Tutorial 9

JFET

Pinch-off conditions

(1) For $V_{GS} = 0V$ $\longrightarrow$ $V_{GD} = V_{GS} - V_{DS} = 0 - V_{DS} = V_p$

(Remember V_p is a negative number)

if the channel is @ pinch off, then

$$V_{DS} = -V_p$$

(2) For $V_{GS} < 0V$

channel is pinched off when

$$V_{GD} = V_{GS} - V_{DS}$$

← the value of V_{GD} when this condition is satisfied is V_p

$$\Downarrow$$

$$V_{GD} = \underbrace{V_{GS} - V_{DS}}_{} = V_p$$

$$V_{DS} = V_{GS} - V_p$$

I_{DSS} ← saturation current value for $V_{GS} = 0V$.

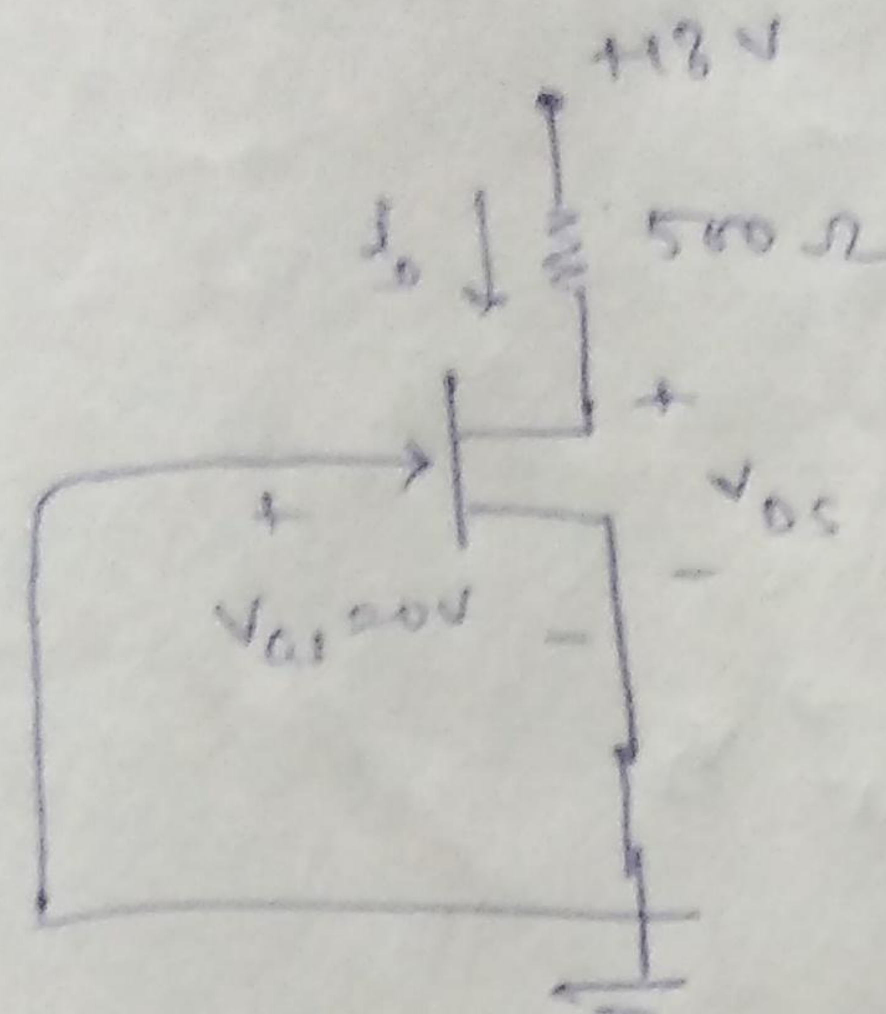
$$i_D = \frac{2I_{DSS}}{-V_p}\left(1 - \frac{V_{GS}}{V_p}\right)V_{DS}$$

