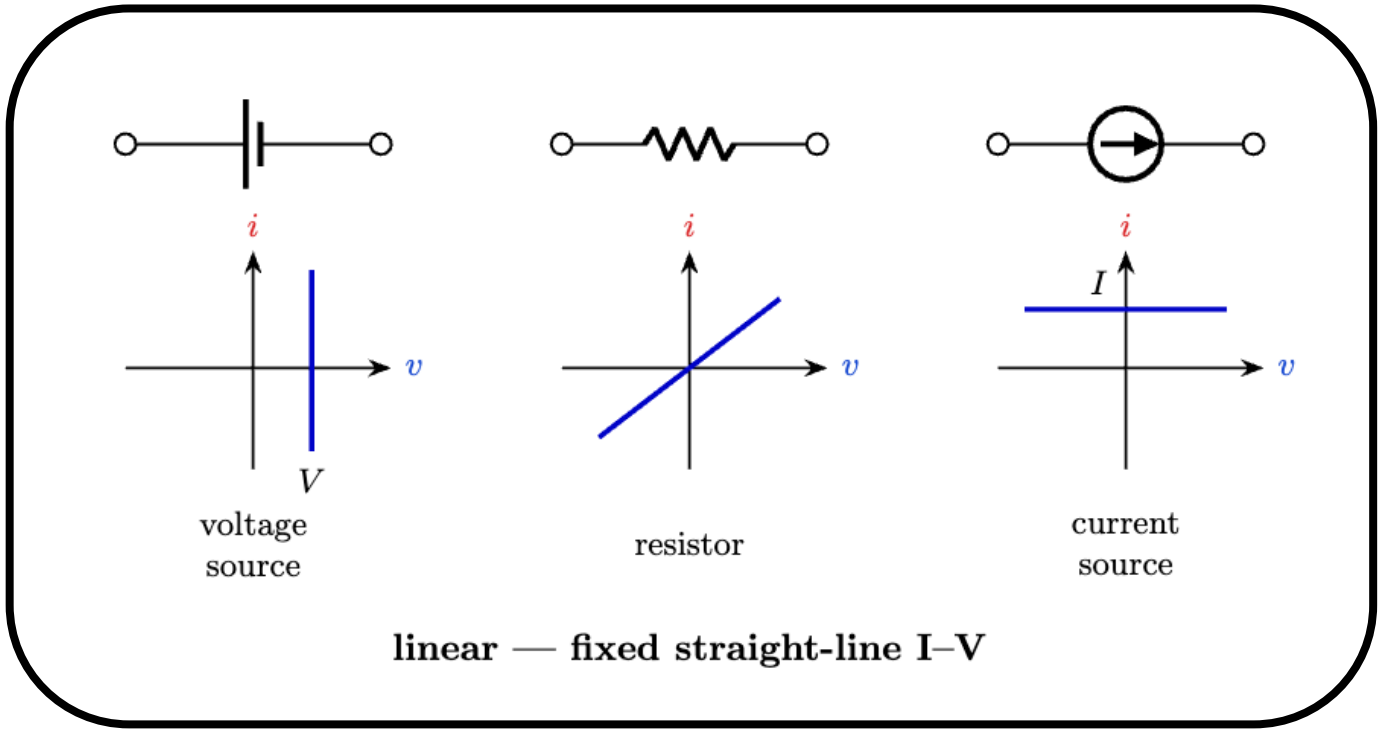
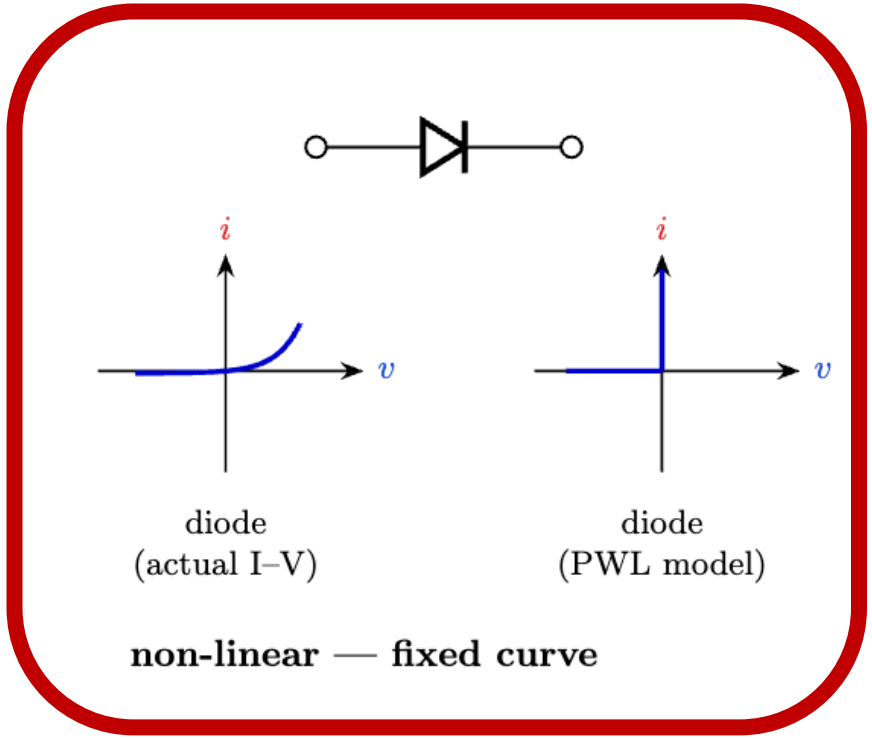
Diode and MOSFET IV characteristics

IV characteristics of different devices

Linear IV Char.



Non-Linear IV Char.



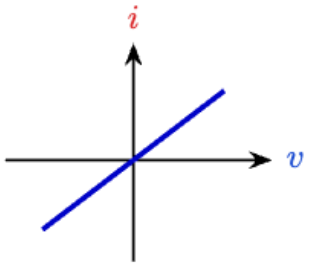
Non-Linear I-V Char.

