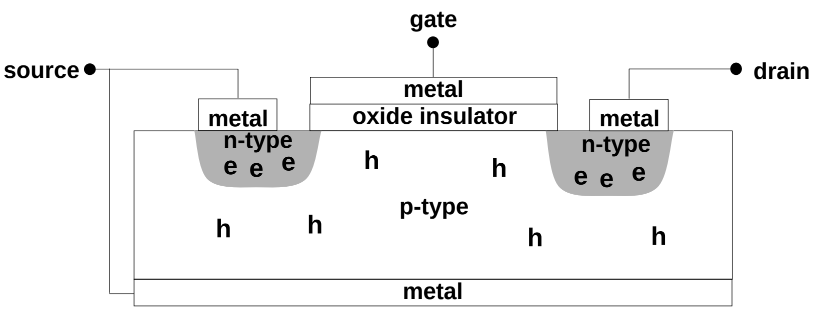
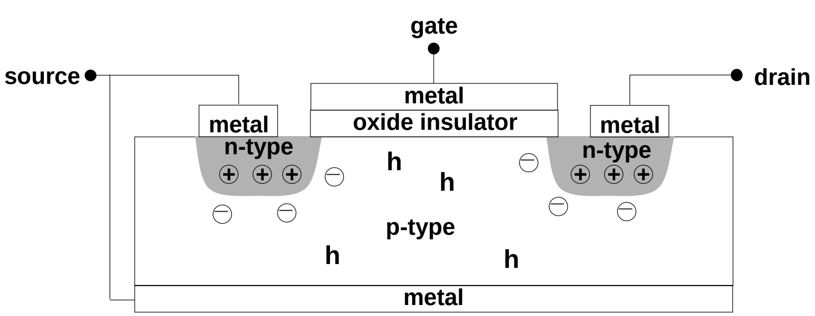
NMOS (N-Channel Metal Oxide Semiconductor) Transistor



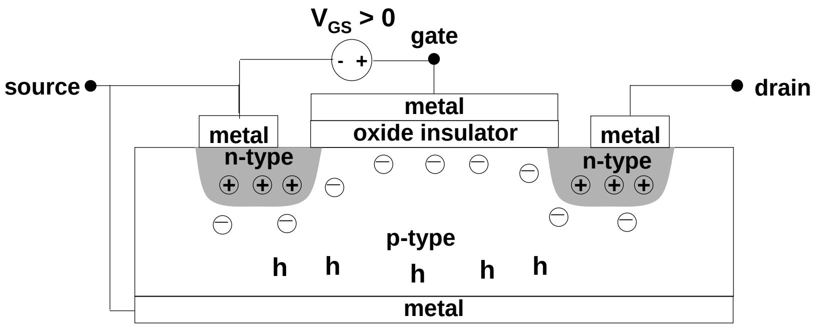
NMOS Transistor in Equilibrium



When the transistor is left alone, some electrons from the n-type wells diffuse into the p-type material to fill holes.

This creates negative ions in the p-type material and positive ions are left behind in the n-type material.

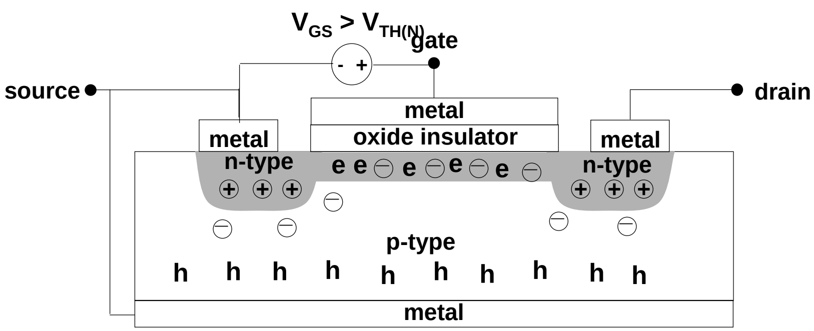
NMOS Transistor in Cutoff



When a small, positive V_{GS} is applied, holes "move away" from the gate.

