Derivation of I-V characteristics:

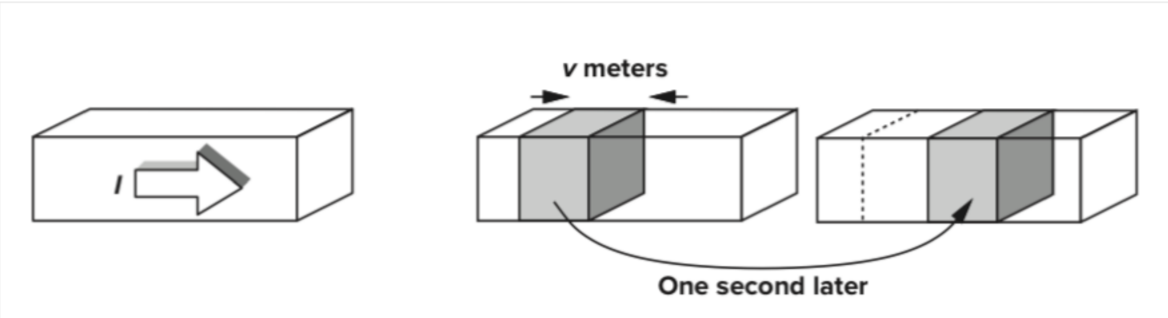
relationship between drain-current & its terminal voltage (MOSFET)

* Consider a semiconductor bar carrying a current I.

$Q_d \rightarrow$ mobile charge density along the dir^n of current in coulombs/meter

$v \rightarrow$ velocity of charge in m/sec.

$$I = Q_d \cdot v \longrightarrow \text{why}$$



charge enclosed in 'v' meters of the bar must flow through section in 1 second.

total charge in 'v' meters $= Q_d v$

* Consider NFET whose S & D are connected to ground.

→ onset of inversion occurs @ $V_{GS} = V_{TH}$

→ inversion charge density produced by gate-oxide capacitance $\propto V_{GS} - V_{TH}$