Linear IV Char.

$$I = kV$$

$$y = mx$$



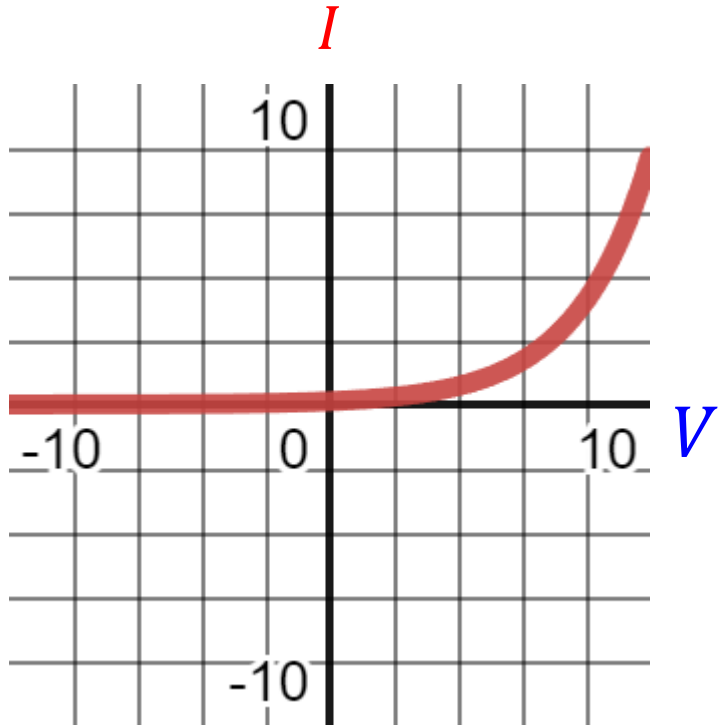


resistor

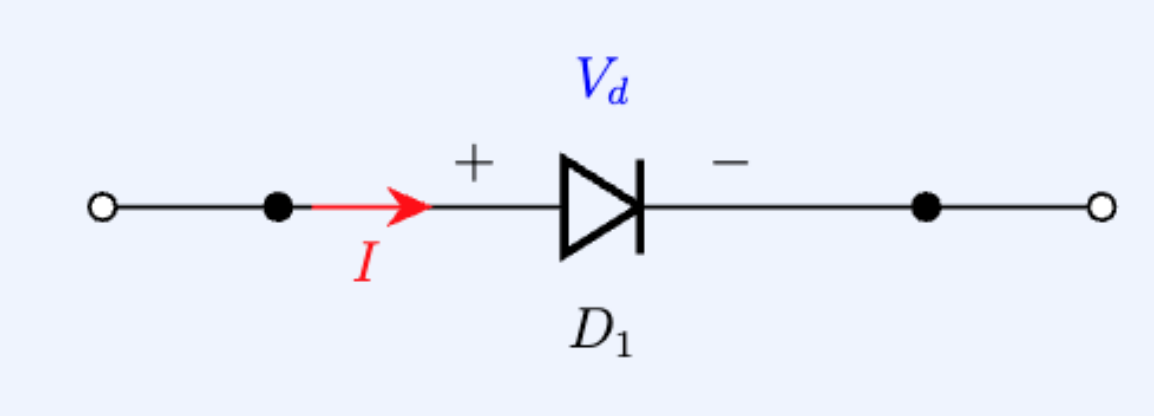
Non-Linear IV Char.

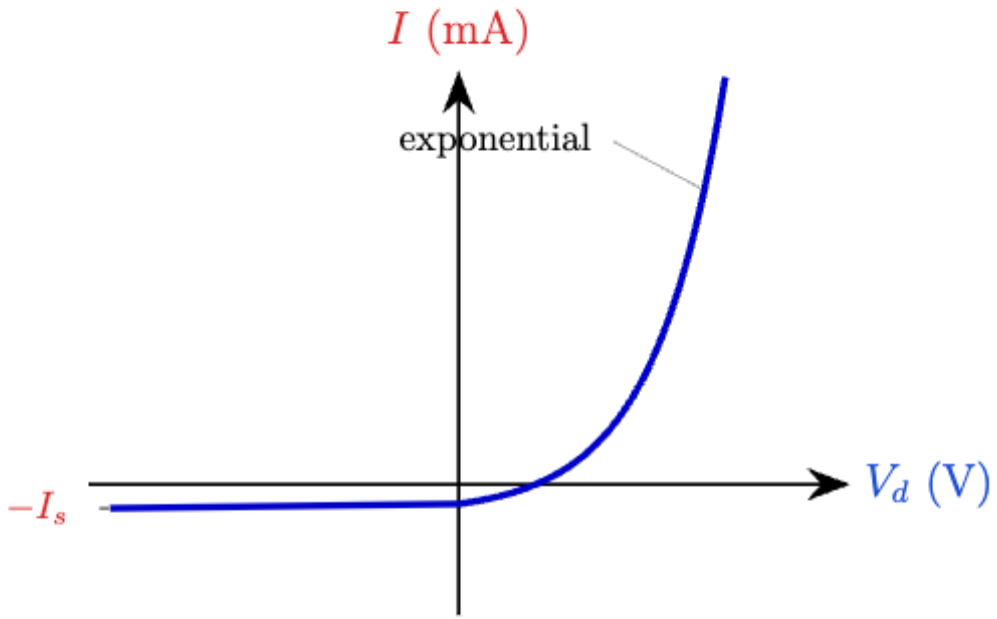
$$I = kV^2 \qquad I = \mathrm{A} \cdot \exp\left(\frac{V}{b}\right)$$

$$y = ax^2 \qquad y = \mathrm{A} \cdot \exp\left(\frac{x}{b}\right)$$



Diode I-V Char. (Shockley Model)





$\boldsymbol{V_d}$ voltage across the diode

I_s reverse saturation current

n ideality factor (≈ 1 for **Si**)

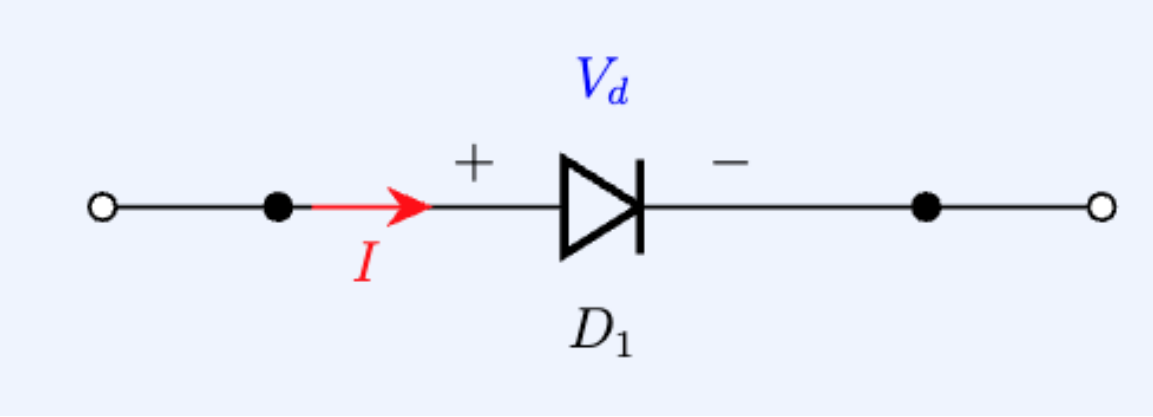
Current

$$\boldsymbol{I} = I_s \left[\exp\left(\frac{q\boldsymbol{V_d}}{nkT} \right) - 1 \right]$$

