeled *1-6*), 4 AND gates in one IC package (labeled *A1-A4*), and 4 OR gates in one IC package (labeled *O1-O4*). The actual labels are on the schematic, but may not be on the actual Experimental Logic Board.

There are 3 sockets available for each connection point on the board. If you have trouble putting a wire in one socket try one of the two other corresponding sockets.

All switches, LED's, AND gates, and OR gates are equivalent to their respective sets, i.e. *Switch A* may be interchanged in an experiment with *Switch B* as long as the substitutions are kept track of.

Each of the AND gates and OR gates has an *A* and *B* input and a *Q* output (and 3 sockets associated with each of one). The *A* and *B* inputs are interchangeable and will perform identically if swapped.

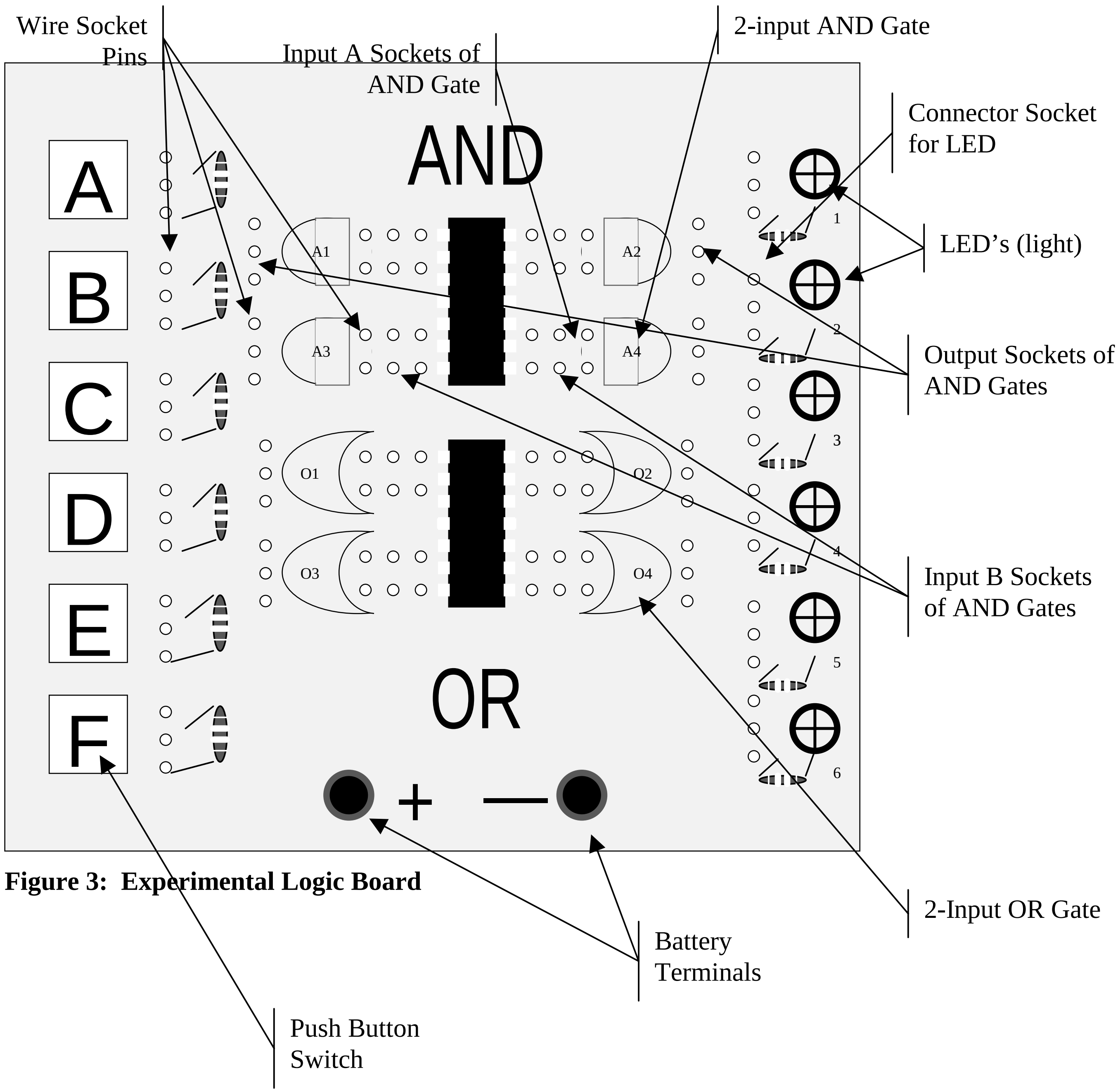


Figure 3: Experimental Logic Board

Activity 1: Test A Switch/Light Setup

1. A switch is used to control the flow of electricity in a circuit. It is either closed and allows electrical current to flow through the circuit, or it is open and prevents current from flowing. The switches are labeled *A-F* in **Figure 3**, but they may not be labeled on the actual board. The switch is *closed* (and the current flows) when the switch is depressed and *open* when it is released.
2. Connect a wire from one of the three holes beside *Switch A* to one of the three holes beside *LED 1*. An LED is a *Light Emitting Diode*. When current flows in the forward direction through the diode it produces light. (A diode is like a one-way street for electrons.)
3. Connect a wire from *Switch B* to *LED 2*.
4. Connect a long wire from the positive (**+**) side of the Experiment Board's power terminal to the positive post on the lantern battery. (There is a small hole on the side of the Experiment Board's power terminals that allows a wire to be threaded through and then screwed down tight.)
5. Connect a long wire in a similar manner from the Board's negative (**-**) terminal to the negative post on the lantern battery. Power is now being supplied to the board. Please disconnect the power before adding or removing wire connections to the Board. Voltage spikes are dangerous to integrated circuits (ICs).
6. Press *Switch A. LED 1* should light. Press *Switch B. LED 2* should light. If either of the LED's fail to light check your connections. If you believe that one of the lights or switches is not functioning properly, try another switch or another LED and see if you can troubleshoot the problem.