Electrons from complete atoms elsewhere in the p-type material move to fill holes near the gate instead.

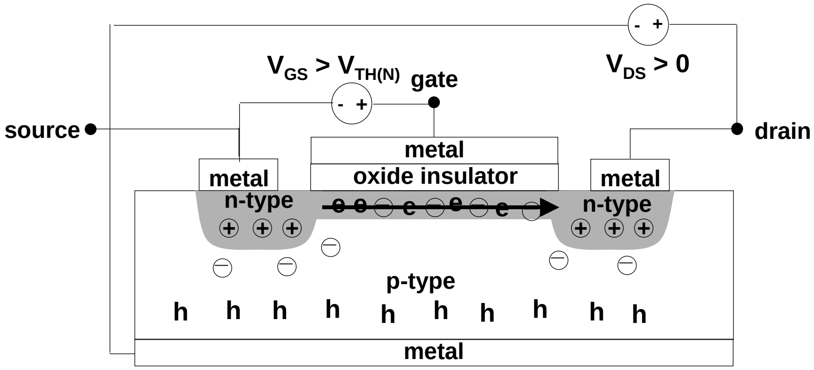
NMOS Transistor Channel



When V_{GS} is larger than a **threshold** voltage $V_{TH(N)}$, the attraction to the gate is so great that free electrons collect there.

Thus the applied V_{GS} creates an **induced n-type channel** under the gate (an area with free electrons).

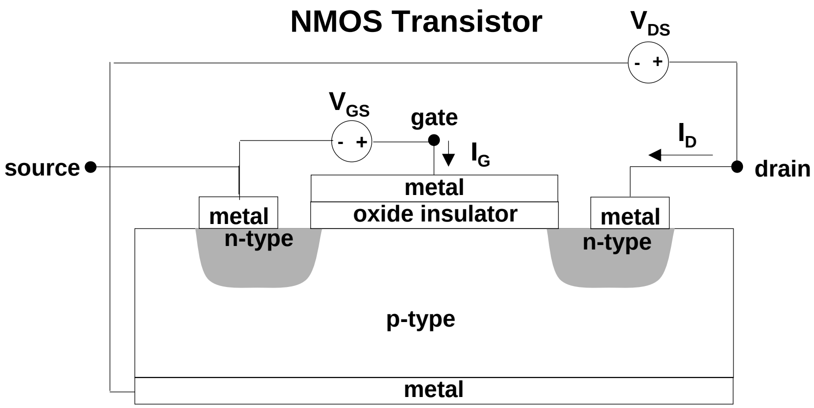
NMOS Transistor Drain Current

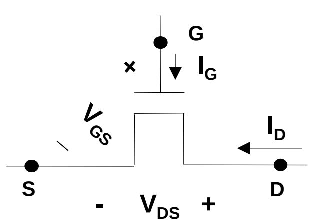


When a positive V_{DS} is applied, the free electrons flow from the source to the drain. (Positive current flows from drain to source).

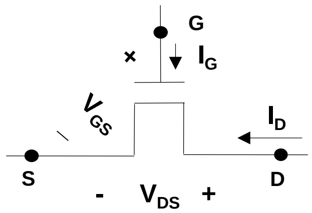
The amount of current depends on V_{DS}, as well as the number of electrons in the channel, channel dimensions, and material.

NMOS Transistor





NMOS I-V CHARACTERISTIC



- Since the transistor is a 3-terminal device, there is no single I-V characteristic.
- Note that because of the insulator, $I_G = 0$ A.
- We typically define the MOS I-V characteristic as

  I_D vs. V_{DS} for a fixed V_{GS}.

MODES OF OPERATION

For small values of V_{GS}, $V_{GS} \leq V_{TH(N)}$, the n-type channel is not formed. No current flows. This is **cutoff mode**.

When $V_{GS} > V_{TH(N)}$, current I_D may flow from drain to source, and the following modes of current flow are possible.