Thermal Voltage

$$V_T = \frac{kT}{q} \approx 25.9 \text{ mV at } 300 \text{ K}$$

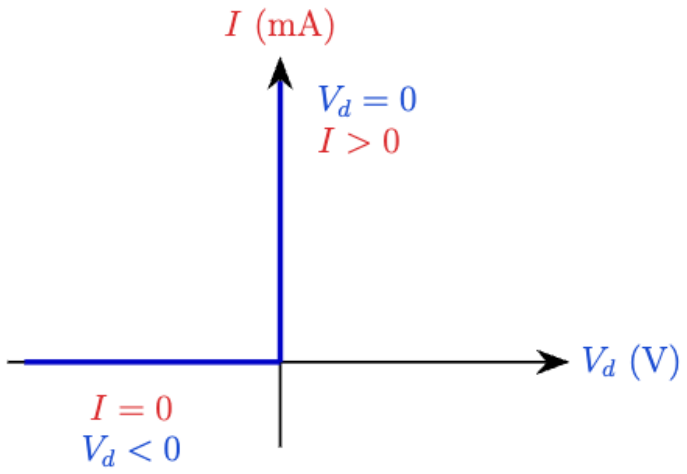
Ideal Diode I-V Char. (Picewise Linear)



$\boldsymbol{V_d}$ voltage across the diode

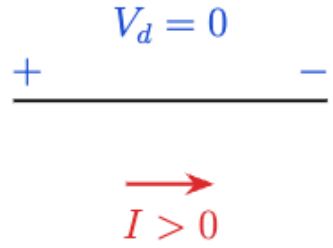
V_{Do} Threshold Voltage

Current



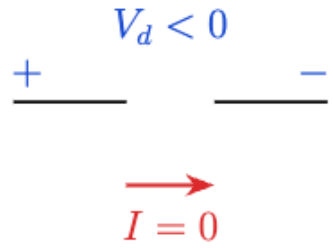
Ideal Diode Model ($V_{Do} = 0$ V)

Forward Bias:



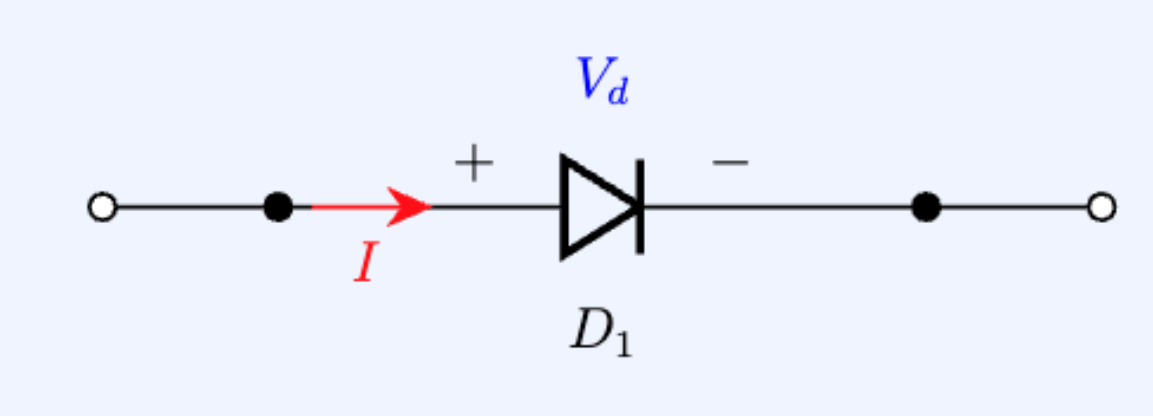
Short Circuit

Reverse Bias:



Open Circuit

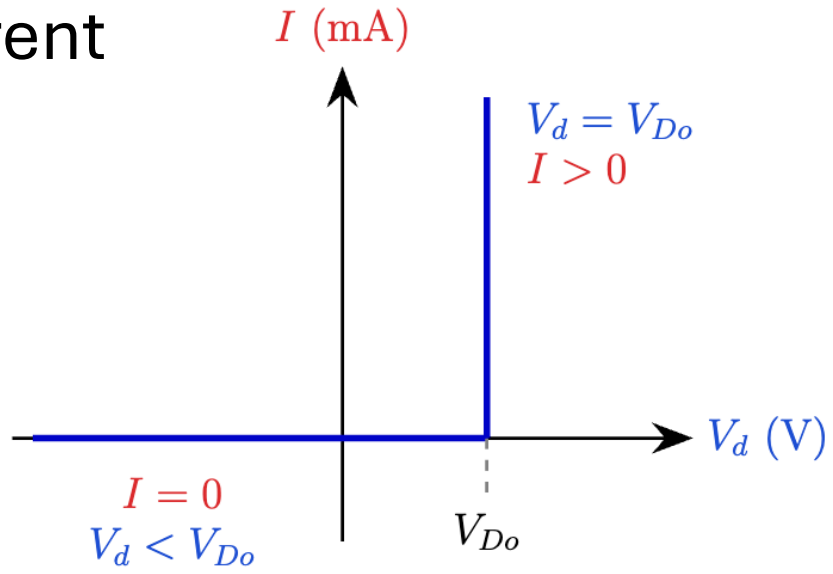
Constant Voltage Drop (CVD) Diode I-V Char.



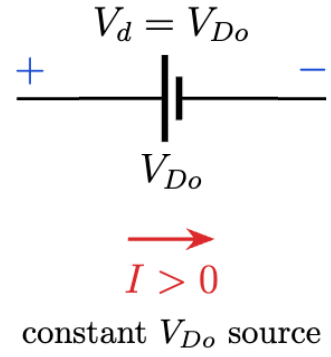
$\boldsymbol{V_d}$ voltage across the diode

V_{Do} Threshold Voltage

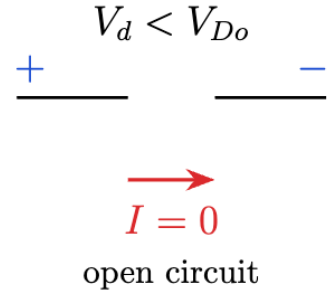
Current



Forward Bias:

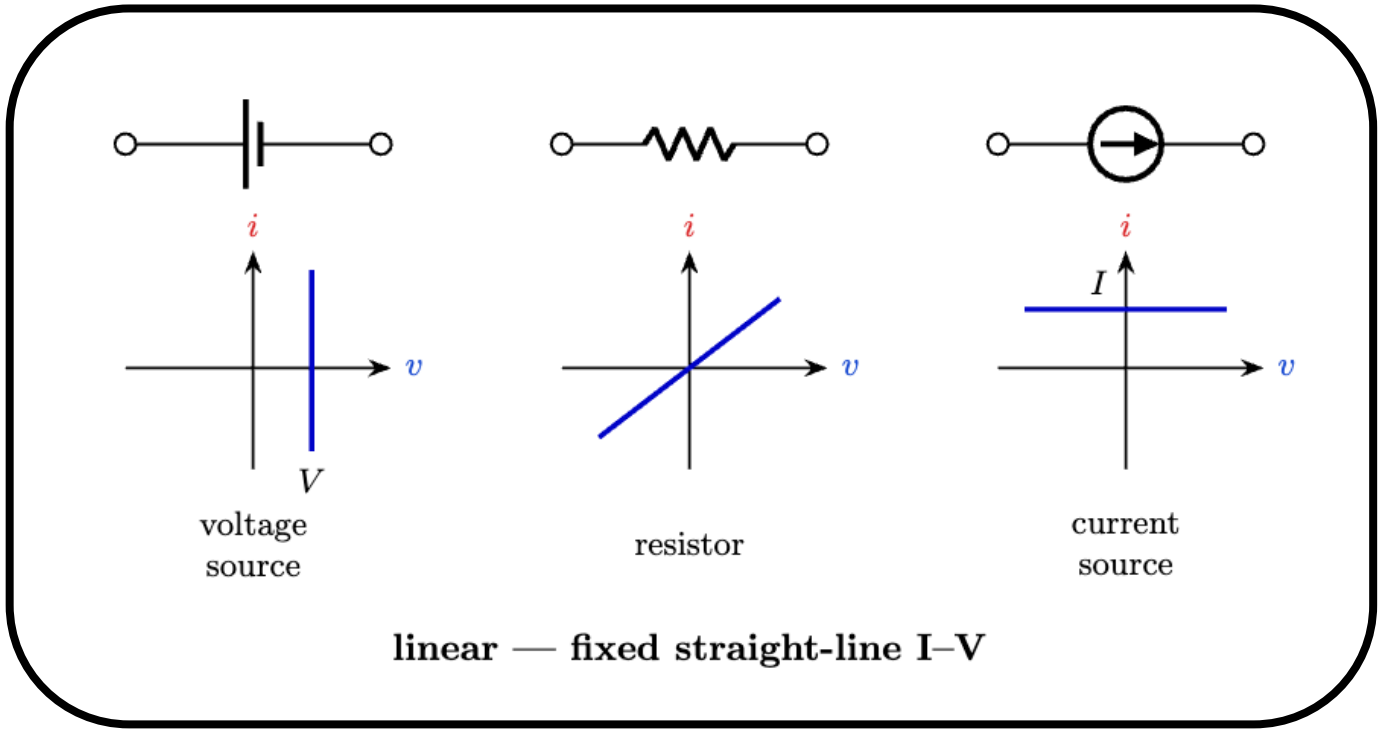


Reverse Bias:

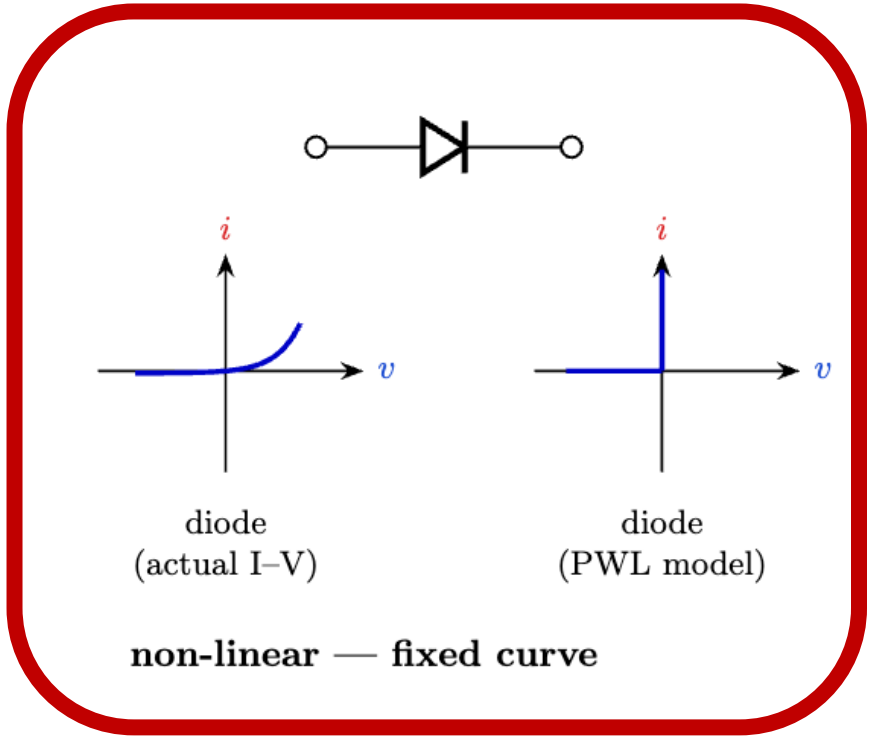


IV characteristics of **Two Terminal** devices

Linear IV Char.



Non-Linear IV Char.



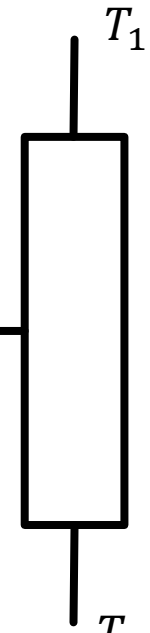
Three terminal Devices

IV of two terminal can be controlled using a third terminal.

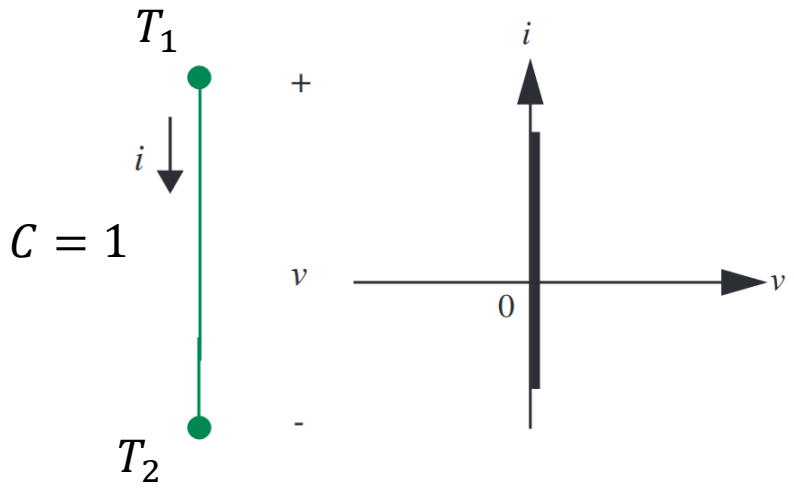
Example: Switch, MOSFET, BJT

Switch

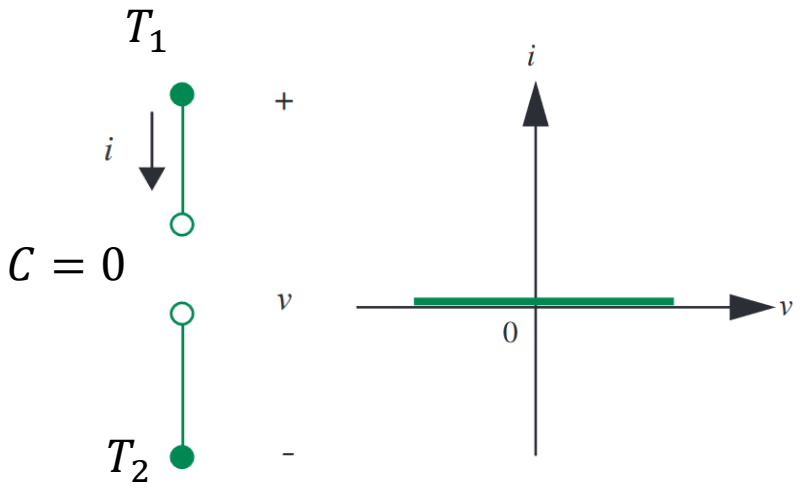
Control Signal (Physical/Voltage/Current) → C



