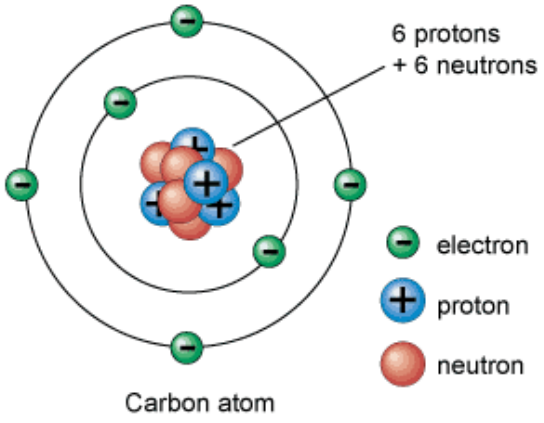
ATOMS & TRANSISTORS (and GATES, and "CHIPS" – actually chip-"Packages"**)**

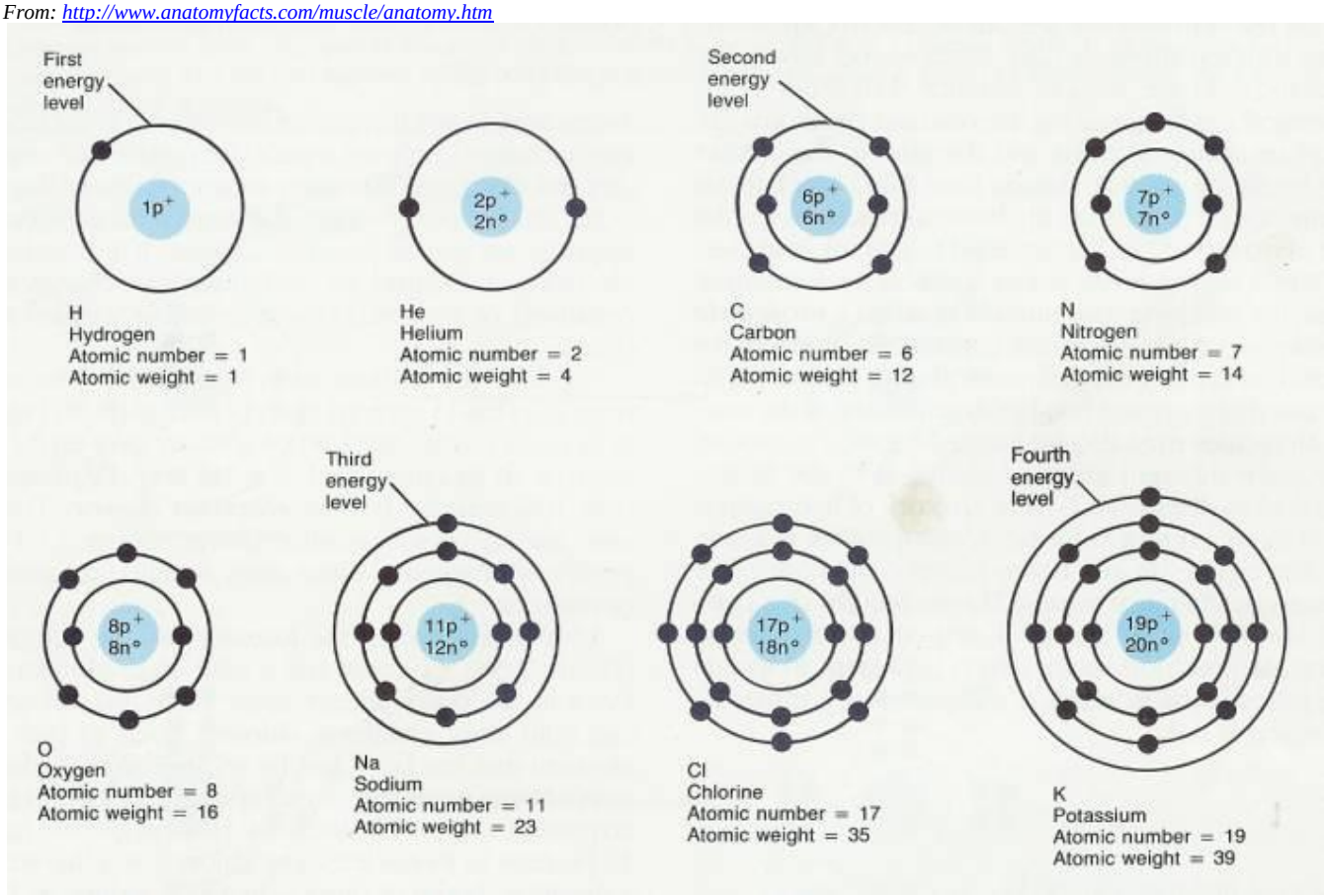
by JT Wunderlich PhD

ATOM: Smallest particle of a substance that can exist by itself or be combined with other atoms to form a molecule
MOLECULE: Smallest particle of a substance that retains all properties of the substance and is composed of one or more atoms
From: http://www.merriam-webster.com/dictionary/atom :
CRYSTAL LATTICE STRUCTURE: a unique arrangement of atoms or molecules in a crystalline liquid or solid.[1] A crystal structure describes a highly ordered structure, occurring due to the intrinsic nature of molecules to form symmetrical patterns. A crystal structure can be thought of as an infinitely repeating array of 3D 'boxes', known as unit-cells.
From http://en.wikipedia.org/wiki/Crystal_structure

Anatomy of an Atom (Bohr Model); electrons circling a nucleus containing protons and neutrons.
From: http://www.freethought-forum.com/forum/showthread.php?t=24978&garpg=2

