

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

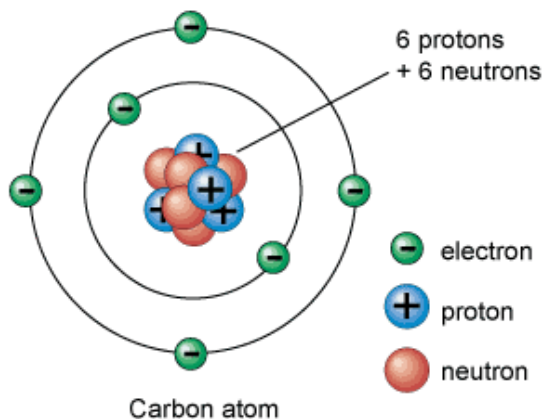
From: <http://www.merriam-webster.com/dictionary/atom> :

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

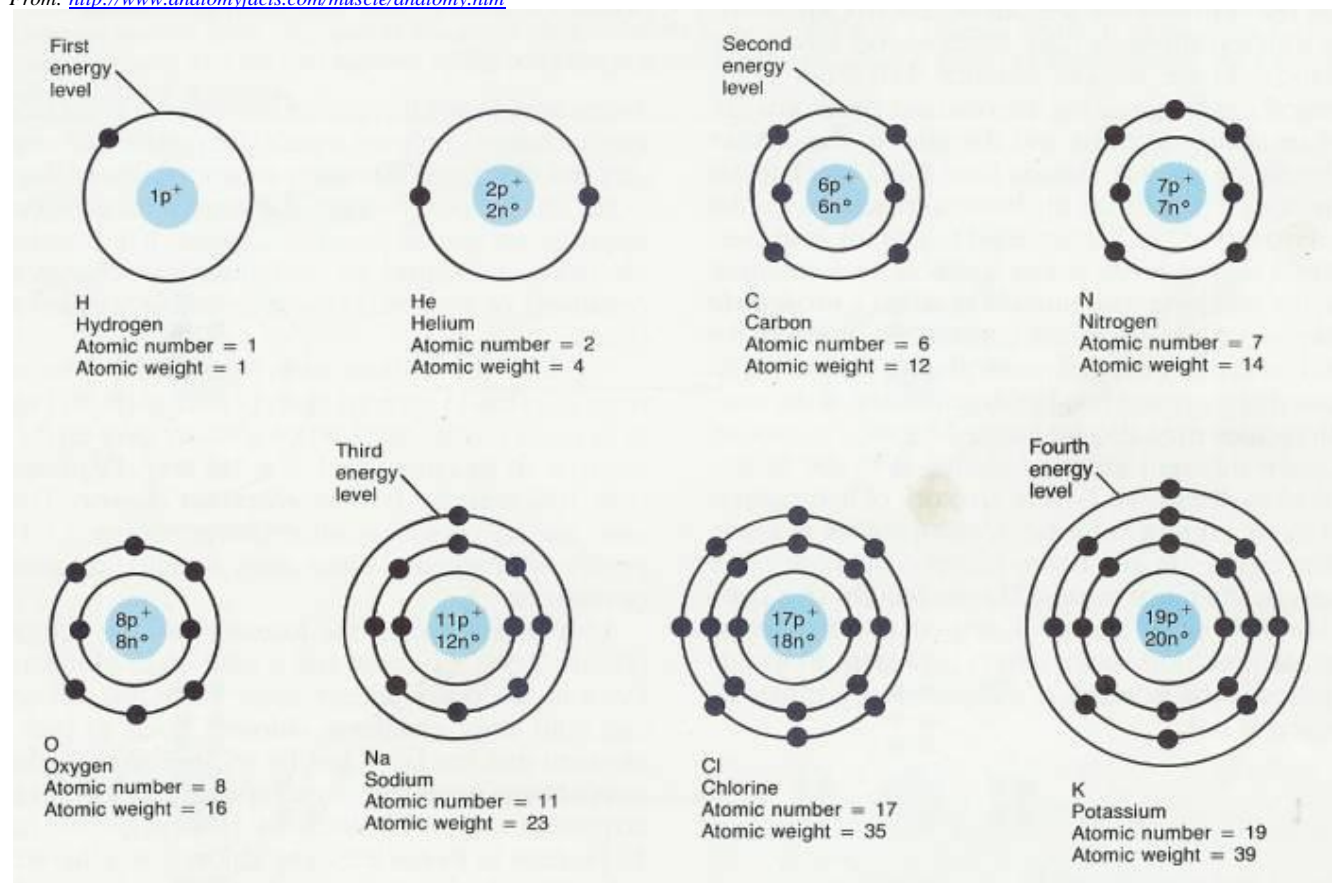
Anatomy of an Atom (Bohr Model); electrons circling a nucleus containing protons and neutrons.

From: <http://www.freethought-forum.com/forum/showthread.php?t=24978&garp=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 grid of every element that exists, arranged in order of atomic number, the 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>

