Field-effect transistor (FET)

Metal ⇒ M ⇒ Gate = G

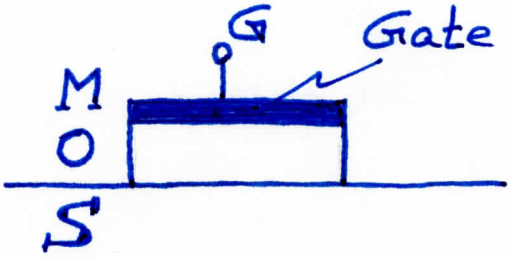
Oxide (e.g. SiO_2) ⇒ Insulator

Semiconductor ⇒ S (e.g. **Si**)

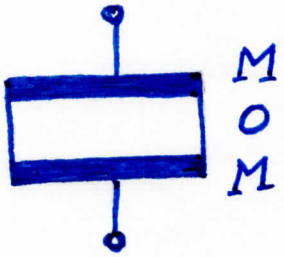
⇒ MOSFET

MOS ⇒ Similar to a capacitor **C**

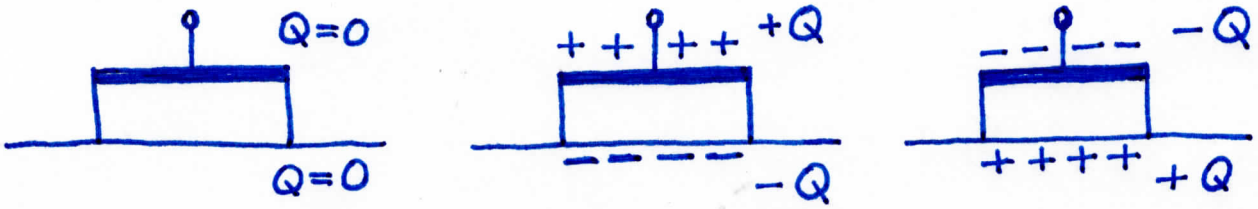
FET



C

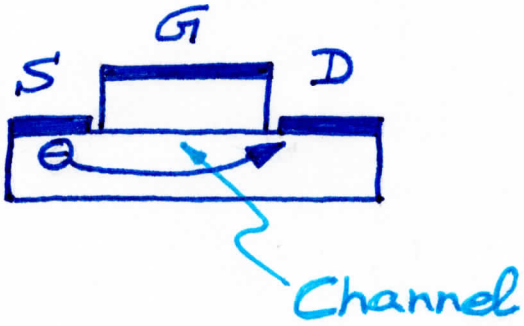


Gate charge induches charge in semiconductor



⇒ Overall charge neutrality

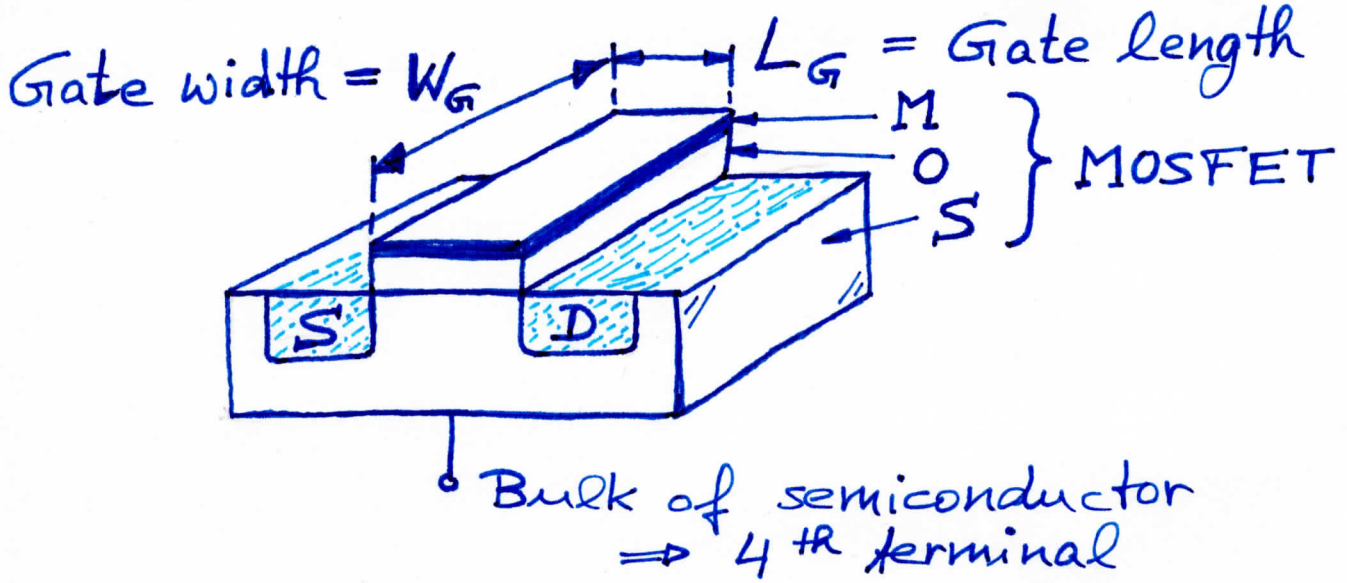
Three electrodes: G (Gate), S (Source) & D (Drain)



