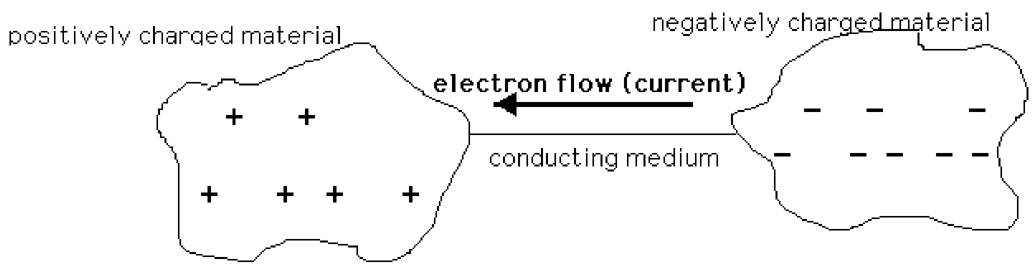
CS240 Laboratory 5
Electrical and Digital Laboratory Concepts

- **Basic Concepts of Electricity**
- **Transistors**
- **Circuit Equivalence**
- **Universal Gates**
- **Integrated Circuits**
- **Tools and Techniques for Building and Simulating Circuits**

Electricity = **the movement of electrons** in a material

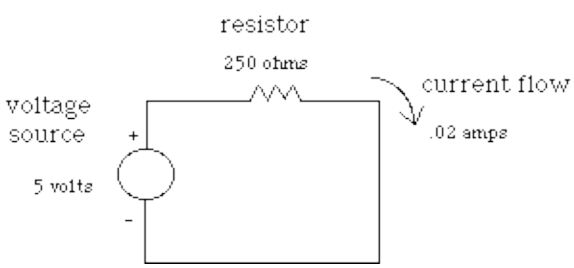
Materials tend to have a net negative or positive charge

Difference of charge between two points = **potential difference (V)**



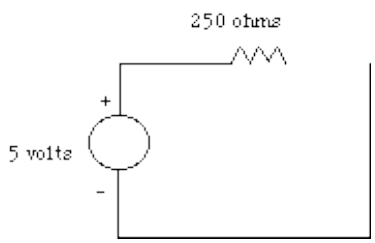
Rate at which electrons flow through = **current (A)**.

Ease of conduction, or current flow = **resistance (Ω)**

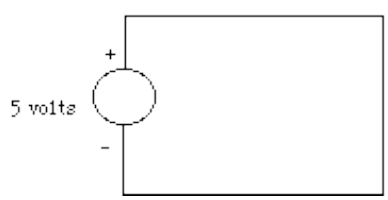


Ohm's Law, V = IR.

Open circuit = no current

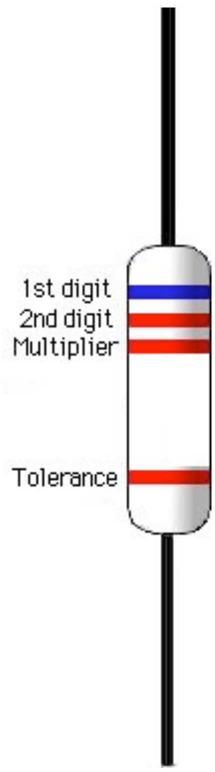


Short circuit = infinite current, since V/0 = infinite current:



Infinite current swiftly results in the destruction of the circuit!

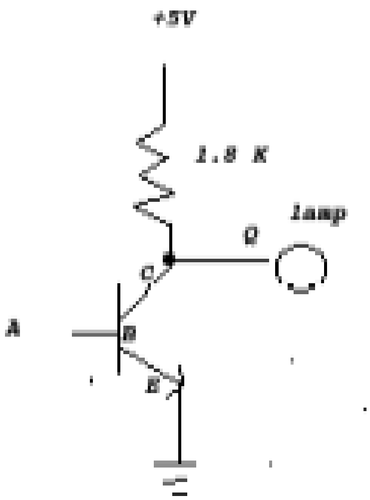
Resistor Color Codes



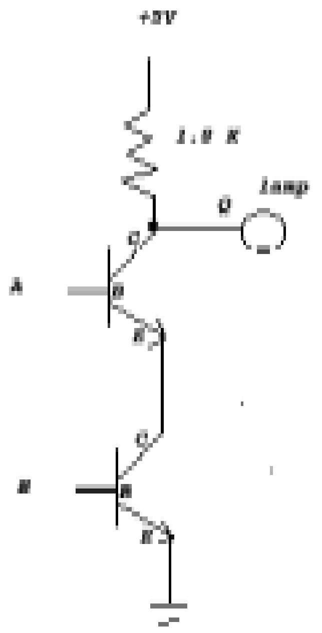
color	digit	multiplier
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000 (1K)
Yellow	4	10000 (10K)
Green	5	100000 (100K)
Blue	6	1000000 (1M)
Violet	7	10000000 (10M)
Gray	8	
White	9	

