Science Fair® ELECTRONIC DIGITAL LOGIC LAB KIT

Catalog Number: 28-226

25 EXPERIMENTS IN DIGITAL LOGIC CIRCUITRY

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CUSTOM MANUFACTURED FOR RADIO SHACK A DIVISION OF TANDY CORPORATION

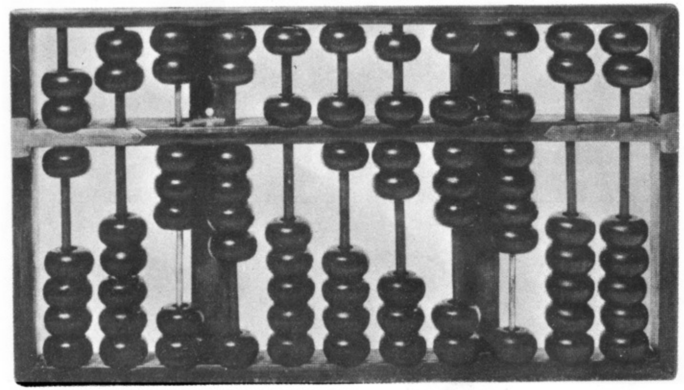
If you were asked to name the most significant technological device in the present decade you would probably conclude that it must be the computer. The computer is responsible for many important events in many areas of life. Modern space travel would be impossible without the split-second capability of the computer to analyze the many factors involved in sending a space ship on a million-mile journey with pinpoint accuracy. Computers have taken over many everyday jobs in the business world. Accounting, inventory control, purchasing, billing and many other jobs are now handled by computers at much faster speeds and with a greater degree of accuracy than was ever thought possible several years ago.

In the industrial world computers control the operation of giant steel mills, automobile production and all kinds of complex machinery. In the world of commerce computers are used to mail advertisements, handle airline reservations and many other tasks. In education computers have appeared in colleges, high schools and elementary schools as an aid to the classroom teacher. Certain learning programs have been put entirely on computers for independent study and review. They are used extensively in research to organize and evaluate data taken in various tests and experiments.

In the field of medicine computers are used to provide special analysis of test information, assist doctors in diagnosis and treatment, and monitor pulse, temperature and other vital facts about hospital patients.

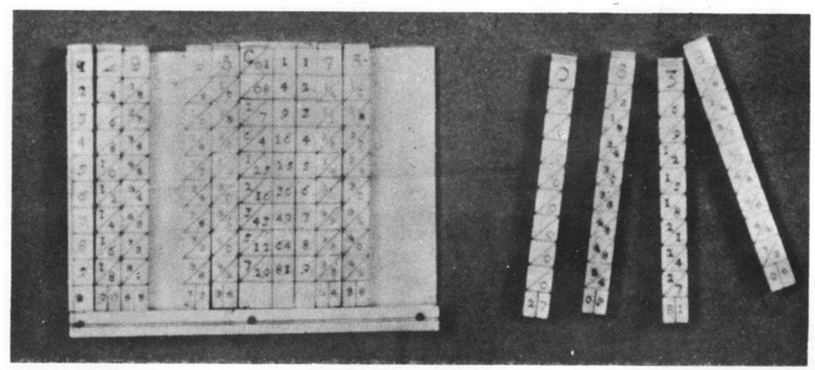
We could go on and on with illustrations of how computers are used by the law enforcement agencies, by government agencies, by the military organizations and others.

There are many personal uses of the computer. The recent interest in hand-held calculators is an example of how computer technology has been made readily available to the general public. TV games such as ping-pong and road racing are made possible by computer technology. You can even buy an electronic chess game in which your opponent is a computer. The computer makes instant decisions on the proper move and is extremely difficult to beat.



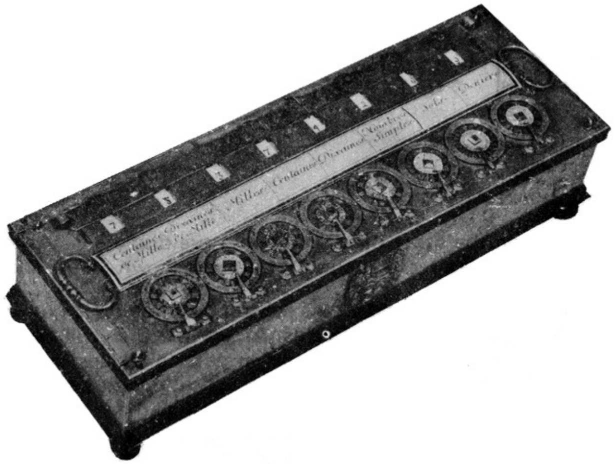
ABACUS (STILL USED IN SOME PARTS OF THE WORLD)

Although computers seem to have come into prominence only recently they have a long and interesting history. The earliest known computer was probably the abacus. Although generally thought of as an oriental device, the abacus was used by the ancient Romans and Greeks also. The Chinese saunpan and the Japanese soroban are still in use today, more as curios than as practical instruments.



JOHN NAPIER'S "BONES" USED FOR MULTIPLICATION AND DIVISION

In 1617 John Napier devised a scheme for multiplying numbers using strips of bone on which he engraved the multiplication tables. The first mechanical calculator was built in 1642 by a Frenchman, Blaise Pascal, who was only 19 at the time. Pascal's Machine, as it was called, could perform addition and subtraction. In 1671 a German scientist, Gottfried Leibnitz, built the first calculator which could also multiply and divide. These early calculatcrs were all hand operated with gears and cylinders used to perform the required operations.

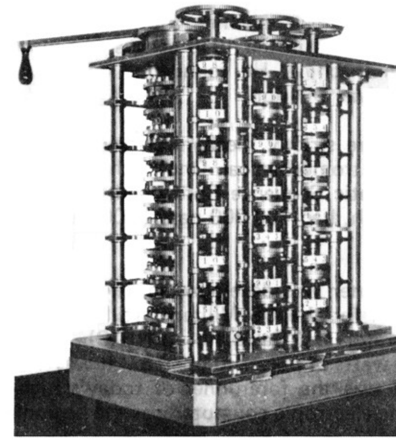


BLAISE PASCAL'S MECHANICAL CALCULATOR

In 1812 Charles Babbage began work on a new kind of calculator which he called a Difference Engine. He never completed this machine before he began developing a newer machine called the Analytical Engine. Although he died in 1871 before he was able to complete this machine his ideas were a century ahead of his time. His machine contained all the elements of a modern-day computer, except, of course, it was all done mechanically.

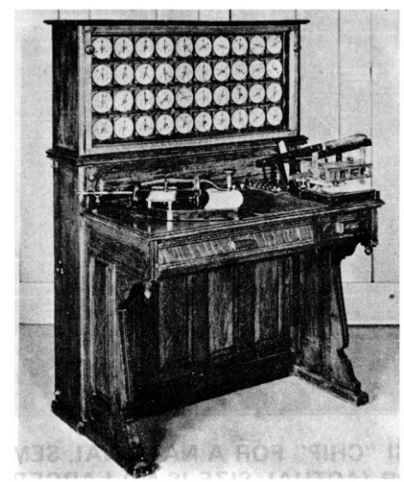
There were several other attempts made at producing a commercially practical calculator in the 1800's. It was not until 1884 that William Burroughs invented his hand crank adding-printing machine. His machine was the forerunner of the practical machines we have today. The Burroughs Corporation is still a leader in the computer field today.

Another calculator appeared in 1885, designed by Dorr Felt who became the founder of the Victor Comptometer Corporation. Other devices, providing more complex procedures followed on into the early 1900's.



CHARLES BABBAGE'S DIFFERENCE ENGINE

You are probably familiar with the punched cards that are used by some computers for putting data into the machines. The first use of punched cards dates back to the early 1700's where they were used to control the operation of weaving machines (looms). In 1801 Joseph Jacquard invented an automatic textile loom which revolutionized the weaving industry. He also used the punched card system to control all the operations of the loom. Babbage, mentioned earlier, borrowed the punched card idea to control his Analytical Engine. The punched card idea was first applied to data processing in 1887 when Herman Hollerith developed a system of using the cards to process the US Census taken in 1890. The cards were all hand punched and the data was tabulated on a simple electrical machine. He formed a company which later became part of the IBM company.



HOLLERITH'S CARD TABULATOR USED FOR 1890 CENSUS

In 1907, one of the Census Bureau machine shop workers, James Powers, developed another punched card system used in the 1910 census. His machine was faster and more accurate than the Hollerith machine. He founded a company which later became the Sperry Rand Corporation, Univac Division.

All of the early machines were strictly mechanical devices. In the late 1800's and early 1900's the machines were electromechanical. One of the most significant electromechanical machines was the Automatic Sequence Controlled Calculator (ASCC) built in 1944. It was 51 feet long, 8 feet high, had 760,000 parts, 500 miles of wire and weighed about 5 tons.

The first all-electronic computer was developed in 1946. It was developed to compute fire and ballistic information for the US Military artillery. This machine was called the Electronic Numerical Integrator and Calculator (ENIAC). It used about 19,000 vacuum tubes and required 130,000 watts of power to operate. It was much faster than the electromechanical computers and was the forerunner of today's high-speed computers. Along with the development of the electronic computer was the beginning of the use of magnetic storage devices.

Beginning with the early 1950's computers have undergone some interesting and radical improvements. The so-called first generation computers used vacuum tubes and by today's standards were quite slow and somewhat limited in their capabilities. The second generation of computers (built in the 60's) used transistors and operated at higher speeds with increased capability. Today's third generation computers utilize integrated circuits (particularly large scale integrated circuits, LSI). They operate at extremely high speeds, are capable of very complex operations and are considerably smaller than any preceding computers.

SC/MP MICROPROCESSOR

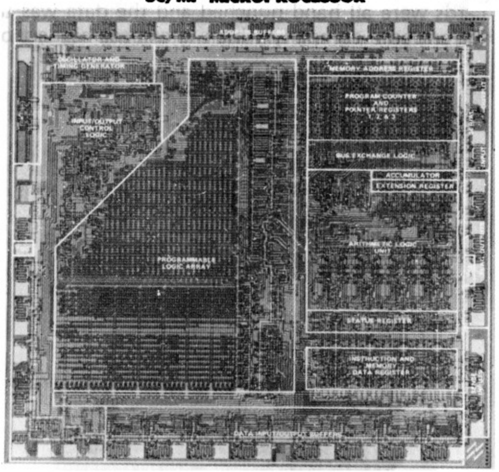
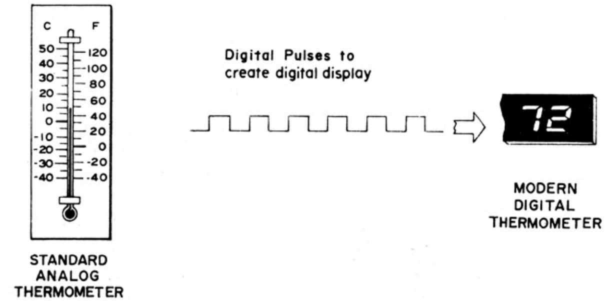


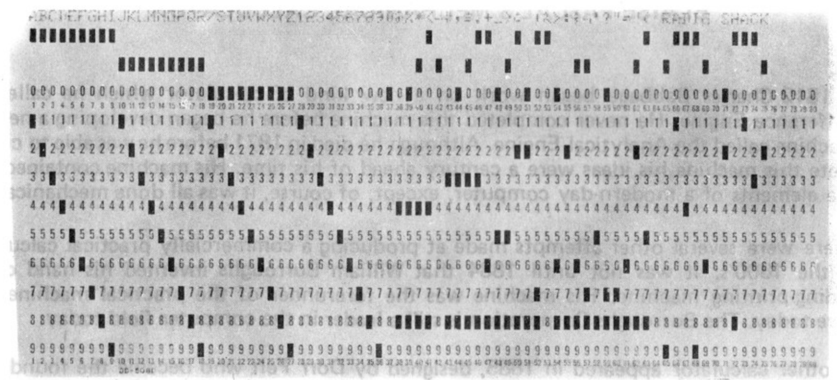
PHOTO OF AN LSI "CHIP" FOR A NATIONAL SEMICONDUCTOR MICROPROCESSOR (ACTUAL SIZE IS NO LARGER THAN THE HEAD OF A THUMBTACK)

At the heart of all modern-day computers is digital logic circuitry. Early computers were analog devices. An analog computer performs calculations by using either a mechanical or electrical analogy of the problem to be solved. Analog quantities have an infinite number of possible values. For example temperature as measured on an analog device such as a thermometer can be at any place on the scale.



Digital quantities, on the other hand, can only have discrete values such as 1, 2, 3, etc. Digital quantities are measured by counting pulses as shown in the above figure.

In digital systems all the data and all the control information is expressed using only two levels of data. Consider the punched cards. At any place on the card there are only two possible values, hole or no hole. This results in putting an electrical signal into the computer which is either on or off. The on and off conditions are usually represented by two distinct voltage levels. Since the exact voltage levels may differ with different systems, the general symbols 1 and 0 are used to designate the logic levels. 1 means ON and 0 means OFF. In terms of actual voltage levels, 0 usually means ground or 0 volts. 1 usually means a slightly more positive voltage (around 3 volts or so). These are the logic levels used in your Digital Logic Lab.



COMPUTER PUNCH CARD WITH ALPHABET, NUMBERS AND SPECIAL SYMBOLS (READ ACROSS VERTICALLY, FROM LEFT TO RIGHT). COMBINATIONS OF HOLES REPRESENT LETTERS AND SYMBOLS TO THE COMPUTER.

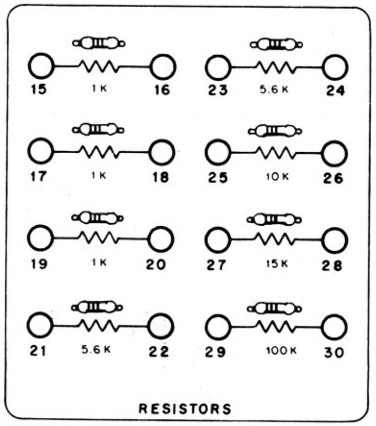
When discussing digital logic circuitry there are various terms used to describe the data levels or the conditions at the input and output of the circuits. ON and Off, TRUE and FALSE, HIGH and LOW, are all terms that refer to the 1 and 0 levels respectively.

As you do the projects in your kit you will be studying individual digital logic circuits. This will provide you with a good understanding of the basic building blocks used in computers, digital test equipment and other digital equipment. A mastery of the contents of this kit will provide you with the first step toward a rewarding future in the field of digital electronics or computer technology.

COMPONENTS

There are 27 separate components in your Digital Logic Lab Kit. We will briefly explain the purpose of each component so that you will understand what each component does. This will help you to understand each of the projects better.

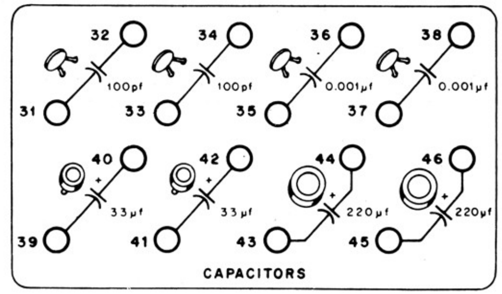
RESISTORS



There are 10 resistors in your kit. They are located in the upper left hand corner of the kit board. Resistors have several important uses in electronic circuits. Resistors are used to limit the amount of electrical current in a circuit. They are also used to set the amount of voltage in different parts of a circuit. The value of a resistor is expressed in Ohms. Generally speaking, in a given circuit the higher the value of a resistor, the lower will be the current flow in the circuit. There are some abbreviations which are used in showing the value of resistors. One of these is the symbol K. The letter K stands for 1000. A resistor with a resistance of 1000 Ohms is sometimes called a 1K Ohm resistor. A 15000 Ohm resistor is called a 15K Ohm resistor. A 5.6K Ohm resistor has a resistance of 5600 Ohms.