We can therefore conclude that:

- A logic switch in the open/unpressed/OFF state causes an LED lamp monitor to be unlit. This is referred to as the *Logic 0* state (sometimes referred to in Boolean Algebra as a *False* condition.) In this example, both the switch and the LED are in the *Logic 0* state. There are some circumstances where a switch in the *Logic 0* state (off) can cause an LED to be in the *Logic 1* state (lit). To do so its logic signals would have to pass through an inverter.
- A logic switch in the closed/pressed/ON state causes an LED lamp monitor to be lighted. This is referred to as the *Logic 1* state, or *TRUE* state.

Activity 2: Determine the Truth Table for a 2-Input AND Gate.

1. Disconnect the power (battery) from the board.
2. Remove the wire connections made in the previous activity.
3. Connect *Switch A* to *Input A* of AND gate *A2*. Take note that the *Input* connectors of AND gates *A2* and *A4* are on the left side of the AND gate symbol and the AND gate output (Q) is on the right side of the symbol. For gates *A1* and *A3* the situation is reversed.
4. Connect *Switch B* to *Input B* of AND gate *A2*.

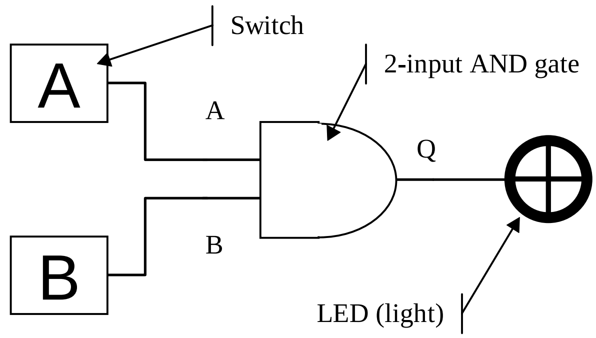


Figure 4: Activity 2 Schematic

5. Connect the Output of AND gate *A2* to *LED 1*.
6. Apply power to the board by reconnecting the battery to the Board's power terminals.
7. Push *Switch A* and *Switch B* at the same time. *LED 1* should light. This indicates that the output of AND gate *A2* is at a *Logic 1* or TRUE. If the LED doesn't light, recheck your steps for loose connections and try to troubleshoot your system.
8. Vary setting the switches' logic levels to match the truth table below of a 2-input AND gate and fill in your results. Check the experimental data with the table in **Figure 1**. Do they match?

Inputs		**Outputs**
B	**A**	**Q**
0	0	
0	1	
1	0	
1	1	

Activity 3: Determine the Truth-Table for a 2-Input OR Gate

1. Disconnect the power from the board.
2. Remove the wire connections made in the previous activity, or substitute a different pair of switches and a different LED if you would like to keep your Activity 2 circuit intact.
3. Connect *Switch A* to *Input A* of OR gate *O2*. The OR gates are in a similar layout to the AND gates.
4. Connect *Switch B* to *Input B* of OR gate O2.
5. Connect the Output of OR gate *O2* to *LED 1*.