Transistors

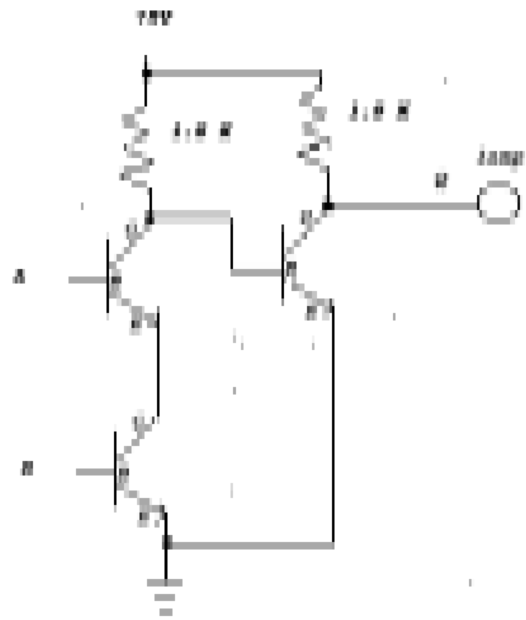
NOT
Uses one transitor



NAND
Uses two transistors



AND
Uses three transistors



Voltage levels can be interpreted as 1s and 0s: all possible inputs and outputs of a circuit can be described using the binary number system.

Positive Logic
High voltage (2 – 5 volts) = 1
Low voltage (0 – 1 volts) = 0

Negative Logic is the opposite assignment

Voltage levels between 1 and 2 volts will cause unpredictable results and must be avoided.

Circuit Equivalence

Two boolean functions with same truth table = **equivalent**

When there is an equivalent circuit which uses fewer gates, transistors, or chips, it is preferable to use that circuit in the design

Example:
Given: F = A'B' + A'B   Q = A' + A'B + A'B'

A	B	A'B'	A'B	F
0	0	1	0	1
0	1	0	1	1
1	0	0	0	0
1	1	0	0	0

A	B	A'	A'B	A' B'	Q
0	0	1	0	1	1
0	1	1	0	0	1
1	0	0	0	0	0
1	1	0	0	0	0

F and Q are equivalent because they have the same truth table.

Identities of Boolean Algebra

- Identity law $1A = A \quad 0 + A = A$
- Null law $0A = 0 \quad 1 + A = 1$
- Idempotent law $AA = A \quad A + A = A$
- Inverse law $AA' = 0 \quad A + A' = 1$
- Commutative law $AB = BA \qquad A + B = B + A$
- Associative law $(AB)C = A(BC)$
  $(A + B) + C = A + (B + C)$
- Distributive law $A + BC = (A + B)(A + C)$
  $A(B + C) = AB + AC$
- Absorption law $A(A + B) = A$
  $A + AB = A$
- De Morgan's law $(AB)' = A' + B'$
  $(A + B)' = A'B'$

Example:

$F = A'B' + A'B$
$\quad = A'(B' + B)$ distributive
$\quad = A'(1)$ inverse
$\quad = A'$ identity

$Q = A' + A'B + A'B'$
$\quad = A'(1 + B + B')$ distributive
$\quad = A'(1)$ null
$\quad = A'$ identity

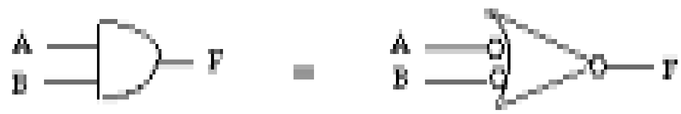
Universal Gates

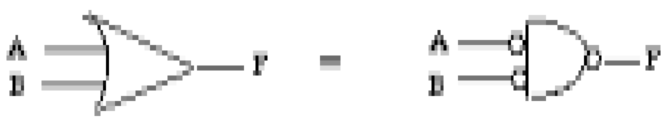
Any Boolean function can be constructed with NOT, AND, and OR gates

NAND and NOR = **universal gates**

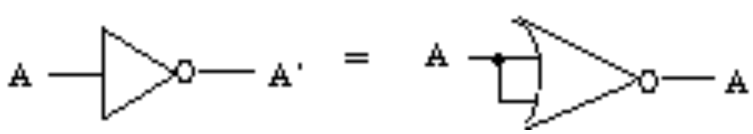
DeMorgan's Law shows how to make **AND** from NOR (and vice-versa)

