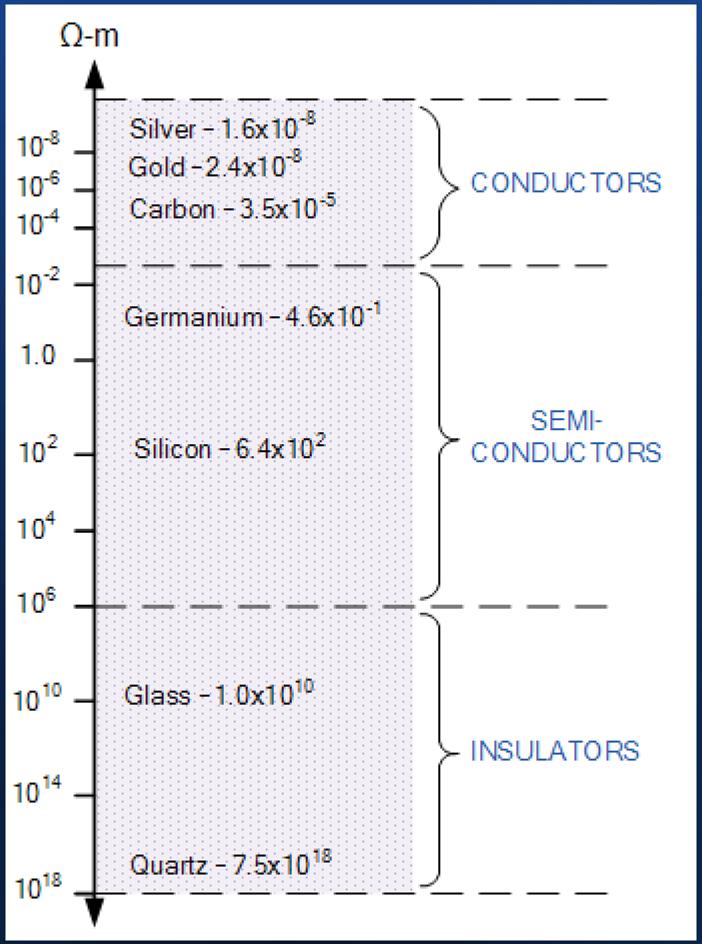
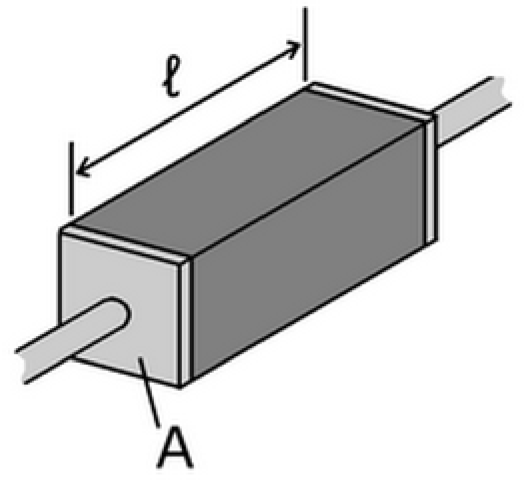
Electrical resistivity quantifies how strongly a given material opposes the flow of electric current.



A low resistivity indicates a material that readily allows the movement of electric charge. Resistivity is commonly represented by the Greek letter ρ.

The SI unit of electrical resistivity is the ohm·metre (Ω·m)
Electrical conductivity is the reciprocal of electrical resistivity.
If a 1 m × 1 m × 1 m solid cube of material has sheet contacts on two opposite faces, and the resistance between these contacts is 1 Ω, then the resistivity of the material is 1 Ω·m.

$$\rho = R\frac{A}{\ell}$$



In a hydraulic analogy, passing current through a high-resistivity material is like pushing water through a pipe full of sand—while passing current through a low-resistivity material is like pushing water through an empty pipe.

If the pipes are the same size and shape, the pipe full of sand has higher resistance to flow. Resistance, however, is not solely determined by the presence or absence of sand. It also depends on the length and width of the pipe: short or wide pipes have lower resistance than narrow or long pipes. All copper wires, irrespective of their shape and size, have approximately the same resistivity, but a long, thin copper wire has a much larger resistance than a thick, short copper wire.

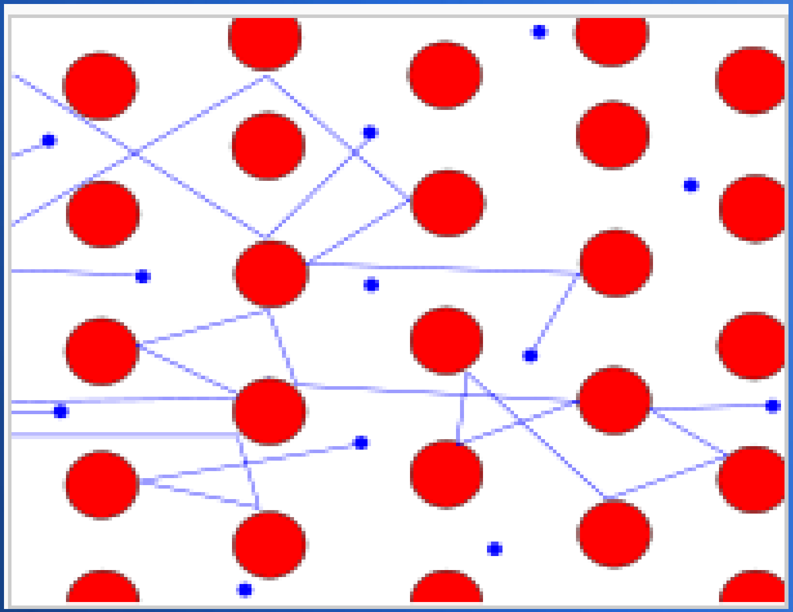
Drude model was proposed in 1900 by Paul Drude to explain the transport properties of electrons in materials.

The Drude model treats electrons (or other charge carriers) like pinballs bouncing among the ions that make up the structure of the material.

Electrons will be accelerated in the opposite direction to the electric field by the average electric field at their location.

With each collision, though, the electron is deflected in a random direction with a velocity that is much larger than the velocity gained by the electric field.

The net result is that electrons take a zigzag path due to the collisions, but generally drift in a direction opposing the electric field.



This simple classical Drude model provides a very good explanation of DC and AC resistivity in metals

Electrical resistivity (also known as resistivity, specific electrical resistance, or volume resistivity) is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current

The resistance of a given object depends primarily on two factors: What material it is made of, and its shape.

For a given material, the resistance is inversely proportional to the cross-sectional area; for example, a thick copper wire has lower resistance than an otherwise identical thin copper wire.