The mode of current flow depends on the propelling voltage, V_{DS}, and the channel-inducing voltage, $V_{GS} – V_{TH(N)}$.

When $V_{DS} < V_{GS} – V_{TH(N)}$, current is starting to flow. I_D increases rapidly with increased V_{DS}. This is **triode mode**.

When $V_{DS} \geq V_{GS} – V_{TH(N)}$, current is reaching its maximum value. I_D does not increase much with increased V_{DS}. This is called **saturation mode**.

NMOS I-V CHARACTERISTIC

Cutoff Mode

- Occurs when $V_{GS} \le V_{TH(N)}$

$$I_D = 0$$

Triode Mode

- Occurs when $V_{GS} > V_{TH(N)}$ and $V_{DS} < V_{GS} - V_{TH(N)}$

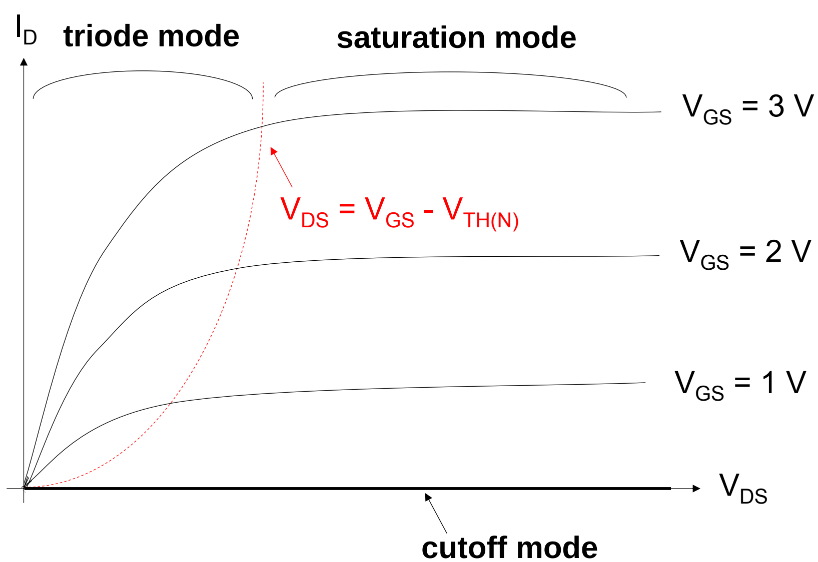
$$I_D = \frac{W}{L}\mu_n C_{OX}\left(V_{GS} - V_{TH(N)} - (V_{DS}/2)\right)V_{DS}$$

Saturation Mode

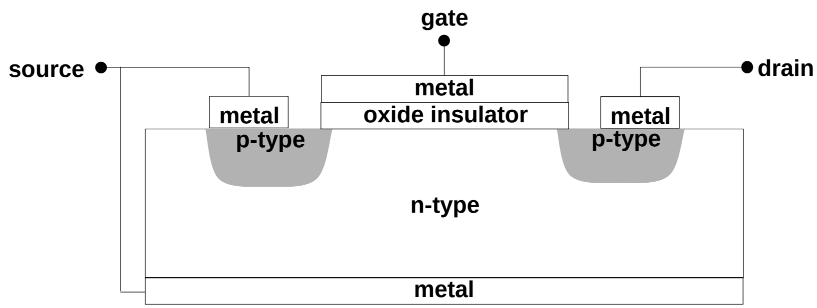
- Occurs when $V_{GS} > V_{TH(N)}$ and $V_{DS} \ge V_{GS} - V_{TH(N)}$

$$I_D = \frac{W}{L}\mu_n C_{OX}\frac{1}{2}\left(V_{GS} - V_{TH(N)}\right)^2\left(1 + \lambda_n V_{DS}\right)$$

