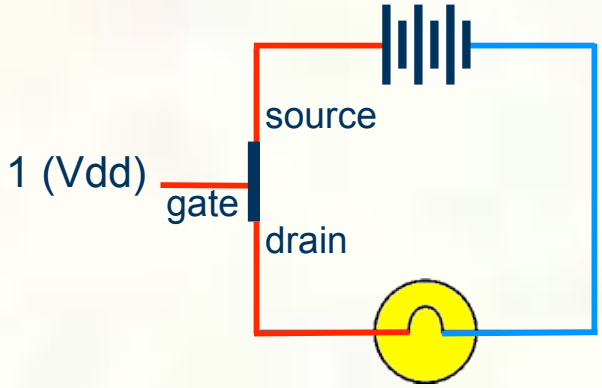
# CMOS Transistors and Boolean Logic Gates

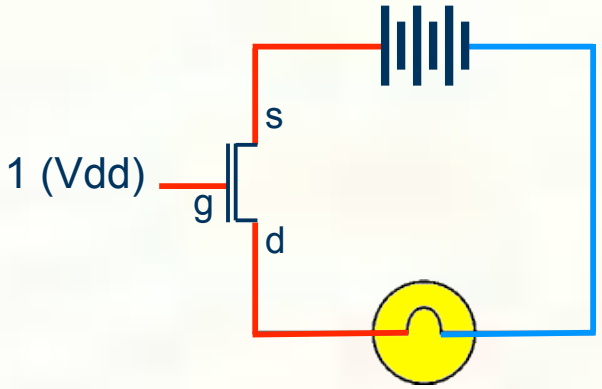
# CMOS Transistors

- 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

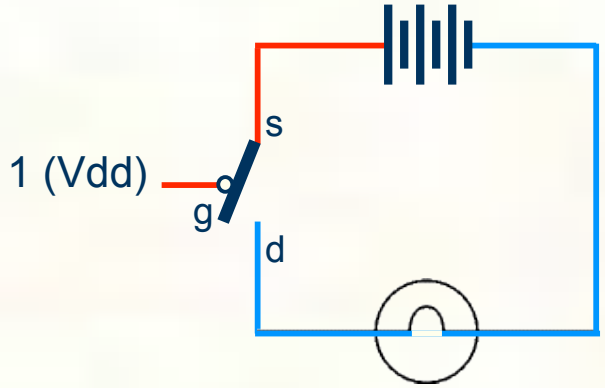
# Two kinds of transistors

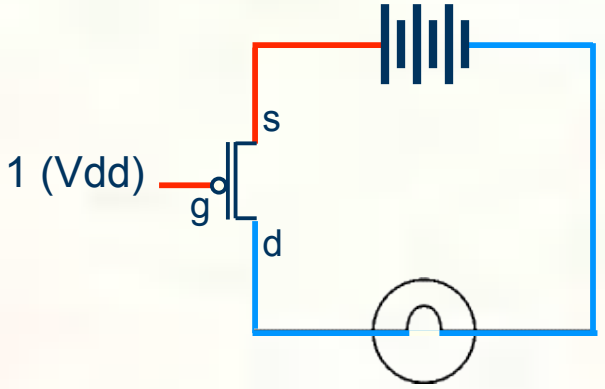
N-type



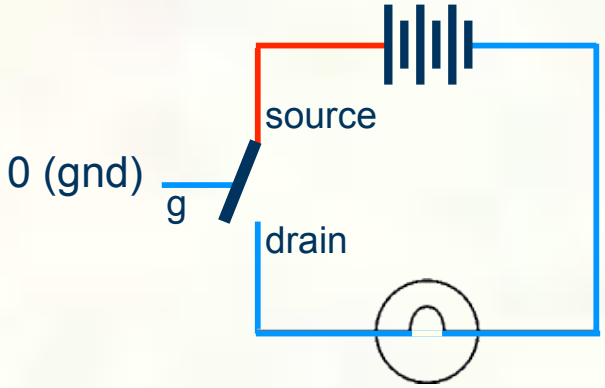

P-type

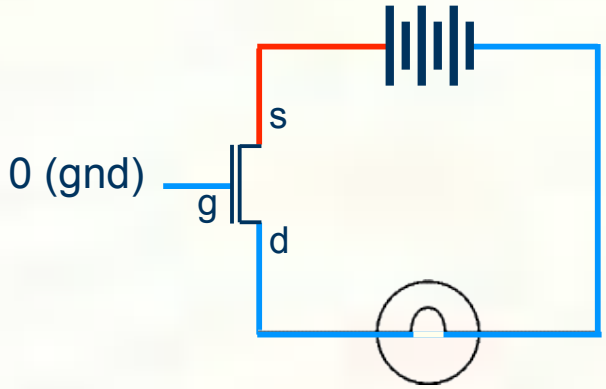