S = Source of charge carriers

D = Drain of charge carriers

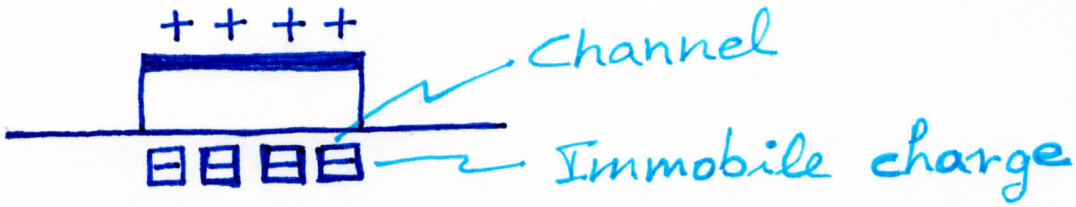
G = Gate between S & D



$V_{GS} > 0$ ⇒ Negative charge induced in channel

$V_{GS} < 0$ ⇒ Positive charge induced in channel

Threshold voltage: Assume there is immobile charge in the channel:



⇒ No electrical conduction in channel

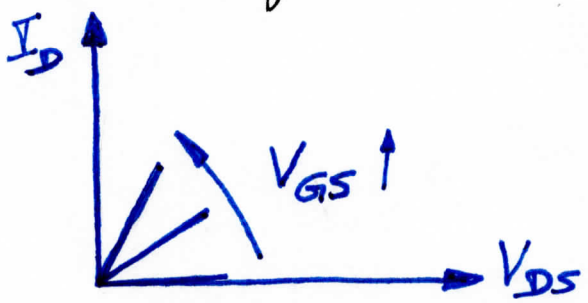
⇒ Voltage needs to exceed "threshold voltage" to induce mobile charges in channel (electrons & holes).

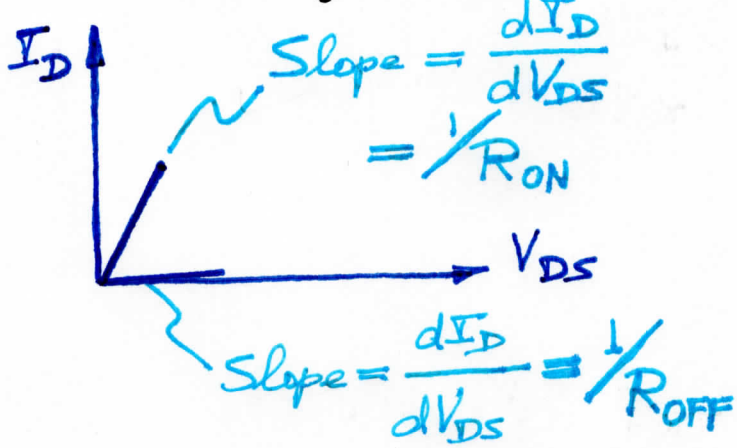
⇒ FETs have a threshold voltage. It can be negative, zero, or positive.

Our intuition: If we apply $V_{GS} > V_{TH}$ (V_{TH} = Threshold voltage) ⇒ Mobile charge is induced ⇒ Current flows in channel.

Output characteristic: I_D versus V_{DS}

① Ohmic regime (= linear regime)





Quantitative formula (not derived here)

$$I_D = k' \frac{W_G}{L_G} (V_{GS} - V_{TH}) V_{DS}$$

- W_G, L_G: Geometry of FET
- k': Physics of semiconductor, e.g. carrier mobility