NMOS I-V CHARACTERISTICS

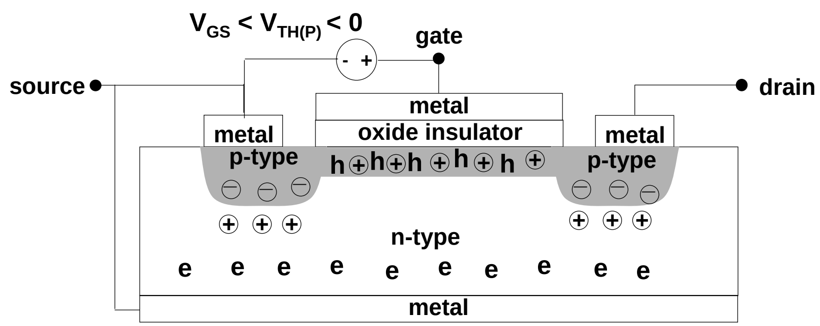


PMOS
(P-Channel Metal Oxide Semiconductor)
Transistor



Same as NMOS, only p-type and n-type switched

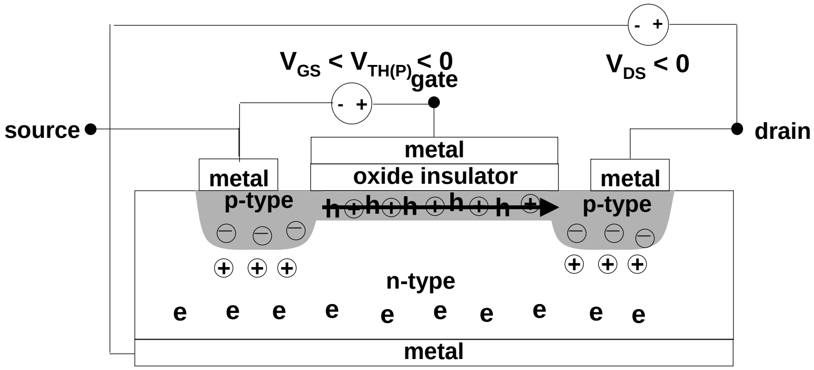
PMOS Transistor Channel



When V_{GS} is more negative than a **threshold** voltage $V_{TH(P)}$, the gate attracts many positive ions and holes (repels electrons)

Thus the applied V_{GS} creates an **induced p-type channel** under the gate (an area with positive ions).

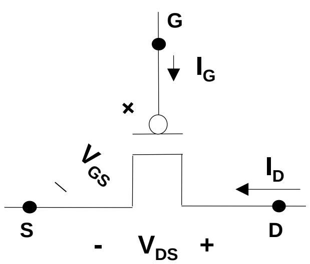
PMOS Transistor Drain Current



When a negative V_{DS} is applied, the positive ions flow from the source to the drain. (Positive current flows from source to drain).

The amount of current depends on V_{DS}, as well as the number of ions in the channel, channel dimensions, and material.

PMOS TRANSISTOR



Symbol has "dot" at gate. NMOS does not.

I_D, V_{GS}, V_{DS}, and $V_{TH(P)}$ are all negative.
These values are positive for NMOS.

Channel formed when $V_{GS} < V_{TH(P)}$. Opposite for NMOS.

Saturation occurs when $V_{DS} \le V_{GS} - V_{TH(P)}$. Opposite for NMOS.

PMOS I-V CHARACTERISTIC

Cutoff Mode

- Occurs when $V_{GS} \geq V_{TH(P)}$

$$I_D = 0$$

Triode Mode

- Occurs when $V_{GS} < V_{TH(P)}$ and $V_{DS} > V_{GS} - V_{TH(P)}$

$$I_D = -\frac{W}{L}\mu_p C_{OX}\left(V_{GS} - V_{TH(P)} - (V_{DS}/2)\right)V_{DS}$$

Saturation Mode

- Occurs when $V_{GS} < V_{TH(P)}$ and $V_{DS} \leq V_{GS} - V_{TH(P)}$

$$I_D = -\frac{W}{L}\mu_p C_{OX}\frac{1}{2}\left(V_{GS} - V_{TH(P)}\right)^2\left(1 + \lambda_p V_{DS}\right)$$

PMOS I-V CHARACTERISTICS