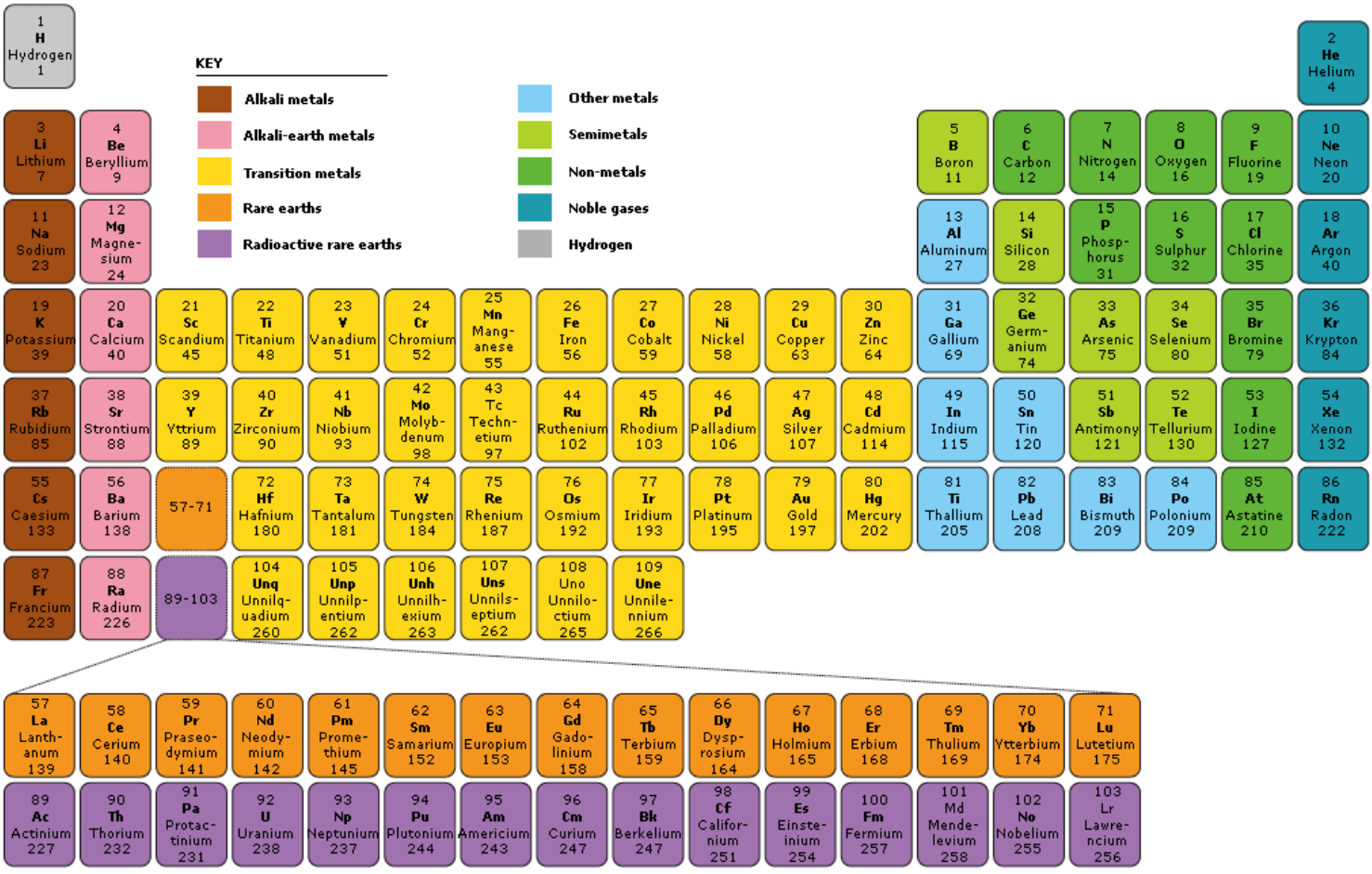


Electrons are in *shells (Energy Levels)* around nucleus, with a certain number of electrons that fit into each shell. The outer shell is called the **valence shell**.
From: http://www.anatomyfacts.com/muscle/anatomy.htm



PERIODIC TABLE is a gri**d of every element that exists,** arranged in order of atomic **number, t**he number of protons each atom has in its nucleus. The **rows are called PERIODS and all have the same number of shells**; and the **columns called GROUPS which all have the same number of electrons in their outermost shell**. Hydrogen (H) is the first element because it has just one proton in its nucleus. Helium (He) is second, because it has two. As you go across a period, atoms get heavier, but also get smaller because the number of electron shells stays the same across the period, but the number of protons in the nucleus increases. The stronger, attractive force from the positively charged protons sucks the negatively charged electrons tighter into the centre.

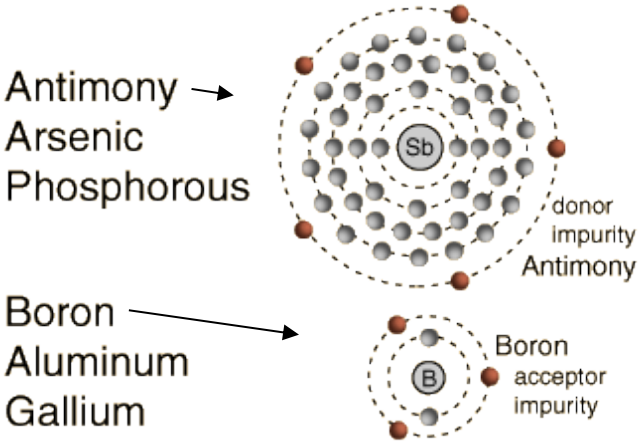
From http://www.infoplease.com/dk/science/encyclopedia/periodic-table.html



A SEMICONDUCTOR can be either a single element (like Silicon, Si), or a compound (like Galium Arsenide, GaAs) Semiconductors are not conductors of electricity like gold (a metal), and not an insulator which prevents electricity from flowing. Semiconductors are useful because they can be "doped" to control electrical properties and to make transistors, the basic building blocks of computers.

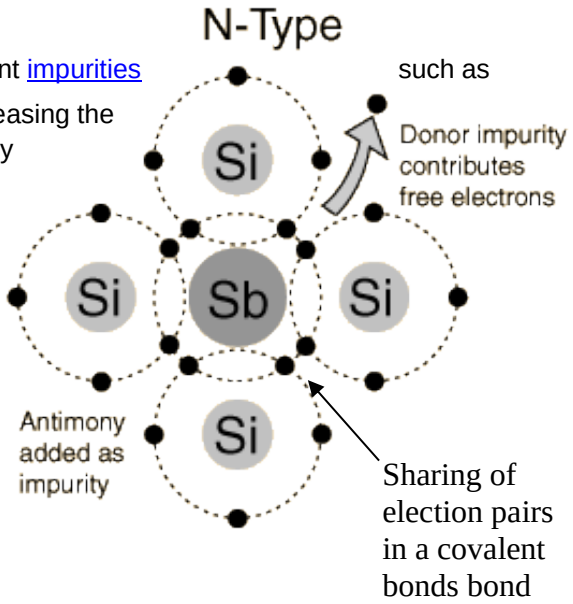
The Doping of Semiconductors

The addition of a small percentage of foreign atoms in the regular crystal lattice of silicon or germanium produces dramatic changes in their electrical properties, producing p-type semiconductors. Impurity atoms with 5 valence electrons produce n-type semiconductors by contributing extra electrons.



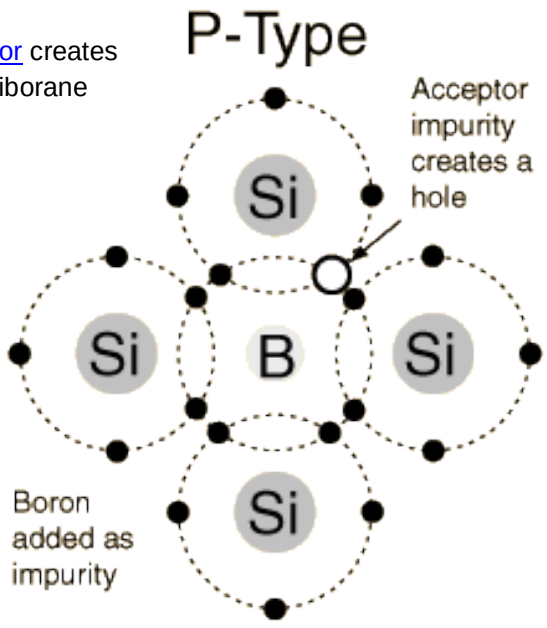
N-Type Semiconductor

The addition of pentavalent impurities such as antimony, arsenic or phosphorous contributes free electrons, greatly increasing the conductivity of the intrinsic semiconductor. Phosphorous may be added by diffusion of phosphine gas (PH3).