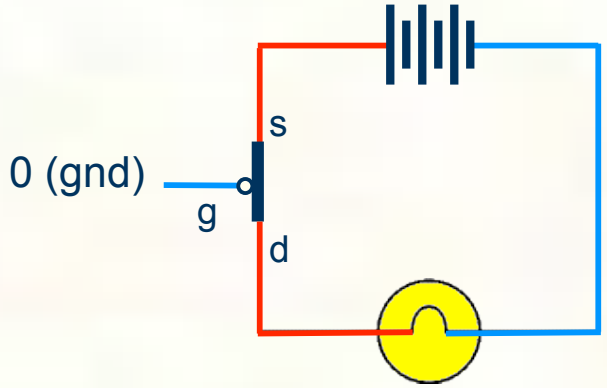
# Two kinds of transistors

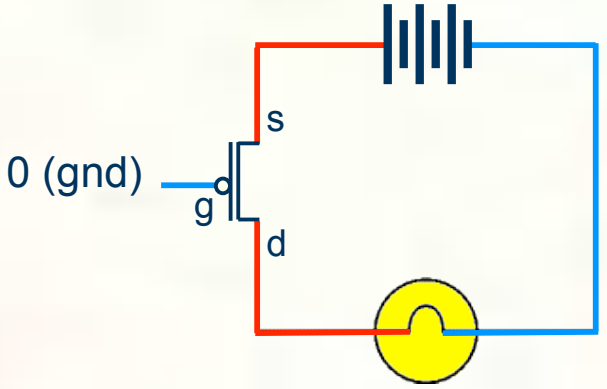
N-type



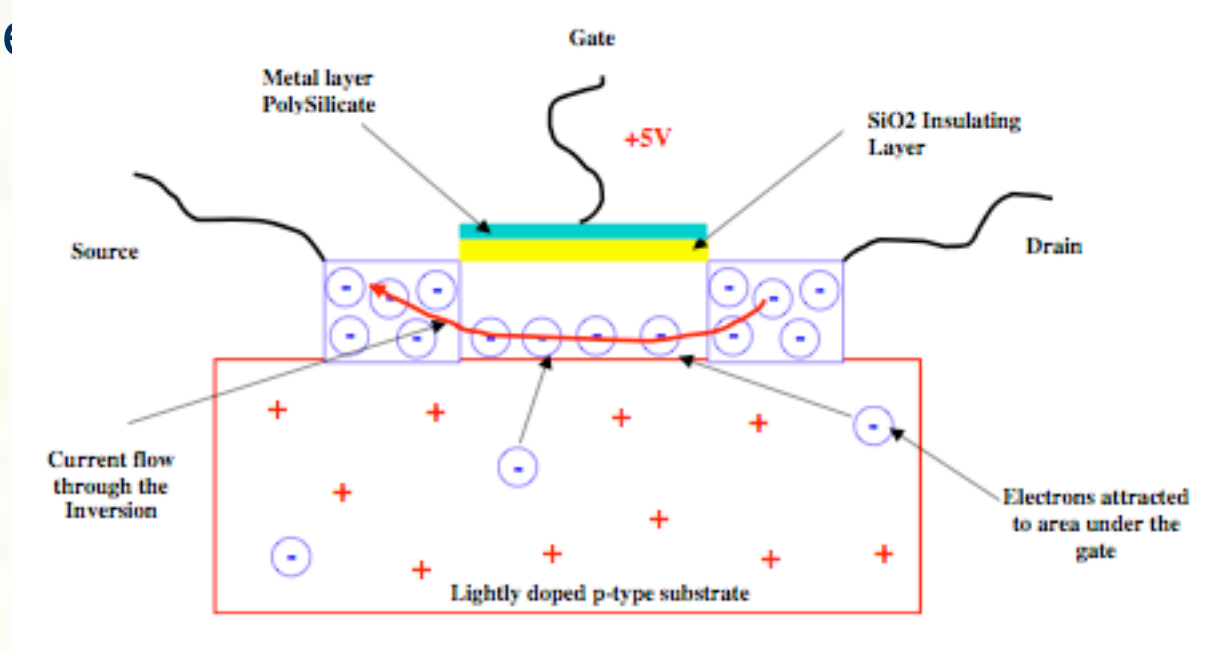

P-type

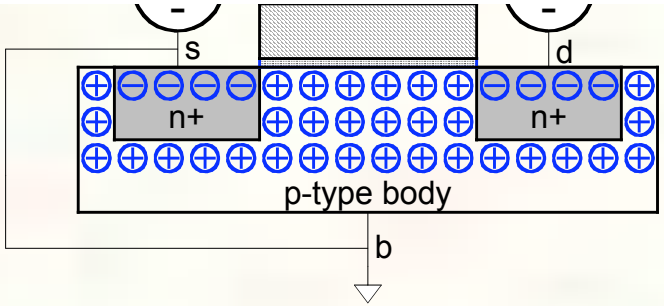


# How they work as switches

N-type



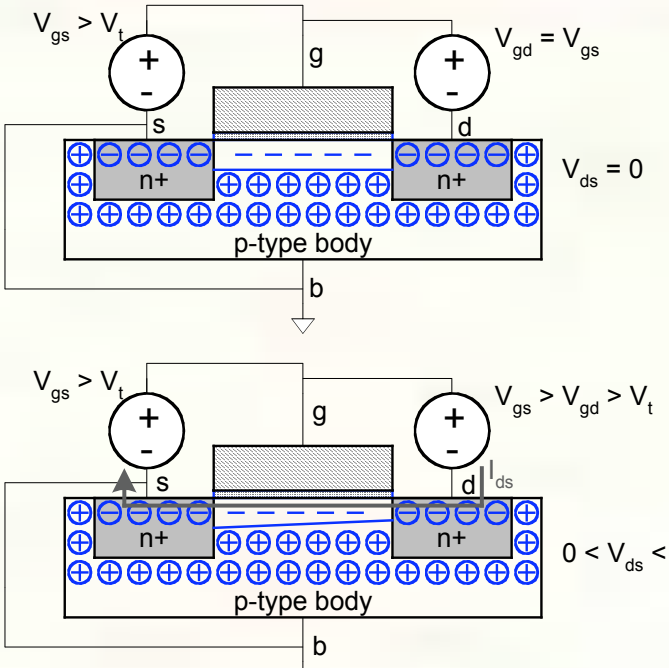



# How they work as switches

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