AB = (A' + B')' (**AND** from NOR)
A + B = (A'B')' (**OR** from NAND)

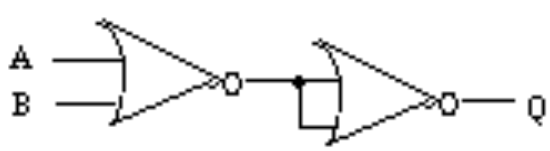




NOT from a NOR



OR from a NOR



To implement a function using only NOR gates:

- apply DeMorgan's Law to each AND in the expression until all ANDs are converted to NORs
- use a NOR gate for any NOT gates, as well.
- remove any redundant gates (NOT NOT, may remove both)

Implementing the circuit using only NAND gates is similar.

Example: $Q = (AB)'B'$

$= (A' + B')B'$

$= ((A'+B')' + B)'$ (NOR gates only, since NOR can be used as a NOT gate)

Simplifying Circuits or Proving Equivalency

General rule to simplify circuits or prove equivalency:

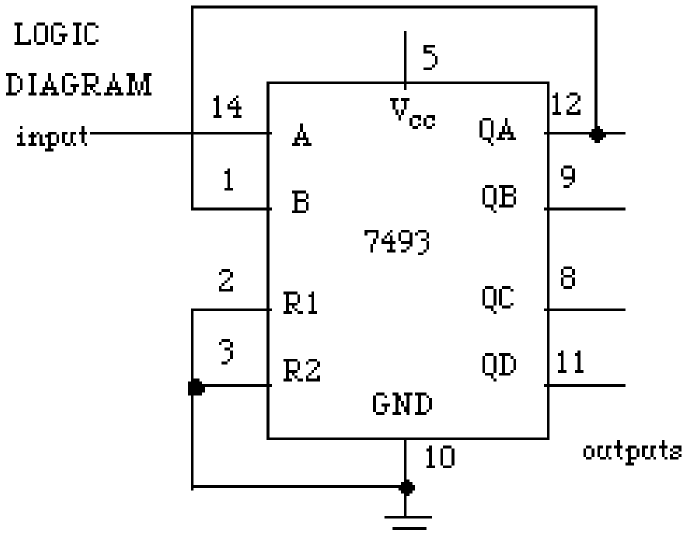
1. Distribute if possible, and if you can't, apply DeMorgan's Law so that you can.
2. Apply other identities to remove terms, and repeat step 1.

EXAMPLE: Is $(A'B)'(AB)' + A'B'$ equivalent to $(AB)'$?

$F = (A'B)'(AB)' + A'B'$	-- can't distribute
$= (A + B')(A' + B') + A'B'$	DeMorgan's
$= AA' + AB' + A'B + B'B' + A'B'$	distributive
$= 0 + AB' + A'B + B' + A'B'$	inverse and idempotent
$= AB' + A'B + A'B'$	identity
$= B'(A + A') + A'B$	distributive
$= B'(1) + A'B$	inverse
$= B' + A'B$	identity
$= B' + (A + B')'$	DeMorgan's
$= (B(A + B'))'$	DeMorgan's
$= (AB + BB')'$	distributive
$= (AB + 1)'$	inverse
$= (AB)'$	identity

Integrated Circuits

Logic diagrams are not the same as pin-outs! Show information about the logical operation of the device.

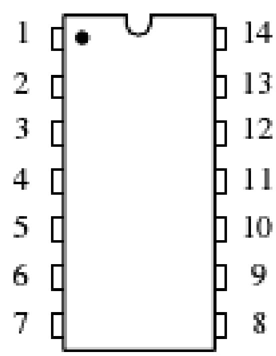


Pin-Out (found in **TTL Data Book** or online) show the physical layout of the pins:

Top left pin is pin 1, always to left of notch in chip, and often marked with a dot

Bottom left pin is almost always connected to ground (0V)

Pins are numbered, starting with "1" at the top left corner and incremented counter-clockwise around the device