P-Type Semiconductor

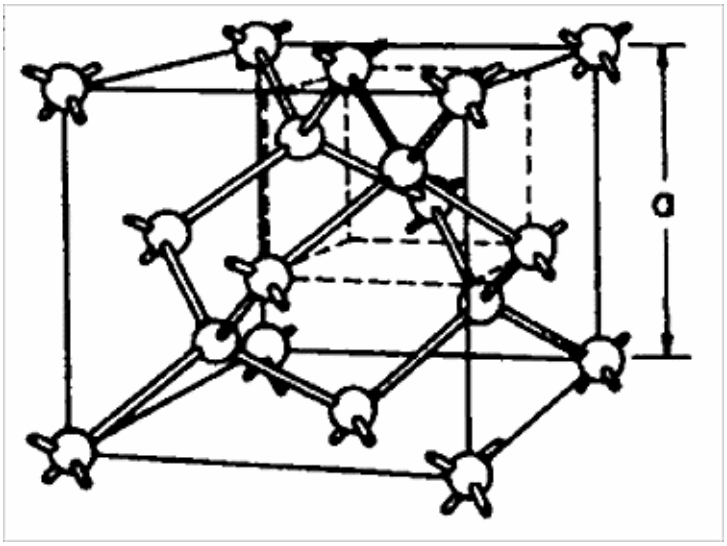
The addition of trivalent impurities such as boron, aluminum or gallium to an intrinsic semiconductor creates deficiencies of valence electrons, called "holes." It is typical to use B_2H_6 diborane gas to diffuse boron into the silicon material.



From: http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html#c3 :

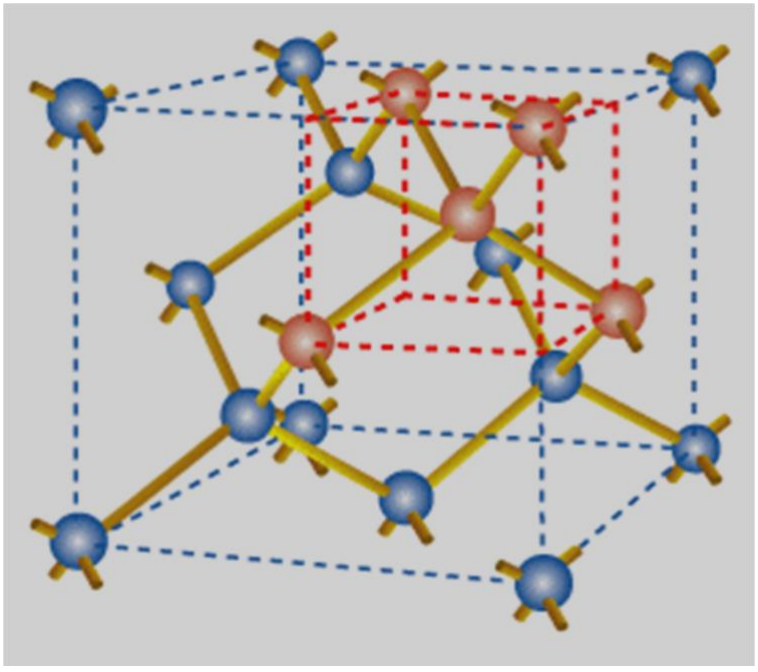
Silicon LATTICE STRUCTURE (un-Doped)

From: http://www.irf.com/technical-info/guide/semi.html



Silicon LATTICE STRUCTURE (Doped)

From: https://sites.google.com/site/reeetech/home/photovoltaic/silicon-cell



Combine N and P type materials to make Transistors (and Diodes)

From: http://content.aviation-safety-bureau.com/allmembers/faa-h-8083-31-amt-airframe-vol-2/sections/chapter-11.php

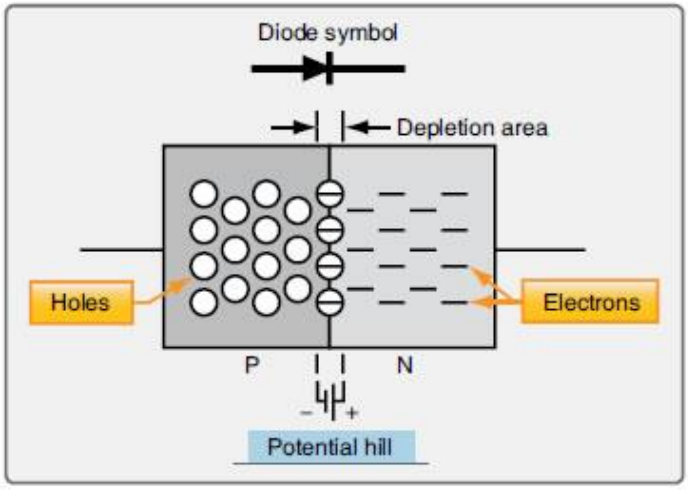


Figure 11-19. *A potential hill.*

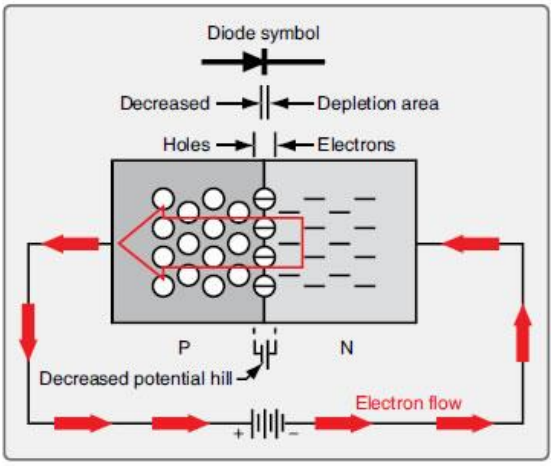


Figure 11-20. *The flow of current and the P-N junction of a semiconductor diode attached to a battery in a circuit.*

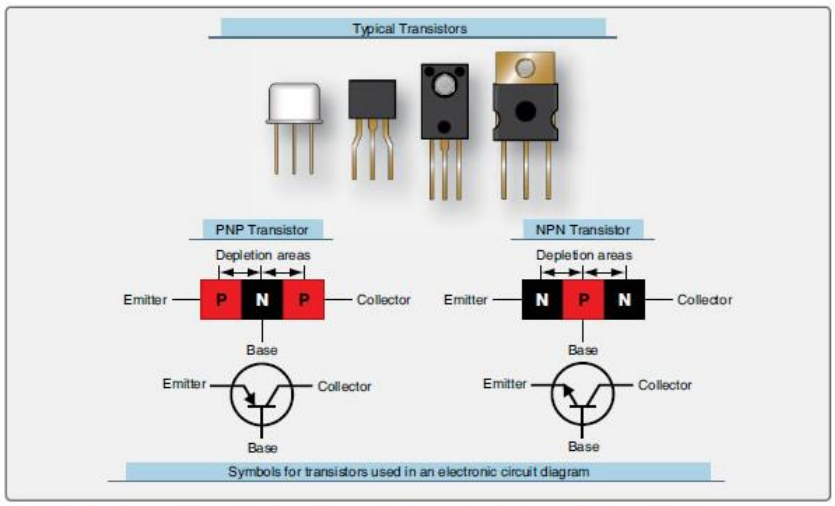


Figure 11-26. *Typical transistors, diagrams of a PNP and NPN transistor, and the symbol for those transistors when depicted in an electronic circuit diagram.*