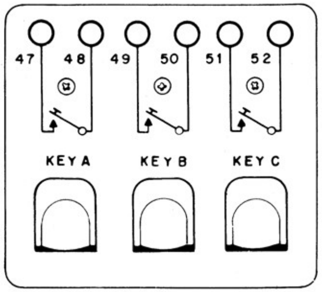
The circuit symbol for a resistor is

CAPACITORS

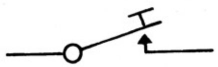


Your kit has eight capacitors. They are located in the lower left hand corner of the kit board. They can be used in different ways in an electronic circuit. They can be used to block a direct current (DC) signal while allowing an alternating current (AC) signal to pass through. They can be used to store electrical energy as in a filter to smooth out pulsating signals. They are used to tune electronic circuits to specific frequencies as in radio receiver and transmitter circuits. They are used to control the timing of events in a circuit. This will be the main application in the circuits in the projects in this kit. The value of capacitors is expressed in units called Farads. The number of Farads is an indication of how much electrical energy can be stored in the capacitor. The larger the value of the capacitor, the more energy it can store. The Farad is a rather large unit and so most capacitors are rated in millionths of Farads, usually called microfarads. Microfarad is abbreviated MFD, μfd, or just μF. Very small capacitors are rated in picofarads (pF). A picofarad is one millionth of a microfarad. The four largest capacitors in your kit are electrolytic types which means they should be connected in a certain way. The + terminal must go to the correct part of the circuit. You will be instructed about this in the projects. The circuit symbol for a capacitor is

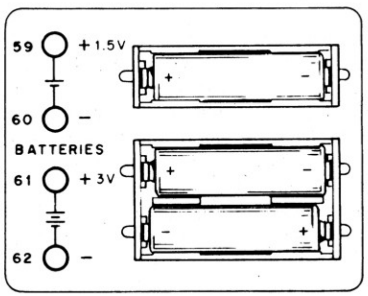
KEYS



There are three key switches in your kit. They are located at the bottom center of the kit board. These key switches are used to control the flow of current in a circuit. When the key is up the switch is open and no current will flow through the switch. When the key is pushed down to make contact with the bottom terminal the switch is closed and current can flow through the switch. The circuit symbol for this kind of switch is

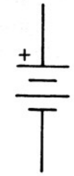


BATTERIES

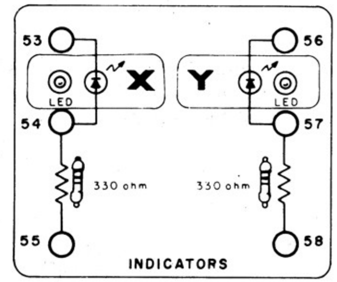


You'll need three type AA Batteries for your kit. We recommend that you use only Alkaline or heavy-duty type, such as Radio Shack's 23-552 or 23-582. Batteries are used to provide the source of electrical voltage. A source of voltage is necessary for operation of an electronic circuit. The voltage forces the current to flow through the various components in the circuit. The batteries are located in the lower right hand corner of the kit board.

The batteries used are size AA, 1½-volt dry cells. In your kit three 1½-volt cells are connected in series to provide a total voltage of 4½ volts to operate the circuits. The batteries are inserted in the battery holders. When putting the batteries in the holders be sure to get them in the right direction as indicated on the holders. The circuit symbol for the battery is

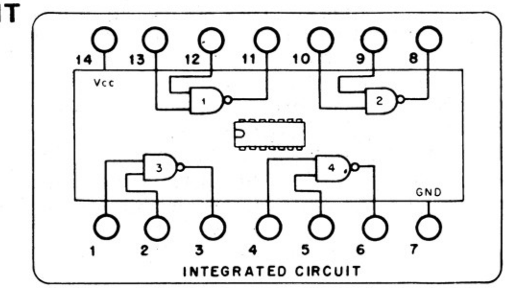


INDICATORS

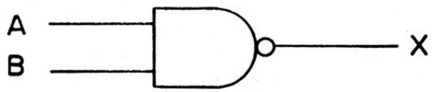


There are two indicators used in your kit. They are located in the upper right hand corner of the kit board. Each indicator is a light-emitting diode (LED). A diode is a device which will pass current in one direction but not the other. A light-emitting diode is a special kind of diode which emits light when current is passed through it. The 330-ohm resistor in series with each LED is used to limit the diode current to the proper value when the diode is turned on. The circuit symbol for the LED is

INTEGRATED CIRCUIT



There is one integrated circuit (IC) in your kit. It is located in the top center of the kit board. An integrated circuit is a special electronic circuit containing many transistors and resistors in a very small package. The particular IC in your kit is a type 7400. This IC contains four separate logic NAND gates. You will learn the basic operation of a logic NAND gate as you go through your projects. The IC is the most critical component in your kit and the most easily damaged. For this reason it should always be the last component connected into the circuit. The positive supply lead to pin 14 of the IC should always be the last connection made when hooking up the various projects. The circuit symbol for an IC depends on the kind of circuit it contains. The symbol for a two-input NAND gate is



The IC in your kit is part of a logic family of ICs known as TTL devices. TTL stands for Transistor-Transistor Logic. This refers to the types of components involved in the internal circuits of the ICs. The majority of TTL devices have type numbers which begin with 74. The IC in your kit is a 7400. All TTL devices have certain common characteristics. They are all designed to operate with a supply voltage of approximately 5 volts. In your kit you will be using three 1½-volt cells in series to provide a total of 4½ volts. In order for the IC to function properly you must connect pin 7 to the circuit ground or common (negative terminal of the battery) and pin 14 to the battery positive terminal. The circuit diagrams showing how various logic circuits are to be connected together do not show these two power supply connections. They are understood to be necessary even though they do not appear on the circuit diagram.

ICs come in several different case styles. Some are packaged in small round metal cases with the leads arranged in a circular fashion on the bottom of the case. This type of case is described as a TO-5 case. Your IC is in a very common package known as a DIP. DIP stands for Dual In-line Package. The IC leads are arranged in two (dual) parallel sections along the sides (in-line) of the package. ICs are available in DIP packages with 8, 14, 16, 24 and 40 pins or leads. Your IC is in a package commonly referred to as a 14-pin DIP.

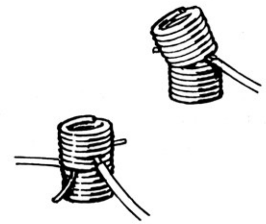
BUILDING THE PROJECTS

BATTERY INSTALLATION

As previously mentioned, your kit uses three AA 1½-volt penlight cells to power the projects. Install the cells in the holders adjacent to terminals 59 through 62. Be sure to observe the polarity (+, –) markings inside the holders. The + end of the cell is the one with the small metal cap. Be sure the batteries are firmly seated in the holders. Since most of the projects use 4½ volts you can install a small jumper wire between pins 60 and 61 following the instructions below. In order to make the batteries last longer don't leave the circuit on longer than necessary to complete the project and be sure to disconnect the batteries from the circuit when each project is completed.

WIRING

The spring terminals and the pre-cut hookup wires supplied with your lab kit make it a snap to wire together the various projects. To connect a hookup wire to a spring terminal, just bend the spring over to one side and insert the wire into the opening. Sometimes two or three hookup wires are connected to a single spring terminal so make sure the first wire doesn't come loose when the second and third wires are installed. The easiest way to do this is to push the spring on the side opposite where the first wire has already been inserted.



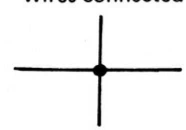
Be sure that only the exposed, shiny part of the hookup wire is inserted into the spring terminal. If the plastic insulation part of the wire is inserted into the spring terminal, electrical contact will not be made. To remove the hookup wires from the spring terminals, just bend each terminal and pull the wires from it.

After a lot of use, the exposed metal ends of some of the hookup wires might break off. If this happens, just remove 3/8" (9.5 mm) of insulation from the broken end and twist the strands together. You can remove the insulation with a wire-stripper tool or a penknife.

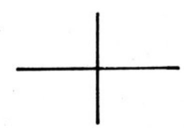
PROJECT INSTRUCTIONS

Each project has an explanation of its purpose and application along with a description of the basic circuit operation. Included is a schematic diagram of the circuit which will allow you to begin learning about electronic schematics. A layout of the kit board is included to show the various connections. Just a brief word about the schematic or circuit diagrams. When two wires cross on the schematic diagram and they are to be connected together, there will be a dot where the wires cross as shown below. If two wires cross each other on the diagram and there is no dot it means that the wires are not to be connected together as shown below.

Wires connected



Wires not connected



There is a simple wire sequence listing for each project. You should connect an appropriate length wire (whatever color wire will reach) between the terminals listed in each grouping. When you come to a new grouping, start new connections. For example, Project #1 has the following wire sequence listing:

60-61, 53-62, 52-59, 51-55

You should connect a wire between 60 and 61. Another between 53 and 62. Another between 52 and 59. Another between 51 and 55.

If there are three terminal numbers in a grouping such as 30-46-47, you would connect one wire from 30 to 46 and another from 46 to 47.

CAUTION: As mentioned previously, the power connection to the IC (pin 14) is left till last. It is important that you make this connection last. With some circuits you may damage the IC if this precaution is not observed. And when you disconnect leads, start by disconnecting pin 14 connection first.

NOTES

TROUBLESHOOTING

If you assemble each project according to its wire sequence listing, you should have no problem getting the projects to work properly. But if you do have a problem, you can usually find and correct it by using the following troubleshooting steps. These steps are very similar to those used by electronics technicians in troubleshooting electronic equipment.

1. Are the batteries fresh? If not, they may be too weak to power the project. This is particularly true of TTL circuitry; if the batteries are weak, some functions may be erratic. **To assure consistent operation, use only fresh 1.5 volt, AA batteries.**

2. Have you assembled the project properly? If everything else checks out OK, check all the wiring connections to make sure you have wired all the terminals correctly. Sometimes it's a good idea to have someone else take a look at it too – a second pair of fresh eyes may see something you have overlooked.

3. How about following the Schematic Diagram and circuit explanation? As you progress in your knowledge and understanding of electronics, you should be able to do some troubleshooting just by following a Schematic, and if some circuit details are provided, you should be able to figure it out for yourself.

4. Try some voltage and current measurements – you'll very soon find out how handy a VOM can be to an electronics technician.

INTRODUCTION TO COMBINATIONAL LOGIC CIRCUITS

In this kit you will be studying two basic types of digital logic circuits. The first group of circuits belong to a division of logic known as **combinational logic.** In these circuits the basic IC gates are connected in different ways to allow certain **combinations** of input data to produce specific results at the output of the circuit. The order in which the data appears at the input to these circuits is not important. The second group of circuits belong to a division of logic known as **sequential logic.** In these circuits the order in which data appears at the inputs is important and the **sequence** of data produces certain specific results at the output of the circuit.

There are five basic logic functions in the combinational logic division. These are named by a particular combination of inputs which produces a unique output result. These are NOT, AND, OR, NAND and NOR. You will be studying each of these basic functions and also some interesting circuits which make use of the basic concepts. You will study the basic operations in two ways. Each function is introduced by a study of one or two simple circuits using just the LED indicator and some switches. Then the same function is studied using the IC to show how these functions are used in digital logic circuits.

The circuits that you will be setting up all use switches to simulate the data conditions at the input of the IC. In actual circuits these input data conditions are established by other electronic circuits and may be switching on and off millions of times each second at frequencies measured in the MHz (megahertz) range.

In addition to setting up the circuits and studying their basic operation you will learn two other ways of expressing the circuit action. Each logic function can be expressed using an equation which shows the relationship between the inputs and the output. These **logic equations** look very similar to regular algebraic equations but the symbols used have special meaning in logic circuits.

Another aid in visualizing the action of logic circuits is the **truth table.** In a truth table, all the possible combinations of input conditions are listed and the corresponding output for each combination is shown. A two-input truth table is shown below. As mentioned in a previous section the input conditions are specified by the logic data level, either 0 or 1.

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

In this table, A and B are the two inputs and X is the output of the circuit. The corresponding output level is also specified by the logic data level. In the projects you will be filling in the truth tables for each logic function.

1. LIGHT EMITTING DIODE OPERATION

This project will teach you the basic operation of the light-emitting diode (LED). The LED is used as the indicator to sense the logic condition of a particular point in each circuit. When the LED is on (emitting light) it indicates the presence of a logic 1 at that point. When the LED is off it indicates the presence of a logic 0 at that point. The LED is basically a diode which will conduct electrical current in one direction but not the other. When it is conducting it will emit light and when it is not conducting it will be dark. We have used red LEDs in your kit but they are also available in other colors.

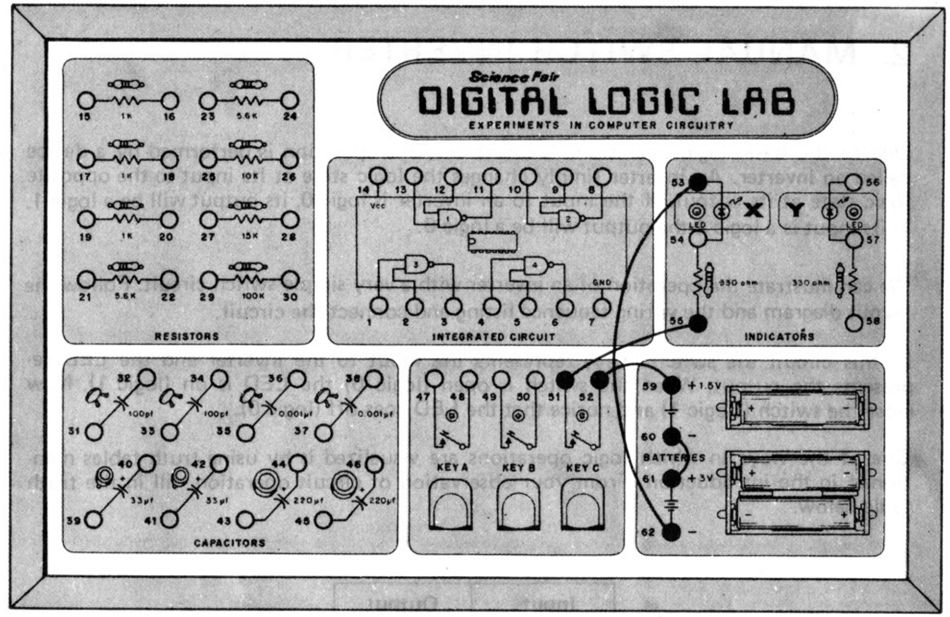
Follow the layout diagram and the wire sequence listing and connect the circuit. When the Key switch is pushed down the LED should light up which means that the diode is conducting current. In this condition the diode is said to be **forward-biased**. When the Key switch is up (open), no current can flow and the LED is off.

This circuit also illustrates the operation of the switch. When the switch is down (closed) current can flow from the Battery through the switch to the LED. When the switch is up (open) there is no complete path for current and the LED is off. **Throughout this kit an open switch will represent a logic 0 and a closed switch will represent a logic 1.**

To demonstrate that the diode will not conduct current in the opposite direction, make the following changes. Remove the wire from 53 to 62 and connect it from 53 to 59. Remove the wire from 52 to 59 and connect it from 52 to 62. Now the diode will not light up, even when the switch is closed. In this condition the diode is said to be **reverse-biased**.

It should be noted that the LED should **never** be connected into the circuit without the series 330 ohm resistor. If it is connected without the resistor the LED will be destroyed.

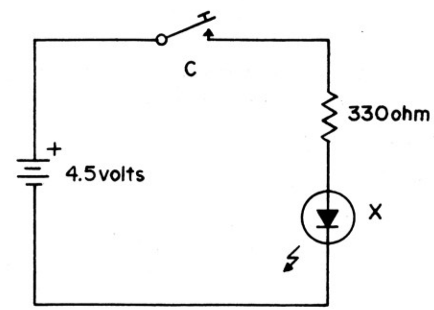
NOTES



Wiring Sequence

60–61, 53–62, 52–59, 51–55

Circuit Diagram



2. MANUAL SWITCH INVERTER

One of the basic logic operations is **inversion**. This operation is performed by a device called an **inverter**. An inverter simply changes the logic state at its input to the opposite logic state at its output. If the input to an inverter is logic 0, its output will be a logic 1. If its input is a logic 1 the output will be a logic 0.

We can illustrate the operation of an inverter with a very simple switch circuit. Follow the layout diagram and the wiring sequence listing and connect the circuit.

In this circuit the switch (Key) represents the input to the inverter and the LED represents the output. When the switch is open (logic 0) the LED is on (logic 1). Now close the switch (Logic 1) and notice that the LED goes off (logic 0).

One of the ways in which logic operations are visualized is by using truth tables mentioned in the introduction. From your observation of circuit operation, fill in the truth table below.

Input (Switch)	Output (LED)
0	
1	

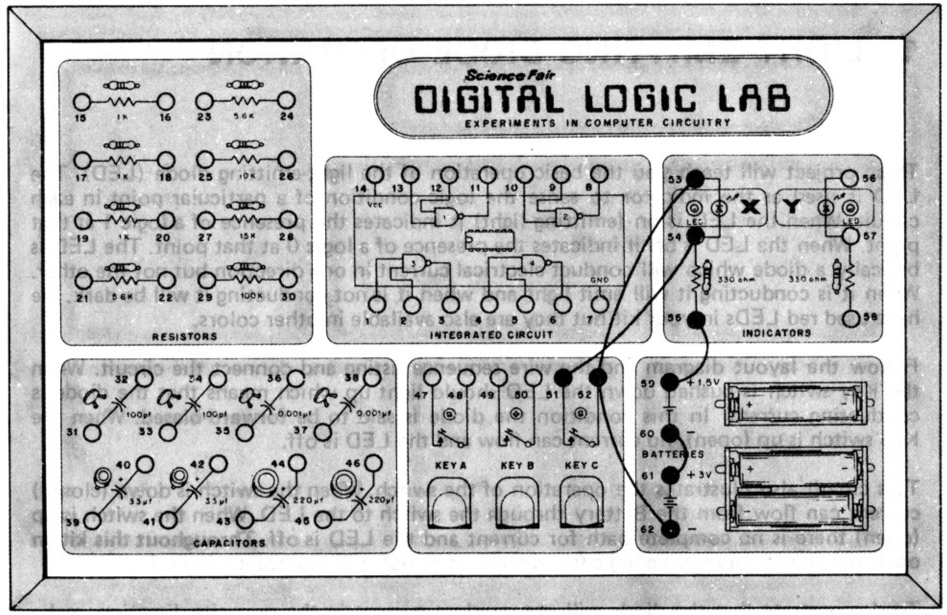
NOTE: Remember, for switch condition, "0" is open and "1" is closed. For LED Output, "0" is not lit and "1" is lit.