→ for $V_{GS} \geq V_{TH}$

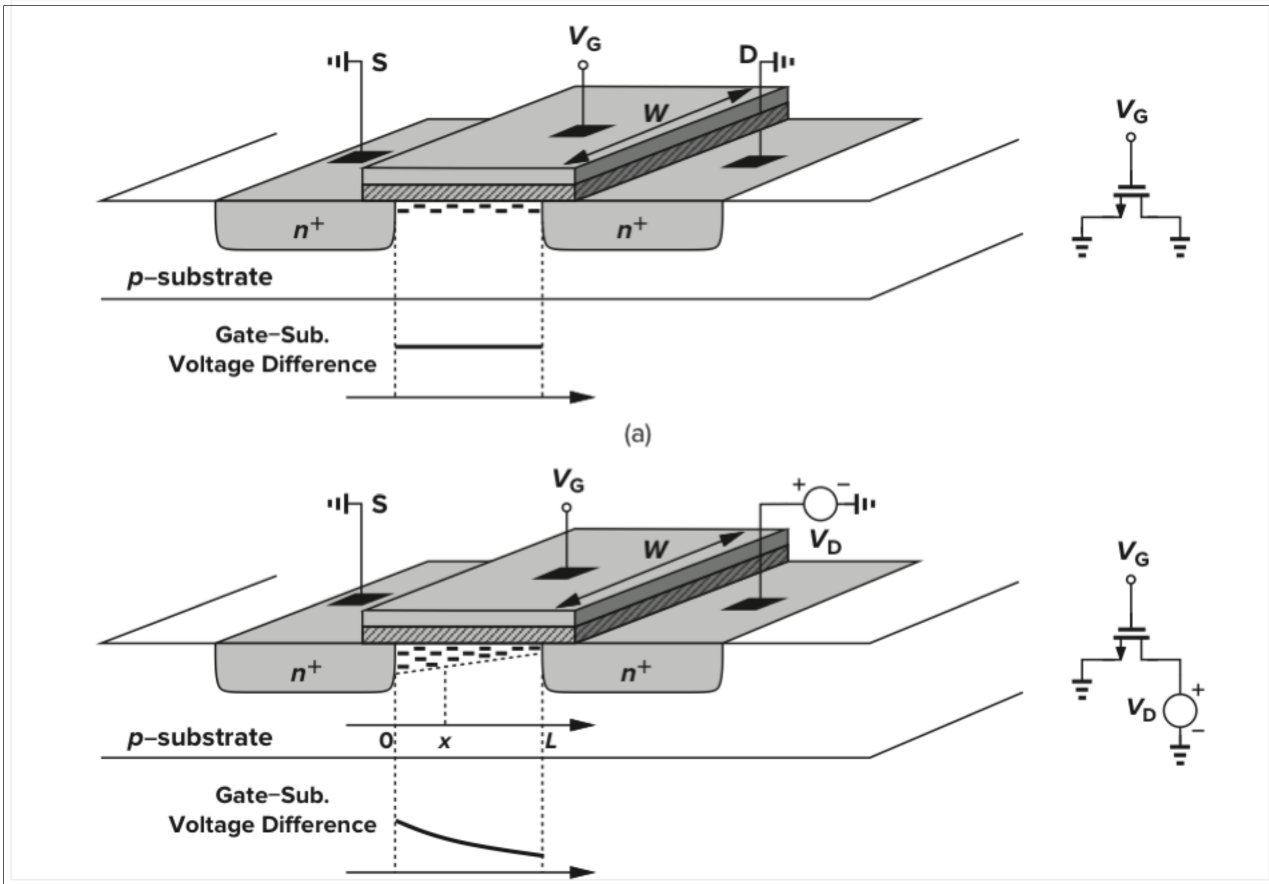
$$Q_d = \underbrace{W C_{ox}}_{\text{total capacitance/unit length}} (V_{GS} - V_{TH})$$

→ if $V_d > 0$

	Source	Drain
channel potential	0	V_D
local voltage difference b/w gate & channel	V_G	$V_G - V_D$

$$Q_d(x) = W C_{ox} [V_{GS} - \underbrace{V_x}_{\text{channel potential at } x.} - V_{TH}]$$

$$I_D = \underbrace{-}_{\text{charge carriers are -ve}} W C_{ox} [V_{GS} - V(x) - V_{TH}] v$$



V_G
S
D
W
n^+
n^+
p–substrate
Gate–Sub.
Voltage Difference
(a)
V_G
S
V_D
W
n^+
n^+
p–substrate
0
x
L
Gate–Sub.
Voltage Difference

for semiconductors,

$$v = \mu E$$

velocity of charge = mobility of charge carrier $\times \vec{E}$

$$E(x) = -\frac{dV}{dx}$$

So,
$$I_D = W C_{ox} [V_{GS} - V(x) - V_{TH}] \mu_n \frac{dV(x)}{dx}$$

boundary conditions $V(0) = 0$
$V(L) = V_{DS}$

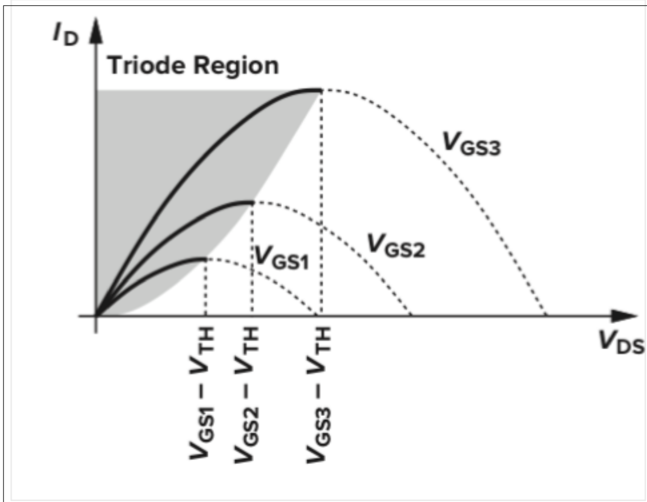
$$\int_{x=0}^{L} I_D \, dx = \int_{V=0}^{V_{DS}} W C_{ox} \mu_n [V_{GS} - V(x) - V_{TH}] dV$$

I_D is constant along channel.

$$I_D = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

L → Effective channel length.