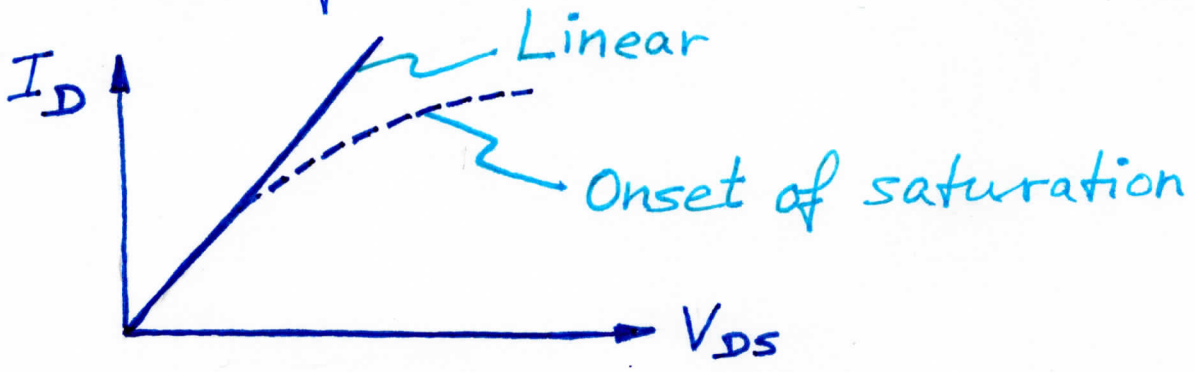
② Intermediate regime

$$I_D = \underbrace{k' \frac{W_G}{L_G}}_{k} \left[(V_{GS} - V_{th}) V_{DS} - \underbrace{\frac{1}{2} V_{DS}^2}_{\text{We initially neglected this factor.}} \right]$$

Q: When can we neglect this factor ?

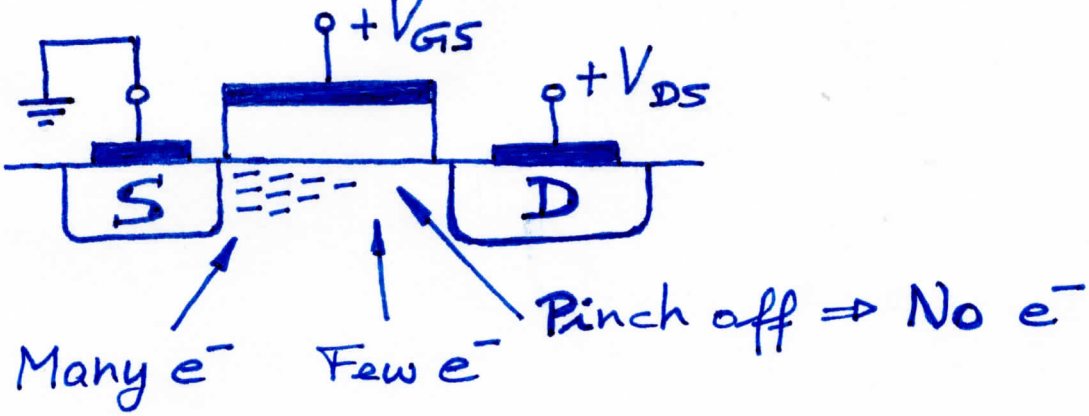
Q: What does this factor do ?

⇒ Onset of saturation



Q: What causes onset of saturation ?

⇒ Pinch-off of channel.



⇒ Channel is pinched off when V_{DS} ↑

⇒ Current does not increase ⇒ Saturation

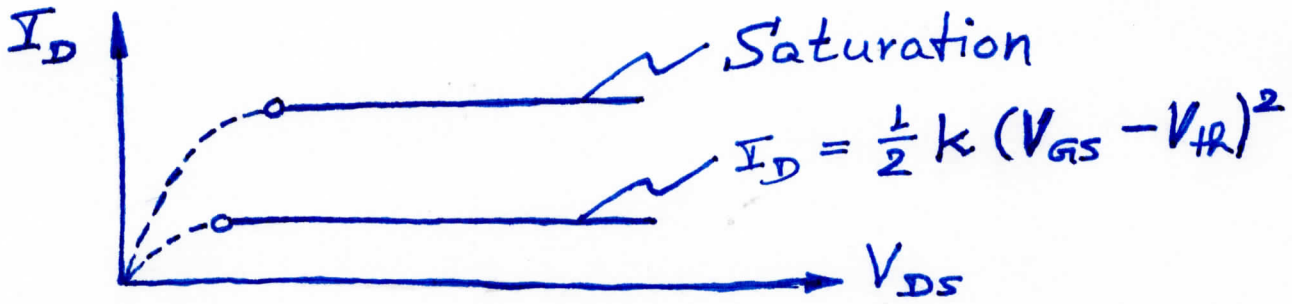
⇒ I_D - versus - V_{DS} slope = 0 at $\boxed{V_{DS} = V_{GS} - V_{th}}$