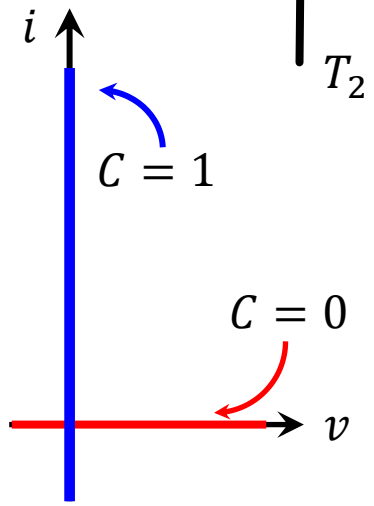
IV characteristics between T_1 and T_2 can be controlled by C



Switch **ON**

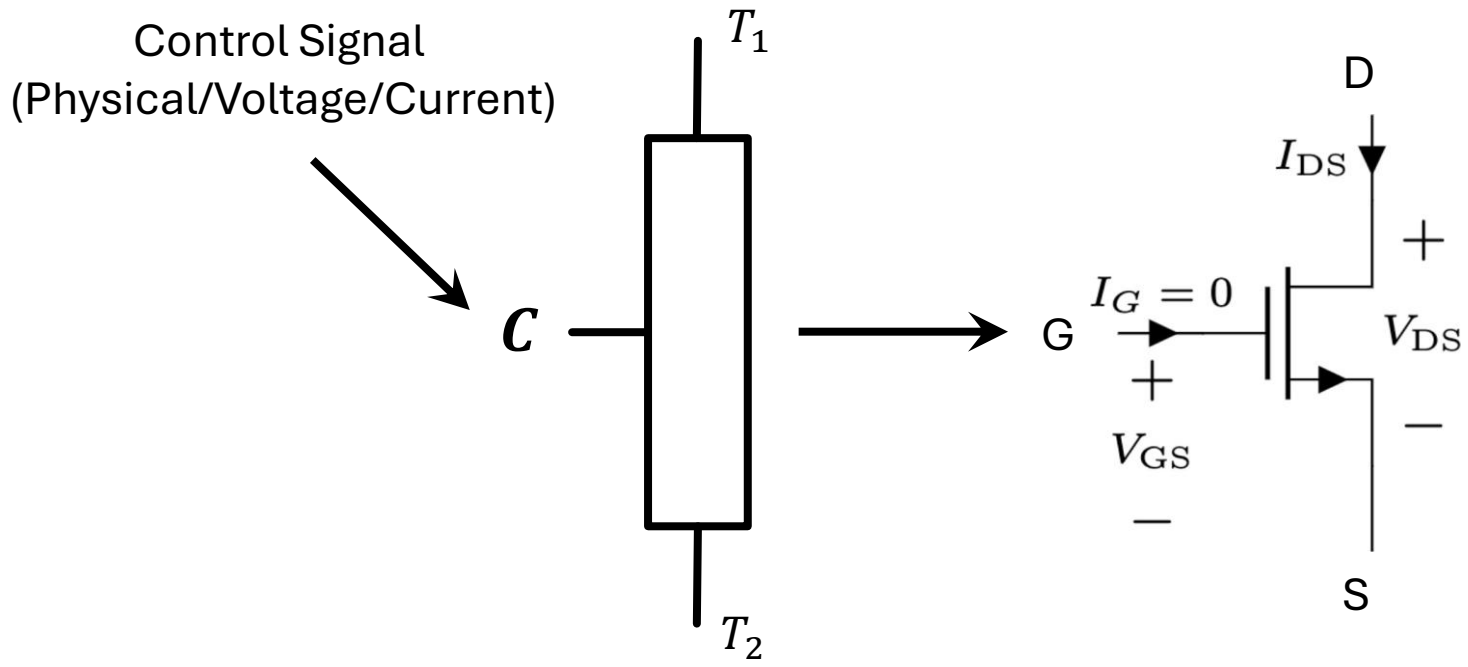


Switch **OFF**

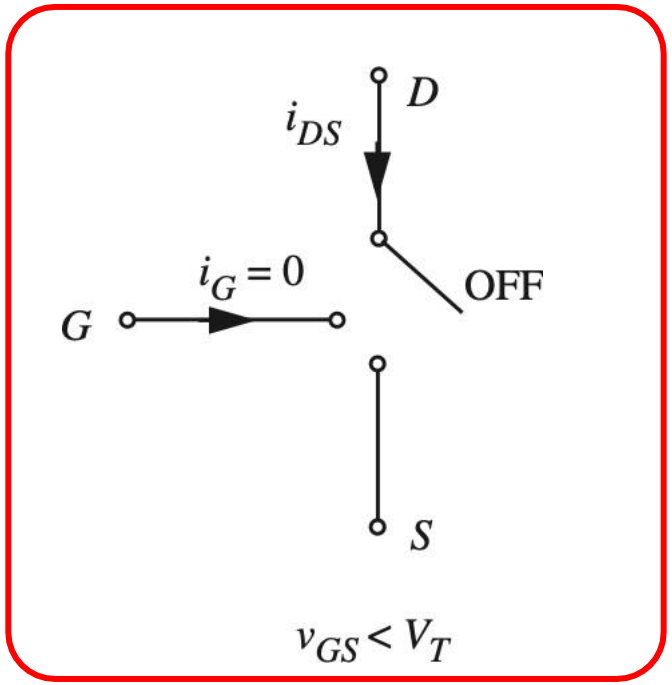


MOSFET S (Switch) - Model

- The MOSFET (approximately) behaves like a switch
- C = V_{GS}.

