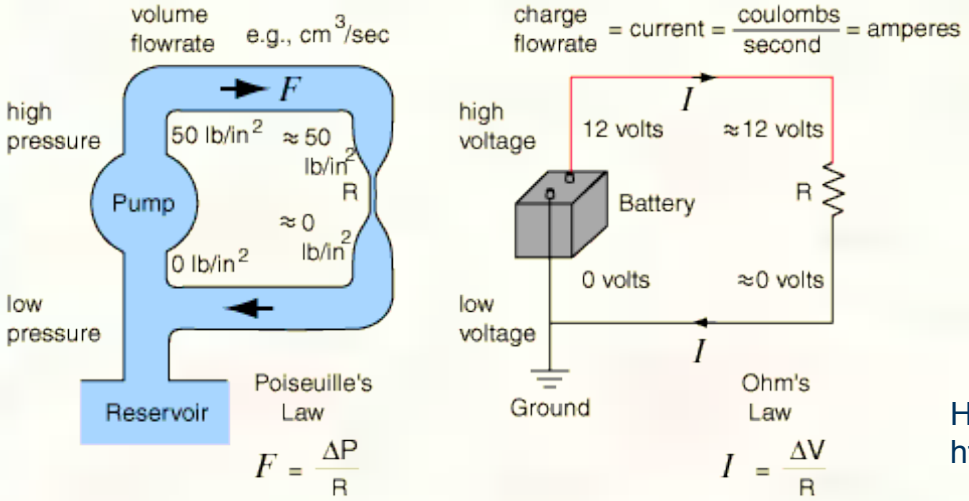
CMOS Transistors and Gates

Simple electronics

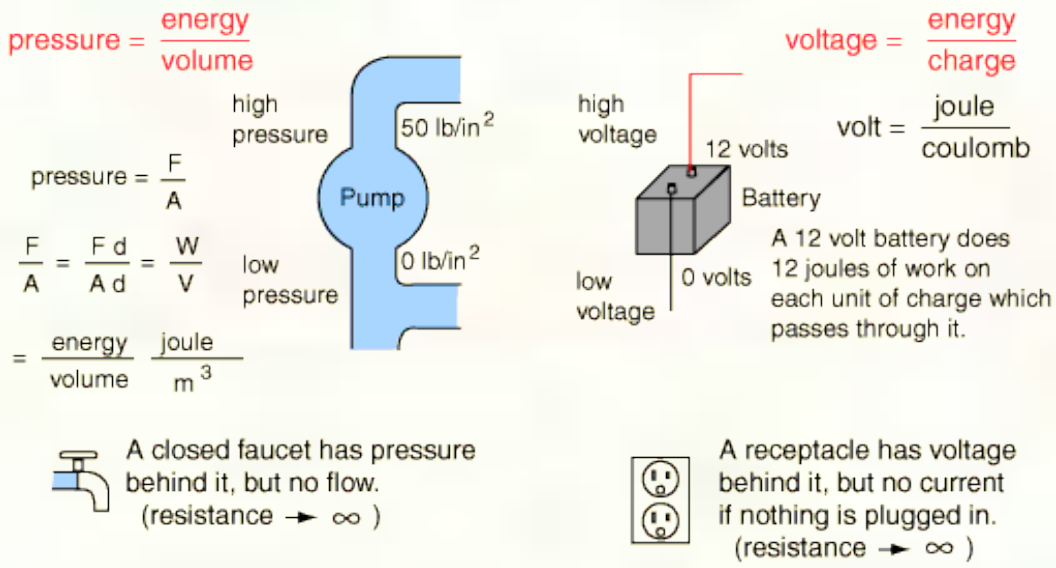
- Ohm's Law - V = IR
  - voltage (V) equals current (I) times resistance (R)
- Hydraulic Analogy
  - Charge ⇒ liquid
  - Current ⇒ flow rate
  - Voltage ⇒ water pressure
  - Resistance ⇒ related to length and radius of pipe (kL/r^4)



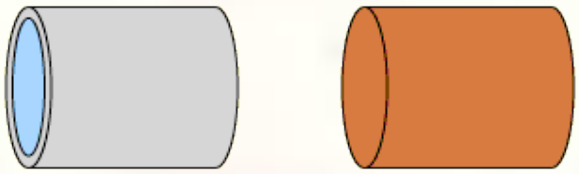
Hydraulic pictures from
http://hyperphysics.phy-astr.gsu.edu

Hydraulic analogy

- Voltage ⇒ water pressure



- Current ⇒ flow rate



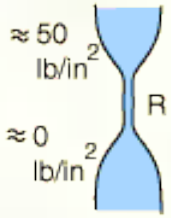
Volume flow rate in m^3/sec, etc.