Also, for a given material, the resistance is proportional to the length; for example, a long copper wire has higher resistance than an otherwise-identical short copper wire.

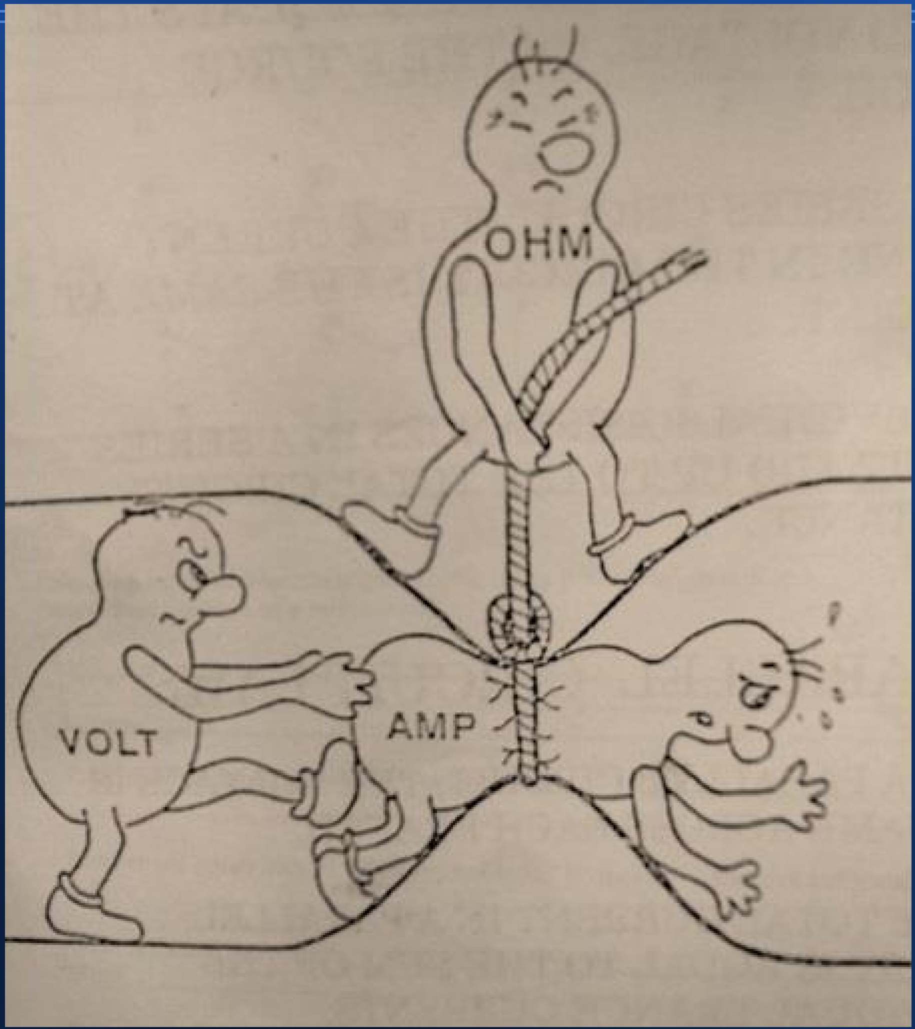
Electrical resistance shares some conceptual parallels with the mechanical notion of friction

Ohm's Law - the most fundamental formula in electrical engineering

Georg Simon Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician.

Ohm's Law

The law states that the direct current flowing in a conductor is directly proportional to the potential difference between its ends. It is usually formulated as $V = IR$, where V is the potential difference, or voltage, I is the current, and R is the resistance of the conductor.



As the electrons bump their way through the material we must keep applying external energy to keep them moving. Each time the electrons collide with the resistor atoms, the electrical kinetic energy is given to the resistor atoms heating them up.

Thus, one parameter that is specified with the resistance value is the ability of the resistance to pass its heat energy safely to the surrounding air.

Resistors

The electrical resistance of an electrical conductor is the opposition to the passage of an electric current through that conductor.

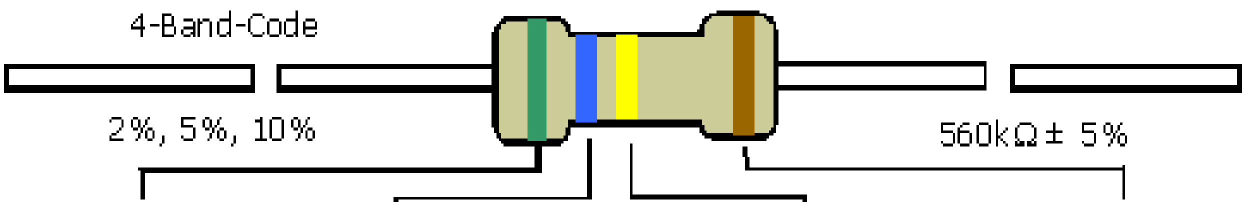
The SI unit of electrical resistance is the ohm (Ω).

For a wide variety of materials and conditions, V and I are directly proportional to each other.

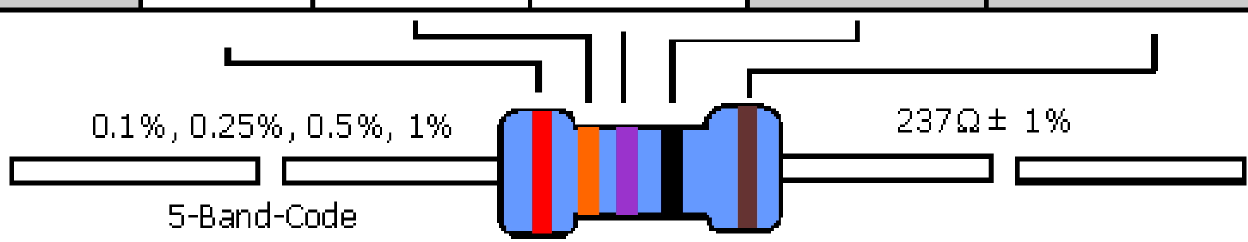
This proportionality is called Ohm's law, and materials that satisfy it are called "Ohmic" materials.

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element.

Resistor Color Code Guide



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)



Short circuit

A short circuit is an electrical circuit that allows a current to travel along an unintended path, often where essentially no (or a very low) electrical resistance is encountered.

A common type of short circuit occurs when the positive and negative terminals of a battery are connected with a low-resistance conductor, like a wire.

With low resistance in the connection, a high current exists, causing the cell to deliver a large amount of energy in a short time.

A large current through a battery can cause the rapid buildup of heat, potentially resulting in an explosion or the release of hydrogen gas and electrolyte (an acid or a base), which can burn tissue, cause blindness or even death.