1 H Hydrogen 1																	2 He Helium 4
3 Li Lithium 7	4 Be Beryllium 9											5 B Boron 11	6 C Carbon 12	7 N Nitrogen 14	8 O Oxygen 16	9 F Fluorine 19	10 Ne Neon 20
11 Na Sodium 23	12 Mg Magnesium 24											13 Al Aluminum 27	14 Si Silicon 28	15 P Phosphorus 31	16 S Sulphur 32	17 Cl Chlorine 35	18 Ar Argon 40
19 K Potassium 39	20 Ca Calcium 40	21 Sc Scandium 45	22 Ti Titanium 48	23 V Vanadium 51	24 Cr Chromium 52	25 Mn Manganese 55	26 Fe Iron 56	27 Co Cobalt 59	28 Ni Nickel 58	29 Cu Copper 63	30 Zn Zinc 64	31 Ga Gallium 69	32 Ge Germanium 74	33 As Arsenic 75	34 Se Selenium 80	35 Br Bromine 79	36 Kr Krypton 84
37 Rb Rubidium 85	38 Sr Strontium 88	39 Y Yttrium 89	40 Zr Zirconium 90	41 Nb Niobium 93	42 Mo Molybdenum 98	43 Tc Technetium 97	44 Ru Ruthenium 102	45 Rh Rhodium 103	46 Pd Palladium 106	47 Ag Silver 107	48 Cd Cadmium 114	49 In Indium 115	50 Sn Tin 120	51 Sb Antimony 121	52 Te Tellurium 130	53 I Iodine 127	54 Xe Xenon 132
55 Cs Caesium 133	56 Ba Barium 138	57-71	72 Hf Hafnium 180	73 Ta Tantalum 181	74 W Tungsten 184	75 Re Rhenium 187	76 Os Osmium 192	77 Ir Iridium 193	78 Pt Platinum 195	79 Au Gold 197	80 Hg Mercury 202	81 Tl Thallium 205	82 Pb Lead 208	83 Bi Bismuth 209	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222
87 Fr Francium 223	88 Ra Radium 226	89-103	104 Unq Unnilquadium 260	105 Unp Unnilpentium 262	106 Unh Unnilhexium 263	107 Uns Unnilseptium 262	108 Uno Unniloctium 265	109 Une Unnilennium 266									
57 La Lanthanum 139	58 Ce Cerium 140	59 Pr Praseodymium 141	60 Nd Neodymium 142	61 Pm Promethium 145	62 Sm Samarium 152	63 Eu Europium 153	64 Gd Gadolinium 158	65 Tb Terbium 159	66 Dy Dysprosium 164	67 Ho Holmium 165	68 Er Erbium 168	69 Tm Thulium 169	70 Yb Ytterbium 174	71 Lu Lutetium 175			
89 Ac Actinium 227	90 Th Thorium 232	91 Pa Protactinium 231	92 U Uranium 238	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 254	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 255	103 Lr Lawrencium 256			

KEY

Alkali metals

Alkali-earth metals

Transition metals

Rare earths

Radioactive rare earths

Other metals

Semimetals

Non-metals

Noble gases

Hydrogen

32

Ge

Germanium

74

Atomic number
is the number of protons
in the atom's nucleus

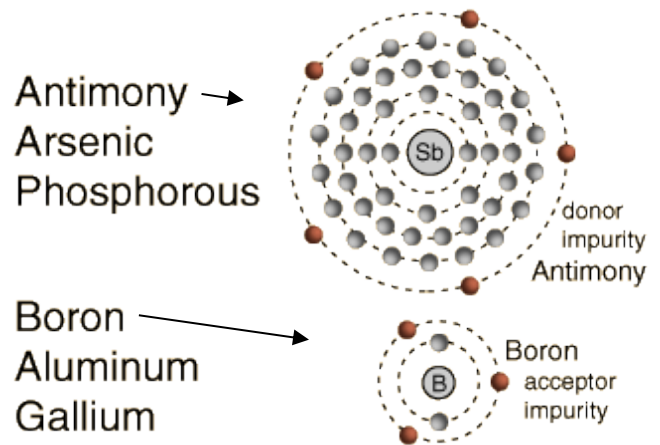
Symbol
is used as a
short-hand
and in chemical
equations

Mass number
is the number
of protons and
neutrons in
the nucleus

A SEMICONDUCTOR can be either a single element (like Silicon, Si), or a compound (like Gallium 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.

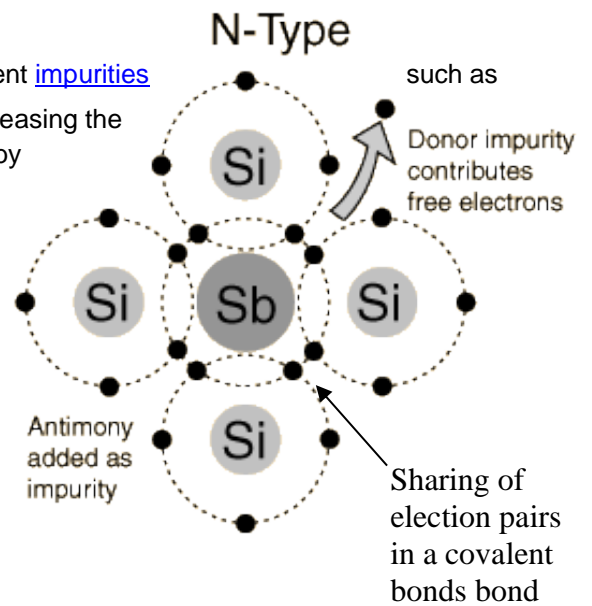
The Doping of Semiconductors

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.

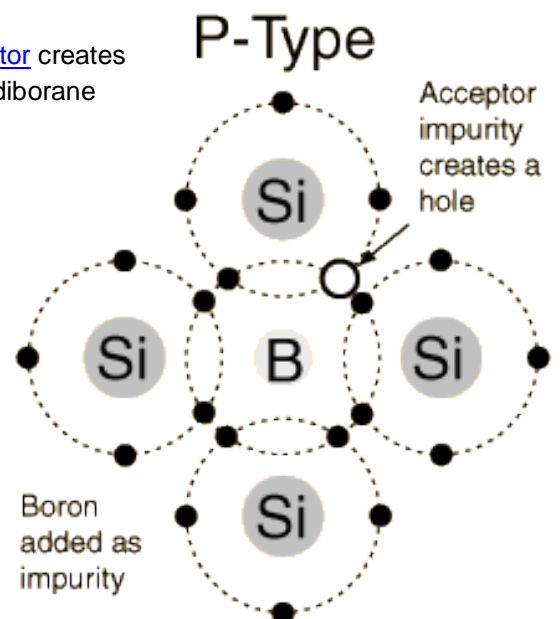


N-Type Semiconductor

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 (PH_3).