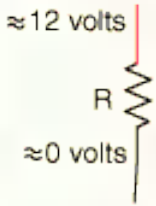
Current flow rate in coulombs/sec = amps

Hydraulic analogy

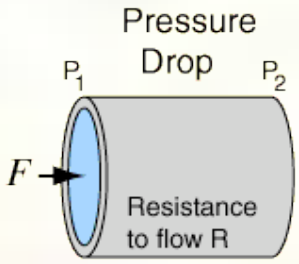
- Resistance ⇒ related to length and radius of pipe (kL/r^4)

The resistance of a constriction in a large pipe is so great that essentially all the pressure drop will appear across the resistance.



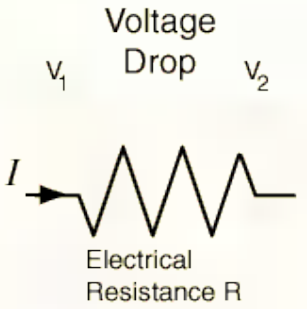


The resistance of a copper wire is so small that essentially all the voltage drop will appear across the resistor (or an appliance).



$$F = \frac{P_1 - P_2}{R}$$

Poiseuille's law for fluids

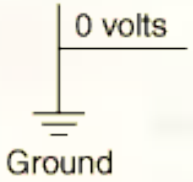


$$I = \frac{V_1 - V_2}{R}$$

Ohm's law for electric circuits

- Ground ⇒ reservoir

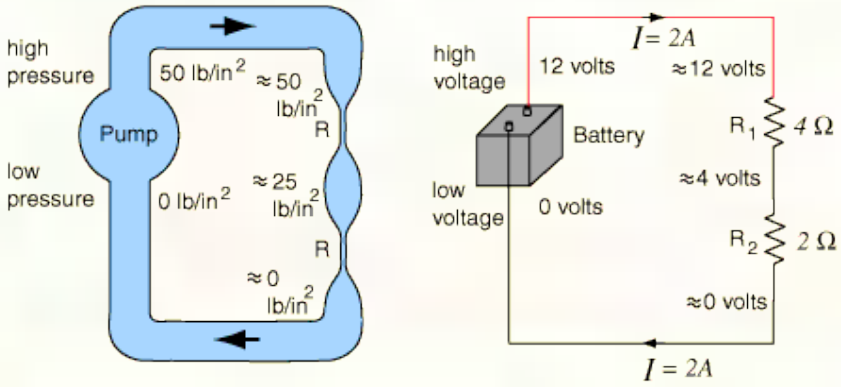
The reservoir can supply water to the circuit, and holds the pressure of the adjacent pipes at the pressure of the reservoir.



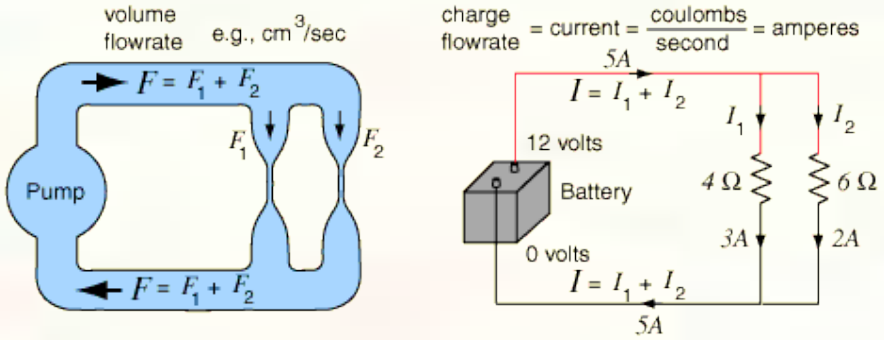
The ground can supply charge to the circuit, but its main function is to hold the voltage of nearby wires at the voltage of the earth.