Overloaded wires can also overheat, sometimes causing damage to the wire's insulation, or a fire.

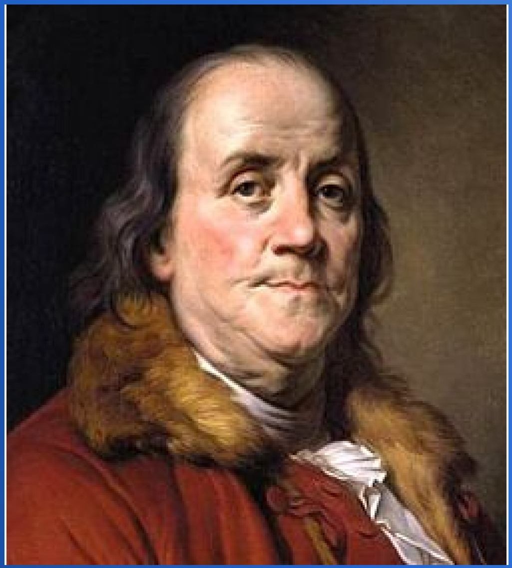
A fuse is a type of low resistance resistor that acts as a sacrificial device to provide overcurrent protection in either the load or source circuit.

Its essential component is a metal wire or strip that melts when too much current flows through it, interrupting the circuit that it connects.

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit.

Benjamin Franklin (1706 - 1790) was one of the Founding Fathers of the United States

When Benjamin Franklin was theorising about the nature of an electric current (long before the discovery of atoms), he thought that it was some sort of 'fluid' that flowed from an area of high pressure, which he labelled as 'positive', to an area of low pressure, which he labelled as 'negative'.



Although we know that, in a metal conductor at least, an electric current is a flow of negative charges (electrons) that flow from negative to positive, many (but by no means all) textbooks still use Franklin's current direction which is called 'Franklinian Flow' or, more commonly, 'Conventional Flow'

Electrons are negatively charged, and so are attracted to the positive end of a battery and repelled by the negative end. So when the battery is hooked up to something that lets the electrons flow through it, they flow from negative to positive

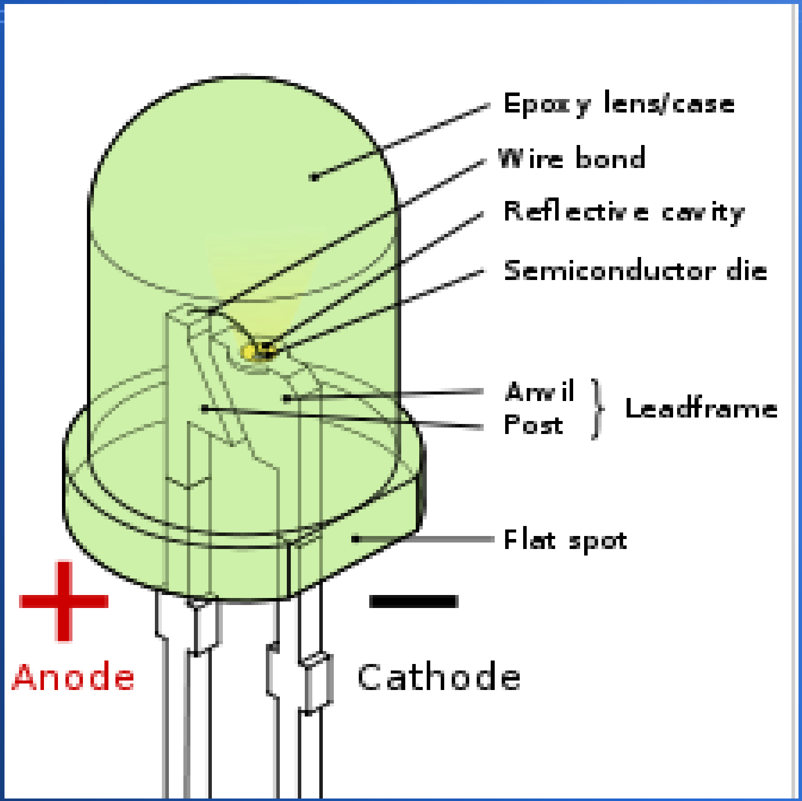
Light Emitting Diode

When a light-emitting diode is switched on, electrons are able to recombine with holes within the device, releasing energy in the form of photons.

This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

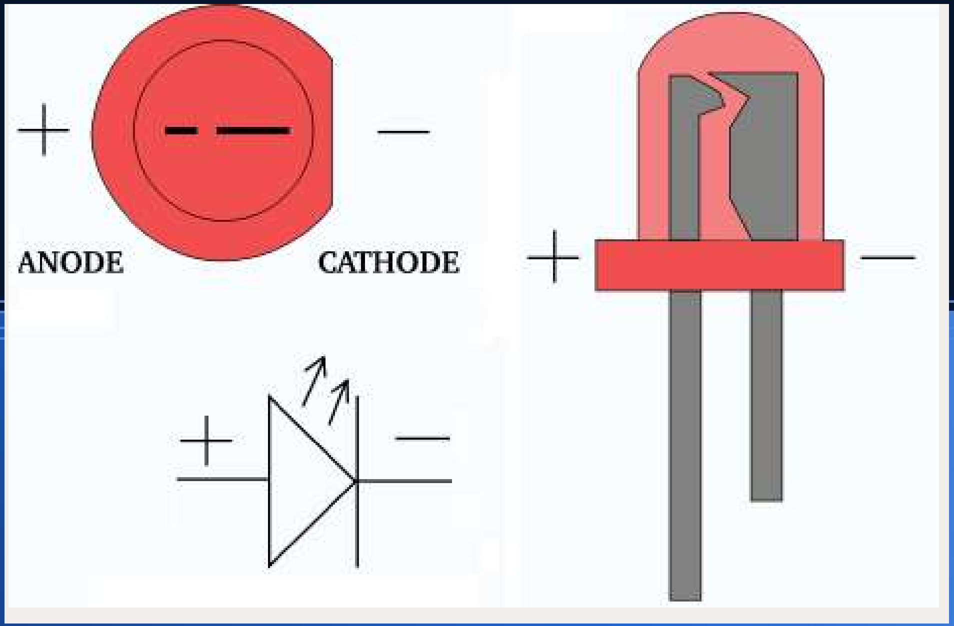
In silicon or germanium diodes, the electrons and holes usually recombine by a non-radiative transition, which produces no optical emission. The materials used for the LED have energies corresponding to near-infrared, visible, or near-ultraviolet light.

An LED is often small in area (less than 1 mm x 1mm), and integrated optical components may be used to shape its radiation pattern. LED anvil can have either polarity.