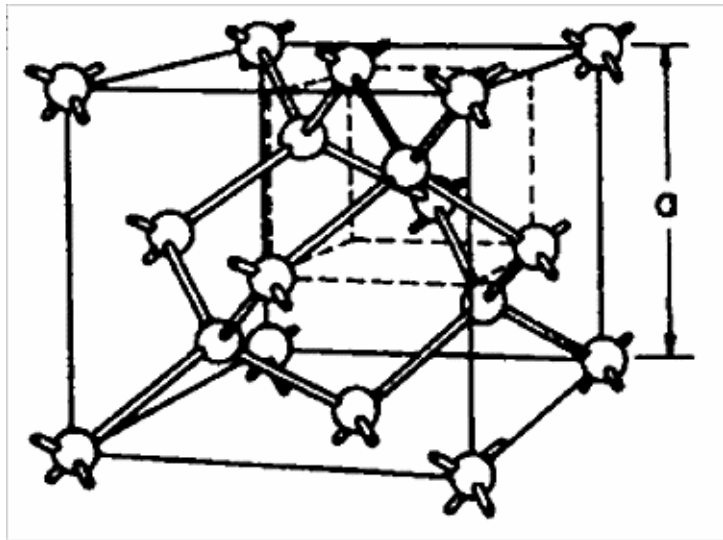
P-Type Semiconductor The addition of trivalent [impurities](#) such as boron, aluminum or gallium to an [intrinsic semiconductor](#) creates deficiencies of valence electrons, called "holes." It is typical to use B_2H_6 diborane gas to diffuse boron into the silicon material.



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

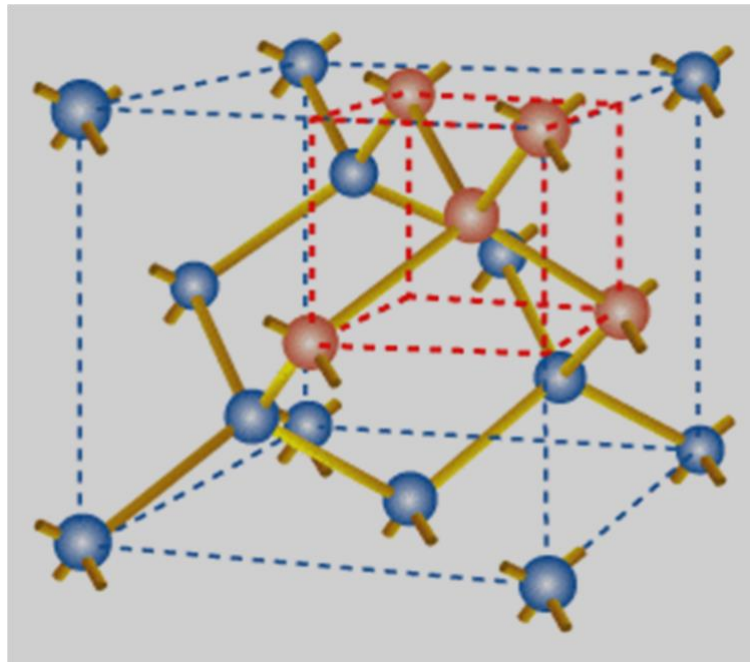
Silicon LATTICE STRUCTURE (un-Doped)

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>

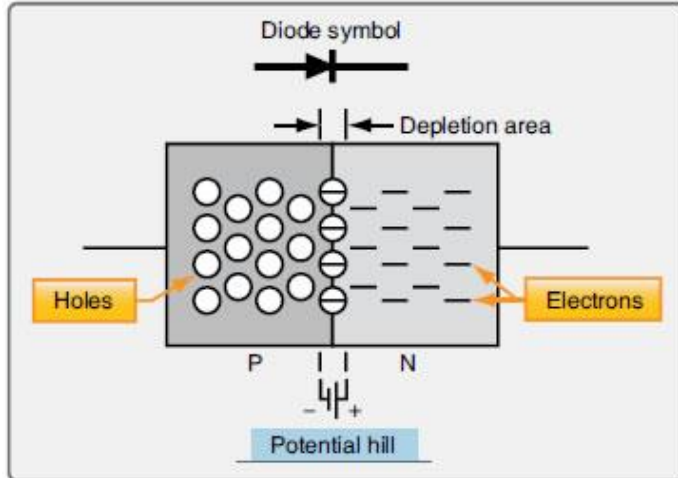


Figure 11-19. A potential hill.

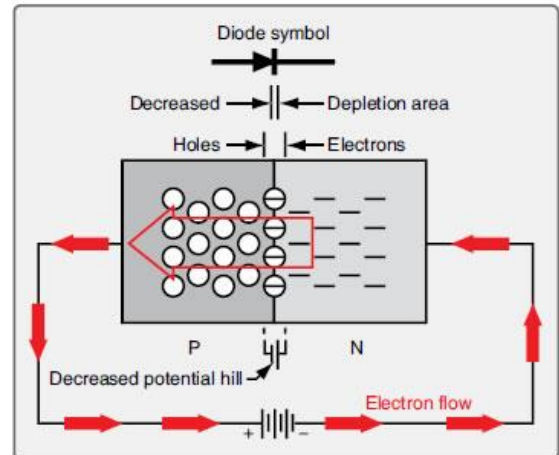


Figure 11-20. The flow of current and the P-N junction of a semiconductor diode attached to a battery in a circuit.

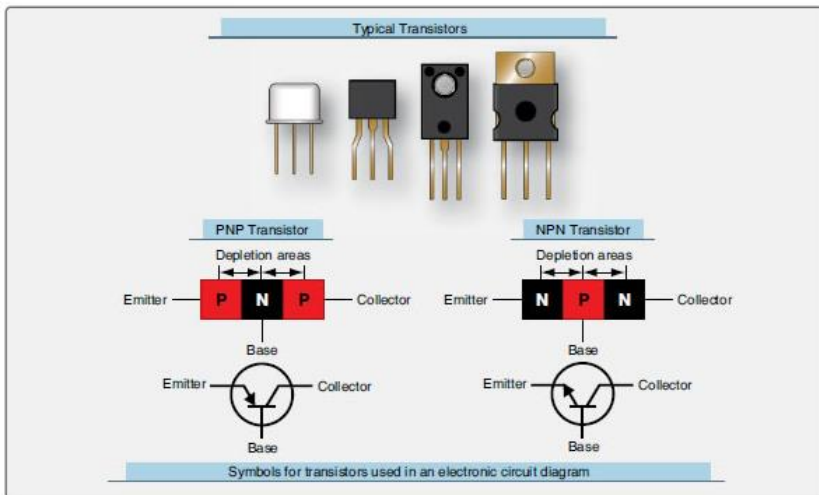


Figure 11-26. Typical transistors, diagrams of a PNP and NPN transistor, and the symbol for those transistors when depicted in an electronic circuit diagram.