③ Saturation ⇒ $\boxed{V_{DS} \geq V_{GS} - V_{th}}$

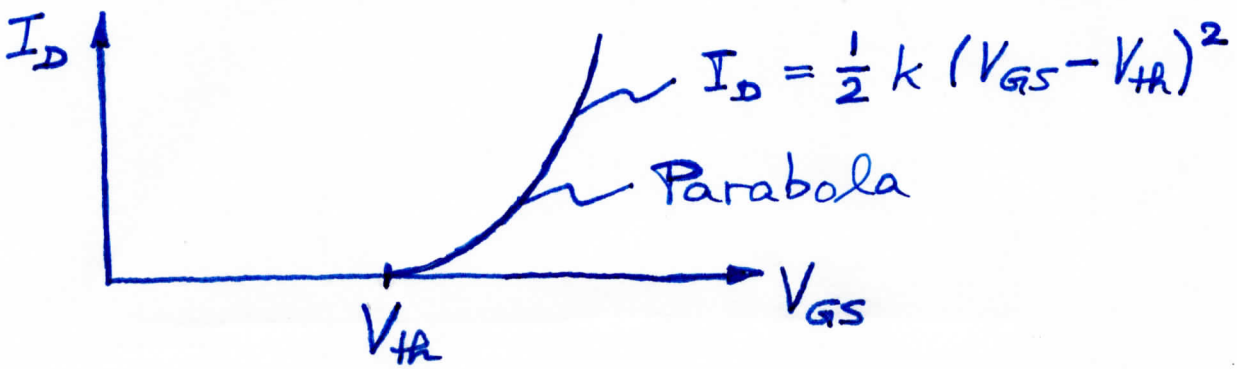
$$I_D = \underbrace{k' \frac{W_G}{L_G}}\left[(V_{GS} - V_{th}) \underbrace{V_{DS}}_{\rightarrow V_{GS} - V_{th}} - \frac{1}{2} V_{DS}^2 \right]$$

$$= k \left[(V_{GS} - V_{th})^2 - \frac{1}{2} (V_{GS} - V_{th})^2 \right]$$

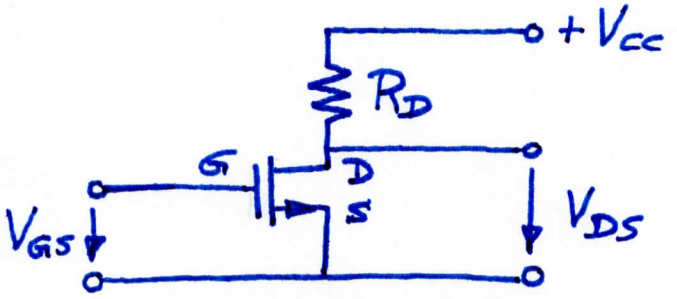
⇒ $\boxed{I_D = \frac{1}{2} k (V_{GS} - V_{th})^2}$



Output current ($\rightarrow I_D$) versus input voltage ($\rightarrow V_{GS}$)



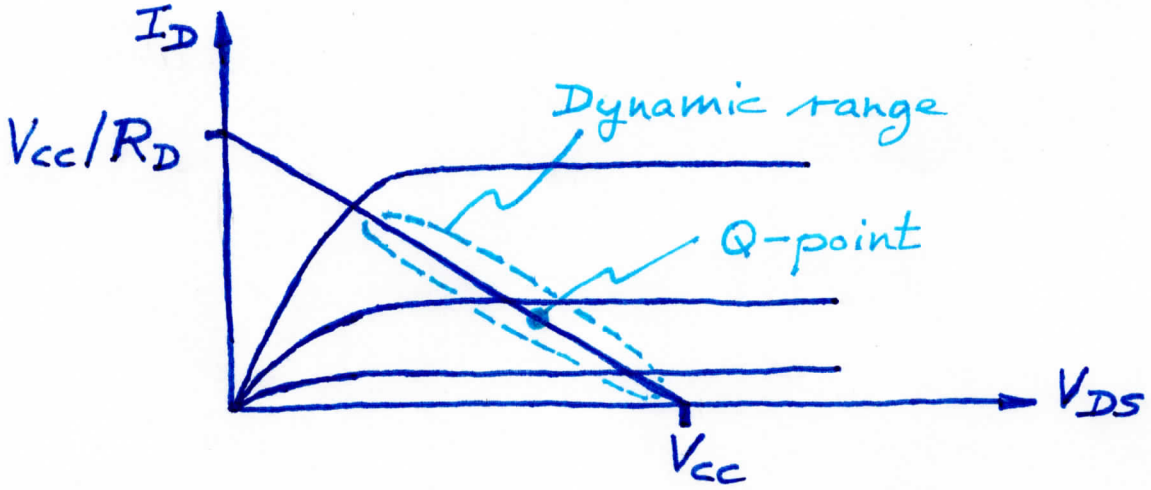
Load line of amplifier circuit



$$V_{RD} = V_{CC} - V_{DS}$$

$$I_D R_D = V_{CC} - V_{DS}$$

$$\Rightarrow \boxed{I_D = \frac{V_{CC} - V_{DS}}{R_D}}$$



Q: We identified 3 regimes: ① Ohmic ② Onset of saturation ③ Saturation. Can you show these regimes in figure above?

Q: For an amplifier, which regime are we operating the transistor in?