(A solar cell is the opposite - a solid-state electrical device, p-n junction, that converts the energy of light directly into electricity (DC) using the photovoltaic effect.)

Light Emitting Diode



An anode is an electrode through which electric current flows into a polarized electrical device.

The direction of electric current is, by convention, opposite to the direction of electron flow.

In other words, the electrons flow from the anode into, for example, an electrical circuit.

The word was coined in 1834 by William Whewell, who had been consulted by Michael Faraday over some new names needed to complete a paper on the recently discovered process of electrolysis.

Notice that the leads of the device are two different lengths. This is to indicate that one “leg” of the device is the anode, and the other is the cathode. On an LED device the longer leg is always the anode, and the shorter leg is the cathode. Current always flows from the anode to the cathode. In a simple circuit, the anode of the LED is connected to the positive voltage supply, and the cathode is connected to ground, or the negative voltage supply.

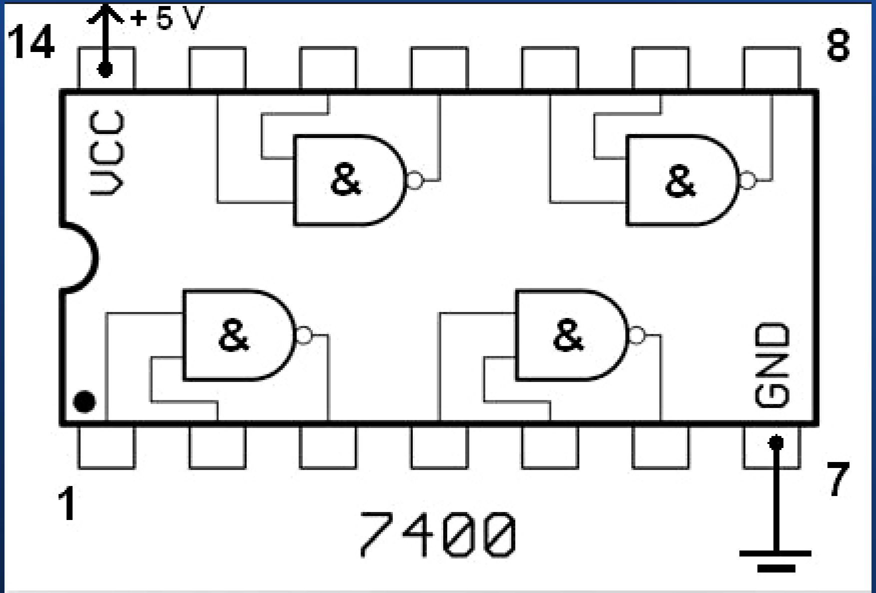
A good way to remember the names using the schematic symbol is that “anode” and “arrow” both start with the letter “a”. So the side of the schematic symbol connected to the “arrow” is the “anode”, making the side connected to the line the cathode.

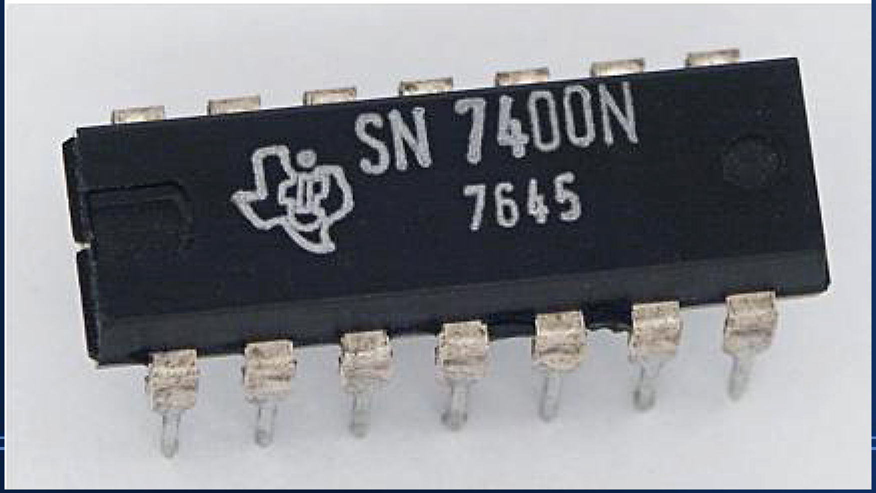
These slides describe how to connect up a 7400 Nand gate and determine its truth table

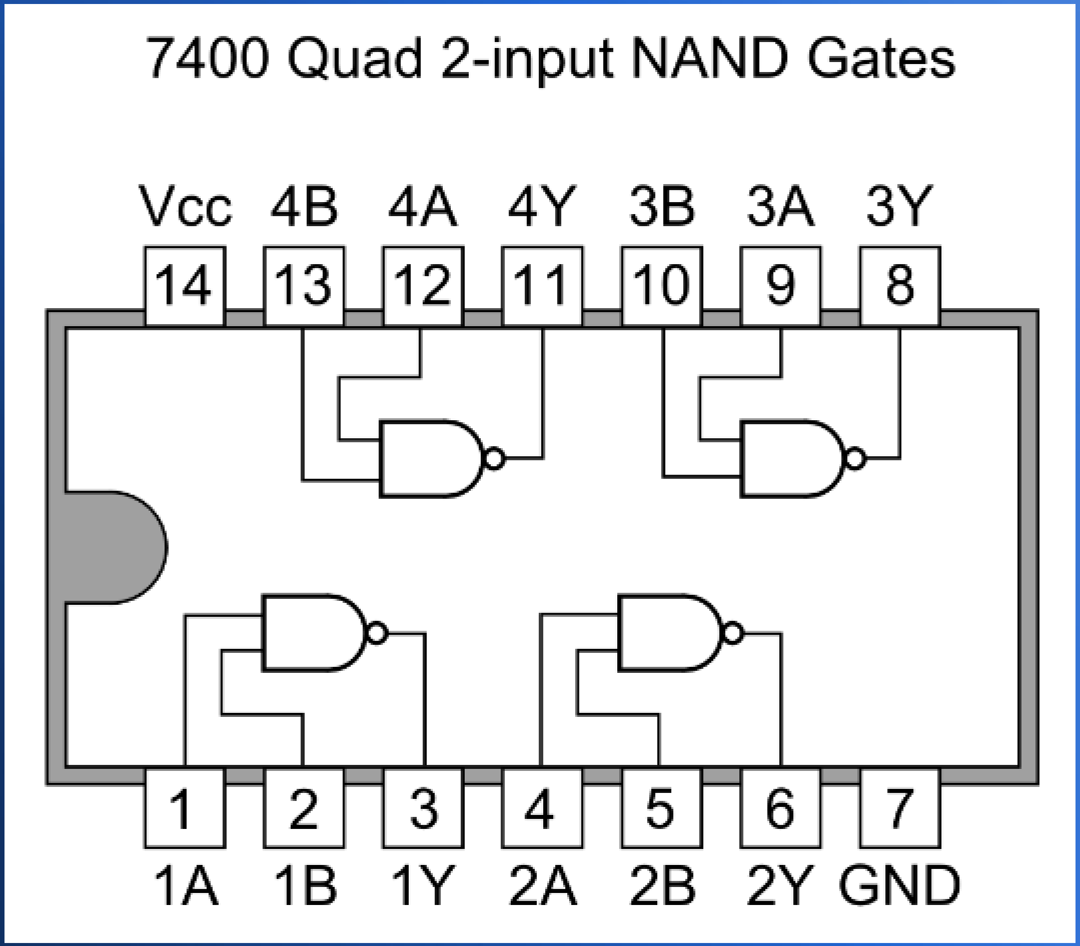
First, connect an LED and resistor between ground an 5V and check it lights