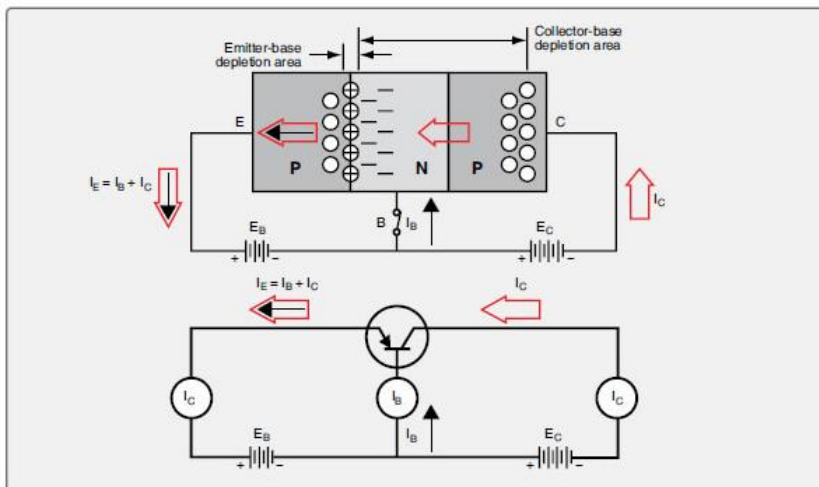


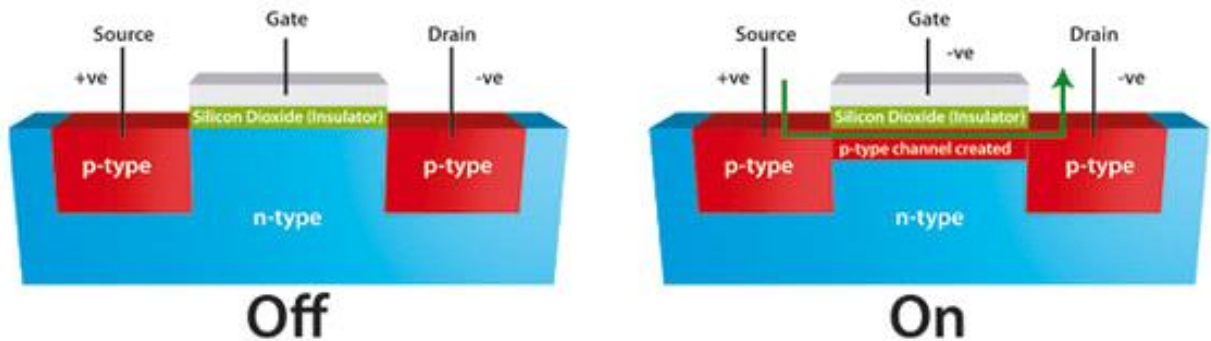
Figure 11-27. The effect of applying a small voltage to bias the emitter-base junction of a transistor (top). A circuit diagram for this same transistor (bottom).

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

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

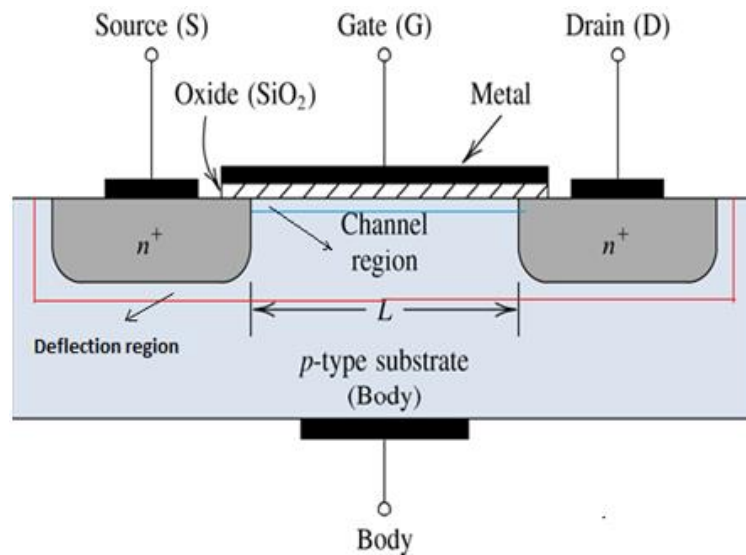
When a voltage is applied to the gate, a magnetic FIELD is created below the gate, which creates a conducting channel between the Source and Drain.

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



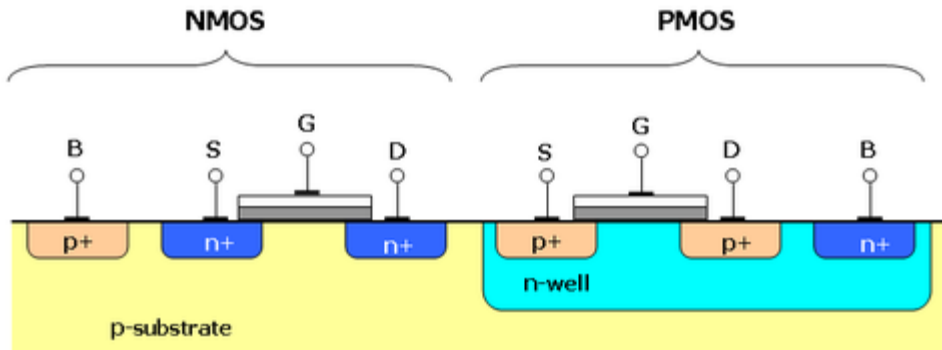
These are called Metal Oxide Semiconductors (MOS), i.e., **MOSFET's**