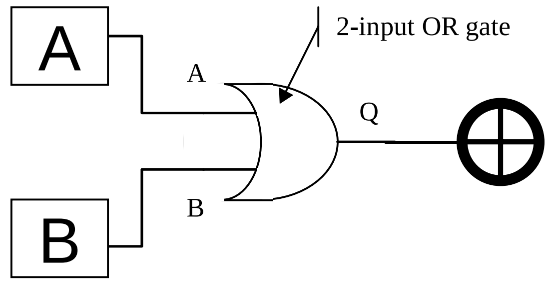


Figure 5: Activity 3 Schematic

6. Apply power to the board by reconnecting the battery to the Board's power terminals.
7. Push *Switch A* or *Switch B*. If the LED doesn't light, recheck your steps for loose connections and try to troubleshoot your system.
8. Vary setting the switches' logic levels to match the truth table below of a 2-input OR gate and fill in your results. Check the experimental data with the table in **Figure 2**. Do they match?

Inputs		**Outputs**
B	**A**	**Q**
0	0	
0	1	
1	0	
1	1	

Activity 4: Construct A 2-Level OR-AND Circuit And Determine Its Truth Table

1. Disconnect the power from the board.
2. Remove the wire connections made in the previous activity.
3. Connect *Switch A* to *Input A* of OR gate *O1*.
4. Connect *Switch B* to *Input B* of OR gate *O1*.
5. Connect *Switch C* to *Input A* of OR gate *O2*.
6. Connect *Switch D* to *Input B* of OR gate *O2*.
7. Connect the Output of OR gate *O1* to *Input A* of AND gate *A4*.
8. Connect the Output of OR gate *O2* to *Input B* of AND gate *A4*.
9. Connect the Output of AND gate *A4* to *LED 1*.
10. Apply power to the board by reconnecting the battery to the Board's power terminals.
11. Vary setting the switches' logic levels to match the truth table below and fill in your results. Answers to the Truth table are at the end of this module.

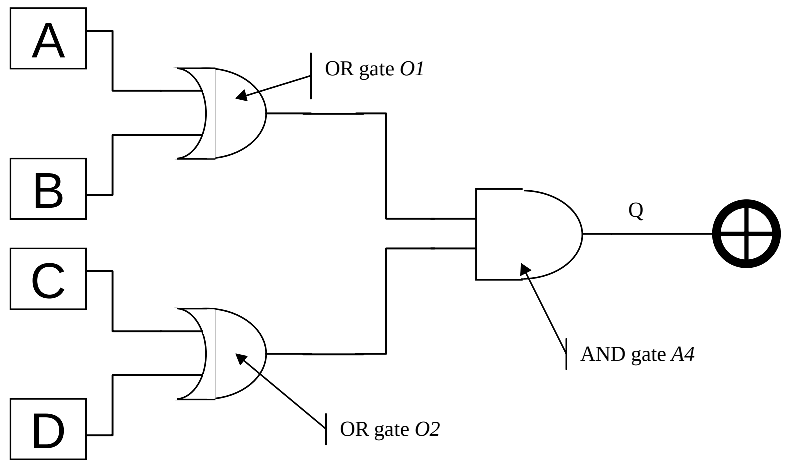


Figure 6: Activity 4 Schematic

Inputs				Outputs
D	**C**	**B**	**A**	**Q**
0	0	0	0	
0	0	0	1	
0	0	1	0	
0	0	1	1	
0	1	0	0	
0	1	0	1	
0	1	1	0	
0	1	1	1	
1	0	0	0	
1	0	0	1	
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	