Next, hard wire the 7400 NAND inputs and confirm it works

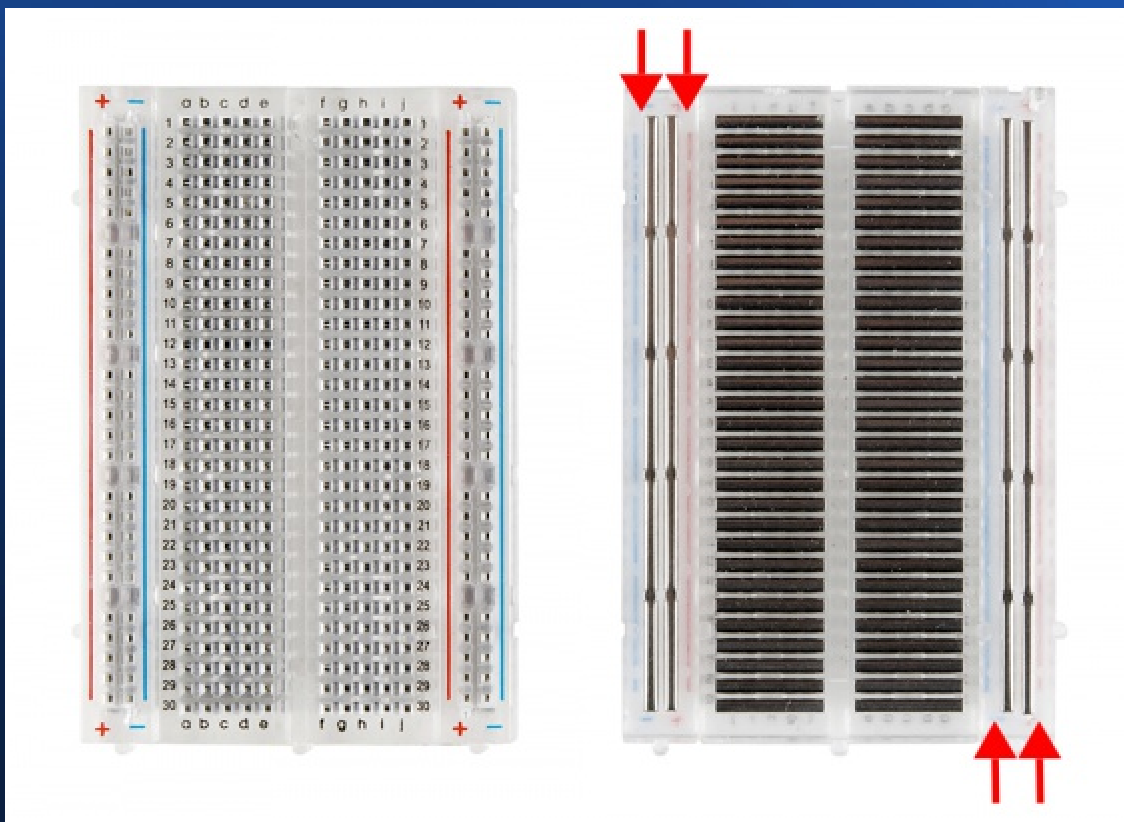
Finally, add the switches and pull down resistors and confirm the truth table