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

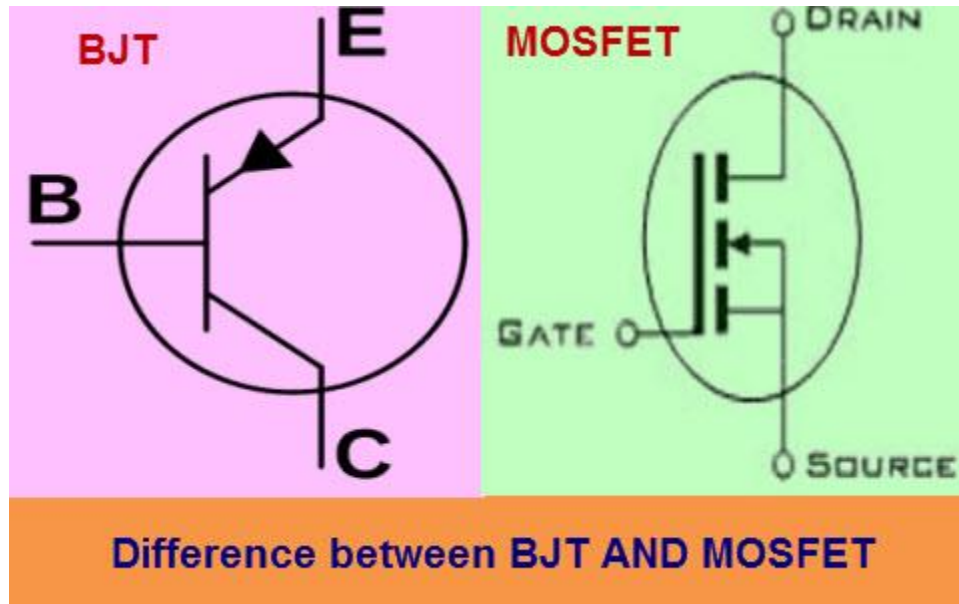


p-MOS has an N substrate, and n-MOS has a P substrate; and they are combined to make CMOS (i.e., Complementary Metal Oxide Semiconductor) circuits

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.

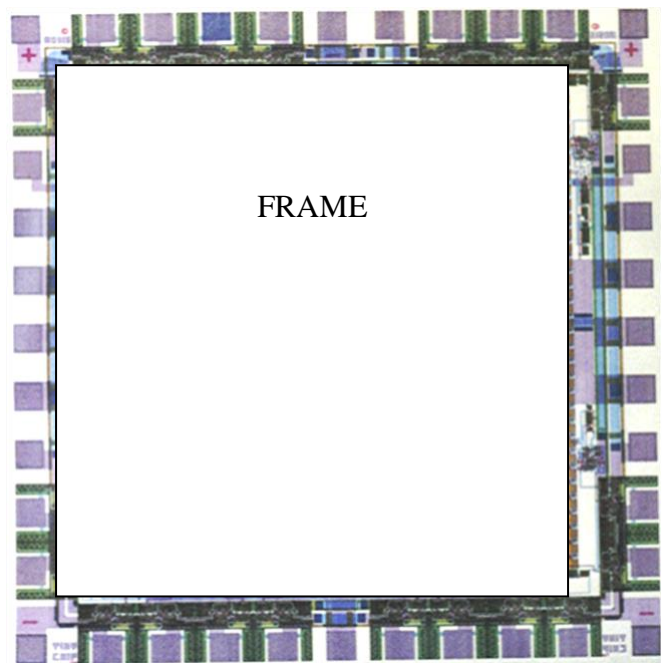
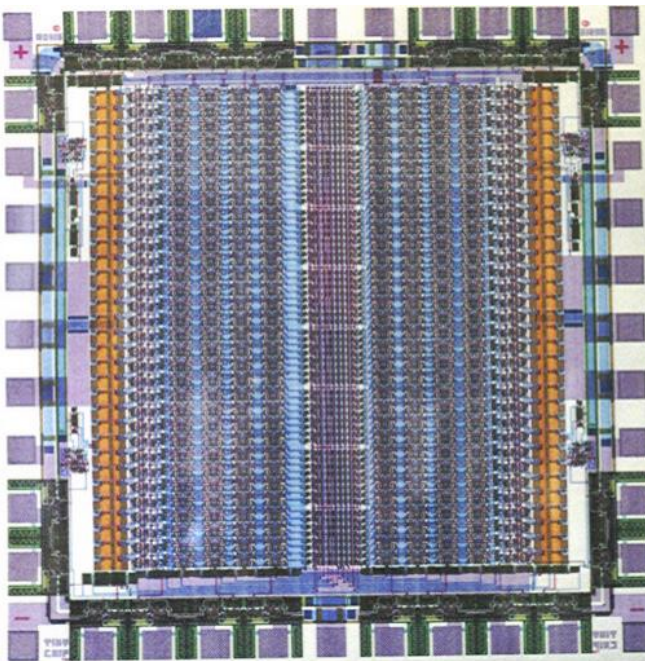
BiPolar (5 volts)
Transistor Circuits

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 CMOS (**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

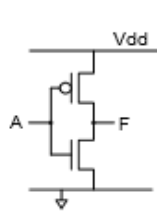


Integrated Circuits (IC's) "CHIPS" of DIGITAL LOGIC GATES

used in Dr. Wunderlich's courses with Lab projects

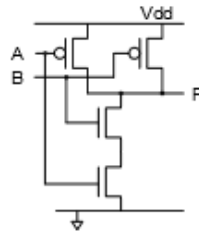
Here are CMOS DIGITAL LOGIC GATES:

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



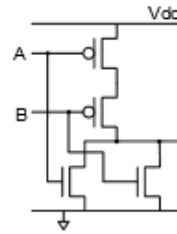
A	F
L	H
H	L

CMOS INVERTER



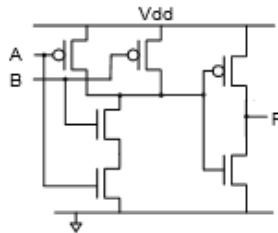
A	B	F
L	L	H
L	H	H
H	L	H
H	H	L

CMOS NAND



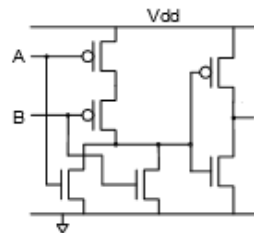
A	B	F
L	L	H
L	H	L
H	L	L
H	H	L

CMOS NOR



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

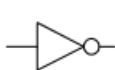
CMOS AND



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

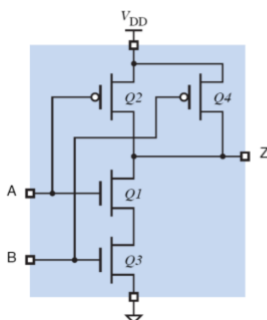
Made with either BJT's (usually in TTL circuits, i.e., Transistor-Transistor-Logic) or with FET's in CMOS circuits.