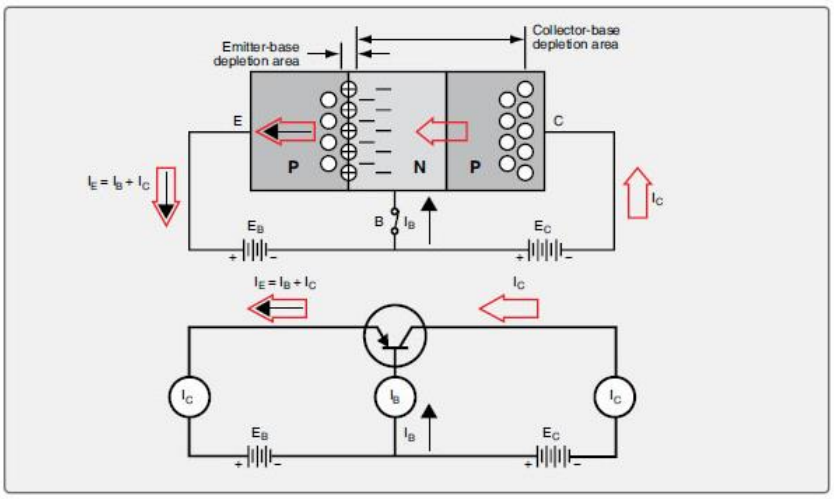


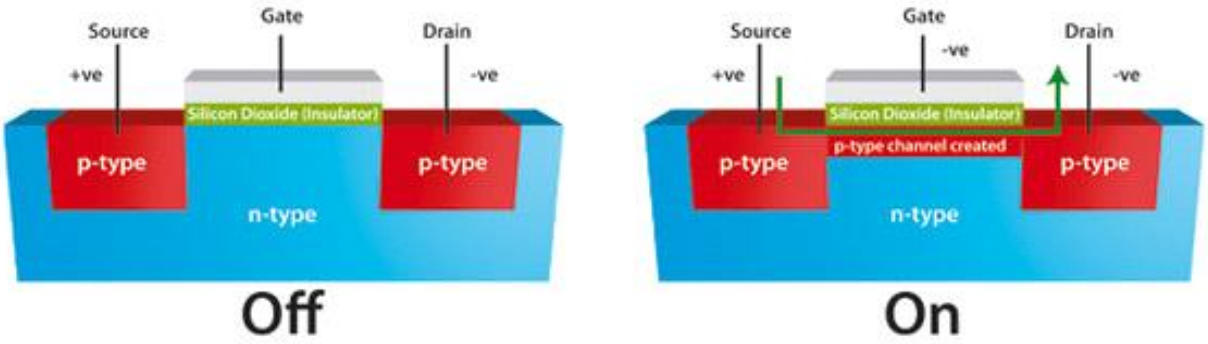
Figure 11-27. *The effect of applying a small voltage to bias the emitter-base junction of a transistor (top). A circuit diagram for this same transistor (bottom).*

NOTE: This is one kind of transistor, called a **Bipolar Junction Transistor (BJT)**

Another type of Transistor is a Field Effect Transistor (FET)

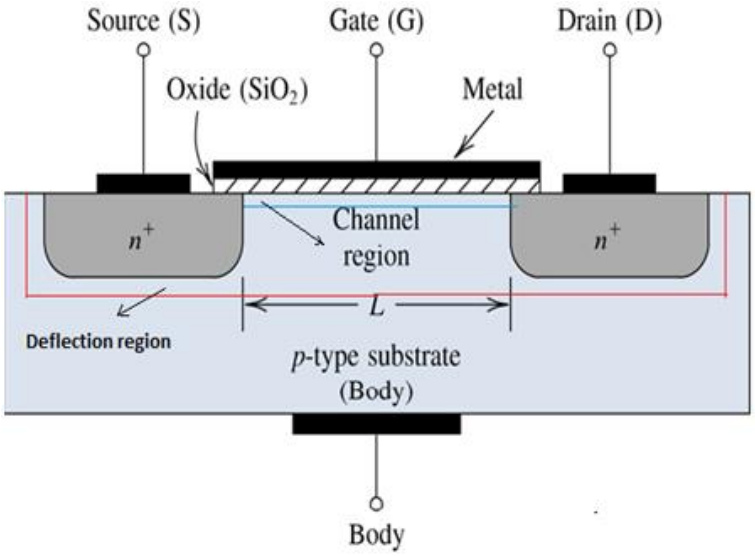
When a voltage is applied to the gate, a magnetic FIELD is created below the gate, which creates a conducting channel between the Source and Drain.

From: http://www.rignitc.com/mosfets/



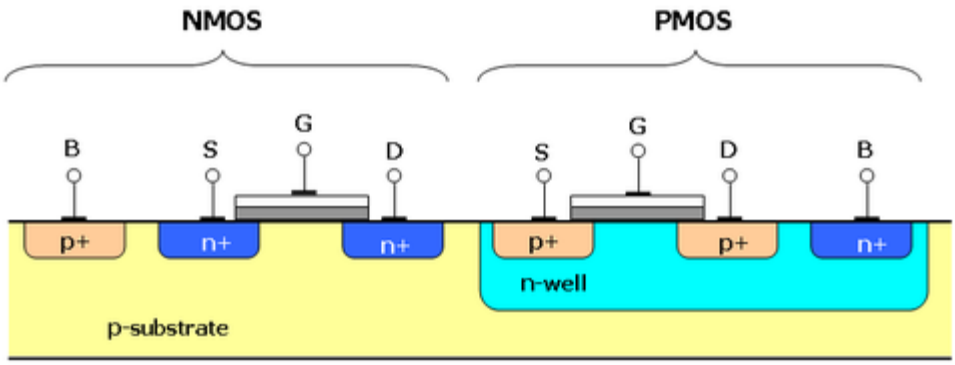
These are called Metal Oxide Semiconductors (MOS), i.e., MOSFET's