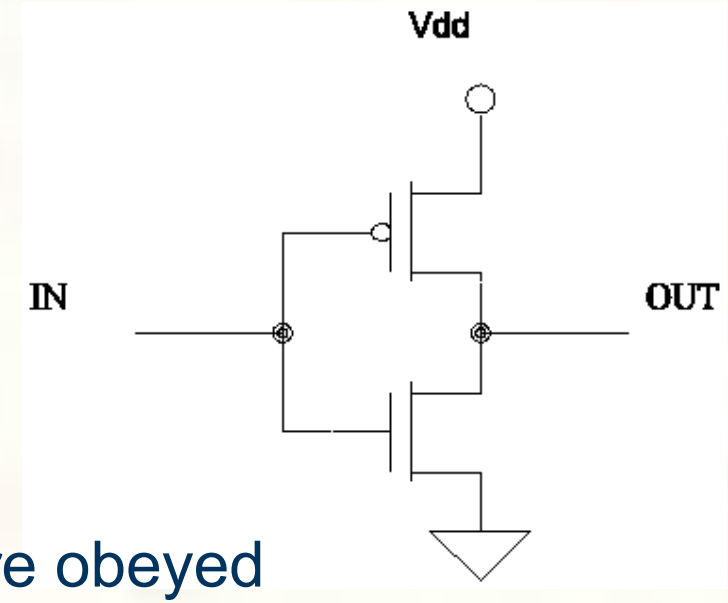
- Never create a path from $V_{dd}$ to gnd
- Don't pass weak values
  - N-type transistors pass weak 1's ($V_{dd}$ - $V_{th}$)
  - N-type transistors pass strong 0's (gnd)
  - Use N-type transistors only to pass 0's (n to negative)
  - Conversely for P-type transistors
    - Pass weak 0's ($V_{th}$), 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