This logic operation is expressed by the logic equation

$$X = \overline{A}$$

This is read, "X is equal to **not** A." X is the output and A is the input. The bar over the A is the symbol for inversion (sometimes called **negation**).

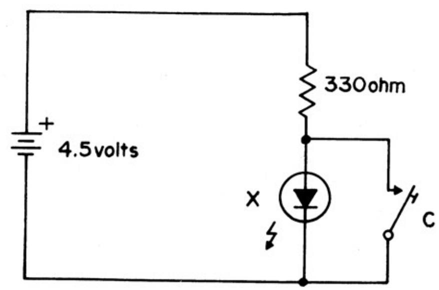
NOTES



Wiring Sequence

60–61, 51–54, 53–52–62, 55–59

Circuit Diagram



3. IC INVERTER

The function of an inverter can be performed by one of the NAND gates in the IC. By connecting the two input leads together to form one input connection, the NAND gate becomes an inverter. In this way the circuit is able to invert the logic condicions at the input. In the schematic diagram the standard triangular symbol is used for the inverter, even though it is made from a NAND gate.

In this circuit, Key A is used to switch the logic state at the input to the inverter. Indicator X (one of the LEDs) tells us what the logic state is at the input. Indicator Y (the other LED) tells us what the logic state is at the output of the inverter.

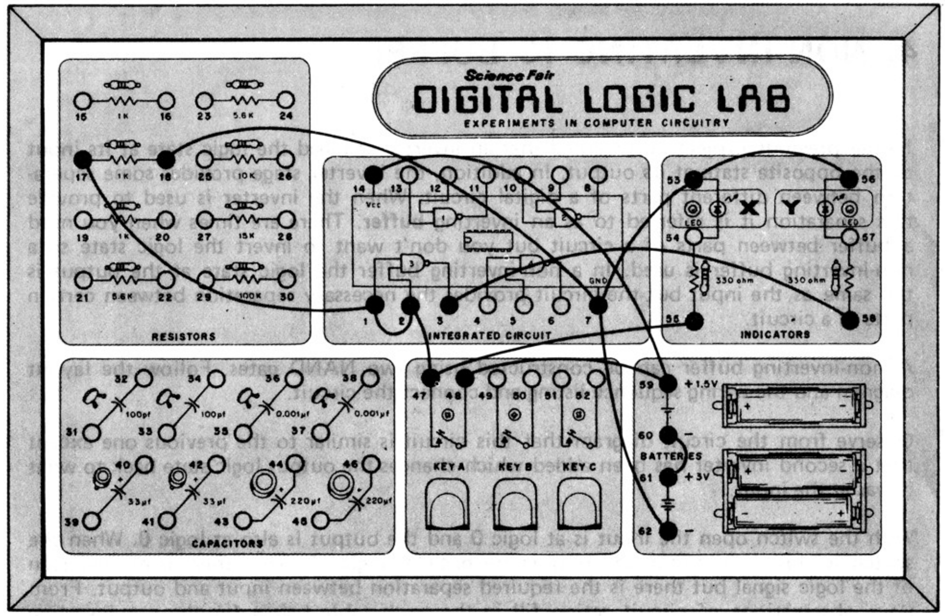
Follow the layout diagram and the wiring sequence listing and connect the circuit.

With the switch open the input to the inverter is connected to the negative or ground side of the circuit through the 1K resistor. This places a logic 0 at the input to the inverter. Notice that the output indicator is on, telling us that there is a logic 1 at the output. Now close Key A. This connects the inverter input to the positive side of the Battery. This voltage places a logic 1 at the input as indicated by the fact that indicator X is on. The output indicator Y has gone out, telling us that the output is at logic 0. Open and close the Key switch a few times until you are sure you understand this relationship between input and output of the inverter. Fill in the truth table below for this inverter.

Input	Output
0	
1	

Compare this truth table with that of Project #2. The two tables should be the same.

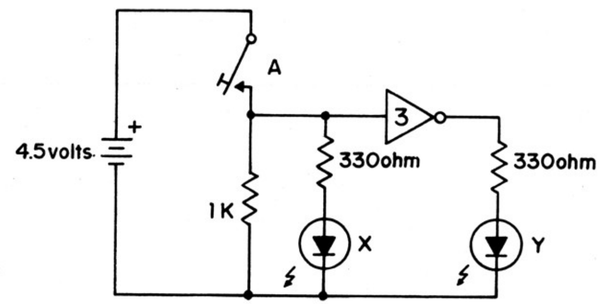
NOTES



Wiring Sequence

60–61, 17–1–2–47–55, 18–7–53–56–62, 3–58, 48–59–14

Circuit Diagram



4. NON-INVERTING IC BUFFER

In the previous project you learned that an inverter changed the logic state at its input to the opposite state at its output. In addition, the inverter stage provides some separation between different parts of a digital circuit. When the inverter is used to provide this separation it is referred to as an inverting **buffer**. There are times when you need a buffer between parts of a circuit but you don't want to invert the logic state so a non-inverting buffer is used. In a non-inverting buffer the logic state at the output is the same as the input but the circuit provides the necessary separation between certain parts of a circuit.

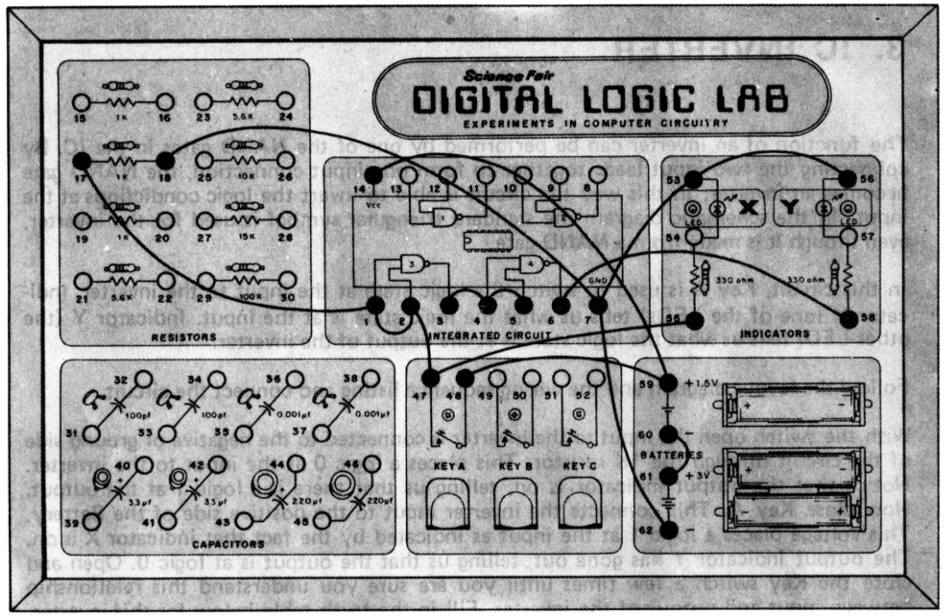
A non-inverting buffer can be constructed using two NAND gates. Follow the layout diagram and the wiring sequence listing and connect the circuit.

Observe from the circuit diagram that this circuit is similar to the previous one except that a second inverter has been added which changes the output logic state back to what it was at the input.

With the switch open the input is at logic 0 and the output is also at logic 0. When the switch is closed the input and output are both at logic 1. Thus there is no inversion of the logic signal but there is the required separation between input and output. From your observations of circuit action fill in the truth table below for the non-inverting buffer.

Input	Output
0	
1	

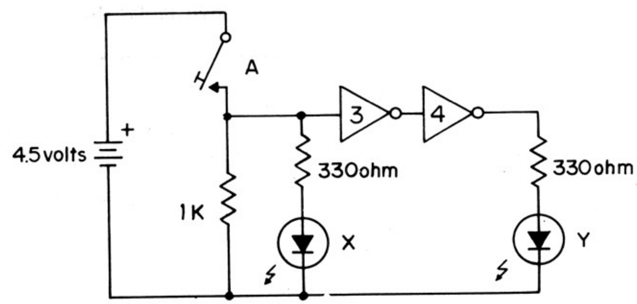
NOTES



Wiring Sequence

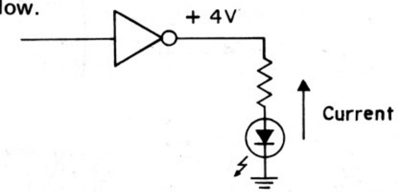
60–61, 17–1–2–47–55, 18–7–53–56–62, 3–4–5, 6–58, 48–59–14

Circuit Diagram



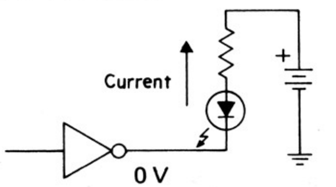
5. ALTERNATE METHOD FOR LED OPERATION

In the two previous projects you have connected the LED and its series resistor between the output of the IC and the circuit common or ground. When connected in this manner the LED provides an indication of the actual voltage level at the output of the IC. In TTL logic circuits a logic 0 level means that the output voltage is at a very low level, usually between 0 and 0.5 volts with respect to the circuit common. This low voltage is not enough to light the LED and so the OFF or logic 0 condition is indicated. When the output of a TTL device goes to a logic 1 level the voltage rises to about 3 or 4 volts above common. When this 3 or 4 volts is applied across the LED circuit the LED will light, indicating the logic 1 level. When the LED is connected in this way the output of the TTL device is the **source** of electrons for operation of the LED. This is illustrated in the circuit diagram below.



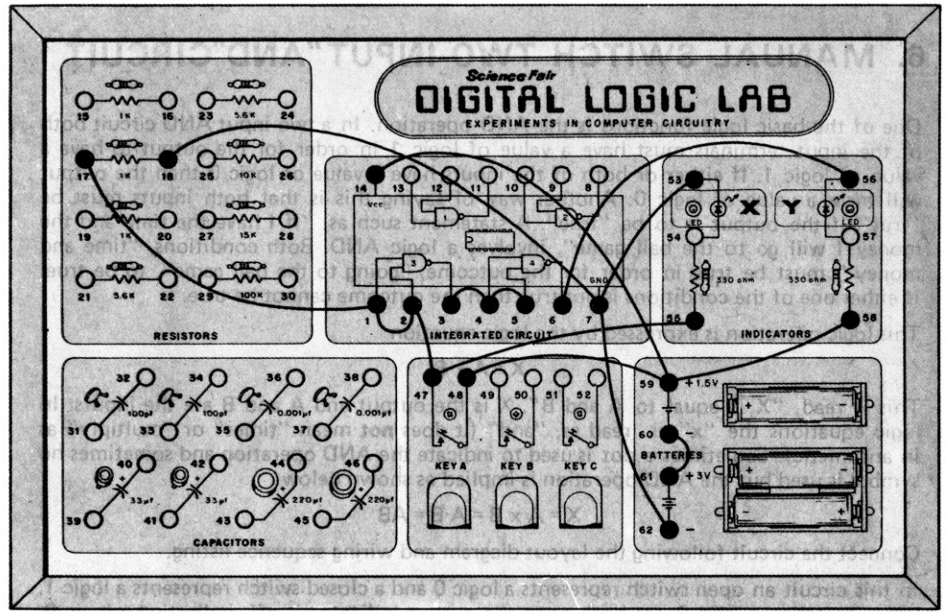
With this hookup the TTL device is said to be **sourcing** the output load. The LED circuit draws about 7 mA when it is on in this circuit. This puts a fairly heavy load on the output of a TTL device. In normal logic circuits when two TTL devices are connected together, the input of the second device only draws about 5μA from the output of the first in the logic 1 state.

In some of the circuits you will be working with, the LED circuit puts too much load on the TTL gate and the circuit will not function properly. The LED can be connected as shown below to alter this condition.



In this circuit when the output of the TTL device is at the logic 1 level the output voltage is around 4 volts above common. Since the top of the LED circuits is 4½ volts above common, there will only be about ½ volts across the LED circuit. This is not enough voltage to turn on the LED and it will remain dark. When the output of the TTL device goes to the logic 0 level it places the bottom of the LED circuit very close to 0 volts. This means that almost the entire 4½ volts from the battery will be across the LED circuit. It will now pass enough current to turn on the LED. This means, of course, that the light will come on when the output is low (0) and will be out when the output is high (1). This is opposite to our normal operation. When connected in this manner the battery is the source of electrons and the TTL device functions as a current **sink**. With this hookup the TTL device is said to be **sinking** the output load.

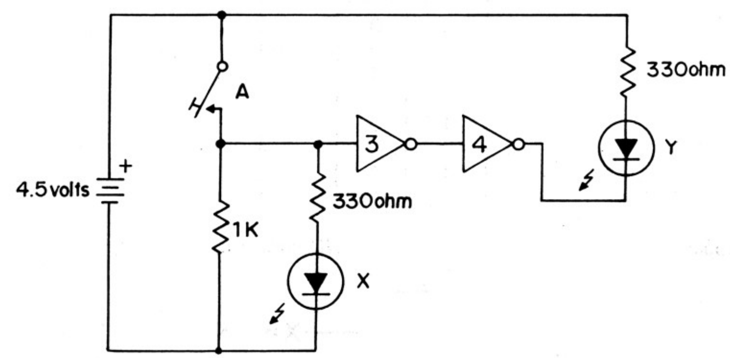
Reconnect the circuit following the layout diagram and the wiring sequence listing. The only change from the previous circuit is the connections to LED Y and its series resistor.



Wiring Sequence

60–61, 17–1–2–47–55, 18–7–53–62, 3–4–5, 6–56, 48–59–58–14

Circuit Diagram



6. MANUAL SWITCH TWO-INPUT "AND" CIRCUIT

One of the basic logic functions is the AND operation. In a two-input AND circuit both of the input terminals must have a value of logic 1 in order for the output to have a value of logic 1. If either or both of the inputs have a value of logic 0 then the output will have a value of logic 0. Another way of saying this is that both inputs must be "true" if the output is to be "true". A statement such as, "If I have the time and the money I will go to the ball game", involves a logic AND. Both conditions, "time and money", must be true in order for the outcome, "going to the ball game", to be true. If either one of the conditions is not true then the outcome cannot be true.

This logic operation is expressed by the logic equation

$$X = A \times B$$

This is read, "X is equal to A **and** B". X is the output and A and B are the inputs. In logic equations the "x" is read as, "and" (it does **not** mean "times" or "multiply" as in arithmetic). Sometimes a dot is used to indicate the AND operation and sometimes no symbol is used but the AND operation is implied as shown below.

$$X = A \times B = A \cdot B = AB$$

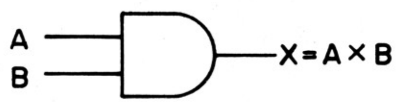
Connect the circuit following the layout diagram and wiring sequence listing.

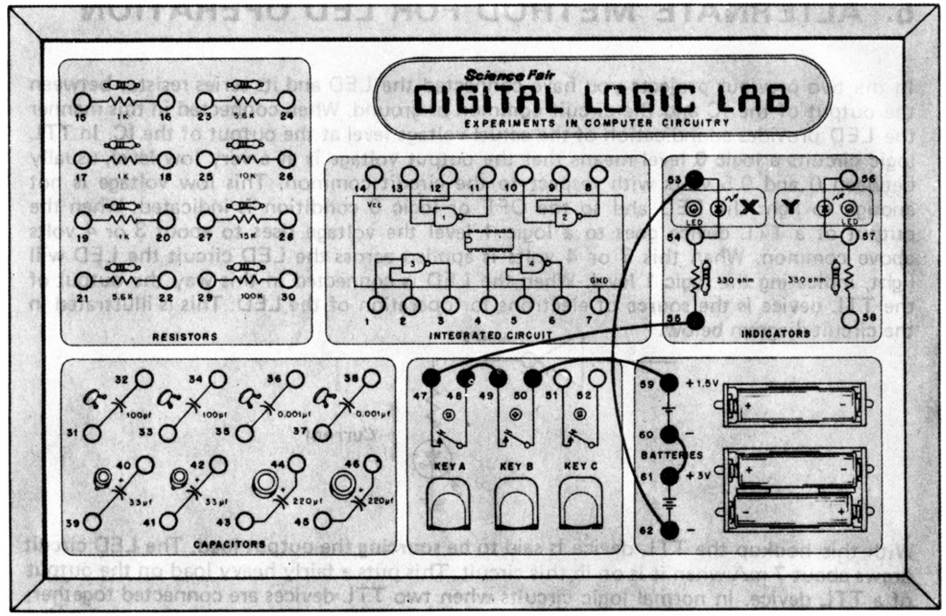
In this circuit an open switch represents a logic 0 and a closed switch represents a logic 1. When switches A and B are both open the output indicator is off, indicating a logic 0. Since the switches are open there is no path for current flow and the LED cannot come on. Close Key A but leave B open. The LED is still off (logic 0) since current cannot flow through the open switch. Now open A and close B and notice that the LED is still off (logic 0). Now close both **A** and **B**. The **LED** will come on (logic 1). With both A and B closed there is a complete path for current flow from the battery to the LED.

Fill in the truth table below for the two-input AND circuit.