From: https://www.elprocus.com/mosfet-as-a-switch-circuit-diagram-free-circuits/

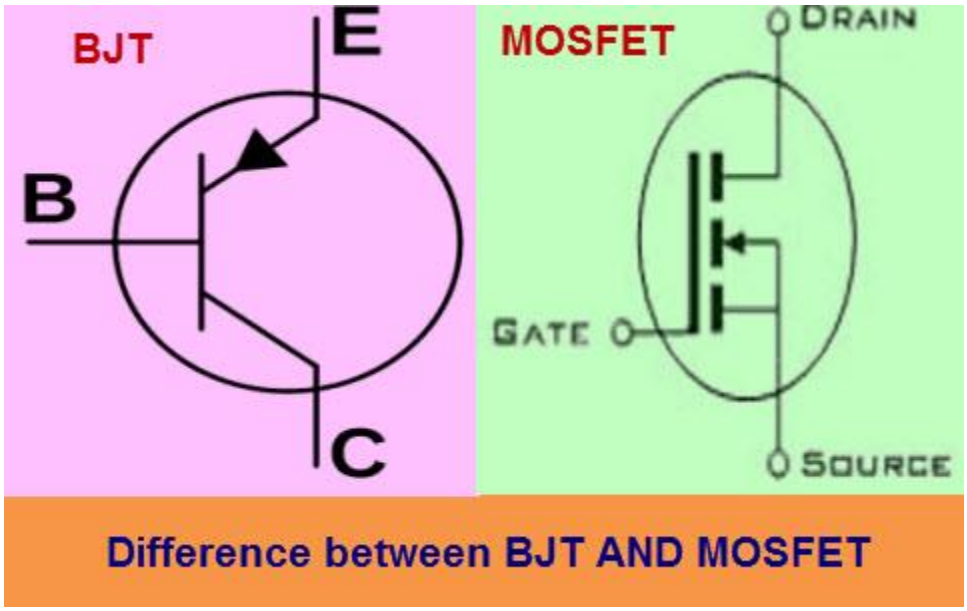


p-MOS has an N substrate, and n-MOS has a P substrate; and they are combined to make CMOS (i.e., Complementary Metal Oxide Semiconductor) circuits

From: https://allthingsvlsi.wordpress.com/2013/04/04/nmos-and-pmos-operating-regions/



Most important things know about transistors in Dr. Wunderlich's introductory Tech course:



From: https://www.elprocus.com/difference-between-bjt-and-mosfet/

- **BJT**
  (**B**ipolar **J**unction **T**ransistor)
  - Functionality:
    Apply small current from Base(B) to Collector(C) to get larger current from Emitter(E) to Collector(C)
  - **5 VOLTS**

- **MOSFET**
  - (**M**etal-**O**xide-**S**emiconductor **F**ield-**E**ffect-**T**ransistor)
    Functionality:
    Apply voltage to Gate(G) to create a magnetic field that creates a conducting channel between the Source(S) and the Drain(D), allowing current to flow between S and D
  - Typically **3.3 VOLTS** *(but also 5 volts sometimes)*

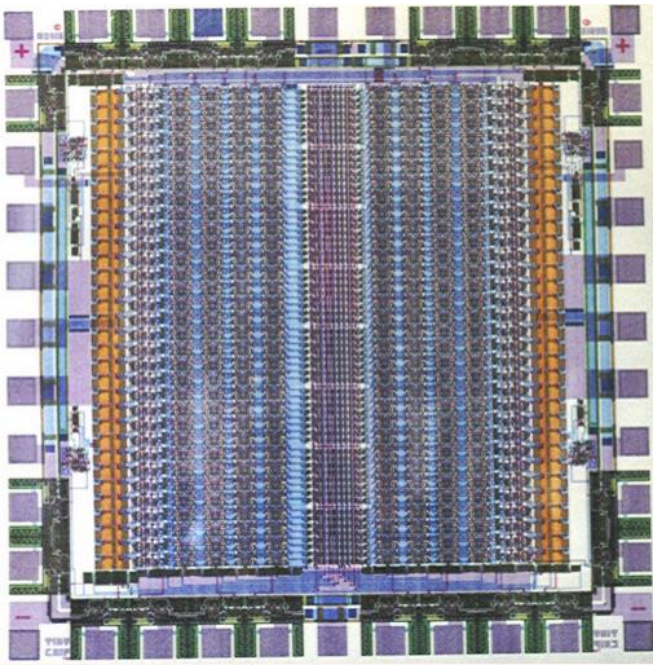
CMOS (2.5, **3.3**, 5, up to 18 volts)
vs.
BiPolar (**5** volts)
Transistor Circuits

Artificial Dendrite Tree Neural Network Chip

(J. Wunderlich 1992 - his 2nd Neural Network Processor)

(**5 volt** CMOS Logic) in a **5 volt** Frame (pad circuits for pin connections) supplied by "*Mosis Tiny-chip"* Manufacturer (USC)

- Chip Pin-Out circuits can be either special **C**MOS (**Complimentary** Metal Oxide Semiconductor) FET's (Field Effect Transistors) or BiPolar BJT's (BiPolar Junction Transistors) to source more output current and to absorb more input voltage spikes

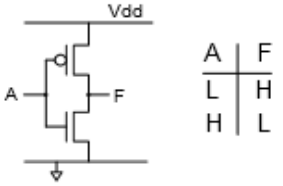


Integrated Circuits (IC's) "CHIPS" of DIGITAL LOGIC GATES

used in Dr. Wunderlich's courses with Lab projects

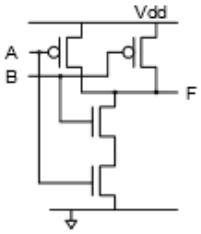
Here are CMOS **DIGITAL LOGIC GATES:**

(L= Low = Logic-0, H = High = Logic-1) From https://learn.digilentinc.com/Documents/313



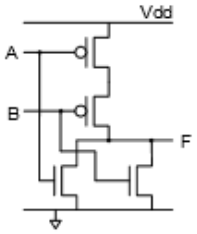
A	F
L	H
H	L

CMOS INVERTER



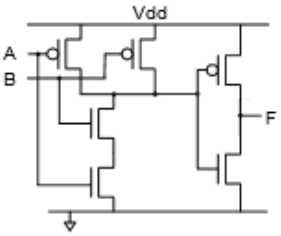
A	B	F
L	L	H
L	H	H
H	L	H
H	H	L

CMOS NAND



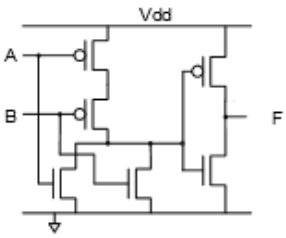
A	B	F
L	L	H
L	H	L
H	L	L
H	H	L

CMOS NOR



A	B	F
L	L	L
L	H	L
H	L	L
H	H	H

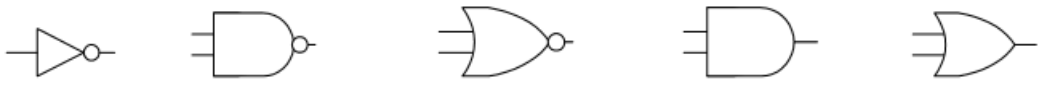
CMOS AND



A	B	F
L	L	L
L	H	H
H	L	H
H	H	H

CMOS OR

Digital Logic Gate Symbols



INV **NAND** **NOR** **AND** **OR**

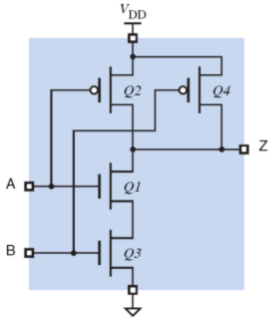
Made with either BJT's *(usually in TTL circuits, i.e., Transistor-Transistor-Logic)* **or with FET's in CMOS circuits.**