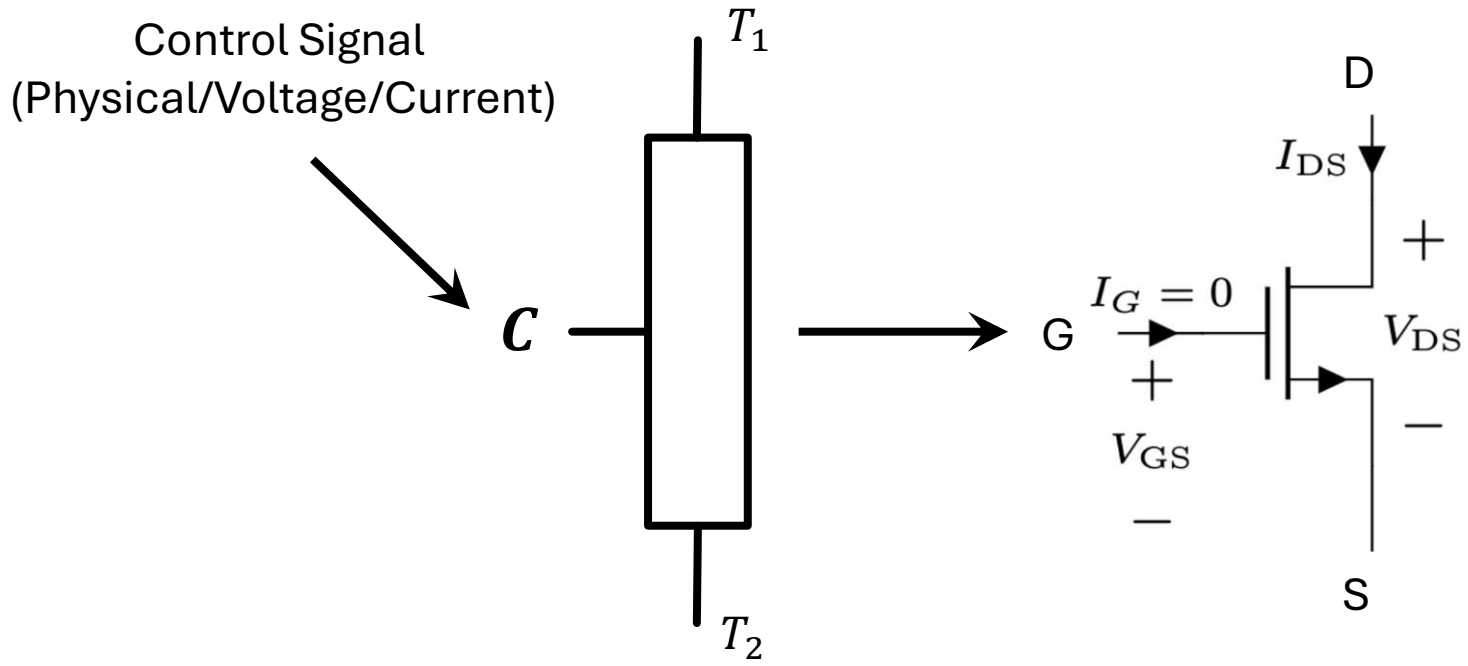


- C = "0" ⇒ $V_{GS} < V_T$

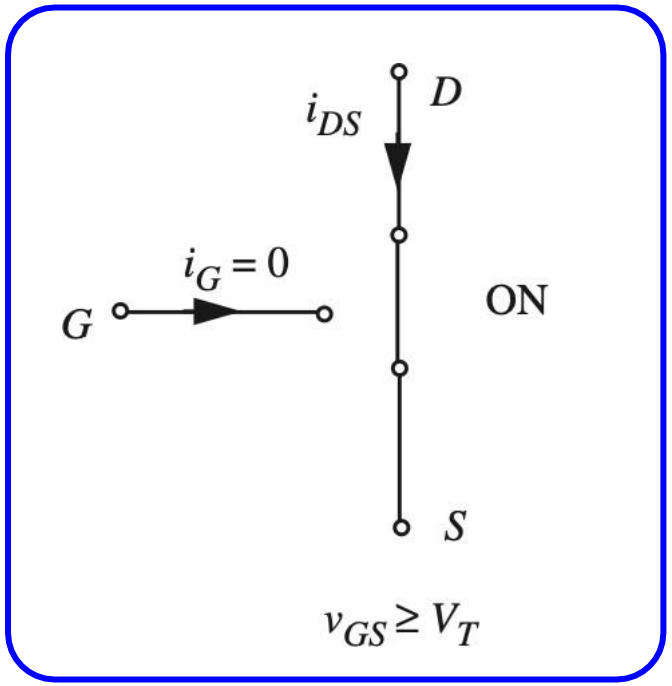


MOSFET S (Switch) -Model

- The MOSFET (approximately) behaves like a switch
- C = V_{GS}.