A	B	X
0	0	
0	1	
1	0	
1	1	

The logic circuit symbol for the two-input AND circuit is

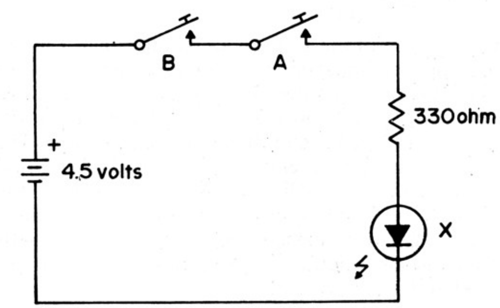




Wiring Sequence

60–61, 53–62, 50–59, 48–49, 47–55

Circuit Diagram



7. IC TWO-INPUT "AND" GATE

The two-input AND function can be performed by properly connecting two NAND gates as shown in the schematic diagram. The combination of one NAND gate and an inverter perform the AND function.

Connect the circuit following the layout diagram and the wiring sequence listing.

When the input switches are open the inputs will be at logic 0. Whenever a switch is closed, that particular input will be at a logic 1 level. The logic level of the output is indicated by LED X.

When both switches are open (logic 0) there is no output indication (logic 0). When either A or B is closed (logic 1) but not both, the output is still logic 0. When both A and B are closed (logic 1) the output will go to logic 1 (LED on).

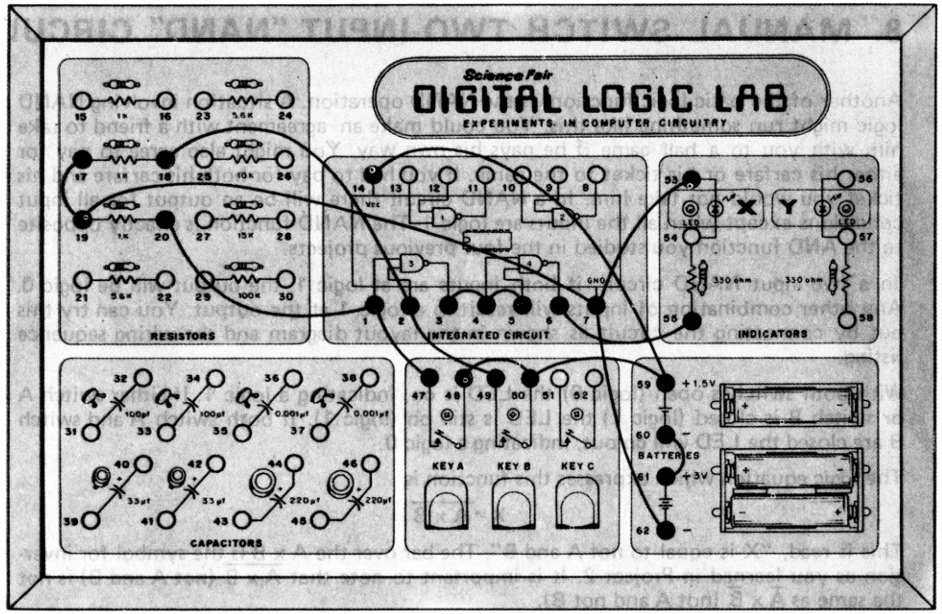
Using your observations of circuit action, fill in the truth table below for the IC two-input AND gate.

A	B	X
0	0	
0	1	
1	0	
1	1	

This table should be identical to the one for Project 6. The logic equation is the same for this circuit as it was for Project 6.

$$X = A \times B$$

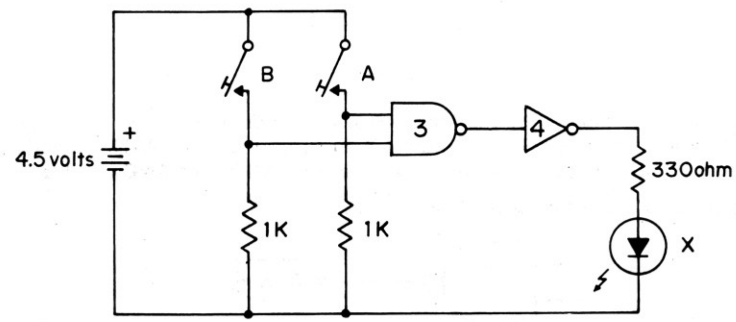
NOTES



Wiring Sequence

60–61, 17–19–7–53–62, 18–2–49, 20–1–47, 3–4–5, 6–55, 48–50–59–14

Circuit Diagram



8. MANUAL SWITCH TWO-INPUT "NAND" CIRCUIT

Another of the basic logic functions is the NAND operation. A situation involving NAND logic might run something like this. You could make an agreement with a friend to take him with you to a ball game if he pays his own way. You might also agree to pay for either his carfare or his ticket to the game. If you had to pay for both his carfare and his ticket you would not take him. In a NAND circuit there will be an output for all input conditions except when all the inputs are logic 1. The NAND function is exactly opposite to the AND function you studied in the four previous projects.

In a two-input NAND circuit, if both inputs are at logic 1, the output will be logic 0. Any other combination of inputs will result in a logic 1 at the output. You can try this out by connecting the circuit as shown in the layout diagram and the wiring sequence listing.

With both switches open (logic 0) the LED is on, indicating a logic 1. If **either** switch A **or** switch B is closed (logic 1) the LED is still on (logic 1). If both switch A and switch B are closed the LED will go out, indicating a logic 0.

The logic equation which expresses this function is

$$X = \overline{A \times B}$$

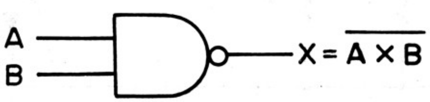
This is read, "X is equal to **not** A and B". The bar over the A x B is the symbol for inversion as you learned in Project 2. It is important to note that $\overline{A \times B}$ (**not** A and B) is not the same as $\overline{A} \times \overline{B}$ (not A and not B).

Let's make out a truth table for this operation. Try the various switch combinations again and fill in the truth table below.

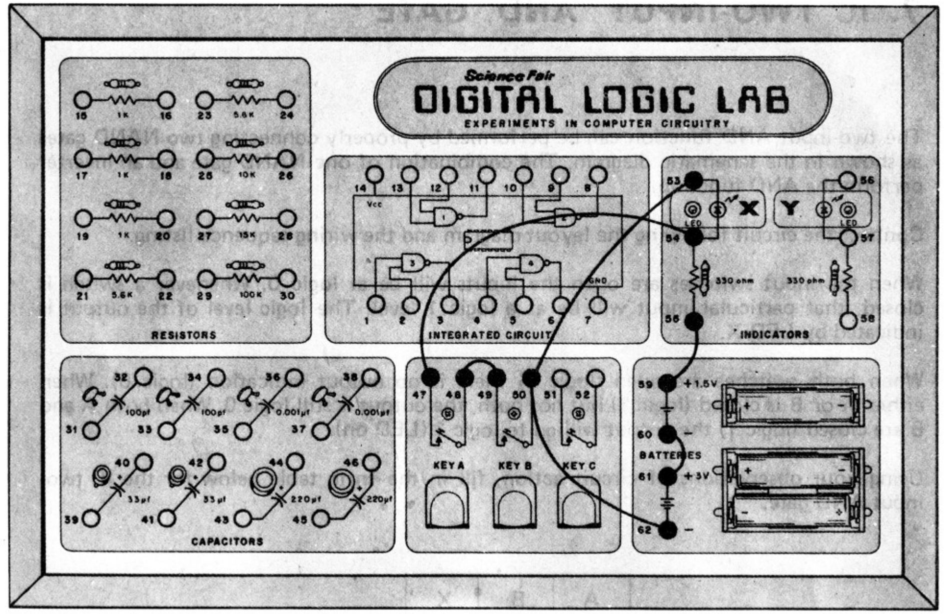
A	B	X
0	0	
0	1	
1	0	
1	1	

Compare this truth table with the one in Project 6. You will notice that column X in this chart is just the opposite of column X in Project 6. The NAND function is the inverse of the AND function. That is why it is called NAND, **N**ot **AND**, or **N**egative **AND**.

The logic circuit symbol for the NAND function is



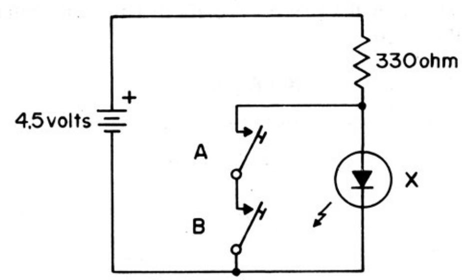
The symbol is similar to the AND symbol except for the small circle at the output. This small circle represents the **inversion** of the AND into a NAND.



Wiring Sequence

60–61, 53–50–62, 48–49, 47–54, 55–59

Circuit Diagram



9. IC TWO-INPUT "NAND" GATE

The two-input NAND function is the basic function of the 7400 IC. This IC is described as a "Quad two-input NAND gate." "Quad" means that there are four separate gates in one package. Each one of the four gates has two input leads.

Connect the circuit following the layout diagram and the wiring sequence listing.

Remember that when the input switches are open, the inputs will be at logic 0. Whenever a switch is closed, that particular input will be at a logic 1 level. The logic level of the output is indicated by LED X.

When both switches are open (0), the LED is on, indicating a 1 at the output. When either A or B is closed (1) but not both, the output is still at logic 1. When both A and B are closed (1) at the same time the output will go to logic 0.

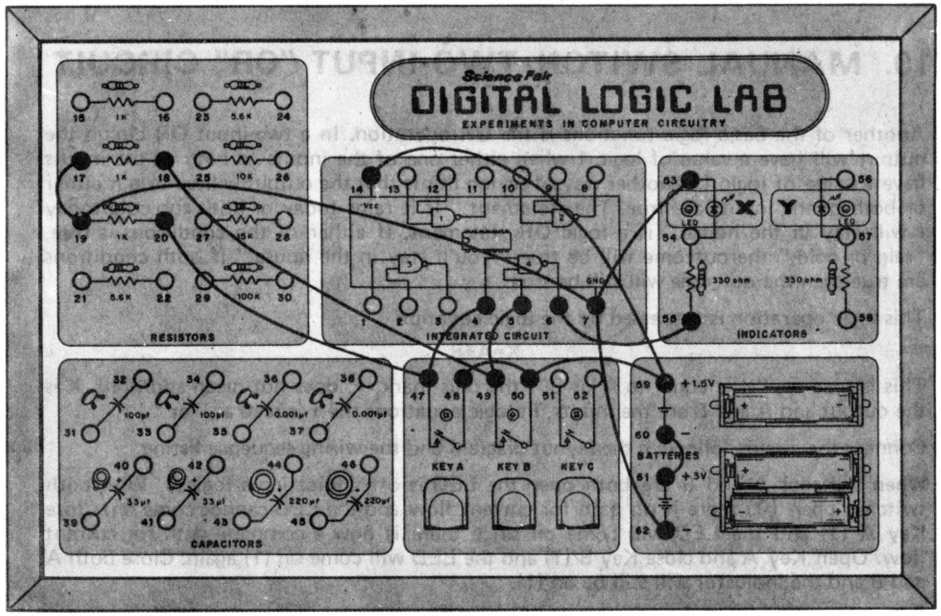
Using your observations of circuit action fill in the truth table below for the two-input IC NAND gate.

A	B	X
0	0	
0	1	
1	0	
1	1	

This table should be identical to the one for Project 8. The logic equation is the same for this circuit as it was for Project 8.

$$X = \overline{A \times B}$$

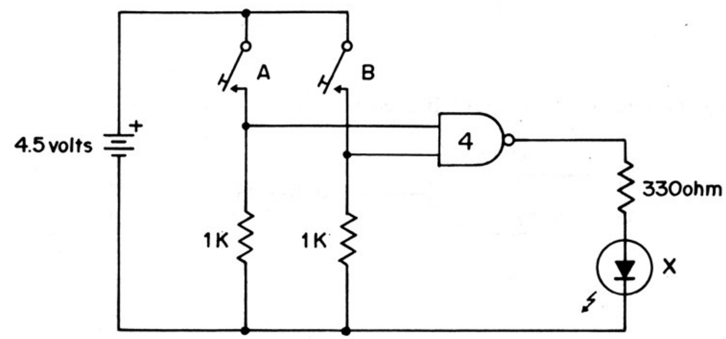
NOTES



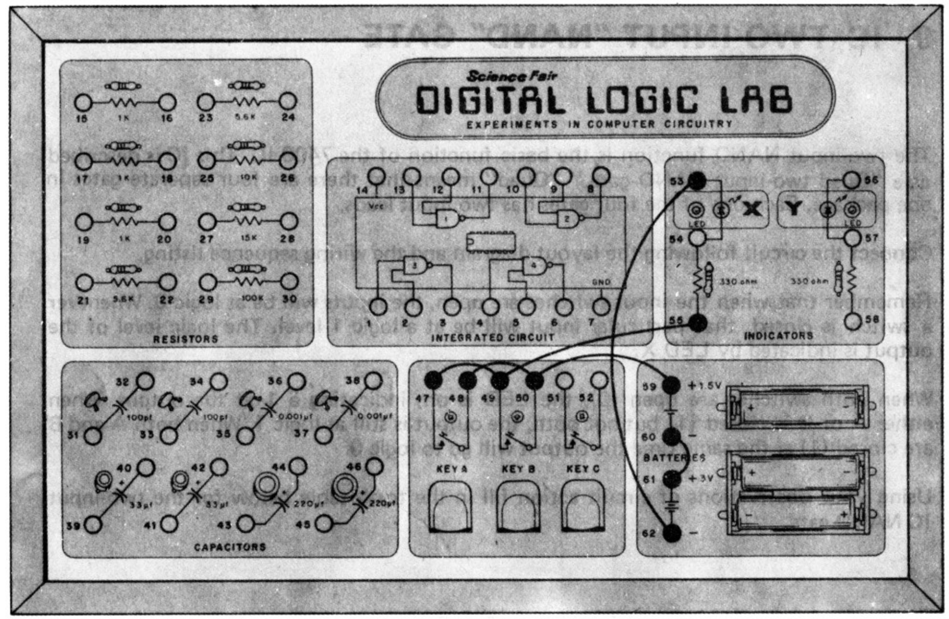
Wiring Sequence

60–61, 17–19–7–53–62, 18–49–5, 20–47–4, 6–55, 48–50–59–14

Circuit Diagram



10. MANUAL SWITCH TWO-INPUT "OR" CIRCUIT



Another of the basic logic functions is the OR operation. In a two-input OR circuit the output will have a value of logic 1 when either one of the inputs or both of the inputs have a value of logic 1. Another way of saying this is that the output will be true if either or both of the inputs are true. The statement, "If it rains today or if it's too cold today I will stay in the house." is a logic OR statement. If either of the conditions is true, "rain or cold," the outcome will be true, "you'll stay in the house." If both conditions are true then the outcome will still be true.

This logic operation is expressed by the logic equation

$$X=A+B$$

This is read as, "X is equal to A **or** B" (the plus mark, +, does not mean addition). X is the output and A and B are the inputs. In logic equations the + is read as, "or".

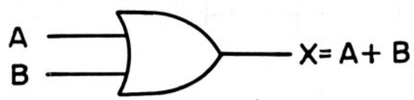
Connect the circuit following the layout diagram and the wiring sequence listing.

When switches A and B are both open the LED is off, indicating a logic 0. With both switches open (0) there is no path for current flow and the LED cannot come on. Close Key A (1) and the LED will come on since there is now a complete path for current flow. Open Key A and close Key B (1) and the LED will come on (1) again. Close both A and B and the indicator will still be on (1).

Fill in the truth table below for the two-input OR circuit.

A	B	X
0	0	
0	1	
1	0	
1	1	

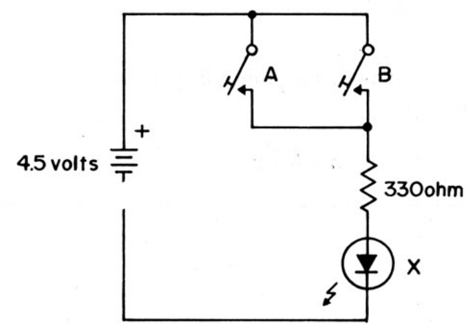
The logic symbol for the two-input OR circuit is



Wiring Sequence

60–61, 53–62, 48–50–59, 47–49–55

Circuit Diagram



11. IC TWO-INPUT "OR" GATE

The two-input OR function can be performed by properly connecting three NAND gates as shown in the circuit diagram below. The combination of one NAND gate and two inverters performs this OR function.

Connect the circuit following the layout diagram and the wiring sequence listing.

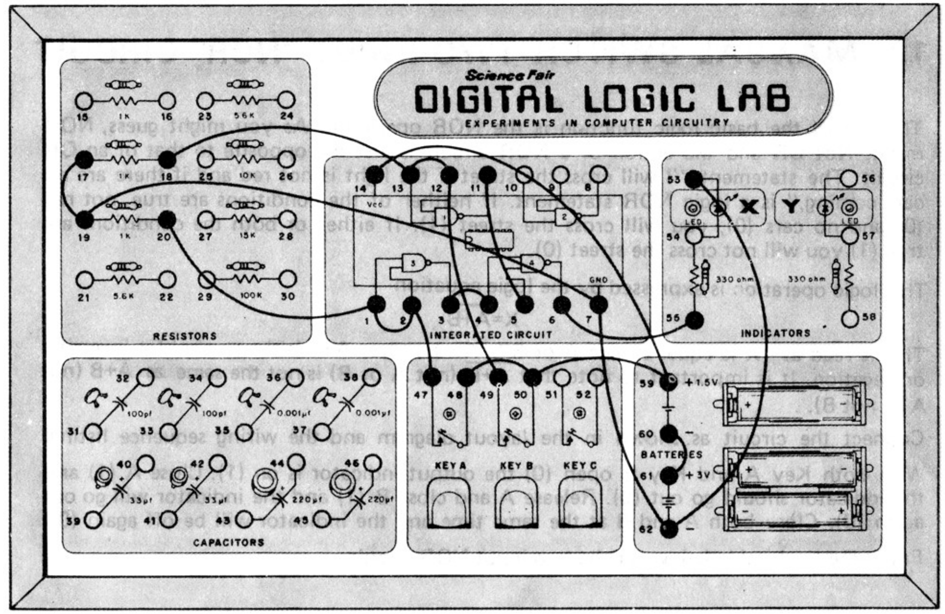
With both switches open (0), the output indicator will be off (0). Close Key A (1) and the output indicator will come on indicating a logic 1. Release Key A and close Key B (1). The output indicator should once again be on (1). Now close both A and B at the same time. The indicator should be indicating a 1. Using your observations of circuit action, fill in the truth table below for the two-input IC OR gate.