The following is from http://www.engr.uconn.edu/~zshi/course/cse2300/lecture2_gates.pdf :

CMOS families:

- 4000 series
- 7400 series:
  - 74HC (high-speed CMOS),
  - 74HCT(High-speed CMOS, TTL compatible)
  - 74AC(Avanced CMOS)
  - 74ACT(Advanced CMOS, TTL compatible)
  - 74FCT(Fast CMOS, TTL compatible)
  - 74FCTT(Fast CMOS, TTL compatible with TTL

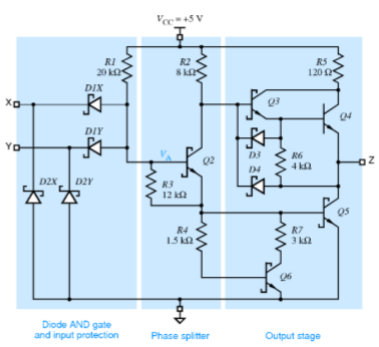
CMOS NAND gate



A	B	Q1	Q2	Q3	Q4	Z
L	L	off	on	off	on	H
L	H	off	on	on	off	H
H	L	on	off	off	on	H
H	H	on	off	on	off	L

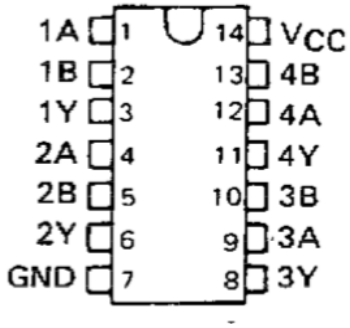
BiPolar Transistors

Example of LS-TTL gates: 2-input NAND

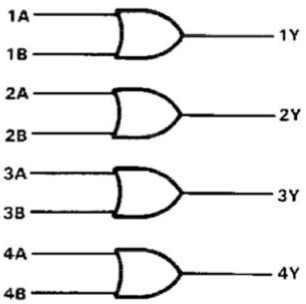


Dr Wunderlich's E273 lab is equipped various **TTL** (Transistor-Transistor-Logic) SSI (Small Scale Integration) IC's (Integrated Circuit) "Chips" . Below is a list of IC's usually found in the lab, Remember that TTL chips require 5Volts DC to operate (unlike CMOS chips used for the old radio shack circuit trainer found in the lab)

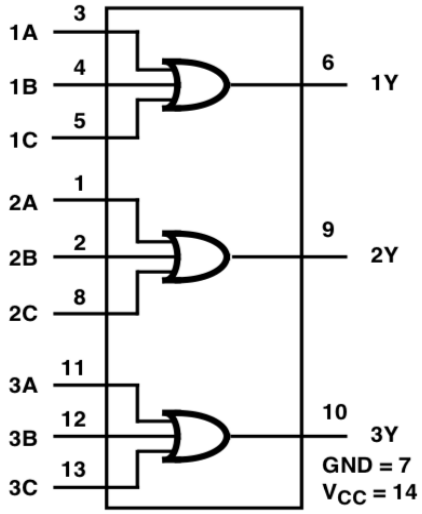
2 Input OR (SN74LS32N):



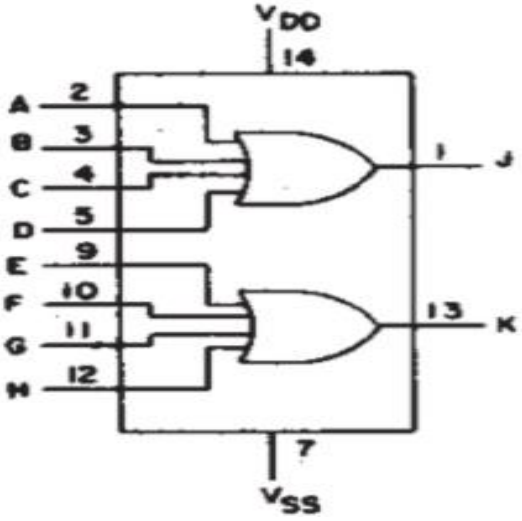
logic diagram



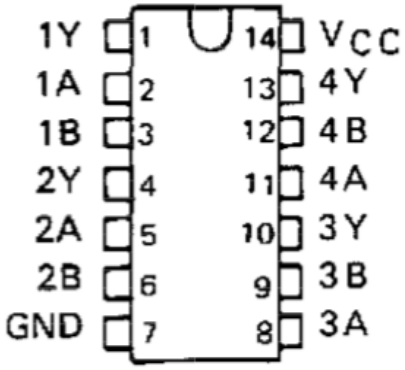
3 Input OR (CD74HC4075E):

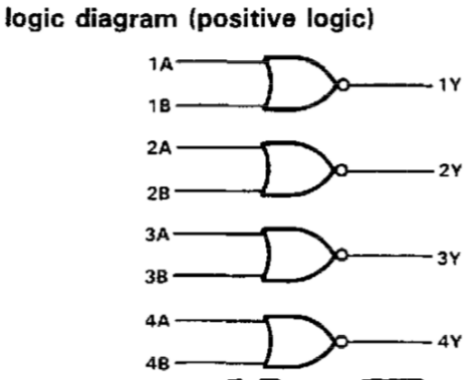


4 Input OR (CD4072BE):

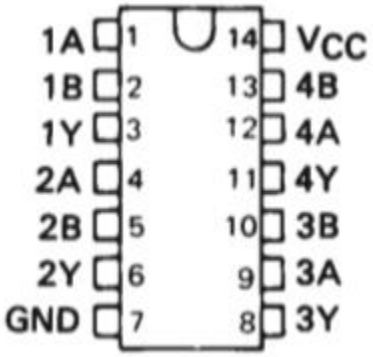


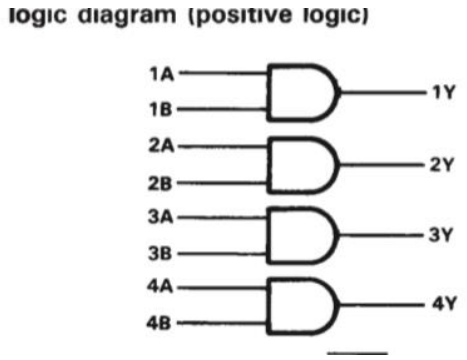
2 Input NOR (SN7402N):