Let's plot I_D vs V_{DS} for different value of V_{GS},


I_D
Triode Region
V_{GS3}
V_{GS2}
V_{GS1}
V_{DS}
$V_{GS1} - V_{TH}$
$V_{GS2} - V_{TH}$
$V_{GS3} - V_{TH}$

Observations:

1. Current capability of device increases with V_{GS}

2. Peak of each parabola occurs @ $V_{DS} = V_{GS} - V_{TH}$

3. Peak current

$$I_{D(max)} = \frac{1}{2} \mu_n C_{ox} \underbrace{\frac{W}{L}}_{\text{Aspect ratio}} \underbrace{(V_{GS} - V_{TH})^2}_{\text{overdrive Voltage}}$$

4. If $V_{DS} \leq V_{GS} - V_{TH}$ device operates in "triode region"

5. If $V_{DS} \ll 2(V_{GS} - V_{TH})$, we have

$$I_D = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

$$\downarrow$$

$$I_D \simeq \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH}) V_{DS}$$

6. for small V_{DS},

each parabola $\approx$ st. line

path from $S \rightarrow D$ $\approx$ linear resistor

$V = IR$

$R = \frac{V}{I}$

$$R_{on} = \frac{\cancel{V_{DS}}}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH}) \cancel{V_{DS}}}$$

$$= \frac{1}{\mu_n C_{ox} \frac{W}{L} \underbrace{(V_{GS} - V_{TH})}_{\text{overdrive voltage}}}$$

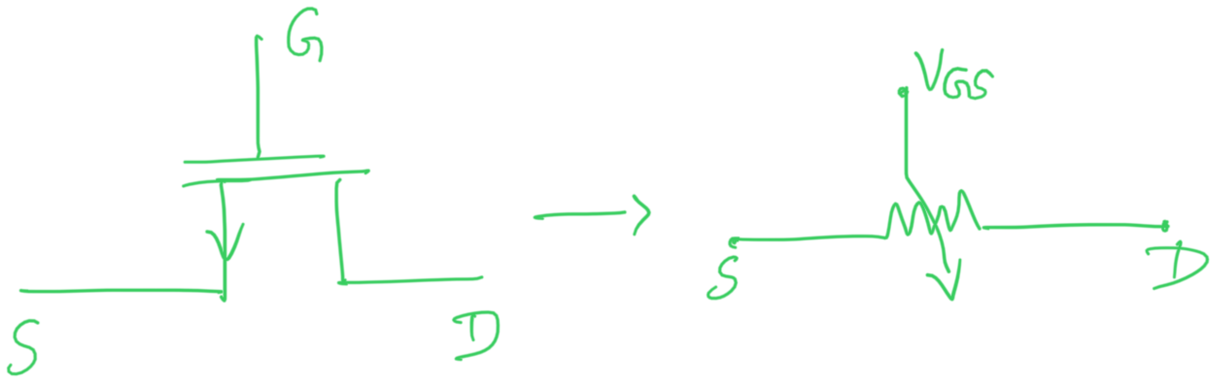
So, MOSFET operate as resistor whose value is controlled by $(V_{GS} - V_{TH})$ i.e overdrive voltage.

remember condition:

$V_{DS} \ll 2(V_{GS} - V_{TH})$

$\hookrightarrow$ MOS device may be "ON" even,

if it carries no current.
device operates in "deep triode region"



$$V_{DS} \ll 2(V_{GS} - V_{TH})$$