A	B	X
0	0	
0	1	
1	0	
1	1	

This table should be indentical to the one for Project 10. The logic equation is the same for this circuit as it was for Project 10.

X=A+B

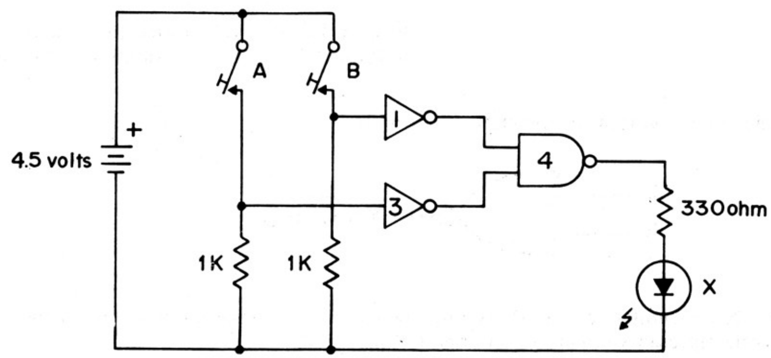
NOTES



Wiring Sequence

60–61, 17–19–7–53–62, 18–13–12–49, 20–1–2–47, 5--11, 3–4, 6–55, 48–50–59–14

Circuit Diagram



12. MANUAL SWITCH TWO-INPUT "NOR" CIRCUIT

The last of the basic logic function is the NOR operation. As you might guess, NOR means **Not OR** and the action of a NOR circuit is just the opposite to that of an OR circuit. The statement, "I will cross the street if the light is not red and if there are no cars coming," is a logic NOR statement. If neither of the conditions are true, not red (0) and no cars (0), you will cross the street (1). If either or both the conditions are true (1) you will not cross the street (0).

This logic operation is expressed by the logic equation

$$X=\overline{A+B}$$

This is read as "X is equal to **not** A or B". The bar over A+B is the symbol for inversion or negation. It is important to note that $\overline{A+B}$ (not A or B) is not the same as $\overline{A}+\overline{B}$ (not A or not B).

Connect the circuit as shown in the layout diagram and the wiring sequence listing.

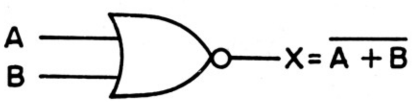
With both Key A and Key B open (0) the output indicator is on (1). Close A (1) and the indicator should go out (0). Release A and close B (1) and the indicator will go out again (0). Close both A and B at the same time and the indicator will be off again (0).

Fill in the truth table below for the two-input NOR circuit.

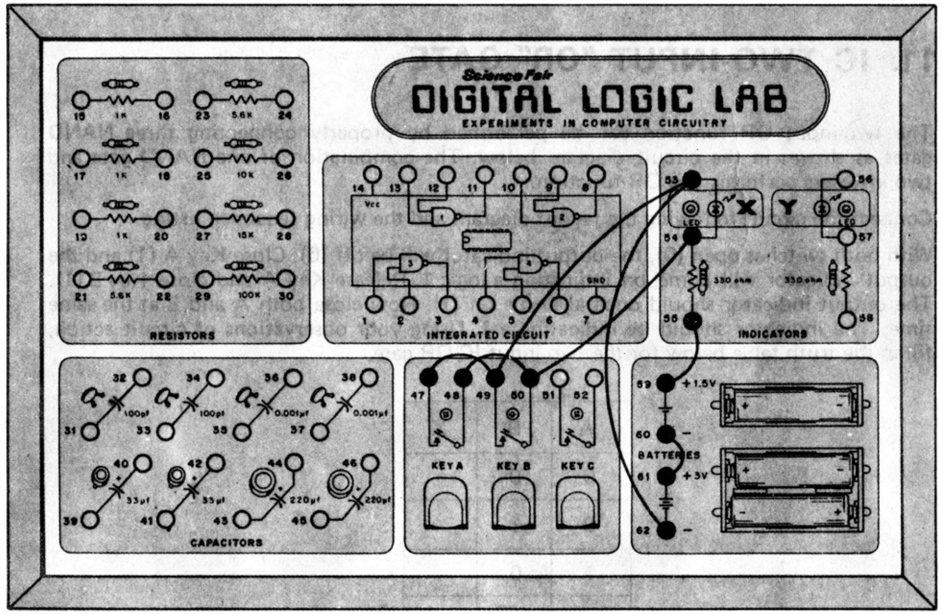
A	B	X
0	0	
0	1	
1	0	
1	1	

Compare this truth table with the one in Project 10. You will notice that column X in this chart is just the opposite of column X in Project 10. The NOR function is the inverse of the OR function.

The logic circuit symbol for the NOR function is



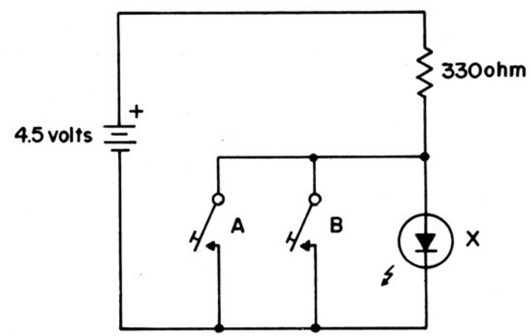
This symbol is similar to the OR symbol except for the small circle at the output. This small circle represents the inversion of an OR into a NOR.



Wiring Sequence

60–61, 47–49–53–62, 48–50–54, 55–59

Circuit Diagram



13. IC TWO-INPUT "NOR" GATE

The two-input NOR function can be performed by properly connecting four NAND gates as shown in the circuit diagram below. The combination of one NAND gate and three inverters perform the NOR function.

Connect the circuit following the layout diagram and the wiring sequence listing.

With both switches open (0), the output indicator will be on (1). Close either Key A (1) or Key B (1) and notice that the output indicator will go off (0). Close both A (1) and B (1) and notice that the indicator will again go off (0).

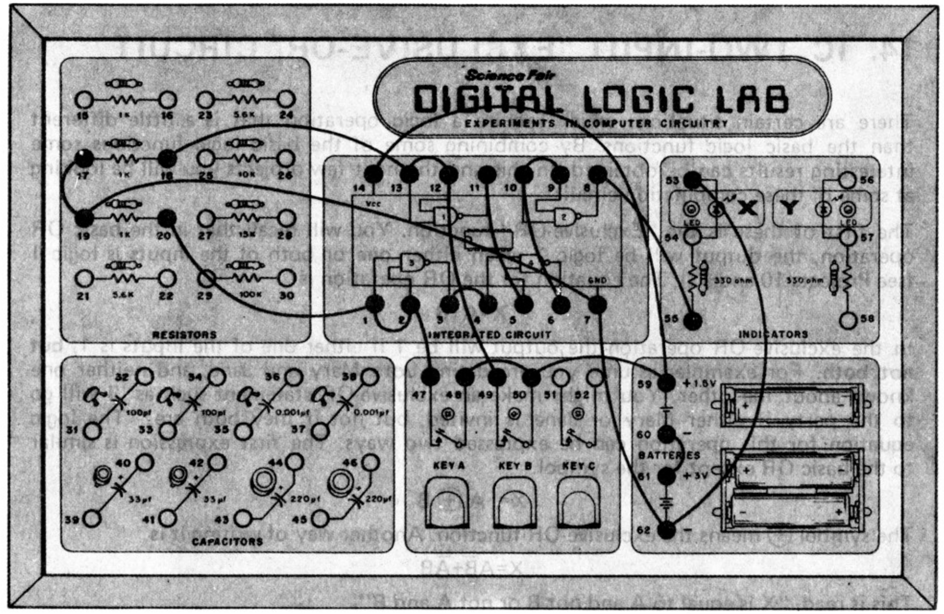
Using your observations of circuit action, fill in the truth table below for the two-input IC NOR gate.

A	B	X
0	0	
0	1	
1	0	
1	1	

This truth table should be identical to the one for Project 12. The logic equation is the same for this gate as it was for Project 12.

$$X=\overline{A+B}$$

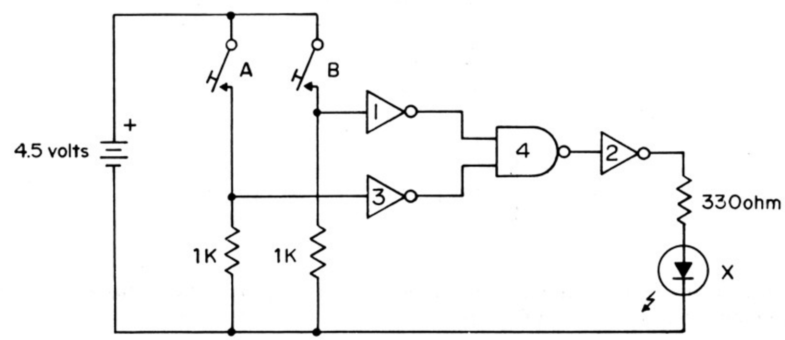
NOTES



Wiring Sequence

60–61, 17–19–7–53–62, 18–13–12–49, 20–1–2–47, 5–11, 3–4, 6–9–10, 8–55, 48–50–59–14

Circuit Diagram



14. IC TWO-INPUT "EXCLUSIVE-OR" CIRCUIT

There are certain situations which require a logic operation that is a little different than the basic logic functions. By combining some of the basic logic functions some interesting results can be obtained. In this and the next few projects you will be looking at some of these combination circuit.

The first of these is the "Exclusive-OR" function. You will recall that in the basic OR operation, the output will be logic 1 when either one or both of the inputs is logic 1 (see Projects 10 and 11) The equation for the OR operation is

$$X=A+B$$

In the exclusive-OR operation the output will be 1 if either one of the inputs is 1, **but not both**. For example, assume you are dating both Mary and Jane, and neither one knows about the other. You might make an exclusive-OR statement such as "I will go to the party if either Mary or Jane is invited, but not if they both are." The logic equation for this operation can be expressed two ways. The first expression is similar to the basic OR except for the symbol.

$$X= A \oplus B$$

The symbol $\oplus$ means the exclusive-OR function. Another way of writing it is

$$X=A\overline{B}+\overline{A}B$$

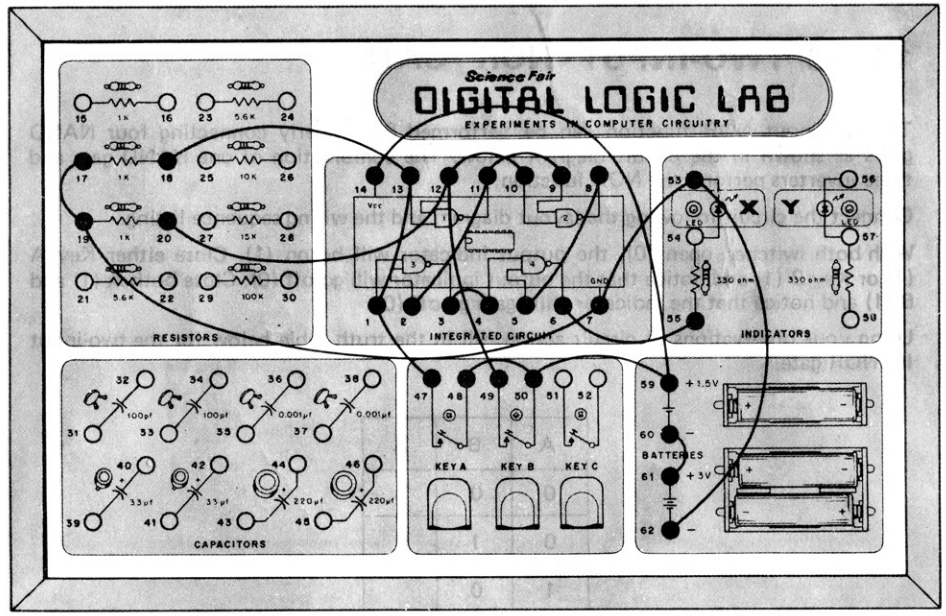
This is read, "X is equal to A and not B or not A and B".

The exclusive-OR function can be implemented by using all four NAND gates as shown in the circuit diagram below. Follow the layout diagram and the wiring sequence listing and connect the circuit.

Go through the following switch sequence and observe the output indicator. Leave both switches open, A=0, B=0. Now close switch A and release it. Close switch B and release it. Now close both A and B at the same time. From your observations of circuit action, fill in the truth table below for the IC two-input exclusive-OR circuit.

A	B	X
0	0	
0	1	
1	0	
1	1	

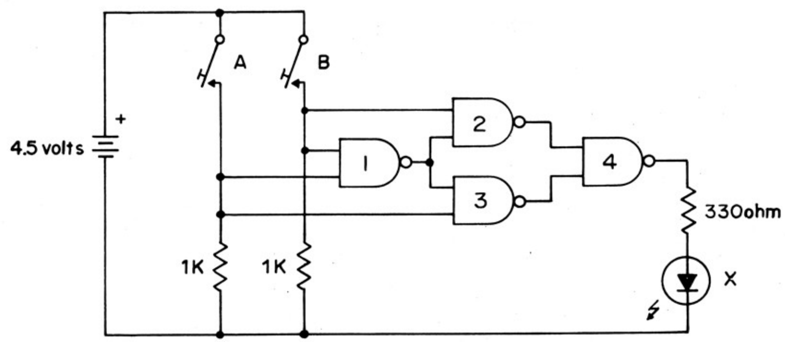
Compare this truth table with the one for Project 11 and note the difference. Leave this circuit connected for the next Project.



Wiring Sequence

60–61, 17–19–7–53–62, 18–13–1–47, 20–12–10–49, 2–11–9, 3–4, 5–8, 6–55, 48–50–59–14

Circuit Diagram



15. IC TWO-INPUT COMPARATOR CIRCUIT

Another interesting operation is the comparator function. The comparator function is just the opposite of the exclusive-OR. In this operation the circuit **compares** the two inputs and will give an output when both inputs are the same. When both inputs are at logic 0 there will be an output of logic 1. When both inputs are at logic 1 there will also be a logic 1 output. When either of the inputs is logic 1 and other is logic 0 the output will be logic 0.

Unfortunately it requires five NAND gates to connect a real comparator circuit. An inverter connected to the output of the exclusive-OR circuit produces the comparator function. Since there are only four gates in your kit you cannot make a real comparator but we can similate the comparator function by making a minor change in the previous circuit. By connecting the output to sink the indicator instead of sourcing it we can simulate the comparator function. (Review Project 5 if necessary for the difference between sinking and sourcing the output load.) Change the connection of the indicator as shown in the diagrams and the wiring sequence listing.

Try the various switch combinations listed in the truth table below and fill in the corresponding output condition.

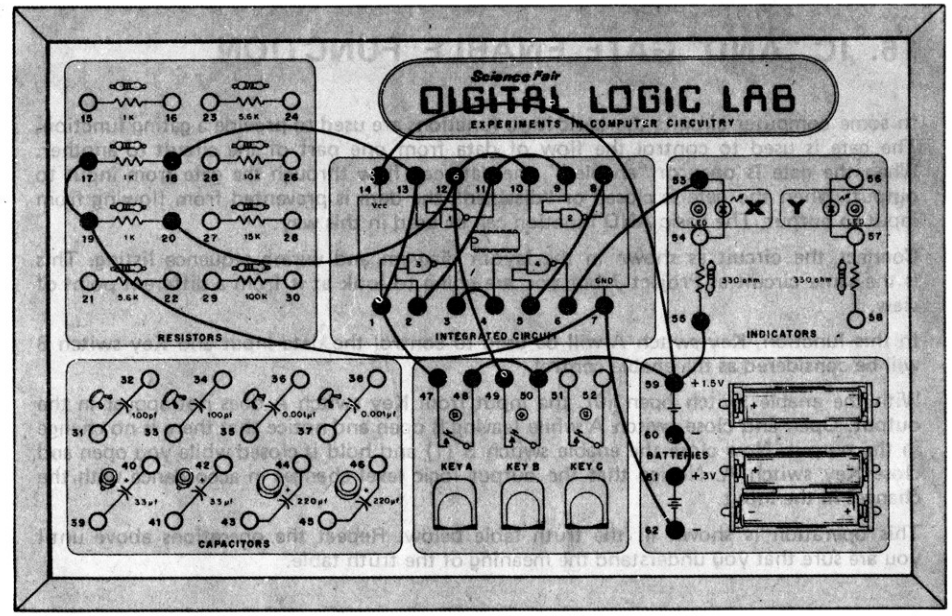
A	B	X
0	0	
0	1	
1	0	
1	1	

The logic equation for this operation is

$$X=AB+\overline{A}\overline{B}$$

This is read, "X is equal to A and B or not A and not B".