← ohmic region

$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

← for active region

Ex 8.1



By Ohm's law

$$i_D = \frac{18 - V_{DS}}{500} \quad \text{--- (1)}$$

Assuming JFET is in active region, then

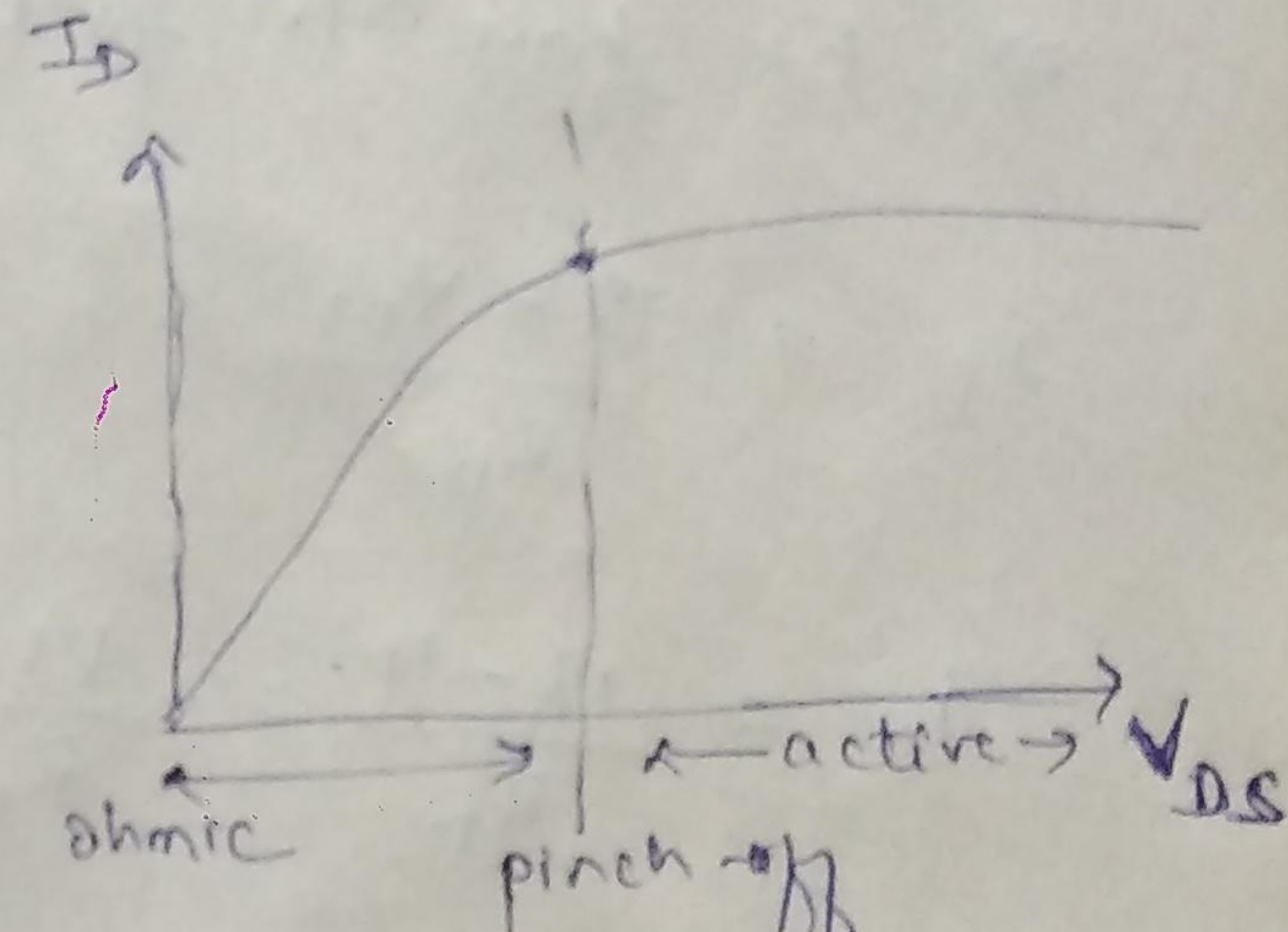
$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$= 8\left(1 - \frac{0}{(-4)}\right)^2 = \underline{\underline{8\,mA}}$$