14
+ 5 V
8
VCC
&
&
&
&
GND
1
7
7400

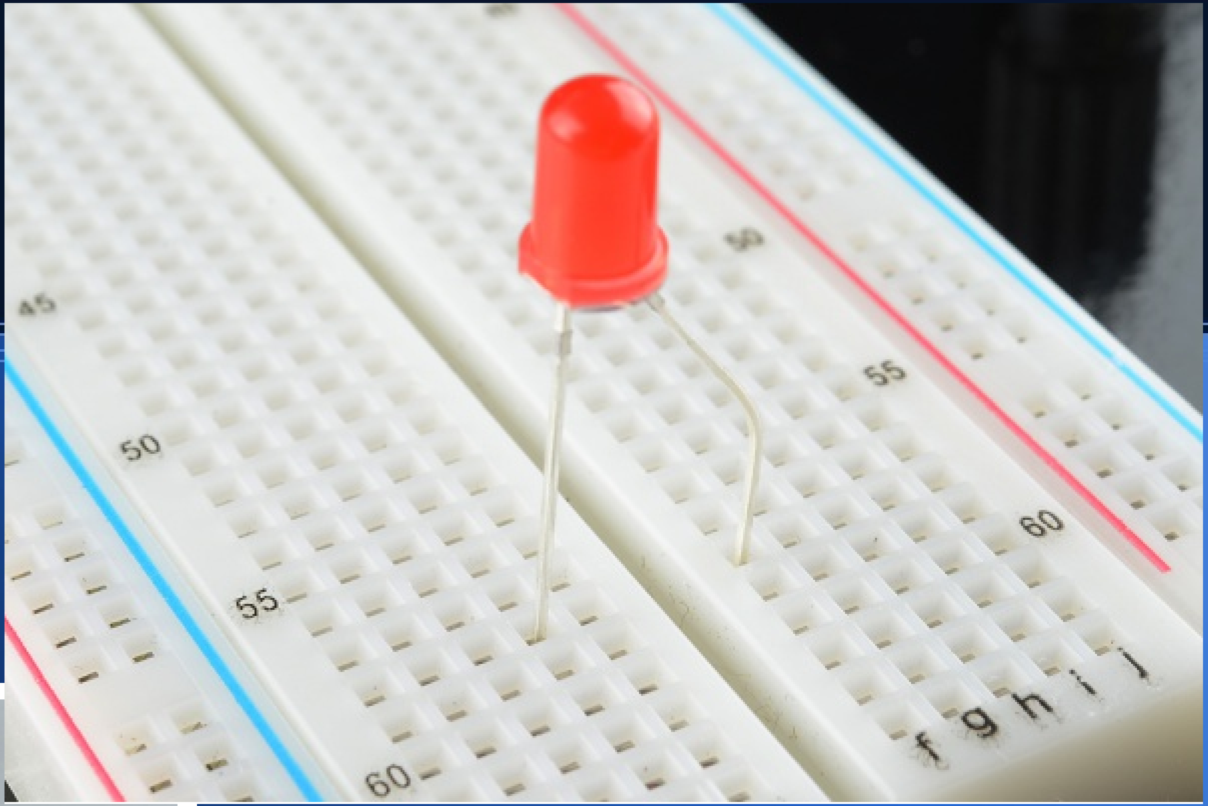

SN 7400N
7645

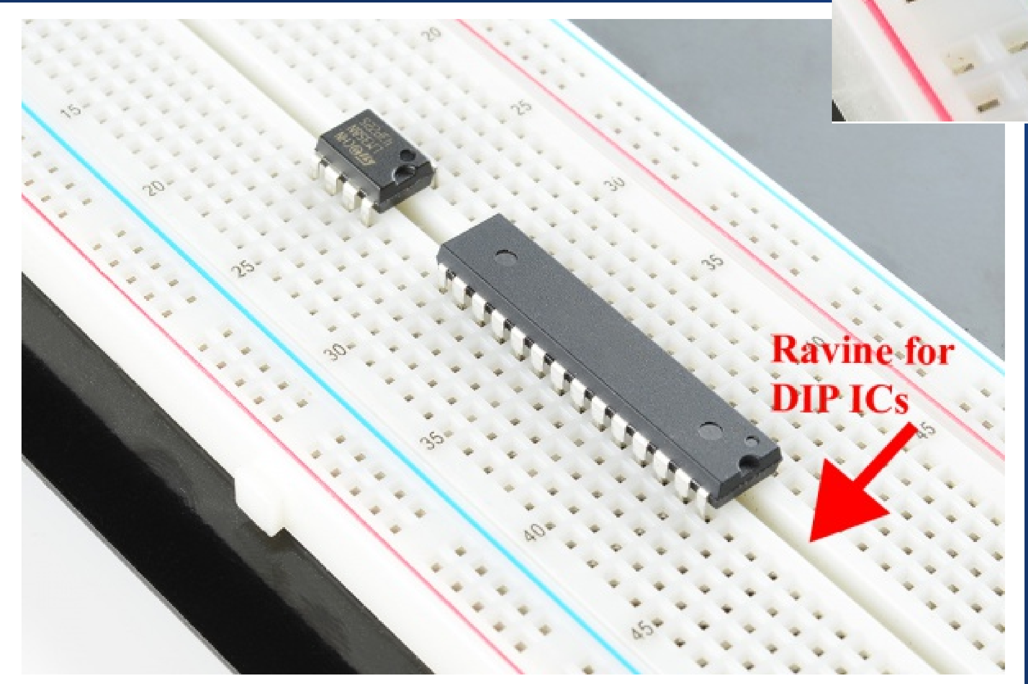

7400 Quad 2-input NAND Gates
Vcc 4B 4A 4Y 3B 3A 3Y
14 13 12 11 10 9 8
1 2 3 4 5 6 7
1A 1B 1Y 2A 2B 2Y GND

A breadboard is a construction base for prototyping of electronics. Originally it was literally a bread board, a polished piece of wood used for slicing bread. In the 1970s the solderless breadboard (AKA plugboard, a terminal array board) became available and nowadays the term "breadboard" is commonly used to refer to these



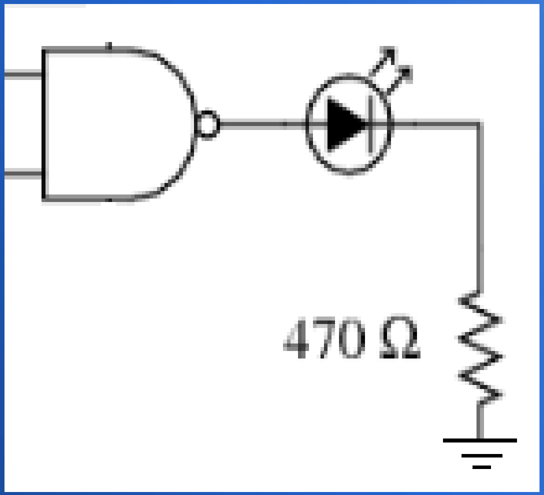
A medium-size breadboard with the adhesive back removed to expose the power rails.




Ravine for
DIP ICs

You can often connect LEDs to give a visual indication of a 1 (LED lighted) or a 0 (LED dark). Here some LEDs are shown, together with a 470 current limiting resistor.

If you connect LED indicators to your circuit remember that an LED is not the same in both directions, and you have to get the correct end connected to the resistor. The other end of each LED is connected to ground (or just "grounded"). Here's the circuit to show the output of a NAND gate



When the output of the gate is a 1, the output voltage will be five (5) volts. Current will flow through the series combination of the resistor and the LED, so the LED will light. When the output of the gate is a 0, the output voltage will be zero (0) volts and the LED will not be lit. Thus, the LED lights up when the output is a 1, and doesn't light when the output is a 0. You can use this indication scheme to show the status for any signal. It doesn't have to be the output of a gate.

LEDs have two properties that you care about:

1. forward voltage drop - how much voltage has to go across the led to light up
2. maximum current - how much current the LED can handle.

The forward voltage drop varies depending on the chemicals/materials used inside the LED but typically, they're

Red	30mA	1.7V
Bright red	30mA	2.0V
Yellow	30mA	2.1V
Green	25mA	2.2V
Blue	30mA	3.3V

If the LED doesn't get this much voltage, it may not light up. The maximum current is exactly that, the maximum the LED can tolerate. If you give it more current than the value the datasheet says the LED can handle, the LED may destroy itself or it may become so bright the color changes (for example red becomes orange).

Even though a datasheet may say the LED supports up to - for example - 20 mA, it doesn't mean you should configure the circuit to give it 20mA. 20 mA for that LED may be super bright.

You might find 10mA is easier on the eyes and bright enough for your needs.

Voltage = Current x Resistance

Voltage is the voltage you supply to the circuit, from which you take out the forward voltage of the LED.
Current is how much current you want to allow through the LED in Amperes : 1A = 1000 mA so 10 mA = 0.01A , 100mA = 0.1A etc

So if your input voltage is 5v and you want to use a LED with a forward voltage of 2.2v at a maximum of 10 mA, then your formula becomes :

5v - 2.2v = 0.01 x R

so R becomes (5-2.2) / 0.01 = 280 ohms.