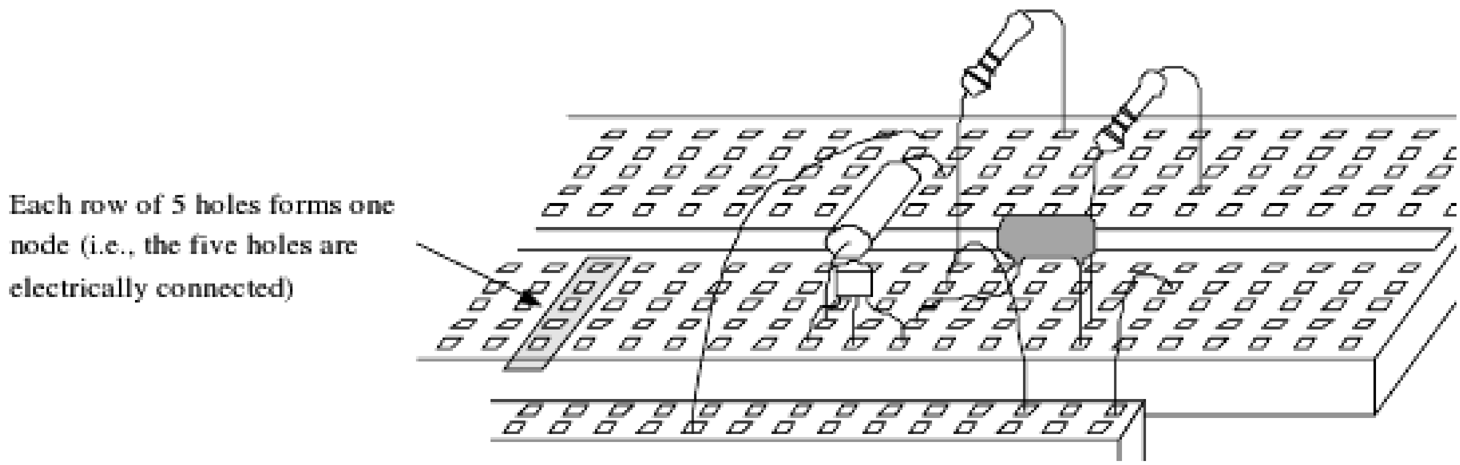


Top right pin is almost always connected to Vcc (+5V)

The chip will not work if it is not connected to power and ground!

Breadboard for wiring circuits
Tool to create prototype circuits before manufacturing PCB

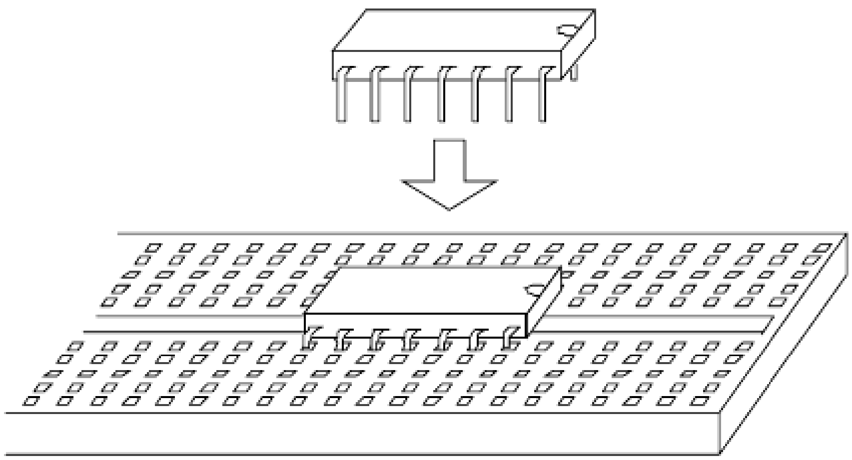
An array of holes in which wires or component leads can easily be inserted

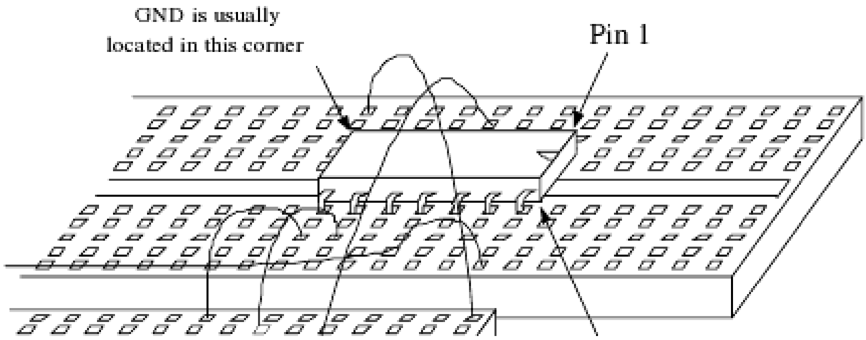


All holes in a row internally connected (use to tie one point to another in the circuit)