Hydraulic analogy

- Resistances in series



- Resistances in parallel

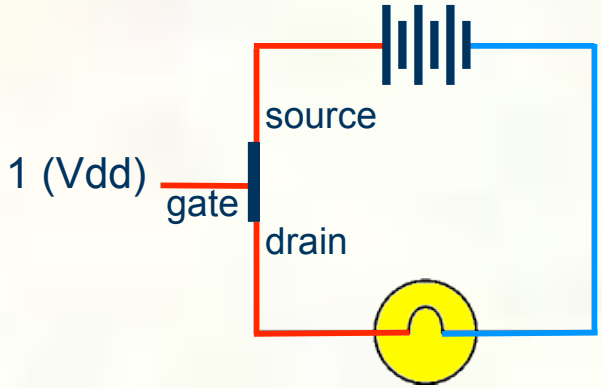


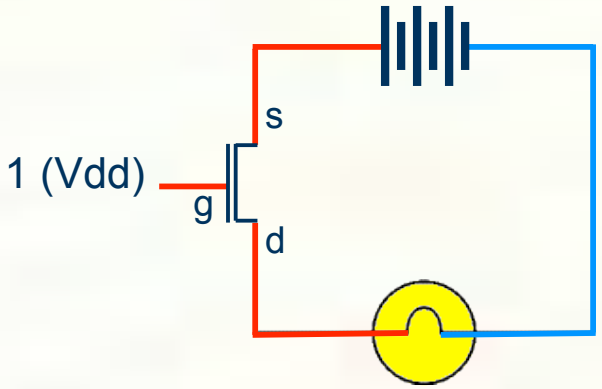
CMOS Transistors

- Need circuits to represent 2 discrete values
  - 1,0 for binary representations
  - True, False for Boolean logic
- Let high voltage (V_{dd}) represent 1, or true
- Let low voltage (0 volts or gnd) represent 0, or false
- If we have some switches to control whether or not these voltages can propagate through a circuit, we can build a computer with them
  - Note, the earliest digital computers were electromechanical, made out of relays, so this is hardly a new idea
- Our switches will be CMOS transistors