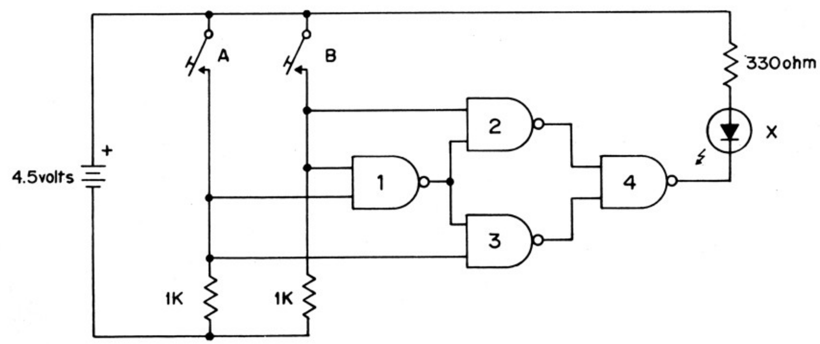
NOTES



Wiring Sequence

60–61, 17–19–7–62, 18–13–1–47, 20–12–10–49, 2–11–9, 3–4, 5–8, 6–53, 48–50–59–55–14

Circuit Diagram



16. IC "AND" GATE ENABLE FUNCTION

In some computer circuits the basic logic functions are used to provide a gating function. The gate is used to control the flow of data from one part of the circuit to another. When the gate is open or "enabled", the data can flow through the gate from input to output. When the gate is closed or "disabled" the data is prevented from flowing from input to output. The basic AND function can be used in this way.

Connect the circuit as shown in the layout diagram and wiring sequence listing. This is the same circuit as Project 7 but you are going to look at it from a different point of view.

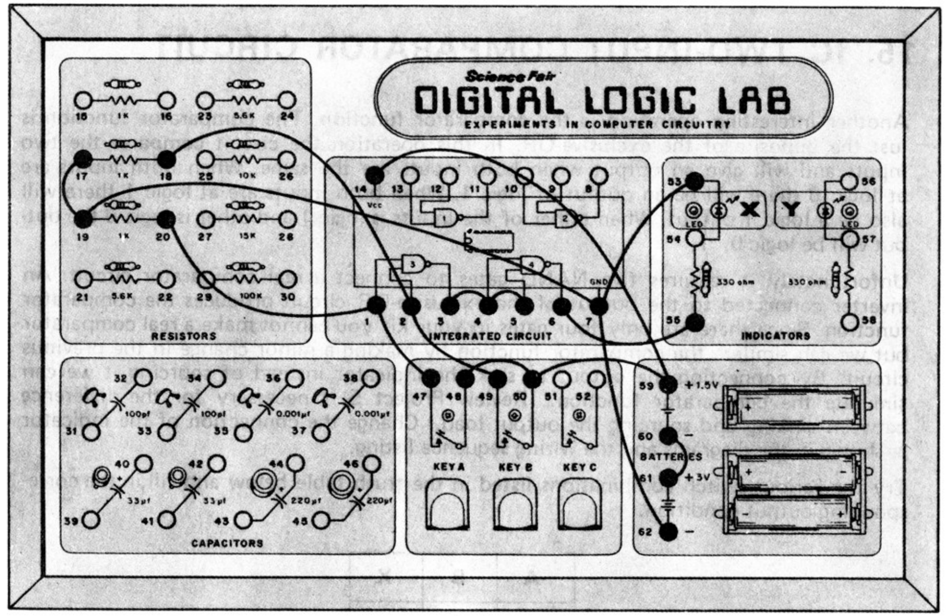
In this function, Key switch A will be used to control the data input and Key switch B will be considered as the enable control.

With the enable switch open (0), the input from Key switch A does not appear in the output. Open and close switch A while leaving B open and notice that there is no change in the output. Now close the enable switch B (1) and hold it closed while you open and close Key switch A. Notice that the output logic level changes in accordance with the changes in the input.

This operation is shown in the truth table below. Repeat the operations above until you are sure that you understand the meaning of the truth table.

ENABLE	OUTPUT
0	0
1	A

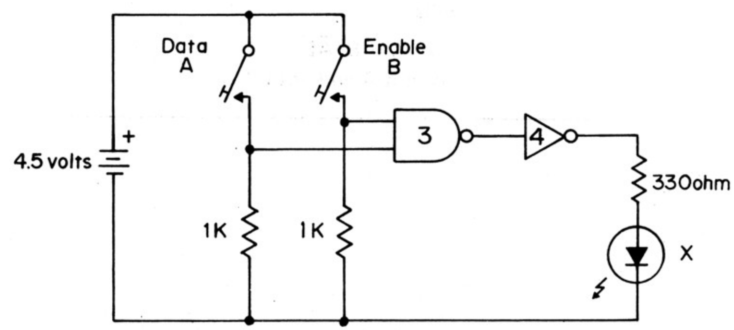
NOTES



Wiring Sequence

60–61, 17–19–7–53–62, 18–2–49, 20–1–47, 3–4–5, 6–55, 48–50–59–14

Circuit Diagram



17. IC "NAND" GATE ENABLE FUNCTION

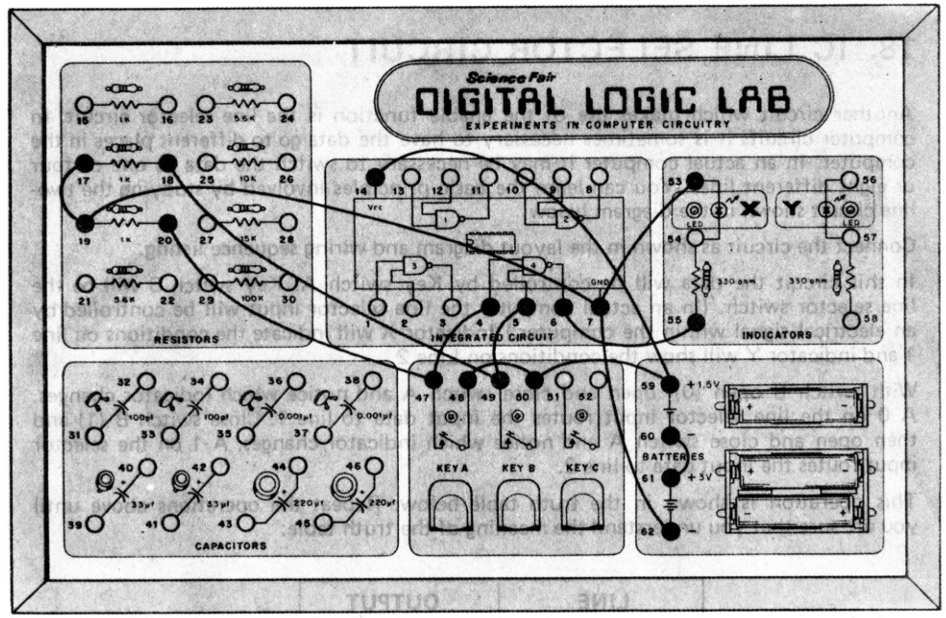
The enable function of the previous circuit can also be performed with a single NAND gate as shown in the circuit diagram below. The operation of this circuit is quite similar to the previous one except that the output data will be inverted from the input. This can be tolerated in some circuits and results in fewer components being used.

Connect the circuit following the layout diagram and the wiring sequence listing. This is the same circuit as Project 9 but once again the viewpoint is different.

Key switch A will control the data input and Key switch B will be considered as the enable control. With the enable switch open (0), the input from Key switch A does not appear in the output and the output remains at the logic 1 level. Open and close switch A and notice that there is no change in the output level. With the enable switch closed (1), open and close switch A and notice that these data changes appear inverted in the output. This operation is shown in the truth table below. Repeat the operations above until you are sure that you understand the meaning of the truth table.

ENABLE	OUTPUT
0	1
1	$\overline{A}$

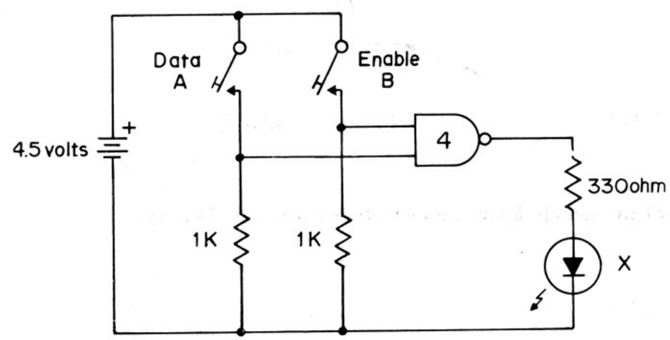
NOTES



Wiring Sequence

60–61, 17–19–7–53–62, 18–49–5, 20–47–4, 6–55, 48–50–59–14

Circuit Diagram



18. IC LINE SELECTOR CIRCUIT

Another circuit which makes use of the enable function is the line selector circuit. In computer circuits it is sometimes necessary to have the data go to different places in the computer. In an actual computer it may be necessary to switch the data to one of four or eight different lines. You can learn the basic principles involved by studying the two-line circuit shown in the diagram below.

Connect the circuit as shown in the layout diagram and wiring sequence listing.

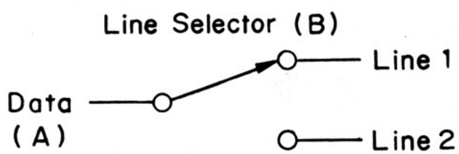
In this circuit the data will be controlled by Key switch A. Key switch B will be the line selector switch. (In an actual computer the line selector input will be controlled by an electrical signal within the computer.) Indicator X will indicate the conditions on line 1 and indicator Y will show the conditions on Line 2.

With switch B open (0), open and close switch A and notice which indicator changes. A 0 on the line selector input routes the input data to line 1. Close switch B (1) and then open and close switch A and notice which indicator changes. A 1 on the selector input routes the input data to line 2.

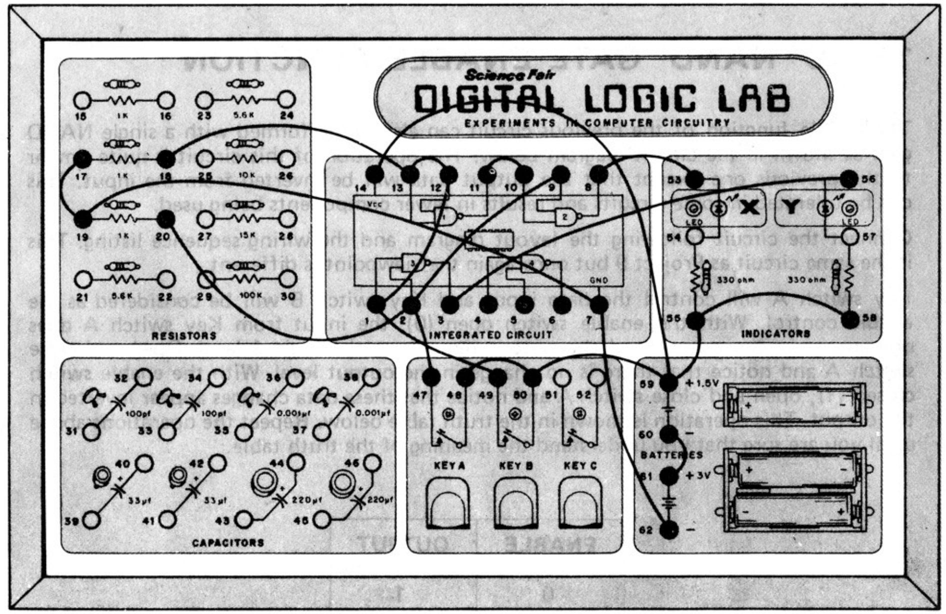
This operation is shown in the truth table below. Repeat the operations above until you are sure that you understand the meaning of the truth table.

LINE SELECTOR	OUTPUT LINE NO.
0	1
1	2

This circuit is the logic equivalent of a SPDT switch as shown below.



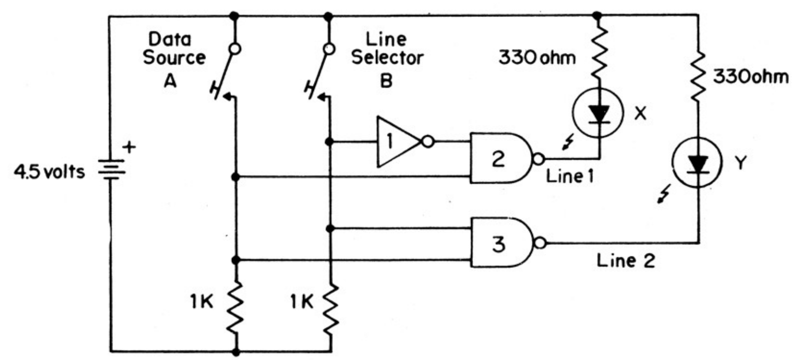
The position of the switch determines which line receives the data.



Wiring Sequence

60–61, 17–19–7–62, 18–13–12–1–49, 20–2–47–9, 3–56, 10–11, 8–53, 48–50–59–55–58–14

Circuit Diagram



19. IC SOURCE SELECTOR

Another computer function which can be illustrated is the source selector circuit. It is sometimes necessary to have data from different sources switched onto one line at different times. In actual computers there may be eight, sixteen or more data sources connected to one line at different times. The source selector circuit allows only one specific data source to be connected to the line at a time. This type of circuit is sometimes called a **multiplexer**. The basic operation of a source selector can be studied with the two-source circuit shown in the diagram below.

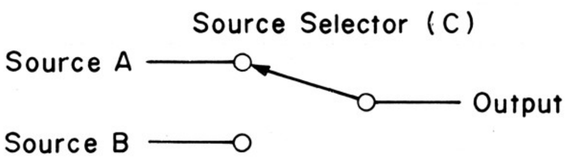
Follow the layout diagram and the wiring sequence listing and connect the circuit.

In this circuit the data will be controlled by switches A and B. Switch C will function as the source selector. (In an actual computer the source selector input will be controlled by an electrical signal within the computer.) Indicator X will indicate the conditions on the output line.

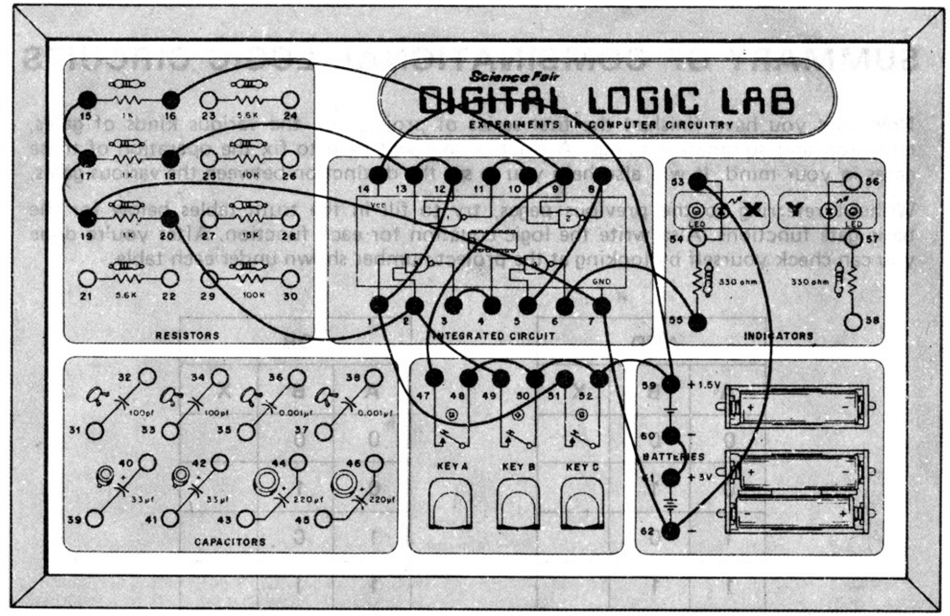
With switch C open (0), determine which input switch controls the output. A 0 on the source selector input selects data source A to appear in the output. Close switch C (1) and notice that Key switch B now controls the output and A has no effect on the output. This operation is shown in the truth table below. Repeat the above operations until you are sure you understand the meaning of the truth table.

SOURCE SELECTOR	SOURCE
0	A
1	B

This circuit is the logic equivalent of a SPDT switch as shown below.



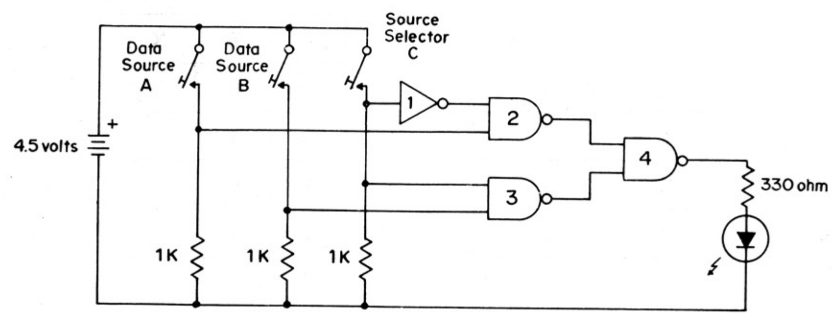
The position of the switch detemines which data source is selected.