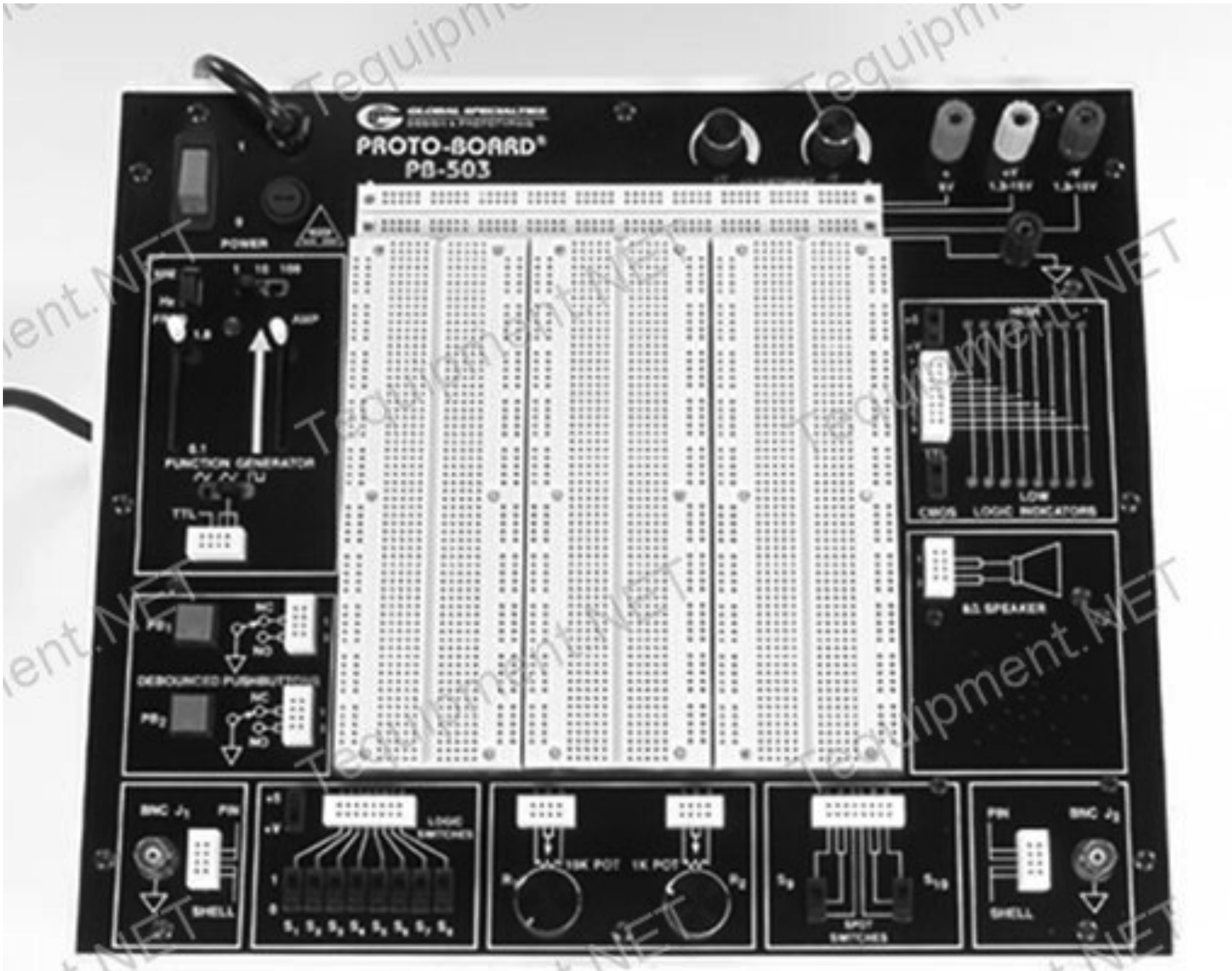
Use .22 gauge wires with 1/4” of insulation stripped from both ends

Insert chips straddling the groove





PB-503 Protoboard



Testing and Debugging

To test, check the output as the inputs are switched through all possible combinations

Problem: wrong output for a particular combination of inputs

Possible causes

1. Power and/or ground not connected

2. Wrong pin connections

3. Wrong gate/chip

4. Bad gate/chip

5. Faulty design

To avoid problems, use a systematic approach to design and implementation!

Debugging Strategies

Following a systematic process to debug and correct a circuit is preferable (and often much less frustrating) than simply tearing out the circuit and starting again.

Logic probe: tool for measuring outputs

1. Check power and ground for each chip

2. Check outputs and trace back to problem

3. If output is incorrect:

    a. Check pin numbers

    b. Check chip number

    c. Bad connection (2 outputs wired together) may need to replace the chips

    d. Bad gate

4. Re-check your design if no problem was found

Once a problem has been corrected, re-test

Circuit Simulation/LogicWorks