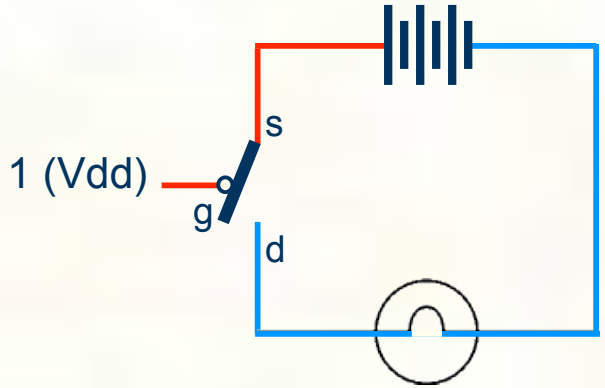
Two kinds of transistors

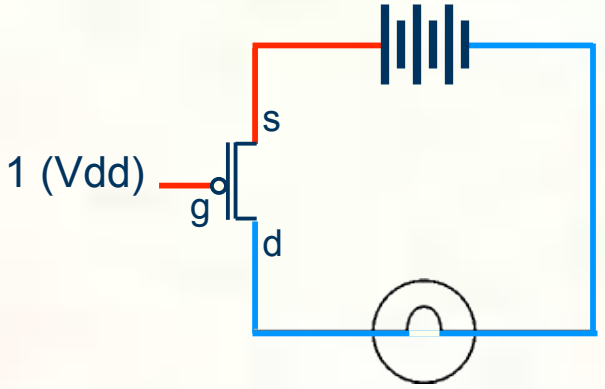
N-type





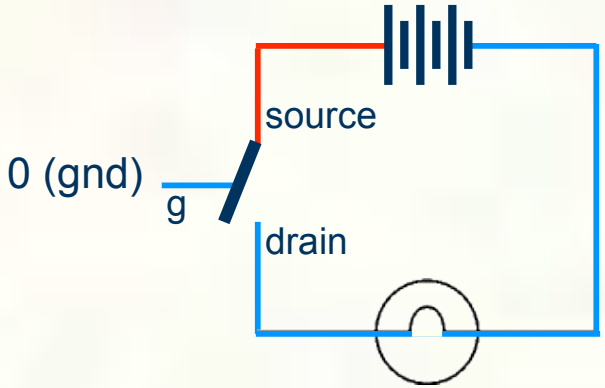
P-type

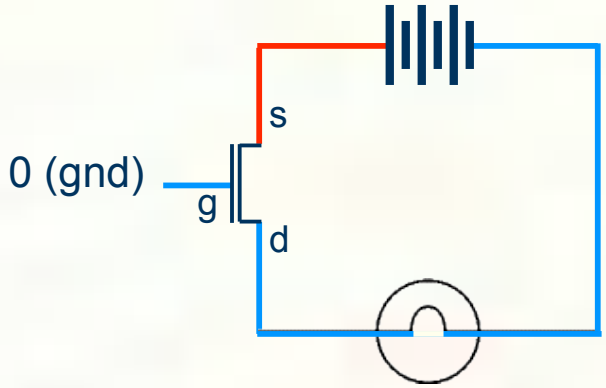




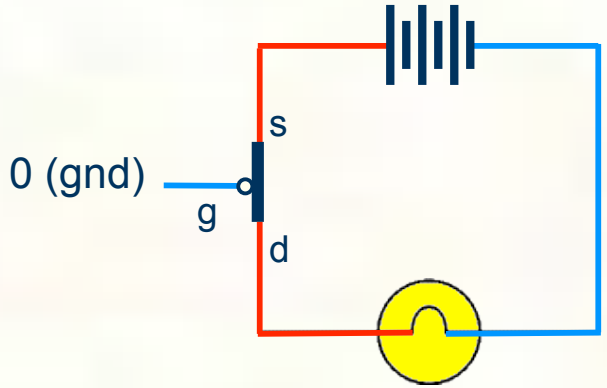
Two kinds of transistors

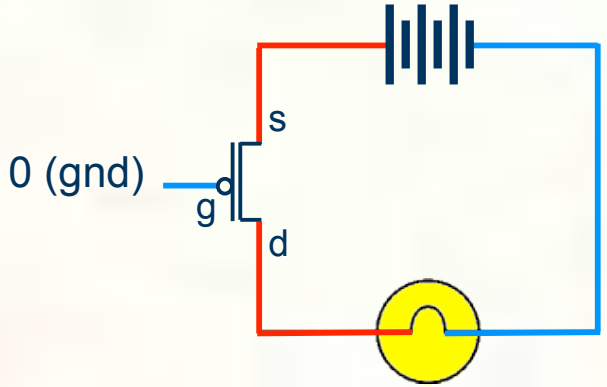
N-type





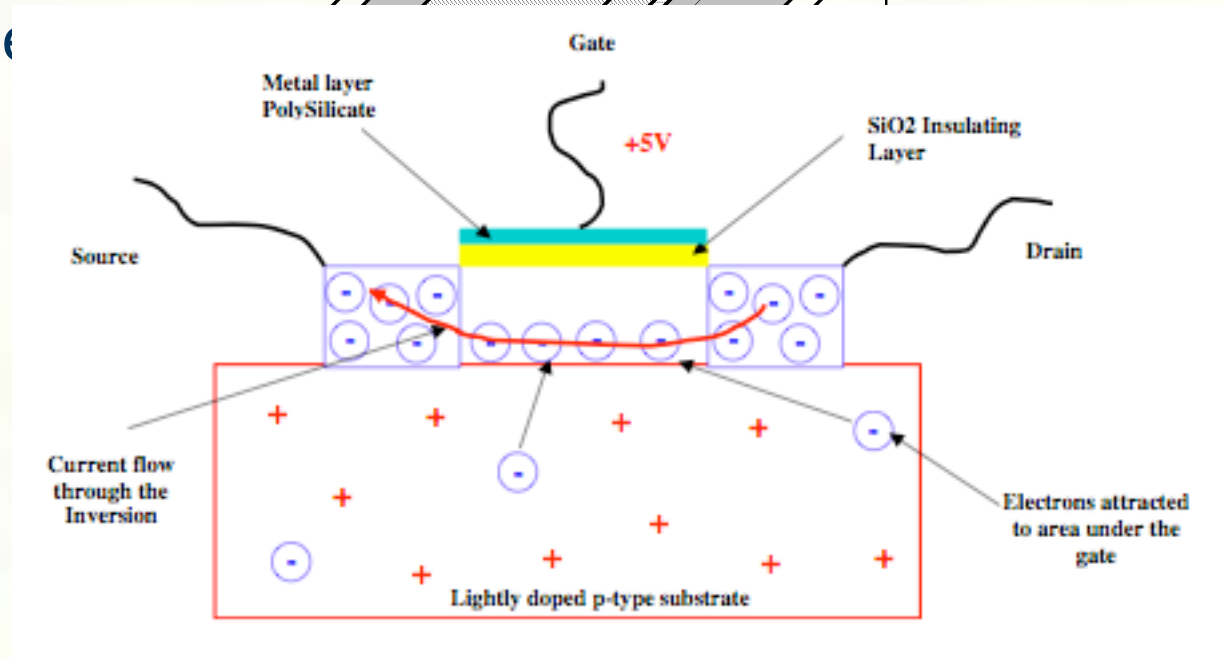
P-type

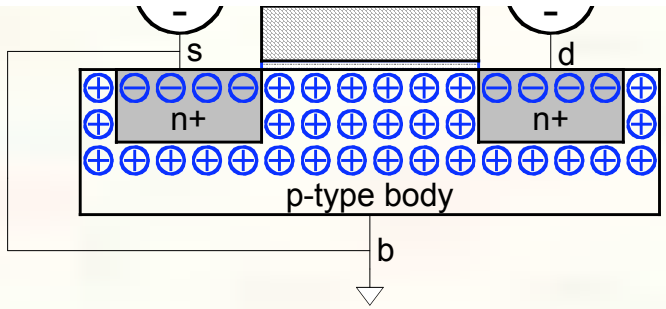




How they work as switches

N-type



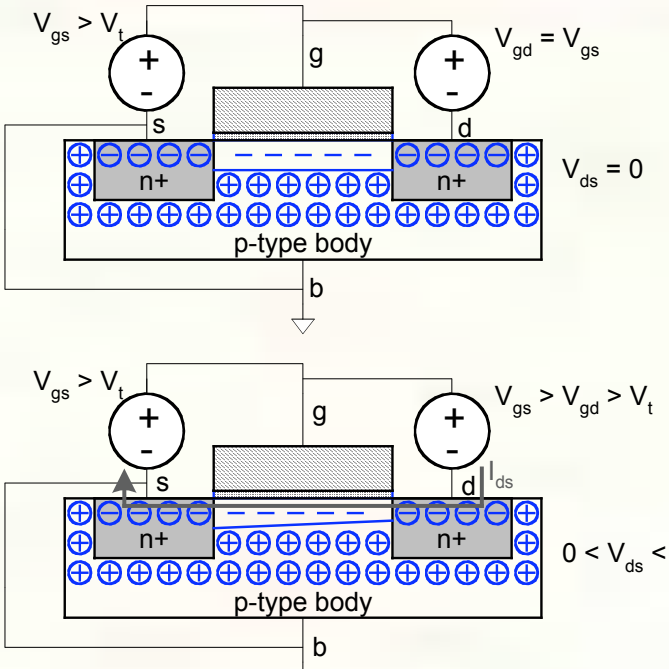


How they work as switches

When $V_{gs} > V_{th}$,the threshold voltage

- excess electrons attracted into channel
- current flows and switch is closed
- drain voltage cannot be more than source voltage = V_g-V_{th}
- this is at most V_{dd}-V_{th}
- V_{dd}-V_{th} is still considered a 1, but a *weak* 1