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(Advanced CMOS)
 - 74ACT(Advanced CMOS, TTL compatible)
 - 74FCT(Fast CMOS, TTL compatible)
 - 74FCTT(Fast CMOS, TTL compatible with TTL)

CMOS NAND gate

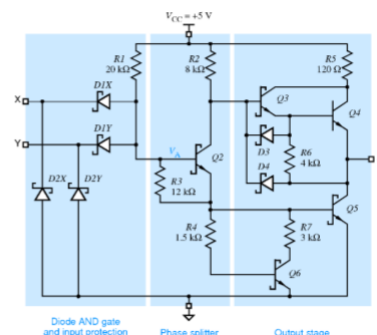


A	B	Q1	Q2	Q3	Q4	Z
L	L	off	on	off	on	H
L	H	off	on	on	off	H
H	L	on	off	off	on	H
H	H	on	off	on	off	L



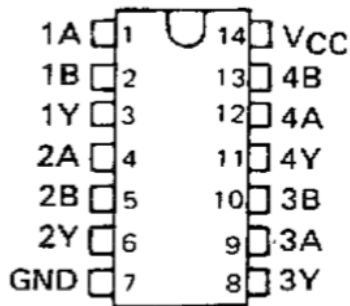
BiPolar Transistors

Example of LS-TTL gates: 2-input NAND

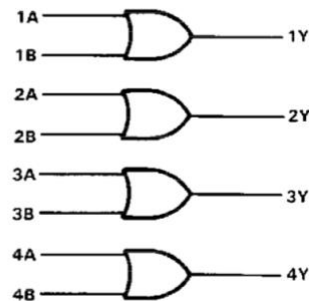


Dr Wunderlich's E273 lab is equipped various **TTL** (Transistor-Transistor-Logic) SSI (Small Scale Integration) IC's (Integrated Circuit) "Chips" . Below is a list of IC's usually found in the lab, Remember that TTL chips require 5Volts DC to operate (unlike CMOS chips used for the old radio shack circuit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

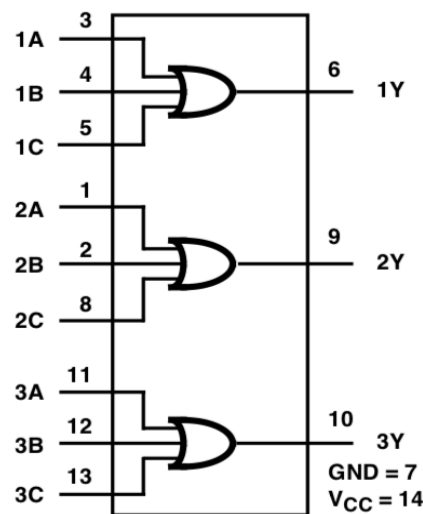
2 Input OR (SN74LS32N):



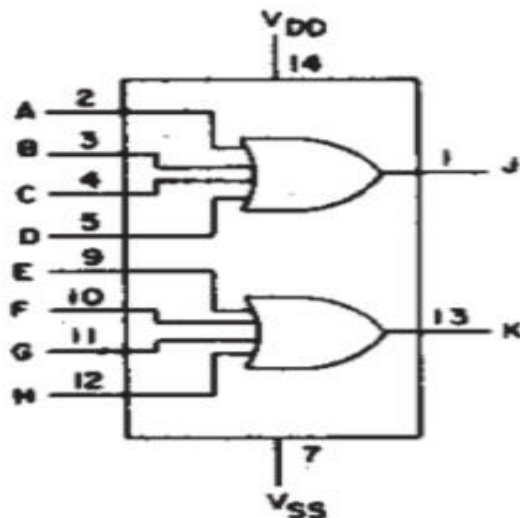
logic diagram



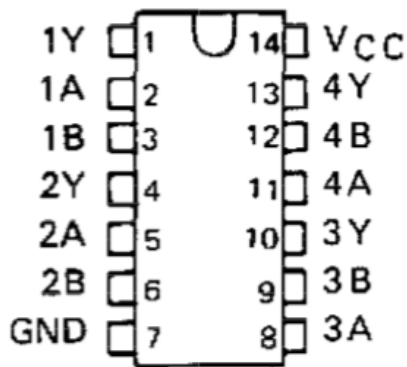
3 Input OR (CD74HC4075E):



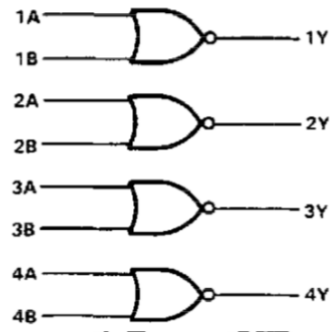
4 Input OR (CD4072BE):



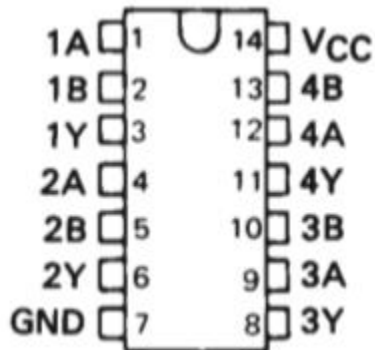
2 Input NOR (SN7402N):



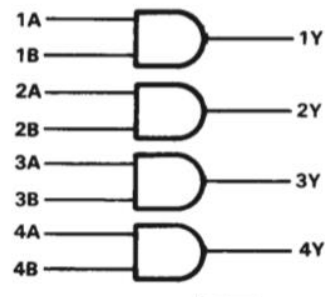
logic diagram (positive logic)



2 Input AND (SN74LS08N):

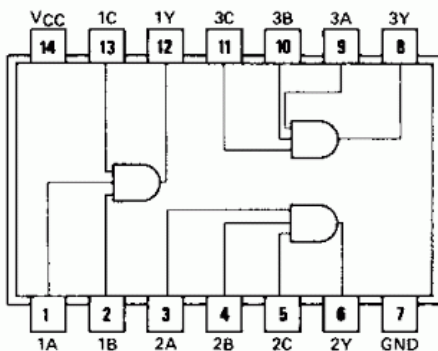


logic diagram (positive logic)