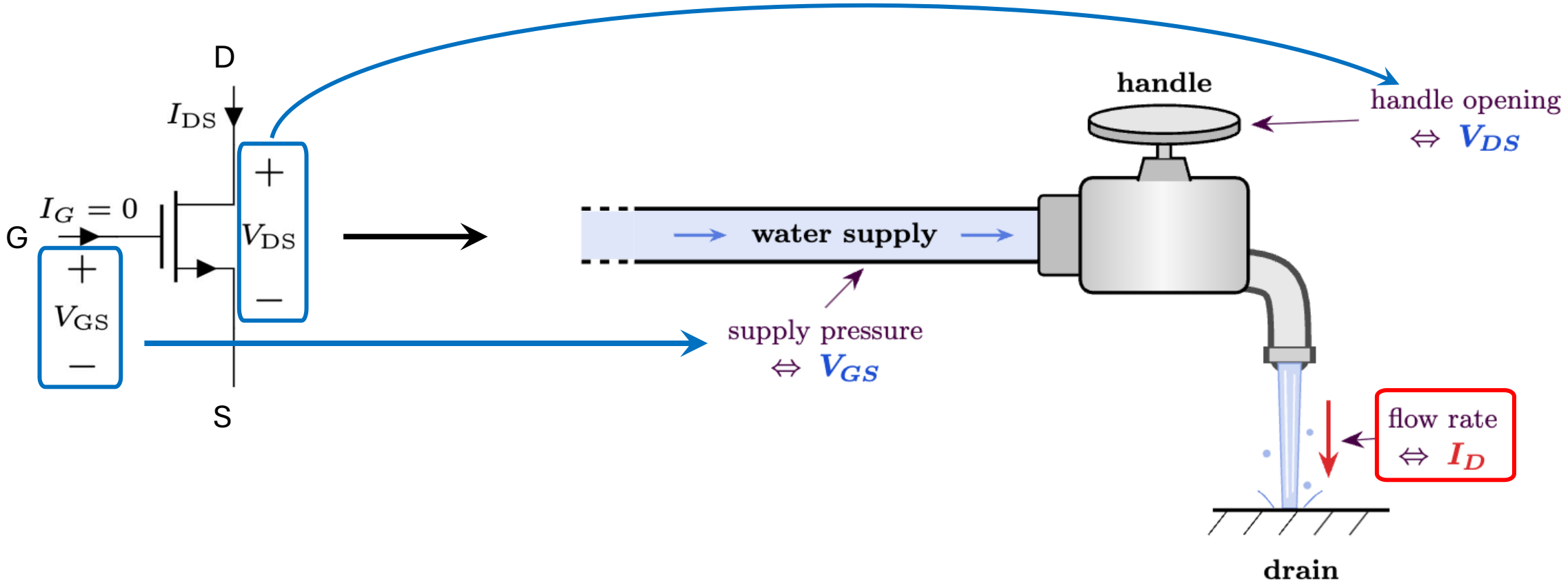


- C = "1" ⇒ $V_{GS} > V_T$



MOSFET Real Operation: Water Tap Analogy

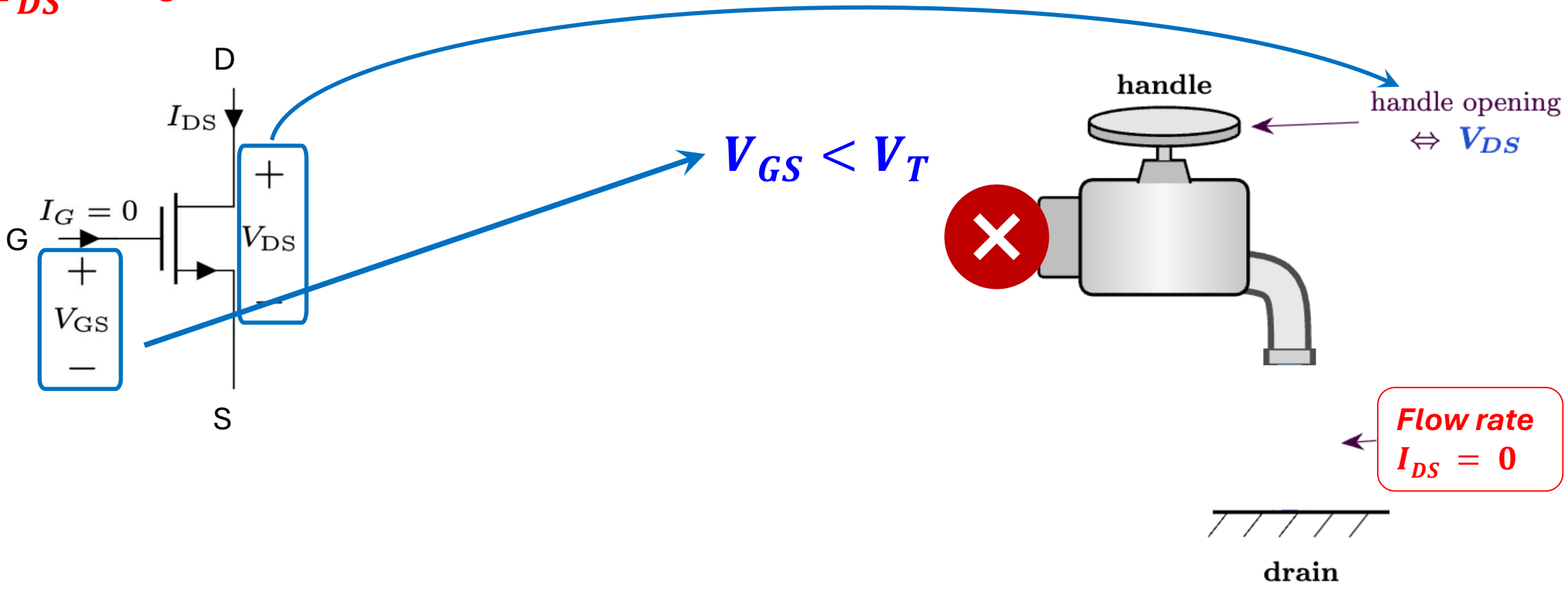
- The actual MOSFET is more nuanced than a simple switch.