Activity 5: Construct A 2-Level AND-OR Circuit And Determine Its Truth Table

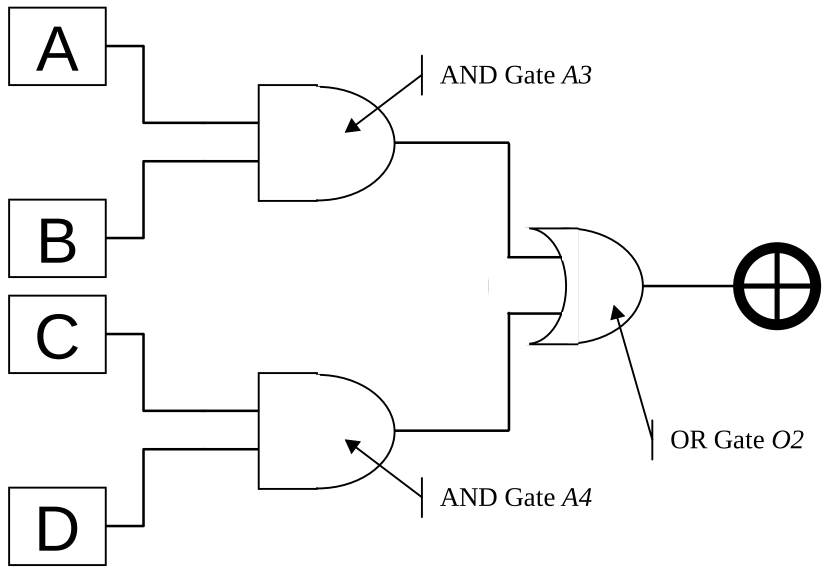


Figure 7: Activity 5 Schematic

1. Disconnect the power from the board.
2. Remove the wire connections made in the previous activity.
3. Connect *Switch A* to *Input A* of AND gate *A3*.
4. Connect *Switch B* to *Input B* of AND gate *A3*.
5. Connect *Switch C* to *Input A* of AND gate *A4*.
6. Connect *Switch D* to *Input B* of AND gate *A4*.
7. Connect the Output of AND gate *A3* to *Input A* of OR gate *O2*.
8. Connect the Output of AND gate *A4* to *Input B* of OR gate *O2*.
9. Connect the Output of OR gate *O2* to *LED 1*.
10. Apply power to the board by reconnecting the battery to the Board's power terminals.
11. Vary setting the switches' logic levels to match the truth table below and fill in your results. Answers to the Truth table are at the end of this module.

Inputs				Outputs
D	C	B	A	Q
0	0	0	0	
0	0	0	1	
0	0	1	0	
0	0	1	1	
0	1	0	0	
0	1	0	1	
0	1	1	0	
0	1	1	1	
1	0	0	0	
1	0	0	1	
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	

Activity 6: Design Your own Logic Circuit

Have the students design their own Digital Logic circuits. Here are some examples of some possible designs.

- Construct a binary adder. Have two switches represent the binary numbers 00, 01, 10, and 11. Have one of three lights light up depending on the results of the switch depressions. No switches pressed = no lights on. If I press the combination 10, then the second LED will light.
- Reverse the adder. Have each switch be given a value (1-6) and depending on which switch is pressed, have a binary number representation light up on the LED's. Ex. If I press Switch C (3) then LED 1 and LED 2 should light up giving a binary value of 3.
- Try and construct more difficult binary adders. What are the limitations of this board?
- You may want to tie this module in with math exercises on Boolean Algebra. The logic board does have a limitation in that it does not have any inverters. Can an inverter be built out of AND and OR gates? The answer is no it cannot. There is a gate called a NAND gate which follows the normal AND truth table except at the output (Q) all the 1's are 0's and vice versa. The neat thing about NAND gates is that you can duplicate the function of any gate (ANDs, ORs, Inverters, or XORs) by tying together NAND gates in different combinations.

- An industrious teacher may want to substitute the AND and OR gates with NAND gates to give the students more experiments in Boolean Logic.

SOLUTIONS TO ACTIVITY 4 AND 5 TRUTH TABLES

Activity 4: OR-AND Circuit

Inputs				Outputs
D	**C**	**B**	**A**	**Q**
0	0	0	0	**0**
0	0	0	1	**0**
0	0	1	0	**0**
0	0	1	1	**0**
0	1	0	0	**0**
0	1	0	1	**1**
0	1	1	0	**1**
0	1	1	1	**1**
1	0	0	0	**0**
1	0	0	1	**1**
1	0	1	0	**1**
1	0	1	1	**1**
1	1	0	0	**0**
1	1	0	1	**1**
1	1	1	0	**1**
1	1	1	1	**1**

Activity 5 AND-OR Circuit

Inputs				Outputs
D	**C**	**B**	**A**	**Q**
0	0	0	0	**0**
0	0	0	1	**0**
0	0	1	0	**0**
0	0	1	1	**1**
0	1	0	0	**0**
0	1	0	1	**0**
0	1	1	0	**0**
0	1	1	1	**1**
1	0	0	0	**0**
1	0	0	1	**0**
1	0	1	0	**0**
1	0	1	1	**1**
1	1	0	0	**1**
1	1	0	1	**1**
1	1	1	0	**1**
1	1	1	1	**1**

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