- if source voltage is 0, then drain voltage is too, so 0 still strong

N-type



CMOS transistor pictures from
UT ECE VLSI course slides

CMOS circuit rules

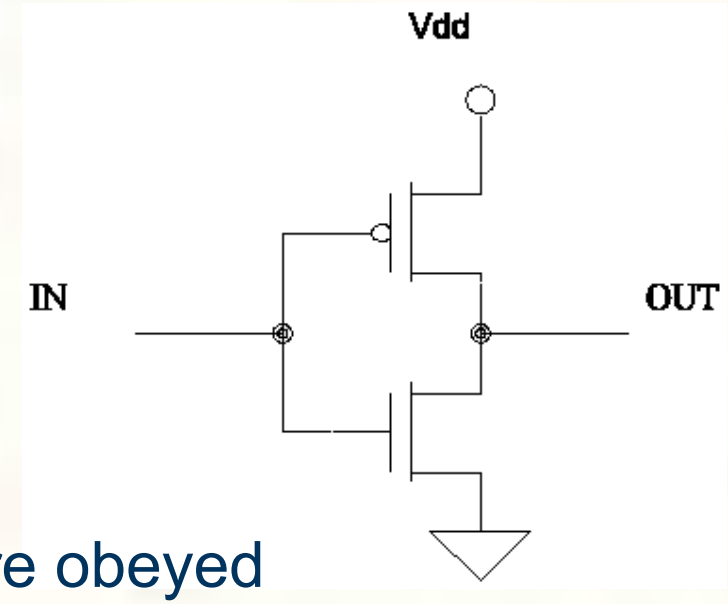
- Never create a path from V_{dd} to gnd
- Don't pass weak values
  - N-type transistors pass weak 1's (V_{dd} - V_{th})
  - N-type transistors pass strong 0's (gnd)
  - Use N-type transistors only to pass 0's (n to negative)
  - Conversely for P-type transistors
    - Pass weak 0's (V_{th}), strong 1's (V_{dd})
    - Use P-type transistors only to pass 1's (p to positive)
- Never leave a wire undriven
  - Make sure there's always a path to V_{dd} or gnd

Example CMOS gate - inverter

Truth table

In	Out
0	1
1	0

Circuit



Note how all 3 design rules are obeyed
Circuit amplifies weak input 1 or 0