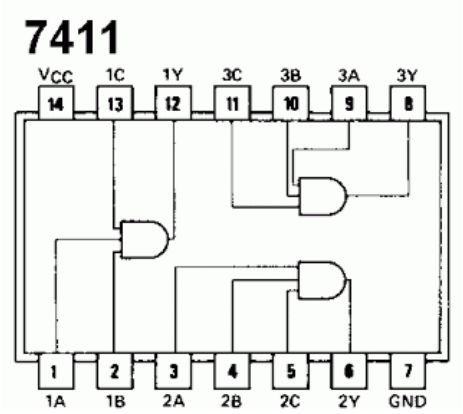


2 Input AND (SN74LS08N):

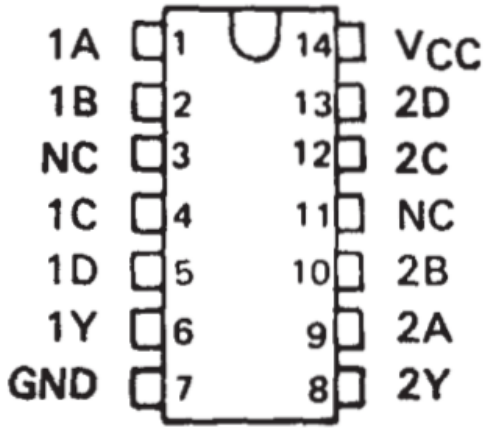


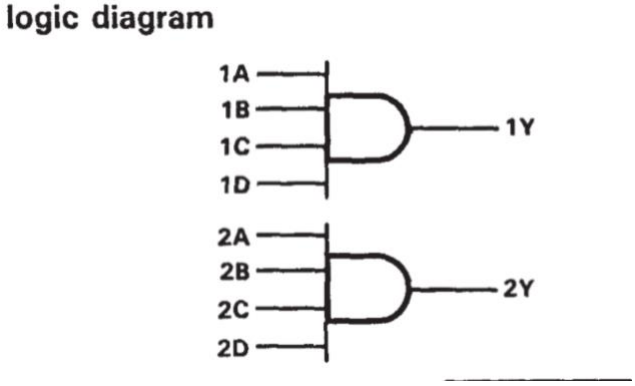


3 Input AND:

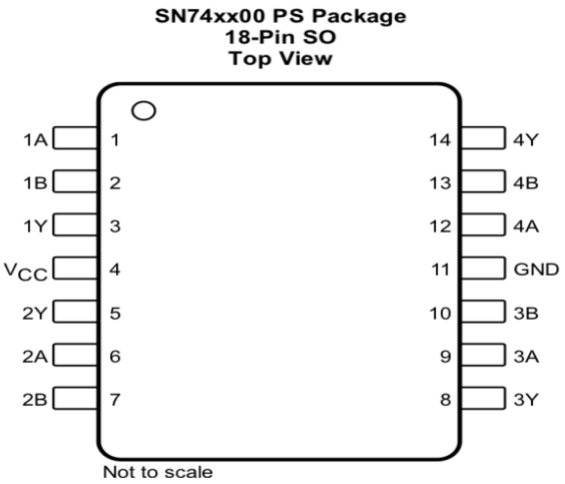


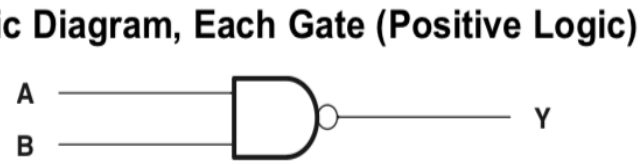
4 Input AND (SN74LS21N):



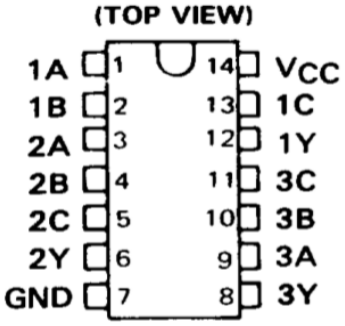


2 Input NAND (SN74LS00N):

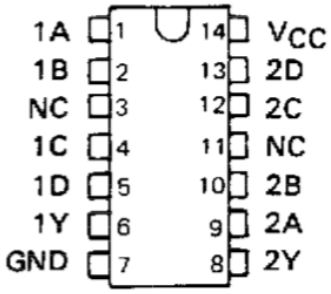


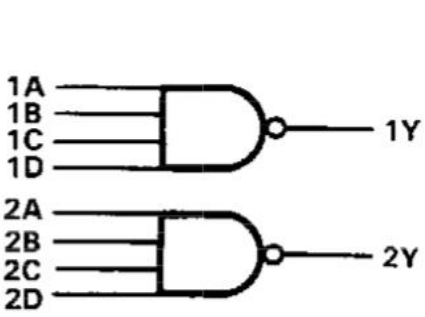


3 Input NAND (SN74LS10N):

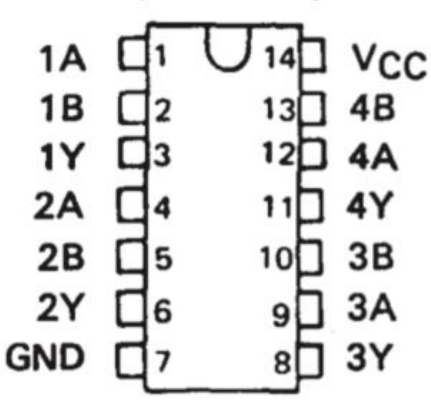


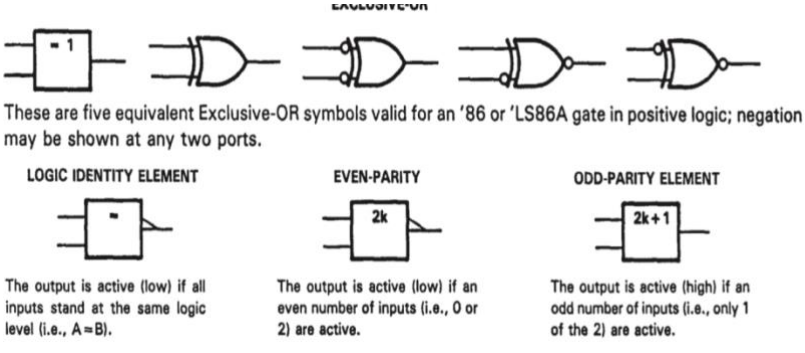
4 Input Quad NAND (74LS20):



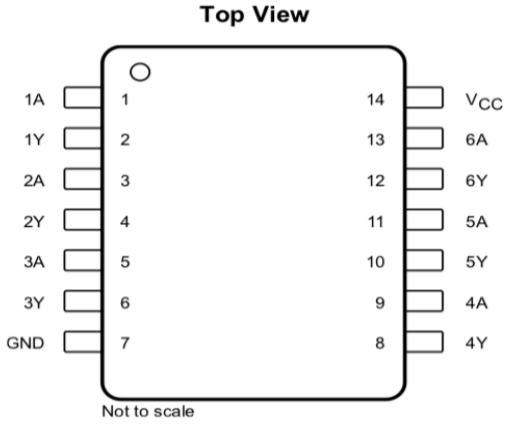


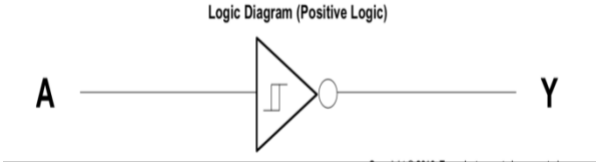
2 Input XOR (SN74LS86AN):