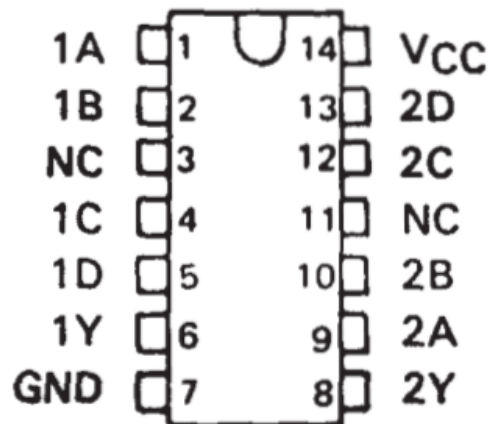


3 Input AND:

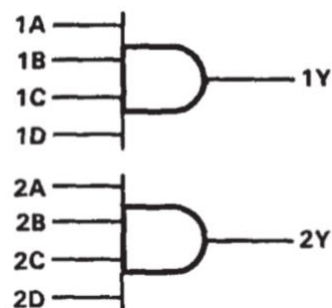
7411



4 Input AND (SN74LS21N):

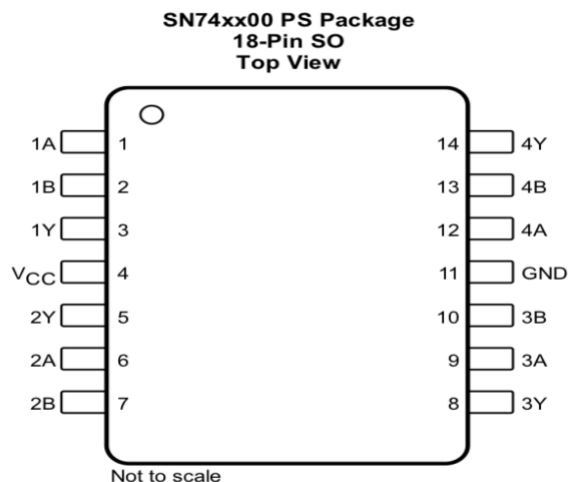


logic diagram

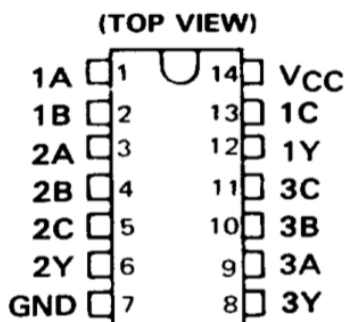


2 Input NAND (SN74LS00N):

Logic Diagram, Each Gate (Positive Logic)

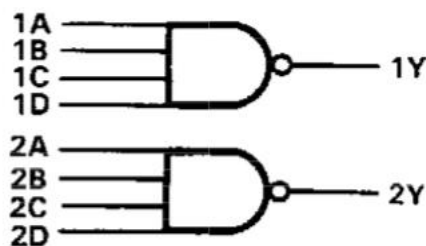
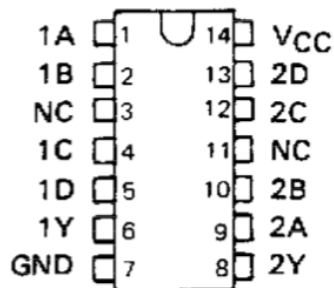


3 Input NAND (SN74LS10N):

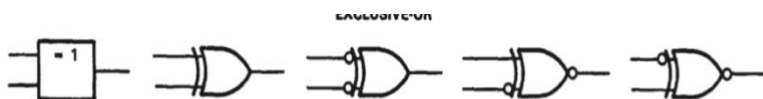
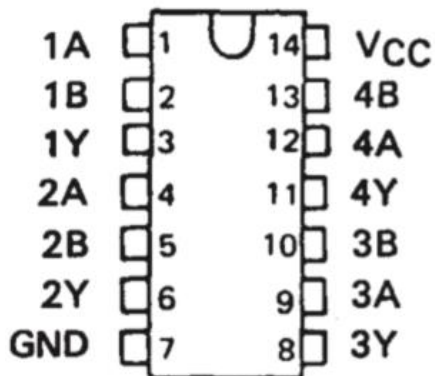


4 Input Quad NAND (74LS20):

logic diagram



2 Input XOR (SN74LS86AN):



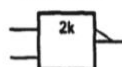
These are five equivalent Exclusive-OR symbols valid for an '86 or 'LS86A gate in positive logic; negation may be shown at any two ports.

LOGIC IDENTITY ELEMENT



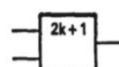
The output is active (low) if all inputs stand at the same logic level (i.e., $A=B$).

EVEN-PARITY



The output is active (low) if an even number of inputs (i.e., 0 or 2) are active.

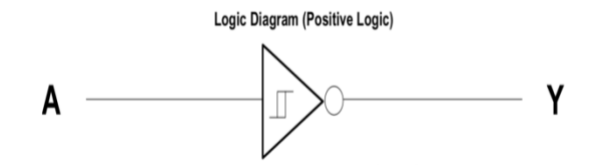
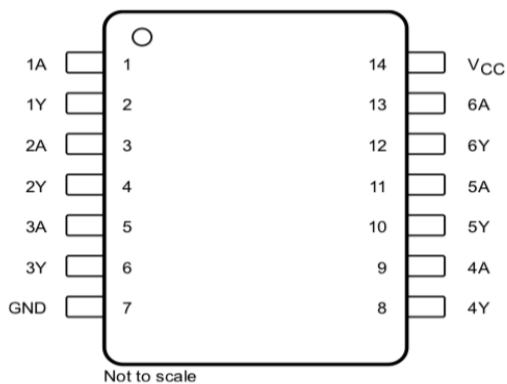
ODD-PARITY ELEMENT



The output is active (high) if an odd number of inputs (i.e., only 1 of the 2) are active.