This 280 ohms is not a standard value, so you can use 270 ohms or 300 ohms, which are easy to find. A lower resistor value means a bit more current is allowed through led, a higher value means less current is allowed.

Because resistors dissipate heat energy as the electric currents through them overcome the "friction" of their resistance, resistors are also rated in terms of how much heat energy they can dissipate without overheating and sustaining damage.

This power rating is specified in the physical unit of "watts."

You might also be interested in knowing how big a resistor you need to use.
The power dissipated in a resistor by limiting the current is determined with the formula
P = I x I x R

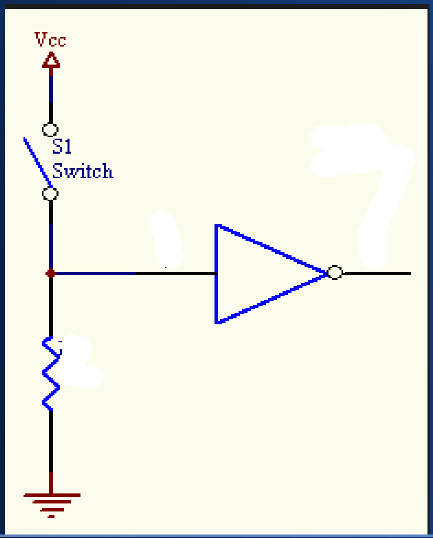
So if we go with the example above where we go with a 270 ohm resistor and 10mA goes through it, then the power will be 0.01 x 0.01 x 270 = 0.027 watts , which means a 0.125w resistor (1/8w) is more than enough for this.

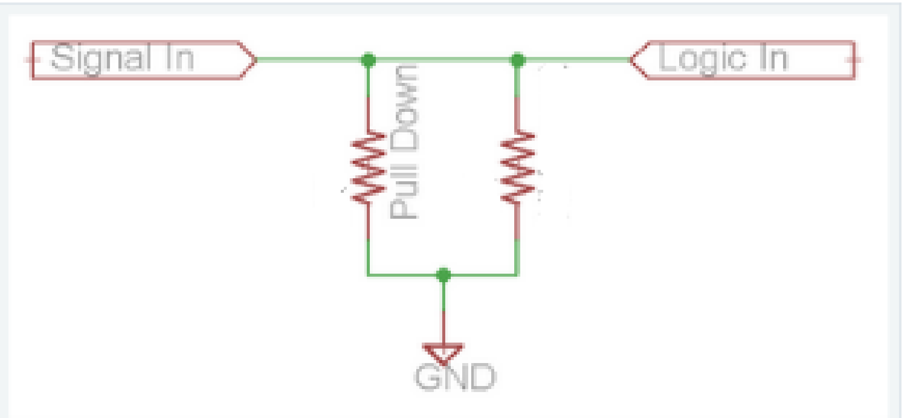
Pull Resistors

In TTL circuits, pull resistors are resistors used to assign a default value to a TTL signal

A pull resistor works because you can basically model most logic inputs as a really big resistor if the input is valid. One terminal of the resistor is your input node, this is what is sampled by your logic device. The other terminal goes to ground. This is standard on most TTL devices. When you put a pull resistor on it you're creating one of two potential circuits. With a pull-down you have a parallel resistance.

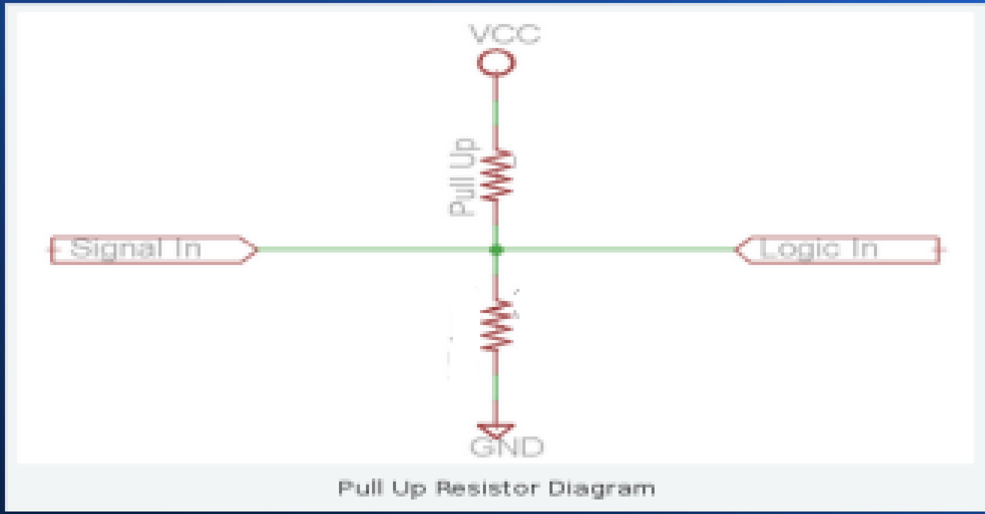
A rule of thumb is to use a resistor that is at least 10 times smaller than the value of the input pin resistance. In bipolar logic families which operate at 5V, the typical pull resistor value is 1-5 kΩ.