Substituting this i_D in eq. (1) to get V_{DS}

$$i_D = \frac{18 - V_{DS}}{500} = 8\,mA$$

$$\Rightarrow V_{DS} = \underline{\underline{14\text{ volt}}}$$



$-V_p$

$= -(-4) = \underline{+4\text{ volt}}$

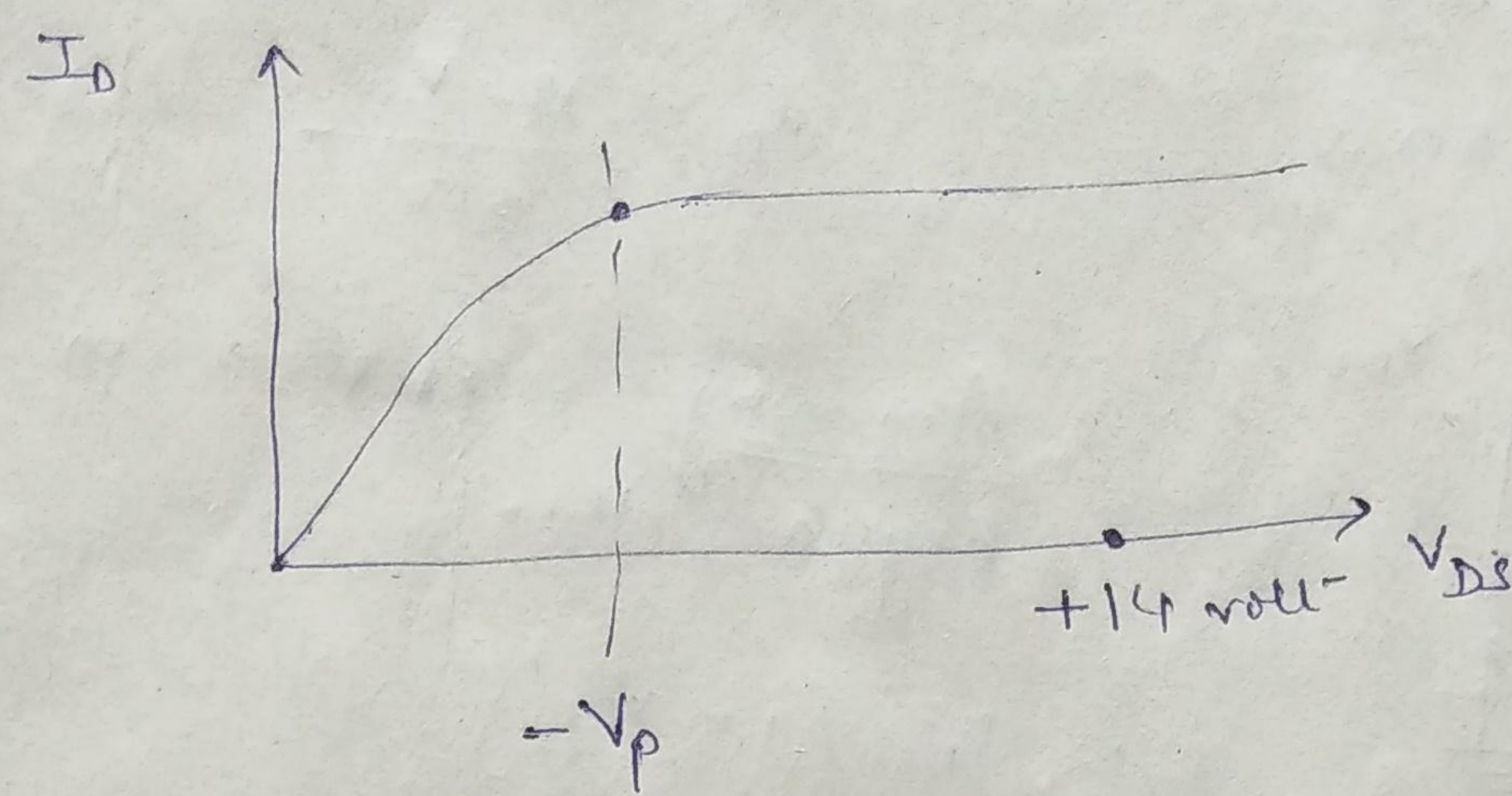
So below +4 volt it is ohmic region and above +4 volt it is active region.

As we are getting V_{DS} as 14 volt

$\Rightarrow$ JFET is in active region

This was our initial assumption. So now our initial assumption has been proved correct.

Q.1 tutorial — extension of Ex 8.1 M Bobrow

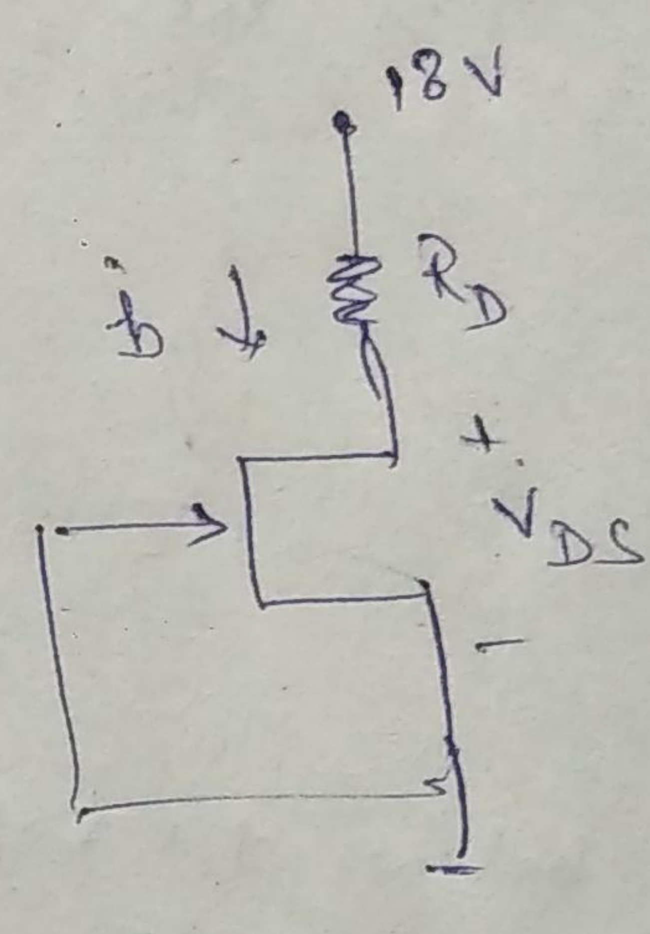


$(= -(-4) = +4$ volt$)$

So observe that $R_D = 500\,\Omega$ is giving V_{DS} of $+14$ volt.
But the question is asking for R_D, when JFET will be at pinch off.