Wiring Sequence

60–61, 15–17–19–7–53–62, 16–9–47, 18–13–12–1–51, 20–2–49, 10–11, 5–8, 3–4, 6–55, 48–50–52–59–14

Circuit Diagram



SUMMARY OF COMBINATIONAL LOGIC CIRCUITS

Now that you have finished the first series of projects on the various kinds of gates, let's stop and summarize things. A brief review will help to fix the operation of these gates in your mind. It will also help you to see the distinction between the various gates.

Without referring to the previous pages, try to fill in the truth tables below for the basic gate functions. Also write the logic equation for each function. After you're done you can check yourself by looking at the project number shown under each table.

AND		
A	B	X
0	0	
0	1	
1	0	
1	1	

X = ______
(See Project 6)

OR		
A	B	X
0	0	
0	1	
1	0	
1	1	

X = ______
(See Project 10)

NAND		
A	B	X
0	0	
0	1	
1	0	
1	1	

X = ______
(See Project 8)

NOR		
A	B	X
0	0	
0	1	
1	0	
1	1	

X = ______
(See Project 12)

Carefully look at the X column for each function. Notice that for each function there is one value of X that is unique. One value of X may be 0 and all the rest 1s or one value of X may be 1 and all the rest 0s. In the spaces below, for each function write the input conditions corresponding to the unique output level. The first one is done for you; you fill in the rest.

In the AND function the unique output is a logic __1__ which occurs when A and B are both __1__ .

In the OR function the unique output is a logic ______ which occurs when A and B are both ______ .

In the NAND function the unique output is a logic ______ which occurs when A and B are both ______ .

In the NOR function the unique output is a logic ______ which occurs when A and B are both ______ .

Now complete these summary statements.

For the AND and NAND functions the unique output conditions are opposite but both occur when A and B are both ______ .

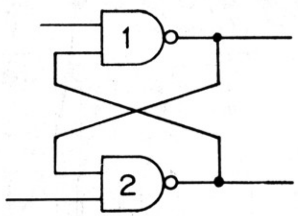
For the OR and NOR functions the unique output conditions are opposite but both occur when A and B are both ______ .

NOTES

INTRODUCTION TO SEQUENTIAL LOGIC CIRCUITS

The next group of circuits which you will be studying are in a division of logic called **sequential logic**. In these circuits the order in which data appears at the various inputs is important. The **sequence** of the inputs determines the logic level at the output of the circuit.

The most common of the sequential logic circuits is the multivibrator (MV). The basic connection for a multivibrator is shown below.



The output of the first gate is connected back to one of the inputs of the second gate. The output of the second gate is connected to one of the inputs of the first gate. This sort of connection provides what we call feedback. The main purpose of the feedback is to cause the gates to be turned on and off at very fast speeds. In these circuits only one gate is on at a time. When 1 is on, 2 is off. When 2 is on, 1 is off.

By modifying the basic circuit slightly and controlling the feedback these circuits can be made to do some very interesting things. There are three types of multivibrators which you will be studying. These are:

1. Astable multivibrator
2. Bistable multivibrator
3. Monostable multivibrator

As you might guess from the names, the difference between the three types of MVs has to do with their stability conditions.

The astable multivibrator is sometimes called a **free-running multivibrator**. The prefix "a-" means "without" and indicates that there is no stable state for this circuit. The two gates continually switch back and forth with first one conducting and then the other. An astable multivibrator is formed by placing resistors and capacitors in both feedback paths to control the speed of the switching action.

The second type of multivibrator, the bistable MV, is usually referred to as a **flip-flop**. The prefix "bi-" means "two" (just like **bi**cycle). This indicates that there are two stable conditions of the flip-flop. In this kind of MV one of the gates can be turned on and it will remain on until the proper sequence of input signals turns the second gate on the first gate off. It will remain in this condition until the first is turned on again. The conducting conditions are sometimes called **states**. The basic bistable flip-flop circuit very closely resembles the basic circuit shown above with the direct feedback between outputs and inputs.

The third kind of MV has only one stable condition or state since the prefix "mono-" means "one" In this type of MV the circuit will have a certain initial state with one of the gates conducting. A proper input signal will cause the gates to switch to the opposite state. They will remain in this second state for a predetermined length of time and then return to the original state. This circuit uses resistors and capacitors in only one of the feedback paths. The monostable MV is sometimes called a **one-shot MV.**

Multivibrators and flip-flops are used extensively in digital circuits and computers to provide counting, timing and memory functions.

NOTES

20. ASTABLE MULTIVIBRATOR

In some equipment employing digital circuits, and many times in other equipment as well, it is necessary to generate an electrical signal. This signal may be a very low frequency which switches back and forth only a few times each second or it may be a much faster signal with a frequency measured in the kilohertz (kHz) or megahertz (MHz) range. The circuits used to generate these signals fall into a broad category called **oscillators**. The astable multivibrator or free-running multivibrator is basically an oscillator as well as a logic circuit.

The circuit diagram of an astable MV is shown below. Notice several things about the diagram as compared to the basic MV diagram in the introductory material on the previous page. First the gates are connected as inverters since we only need their amplifying and inverting properties for this circuit. Second, the feedback paths have been changed to include resistors and capacitors to control the frequency of operation. Third, there are no input connections to this MV. This circuit is a self-starting, free-running MV and does not need an input signal to get it going. It generates the signal itself. We have shown an LED indicator at each output to show the switching action of the MV. In actual circuits there is usually only one output used.

Follow the layout diagram and the wiring sequence listing and connect the circuit. As soon as you make the last connection to pin 14 of the IC, one of the LEDs should come on. It will remain on for a fraction of a second and then turn off as the other LED comes on. The alternate blinking of the LED indicators shows that the circuit is oscillating with first one gate on and then the other.

Try to determine the frequency of oscillation by estimating the time it takes between successive lightings of one LED. This length of time is called the **period** of oscillation and is usually represented by the letter T. The frequency (F) is related to the period (T) by the equation

$$F = \frac{1}{T}$$

If the period is 0.5 second, the frequency is

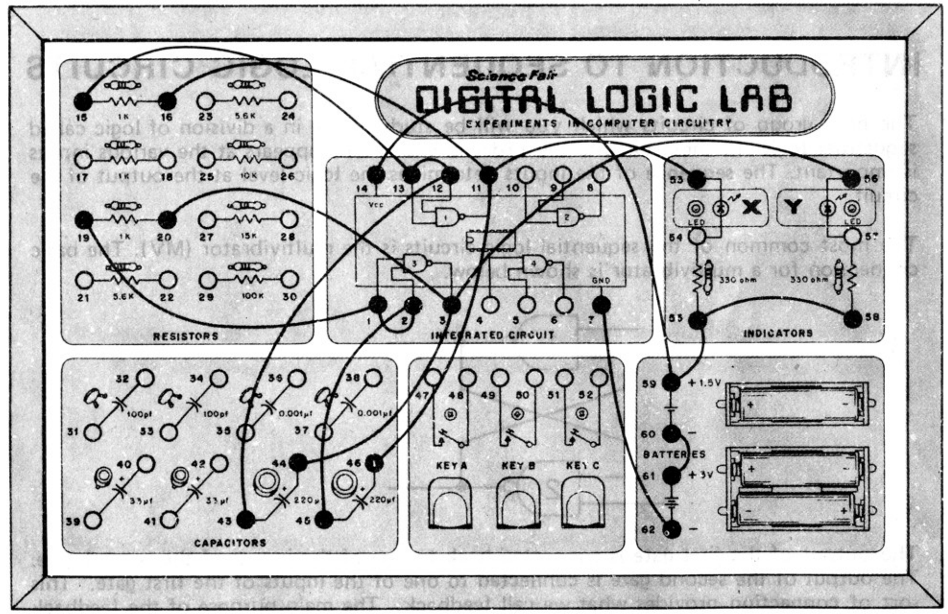
$$F = 1/.5 = 2Hz.$$

You can estimate the period more accurately if you count the time for 10 complete cycles of on and off and then divide the time by 10.

Estimate the period for your MV. ____________ seconds. Calculate the frequency.

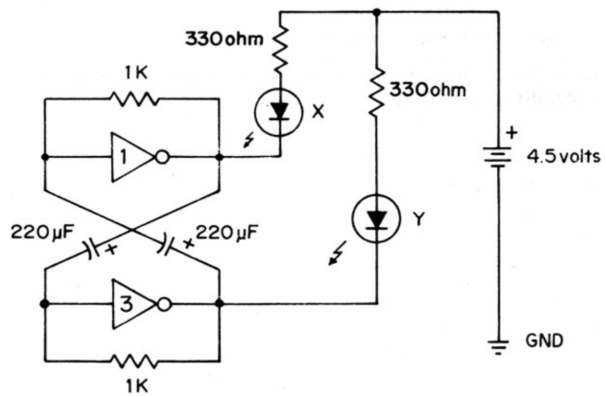
F=1/   = ______ Hz

The frequency of the MV can be changed by using different values of capacitance in the feedback. Temporarily disconnect the lead at pin 14. Move the lead from terminal 43 to terminal 39, from 45 to 41, from 44 to 40, and from 46 to 42. This places the 33μF capacitors in the feedback instead of the 220μF capacitors. Reconnect the lead to terminal 14 and notice how much faster the LEDs switch on and off. The smaller the value of the capacitors, the higher will be the frequency.



Wiring Sequence

60–61, 15–13–12–43, 44–3–20–56, 16–11–46–53, 19–1–2–45, 7–62, 58–55–59–14



21. BISTABLE MULTIVIBRATOR

There are several kinds of bistable multivibrators or flip-flops that are popular in digital circuits. These are.

1. R-S flip-flop
2. J-K flip-flop
3. D flip-flop

You will only be studying the first type since the others require more gates than are available in your kit. The R-S flip-flop is the simplest of the three and is sort of a building block for the other two.

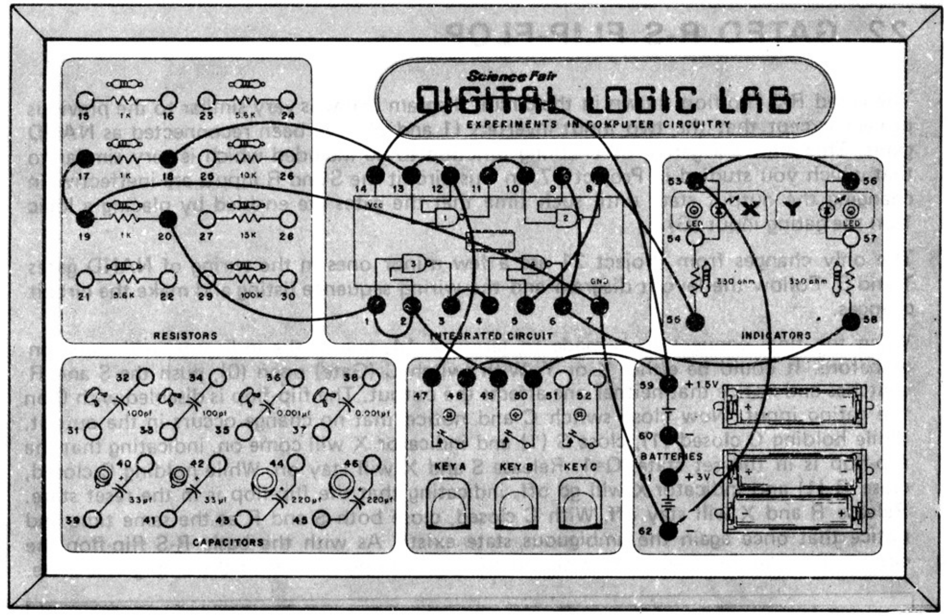
The letters R and S come from the terms **R**est and **S**et. In the circuit diagram below you will notice that the two inputs are labelled S (set) and R (reset). There are two outputs labelled Q and $\overline{Q}$ **(not** Q). Q and $\overline{Q}$ are the symbols used for the two normal outputs of all types of flip-flops. As the symbols imply, the Q and $\overline{Q}$ outputs will always be of opposite logic level in normal operation. If the Q output is at logic 1, the $\overline{Q}$ output will be at logic 0. If Q is 0, $\overline{Q}$ will be 1. The logic level of the outputs are referred to as either the conditions of the flip-flop or the state of the flip-flop. For example, if the Q output is logic 1, the flip-flop is in the **set** state. If the Q output is logic 0, the flip-flop is in the **reset** state.

The inputs to the R-S FF determine the state of the flip-flop (FF is a fairly common abbreviation for flip-flop). Follow the layout diagram and the wiring sequence listing and connect the circuit. When you make the final connection to terminal 14, one of the indicators will be on (1) and one off (0). Try disconnecting the wire to 14 and reconnecting it several times. You may discover that sometimes X will be on and sometimes Y will be on.

Close Key A (S) and then release it. Indicator X will come on and Y will go off, indicating that the FF is in the "set" state. Close Key B (R) and then release it. Indicator Y will come on and X will go off indicating that the FF is in the "reset" state. With both switches open (0), the flip-flop will remain in its previous state. Now close both Keys at the same time and hold them closed (1). Notice that both outputs are at logic 1.

This is a confusing condition because Q and $\overline{Q}$ are both the same which should not be. This particular condition is called the ambiguous state or the illogical state or the disallowed state. In real equipment which uses R-S FF, the circuit is constructed in such a way that it is impossible to have both R and S at logic 1 at the same time. Release both switches and one indicator will go off. The state of the FF will be determined by which of the switches is the last to be released. Try closing both switches and then releasing R first and then S. Then try releasing S first and then R. You will discover that the last switch released will determine the state of the FF. You could use this circuit to compare the reflex action of a couple of your friends. Have each one hold a switch down. At a given signal from you, each one should release his switch. The light will stay on for the one who lets go of the switch last. He is the one with the slowest reflexes.

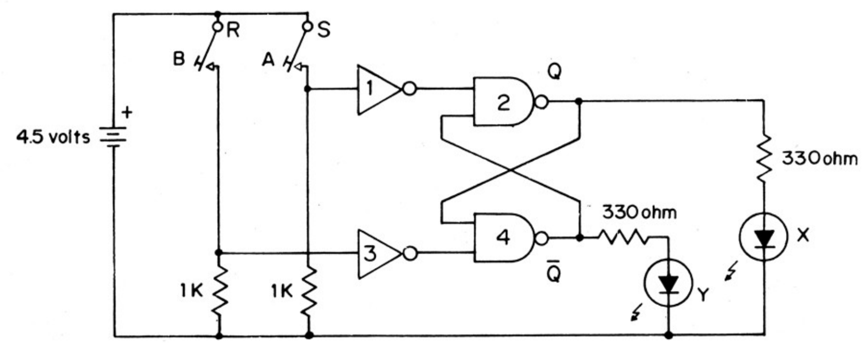
Do not disconnect this circuit as it will be used in the next project.



Wiring Sequence

60—61, 17—19—7—62—53—56, 18—13—12—47, 11—10, 3—4, 6—9—58, 5—8—55, 20—1—2—49, 48—50—59—14

Circuit Diagram



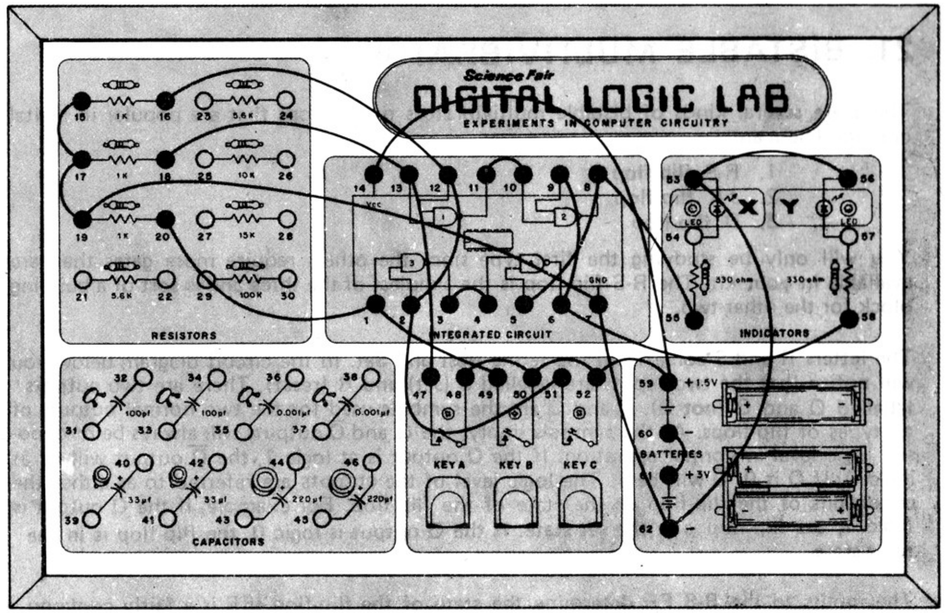
22. GATED R-S FLIP-FLOP

The gated R-S flip-flop shown in the circuit diagram below is very similar to the previous project except that the two input inverters (1 and 3) have been reconnected as NAND gates. This allows a gating or enabling function to be included which is very similar to that which you studied in Project 17. In this circuit the S and R inputs are ineffective in changing the output state until such time that the gates are enabled by placing a logic 1 on the gating input (G).