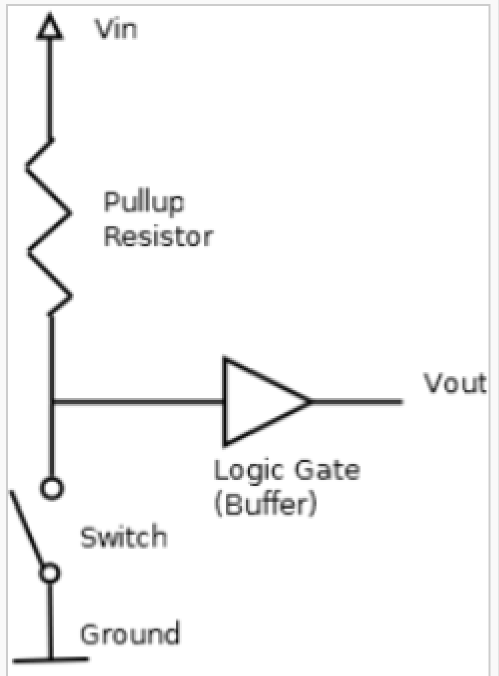


Pull Down Resistor Diagram

With a pull-up resistor you've got a voltage divider



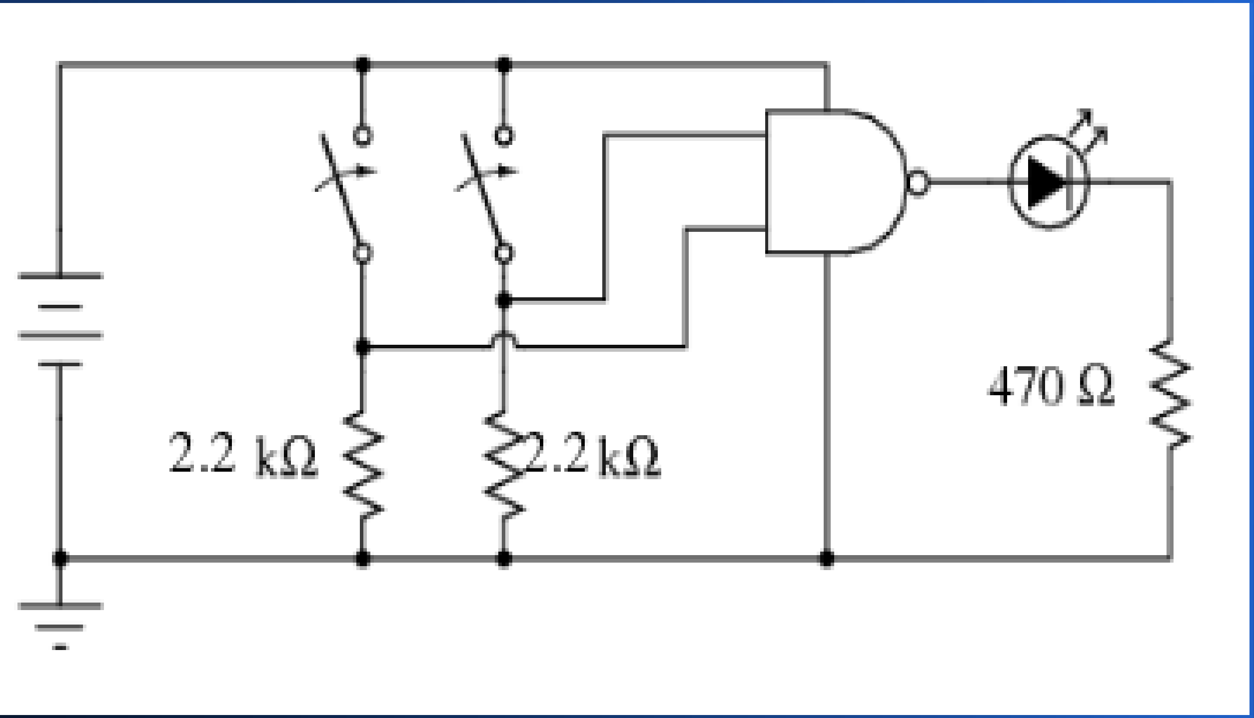
Pull Up Resistor Diagram

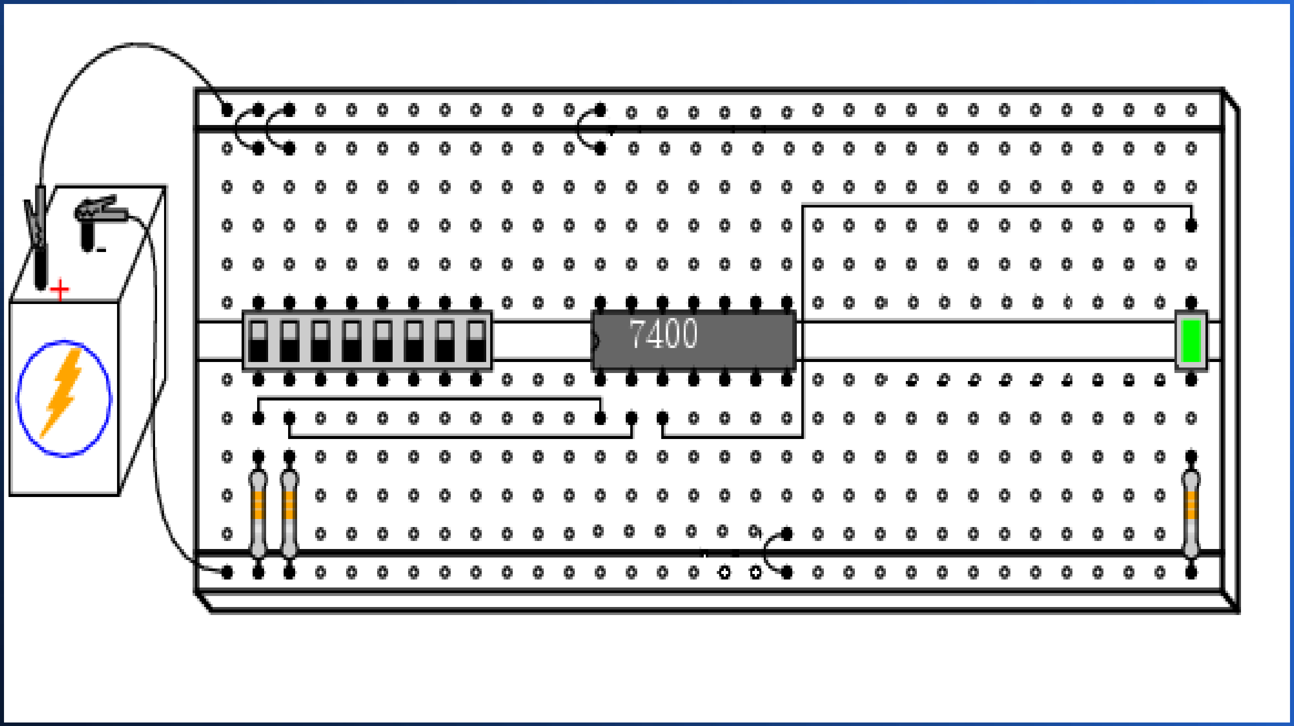


The appropriate value for the pull-up resistor is limited by two factors. The first factor is power dissipation. If the resistance value is too low, a high current will flow through the pull-up resistor, heating the device and using up an unnecessary amount of power when the switch is closed.
This condition is called a strong pull-up and is avoided when low power consumption is a requirement.
The second factor is the pin voltage when the switch is open. If the pull-up resistance value is too high, combined with a large leakage current of the input pin, the input voltage can become insufficient when the switch is open.

The two 2.2 kΩ resistors are placed in the circuit to avoid floating input conditions on the used gate. With a switch closed, the respective input will be directly connected to Vcc and therefore be "high." With a switch open, the 2.2 kΩ "pulldown" resistor provides a resistive connection to ground, ensuring a secure "low" state at the gate's input terminal. This way, the input will not be susceptible to stray static voltages.

SCHEMATIC DIAGRAM




7400