Inverter (SN74LS14N):

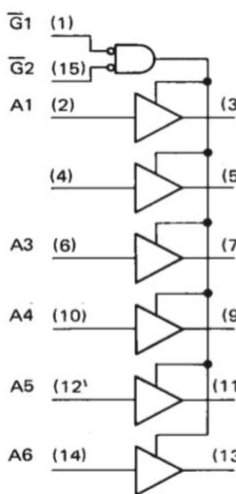
Top View



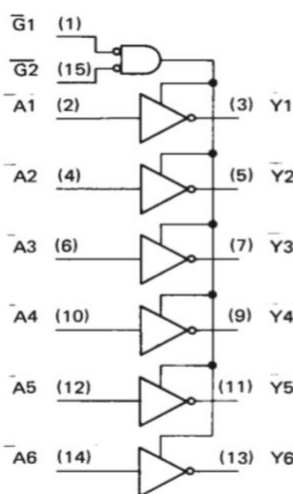
Hex Busdriver with 3-State Outputs (74367AN):

logic diagrams (positive logic)

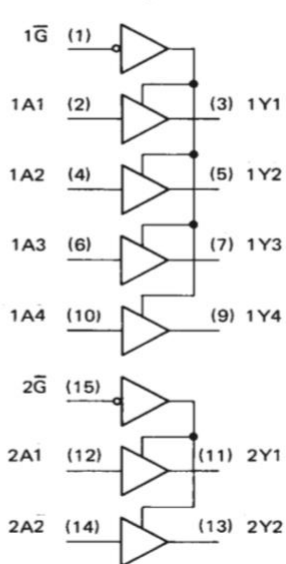
'365A, 'LS365A



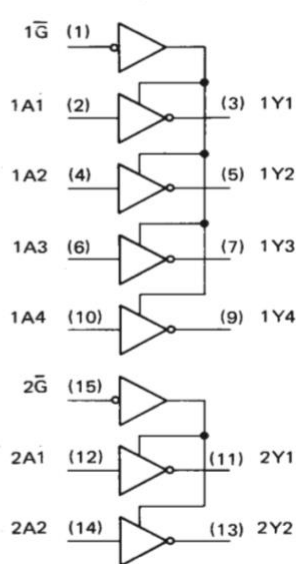
'366A, 'LS366A



'367A, 'LS367A

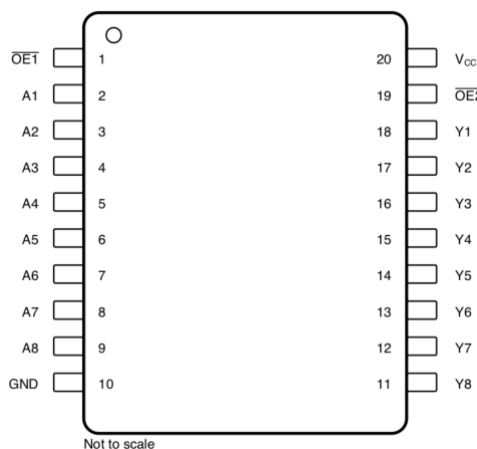


'368A, 'LS368A

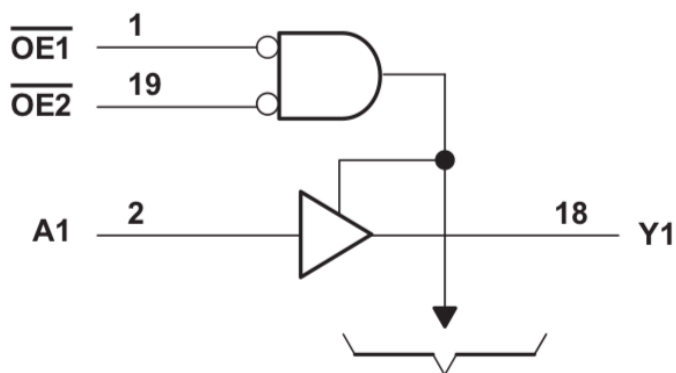


Pin numbers shown are for D, J, and N packages.

Buffer/Drivers 3-States (SN74HC541N):



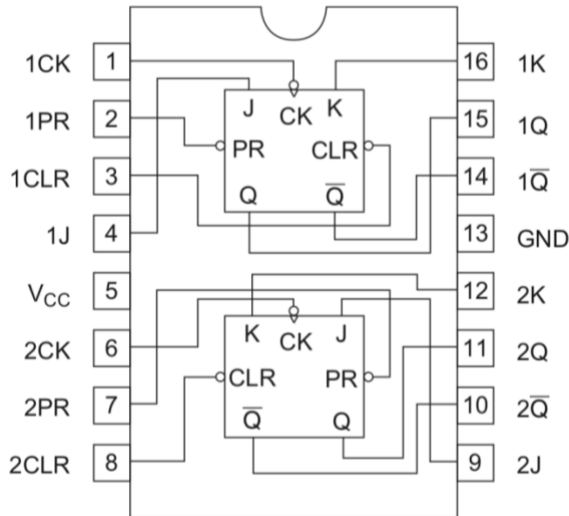
Logic Diagram (Positive Logic)



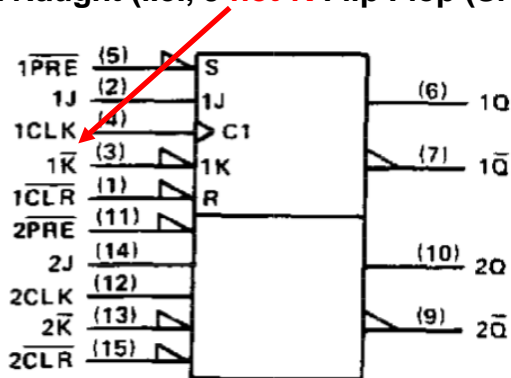
To Seven Other Channels

MEMORY CHIPS

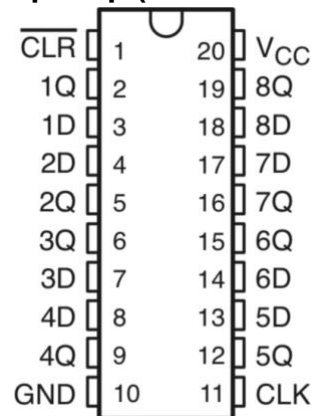
JK Flip Flop (HD74LS76AP):



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



D Flip Flop (SN74LS273N):



DRAM (TMS425612N)