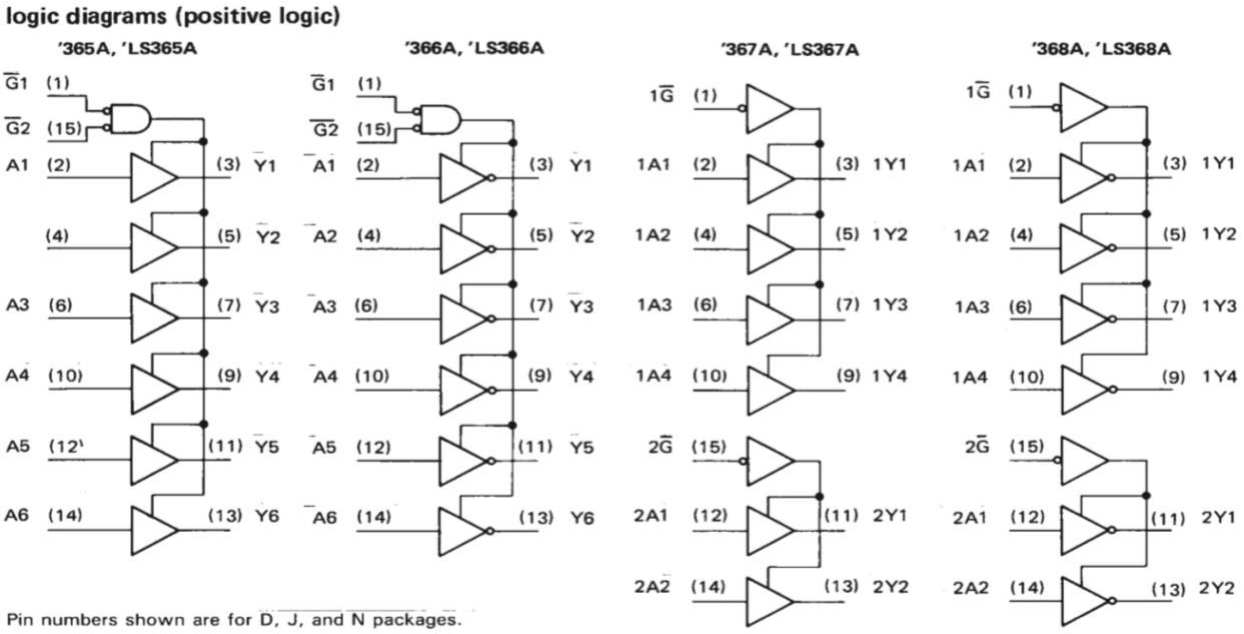


Inverter (SN74LS14N):

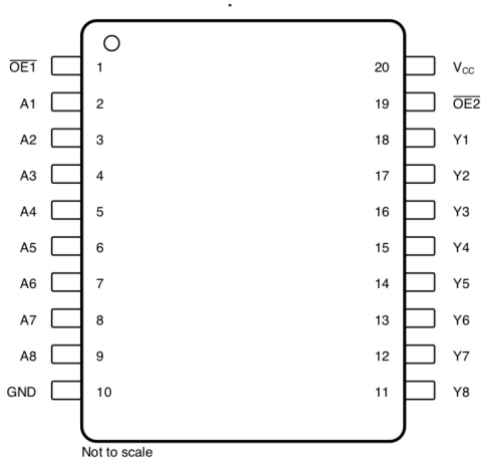


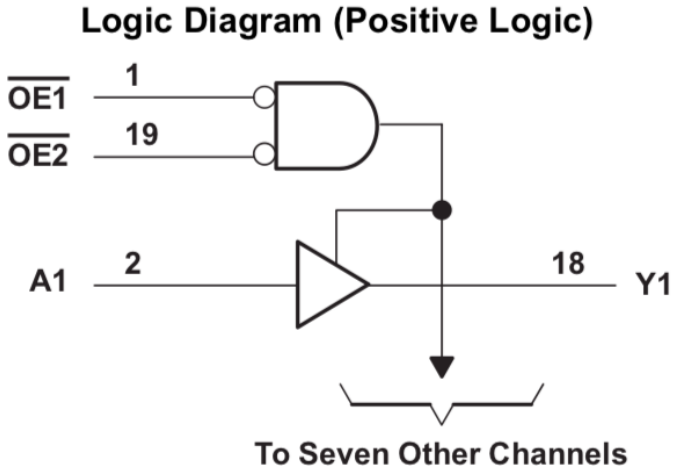


Hex Busdriver with 3-State Outputs (74367AN):



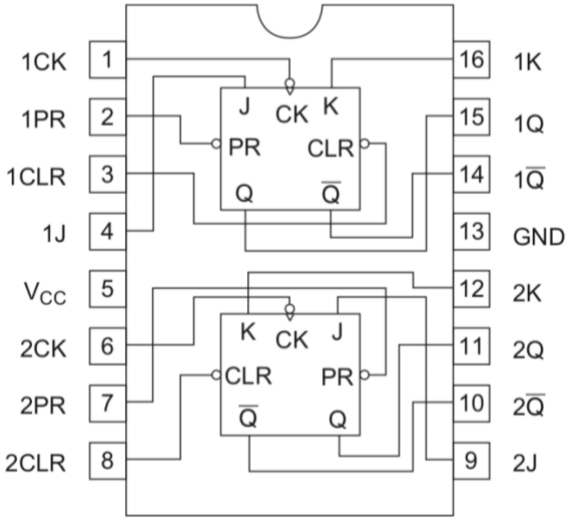
Buffer/Drivers 3-States (SN74HC541N):



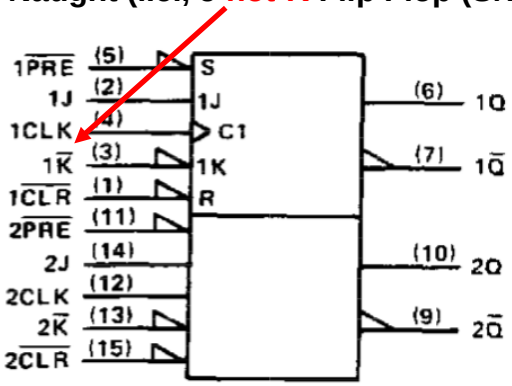


MEMORY CHIPS

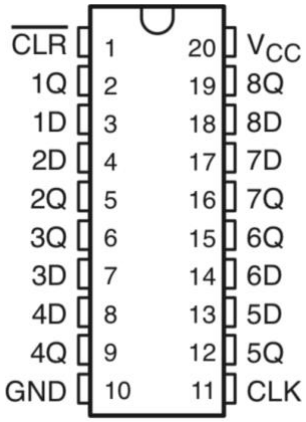
JK Flip Flop (HD74LS76AP):



JK Naught (i.e., J not-K Flip Flop (SN74LS109AN):



D Flip Flop (SN74LS273N):



DRAM (TMS425612N)