MOSFET Real Operation: Water Tap Analogy

Cutoff Mode

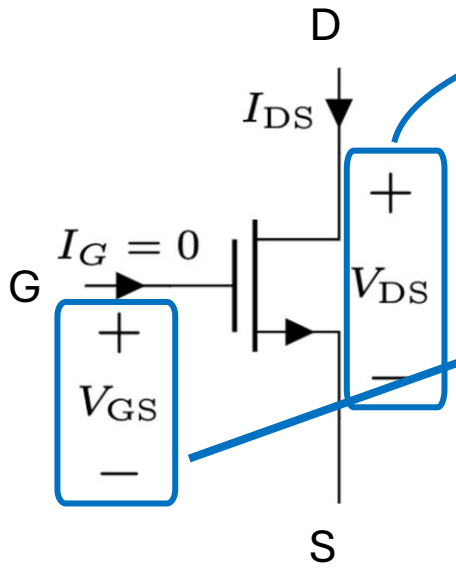
$I_{DS} = 0$



MOSFET Real Operation: Water Tap Analogy

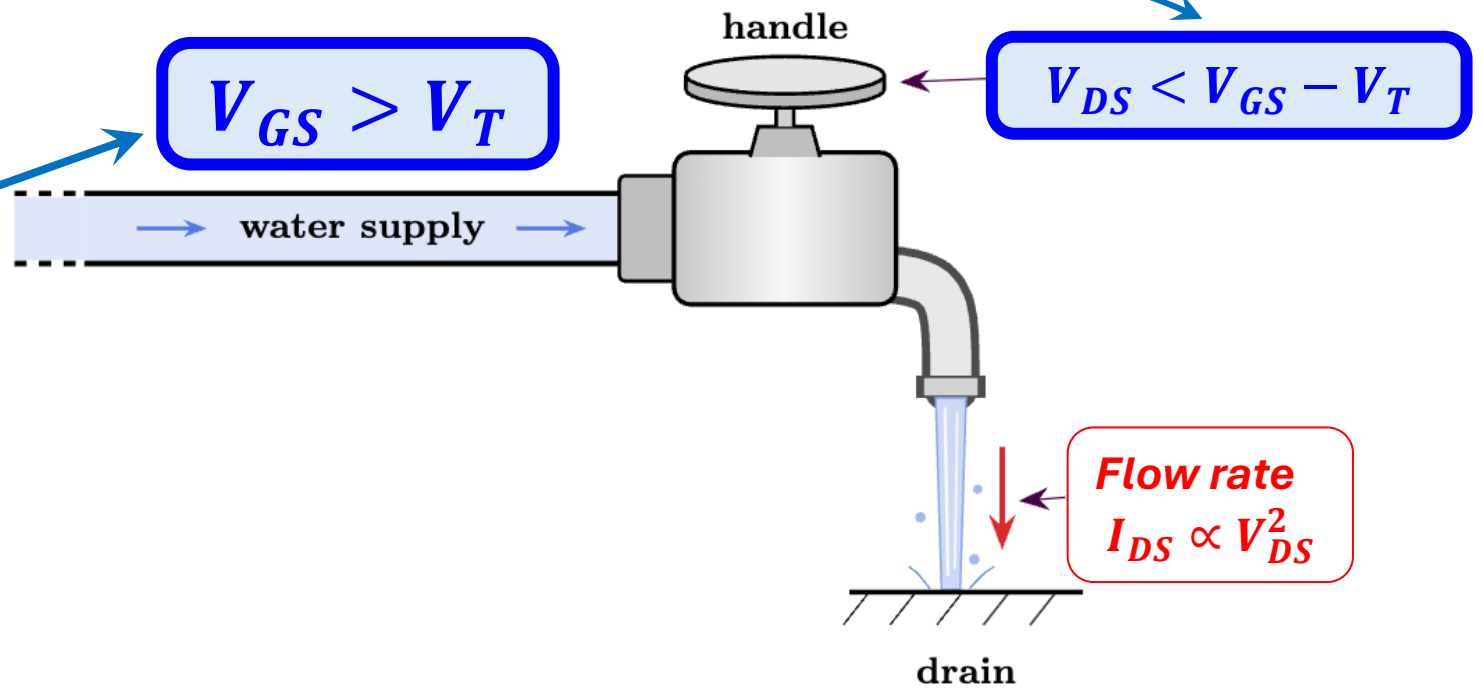
Triode Mode

$$I_{DS} = \mu C_{ox} \frac{W}{L} \left(V_{GS} - V_T - \frac{1}{2} V_{DS} \right) V_{DS}$$



$V_{GS} > V_T$

$V_{DS} < V_{GS} - V_T$

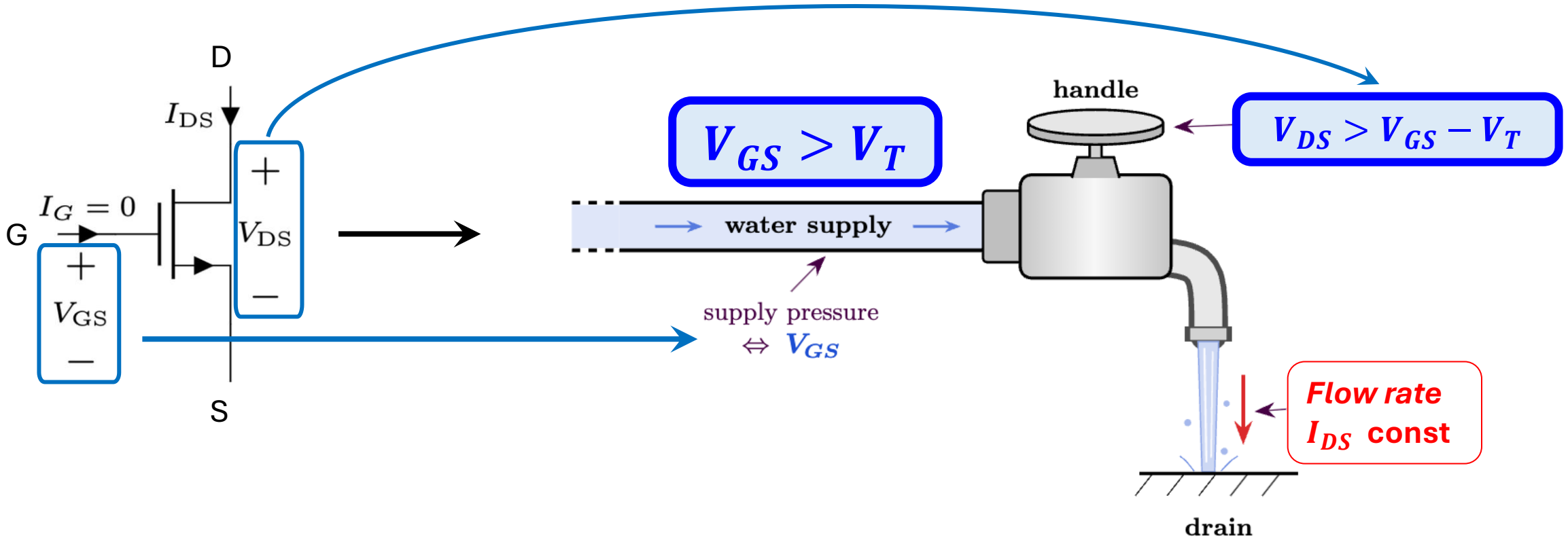


Flow rate
$I_{DS} \propto V_{DS}^2$

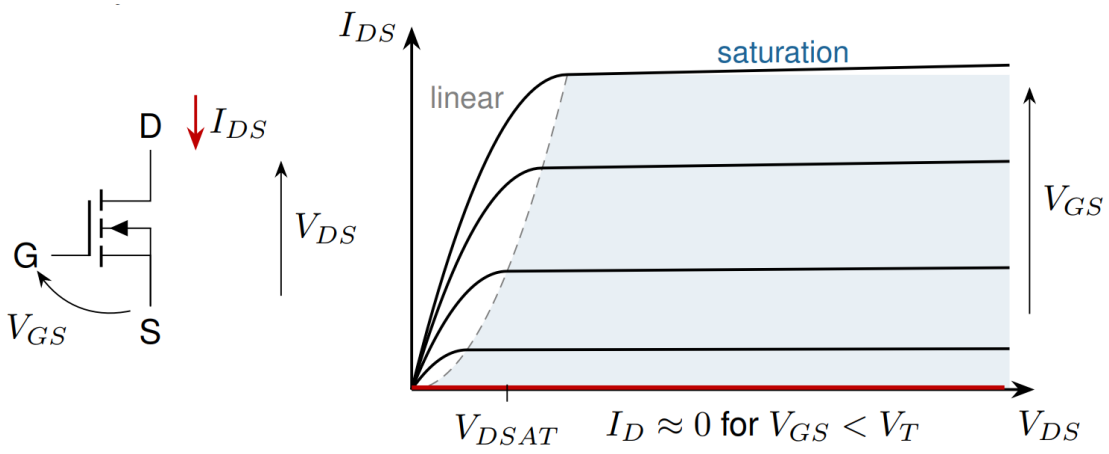
MOSFET Real Operation: Water Tap Analogy

Saturation Mode

$$I_{DS} = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$



MOSFET Real Operation: Summary



NMOS Modes

Cutoff
$V_{GS} < V_T$
$I_{DS} = 0$

Not cutoff
$V_{GS} > V_T$

Triode / Linear
$V_{DS} < V_{GS} - V_T$
$I_{DS} \propto V_{DS}^2$ (linear for $V_{DS} \to 0$)
$I_{DS} = \mu C_{ox} \frac{W}{L} \left(V_{GS} - V_T - \frac{1}{2} V_{DS} \right) V_{DS}$

Saturation
$V_{DS} > V_{GS} - V_T$
I_{DS} constant
$I_{DS} = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$