The only changes from Project 21 are a few minor ones in the wiring of NAND gates 1 and 3. Follow the layout diagram and the wiring sequence listing and make the circuit changes.

When the final connection is made to terminal 14, one of the indicators will come on as before. It could be either X or Y. With switch C (Gate) open (0), push the S and R switches and notice that neither one affects the output. The flip-flop is disabled with 0 on the gating input. Now close switch C and notice that no change occurs in the output. While holding C closed (1), close S (1) and indicator X will come on, indicating that the flip-flop is in the set state, Q=1. Release S and X will stay on. While holding C closed, close R (1) and indicator X will go off, indicating that the flip-flop is in the reset state. Release R and X will stay off. With C closed, close both S and R at the same time and notice that once again the ambiguous state exists. As with the basic R-S flip-flop the circuits they are used with are designed to avoid the possibility of the ambiguous state.

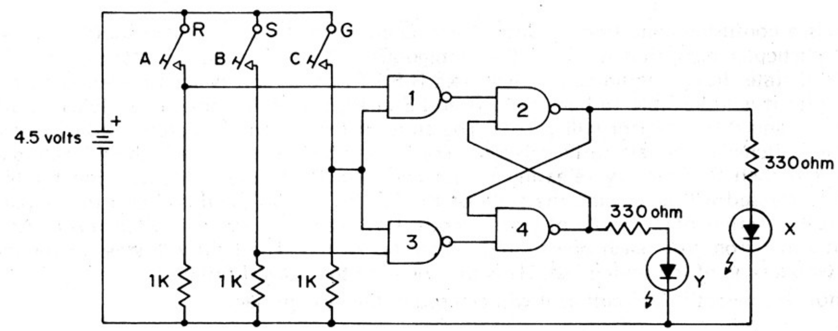
NOTES



Wiring Sequence

60–61, 15–17–19–7–62–53–56, 16–12–2–51, 18–13–47, 11–10, 3–4, 6–9–58, 5–8–55, 20–1–49, 48–50–52–59–14

Circuit Diagram



23. MONOSTABLE MULTIVIBRATOR

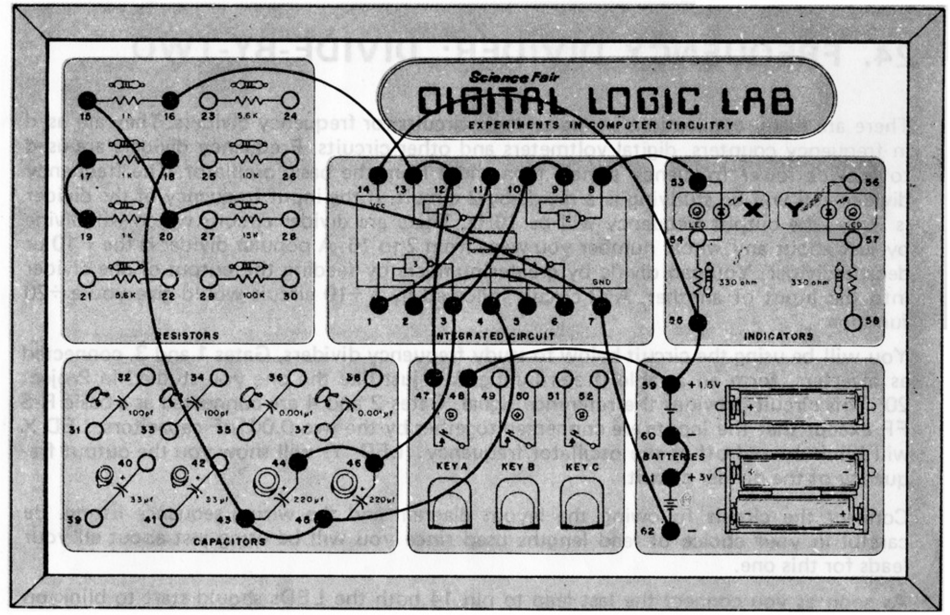
The third type of MV you will come across in digital circuits is the monostable MV. As mentioned in the introductory material, this type of MV has only one stable state. It can be driven out of the stable state by applying an appropriate pulse signal at its input, but it will return to the stable state after a predetermined length of time. The monostable MV is sometimes called a one-shot MV since you only get one pulse of output signal for each input pulse. The one-shot MV is used for FM detection and other purposes in digital circuits. Monostable MVs can be designed to turn on with either a positive pulse or a negative pulse. The circuit shown below will turn on with a positive pulse. When the switch is open, the input to the MV is held at a logic 0 by the 1k resistor to the battery negative terminal. When the switch is closed, the input to the inverter is raised to the logic 1 level since it is now connected to the battery positive terminal.

Follow the layout diagram and the wiring sequence listing and connect the circuit. When the last connection is made to pin 14 the LED should be dark.

Tap switch A lightly to make a momentary contact. The LED will come on for about a second or so and then go out. Try holding switch A closed for different lengths of time (all less than a second). Notice that the LED will stay lit for the same length of time regardless of how long the switch is held down. If you hold the switch down longer than the normal period of the MV the LED will just stay on until you release the switch.

If you happen to have some extra capacitors with values around 100 or 200μF you might try connecting them between terminals 43 and 44 or between 45 and 46. The extra capacitance will cause the LED to stay on longer when it is pulsed on.

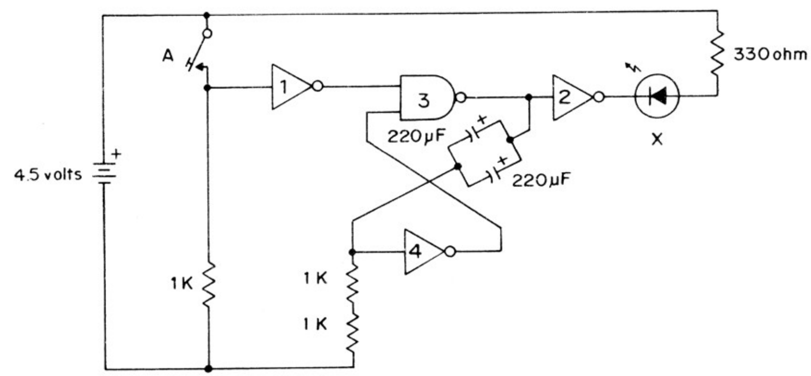
NOTES



Wiring Sequence

60–61, 15–20–7–62, 17–19, 18–43–45–4–5, 1–11, 16–13–12–47, 10–9–3–46–44, 2–6, 8–53, 48–59–55–14

Circuit Diagram



24. FREQUENCY DIVIDER: DIVIDE-BY-TWO

There are many applications in digital logic circuits for frequency dividers. They are used in frequency counters, digital voltmeters and other circuits. Frequency dividers are used to provide lower frequency signals than those from the basic oscillator. The frequency divider you will be studying is a divide-by-2 circuit. If the input frequency of the divider is 20Hz, the output frequency will be 10Hz. There are divider circuits which will divide by just about any whole number you want from 2 to 16. A popular divider is the ÷ 10 or decade divider. You can divide by greater numbers by feeding the output of one divider into the input of another, A÷2 circuit followed by a ÷10 circuit would give you a ÷20 function.

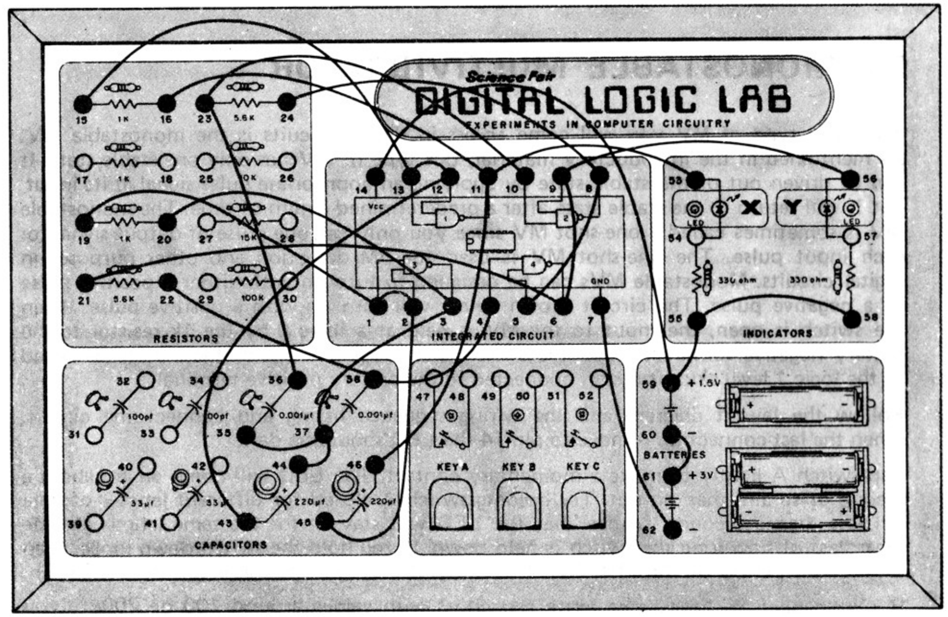
You will be using the circuit below to study frequency dividers. Gates 1 and 3, connected as inverters, form an astable (free-running) MV just like the one you studied in Project 20. This circuit provides the reference signal. Gates 2 and 4 are connected as a basic R-S FF except that the inputs are connected together by the two 0.001μF capacitors. LED X will blink on and off at the oscillator frequency. LED Y will show you the output frequency of the divider circuit.

Connect the circuit following the layout diagram and the wiring sequence listing. Be careful in your choice of lead lengths used since you will be using just about all your leads for this one.

As soon as you connect the last lead to pin 14 both the LEDs should start to blink on and off. Notice carefully that LED X is blinking twice as fast as LED Y. Here's how this one works. The first pulse from the astable MV will drive one of the R-S FF gates on and the other off. Let's say that the output of 4 is driven to 0 and LED Y comes on. The output of gate 3 must go through a complete on-off cycle before the next pulse drives the output of 2 to 0 and 4 to 1. One more complete cycle of output from 3 is necessary before the R-S FF will change states again. It takes two complete cycles of the oscillator to cause one complete cycle to occur at the output of the divider. Thus we have divided the frequency by 2.

Do not take this circuit apart. You will make a few changes in it for the next project.

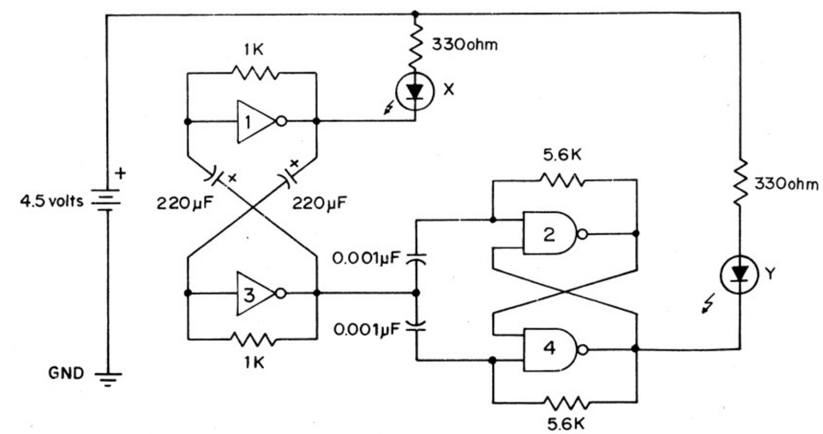
NOTES



Wiring Sequence

60–61, 7–62, 15–13–12–43, 35–37–44–3–20, 16–11–46–53, 19–1–2–45, 36–23–10, 22–38–4, 24–8–5, 21–6–9–56, 58–55–59–14

Circuit Diagram



25. ELECTRONIC GAME

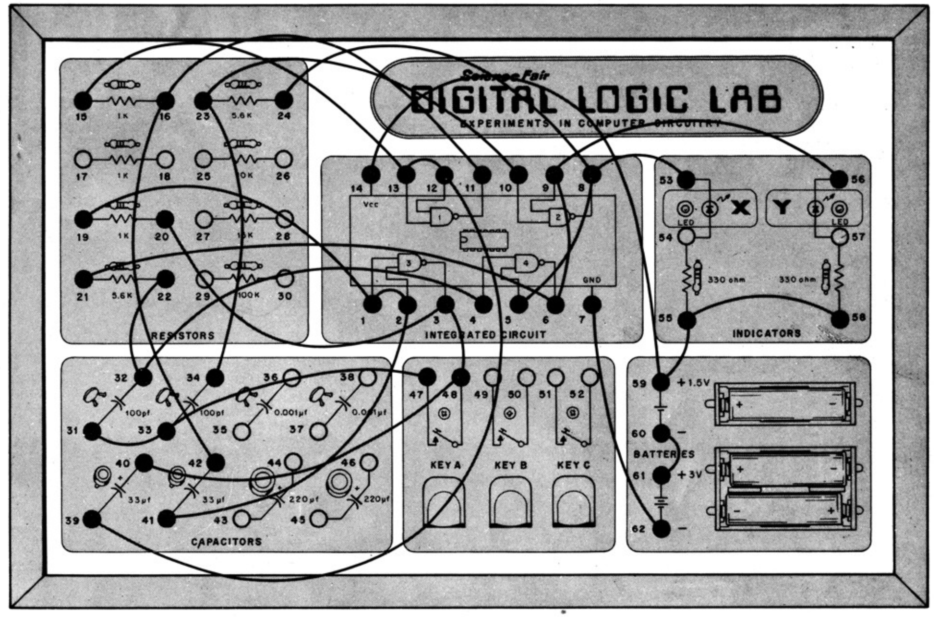
By making a few modifications to the previous circuit you can make an interesting game for yourself and your friends. Look at the circuit below and note the changes. The free-running multivibrator frequency is increased by changing the 200μF capacitors to 33μF. The input coupling capacitors to the R-S FF are changed to 100pF instead of 0.001μF. The LEDs are both connected to the output of the R-S FF. The input to the R-S FF goes through a switch.

Make the necessary changes by following the layout diagram and the wiring sequence listing. When the last connection is made to pin 14, one of the LEDs will be on.

Close Key switch A and the two LEDs will be blinking on and off at a very rapid rate. Release the switch and one of the LEDs will remain on and the other off. Try this a few times and you will notice that sometimes X will remain on and sometimes Y will remain on. The LED which remains on will depend upon which side of the R-S FF received the last effective pulse before you released the switch.

The fun comes in trying to predict which light will remain on when you release the switch. You could work out a system of points such as 1 point for each correct guess, extra bonus points for two or three correct guesses in a row, etc.. If you have an extremely good sense of timing and good reflexes you might try to figure out a way of getting it to stop just where you want it to. At the speed the lights switch on and off it will be very difficult to do this. Have fun!

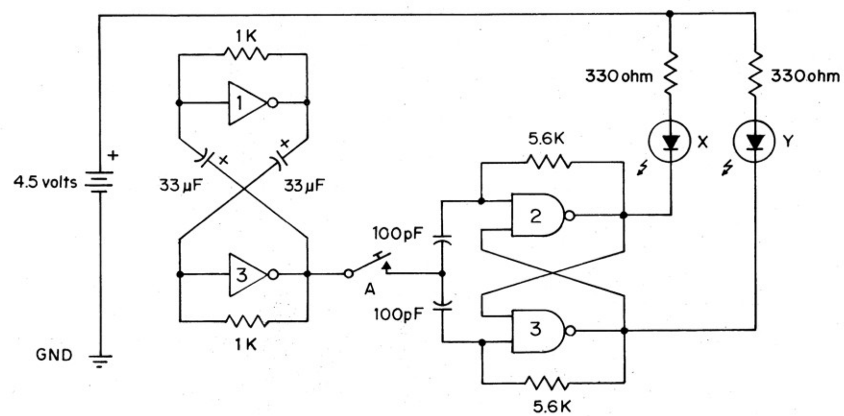
NOTES



Wiring Sequence

60–61, 7–62, 15–13–12–39, 20–3–48–40, 19–1–2–41, 42–16–11,
22–32–4, 21–6–9–56, 34–23–10, 24–8–5–53, 31–33–47, 58–55–59–14

Circuit Diagram



LIST OF EXPERIMENTS

PARTS LIST

NOTE: Most of these parts are already mounted on the platform inside the box. This parts list will just serve to remind you what parts make up your Digital Logic Lab kit.

Description	Part Number
Battery Holder for 1AA Penlight Cell	B-0275
Battery Holder for 2AA Penlight Cells	B-0166
Capacitors	
100 pF ceramic (2)	
0.001 μF ceramic (2)	
33 μF 10 (16)-volt electrolytic (2)	
220 μF 10 (16)-volt electrolytic (2)	
Integrated Circuit, SN7400N	
Vcc(max) = 5V, Pd(max) = 60mW, Icc (max)=48mA	
Key Lever with Knob (3)	K-2547
Light Emitting Diode, SLP24B (2)	L-0703
Platform for Parts and Spring Terminals	Z-3471
Resistors	
330ohm (2)	NEE-0159
1K (3)	NEE-0196
5.6K (2)	NEE-0257
10K	NEE-0281
15K	NEE-0297
100K	NEE-0371
Spring Terminals (62)	HB-4804
Screw, 3 x 6 (8)	HD-2055
Nut, 3mmφ (8)	HD-7003
Wires	
White, 7.5cm (10)	
Red, 15cm (14)	
Blue, 25cm (4)	

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