$\Rightarrow$ We have to find R_D when $V_{DS} = 4$ volt.

$$i_D = \frac{18 - V_{DS}}{R_D}$$



$$i_D = \frac{18-4}{R_D} = \frac{14}{R_D}$$

at pinch off, we can use current eq. for active region —

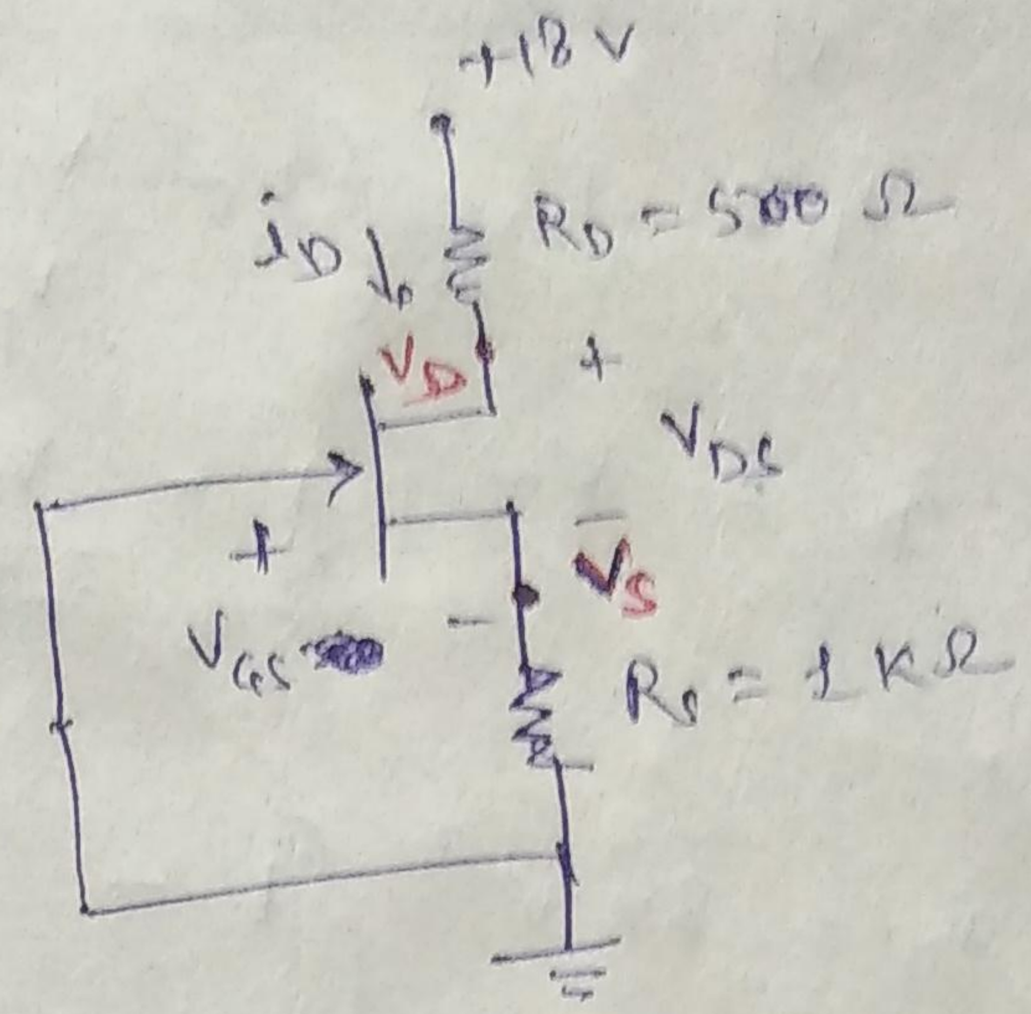
$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$$= 8m\left(1 - \frac{0}{V_p}\right)^2 = 8\,mA$$

$i_D = \frac{14}{R_D}$ $\Rightarrow$ $R_D = \frac{14}{8m} = \frac{14}{8} \times 10^3 = \underline{\underline{1.75\ K\Omega}}$

Q.2 tutorial — Ex 8.2 Boblow

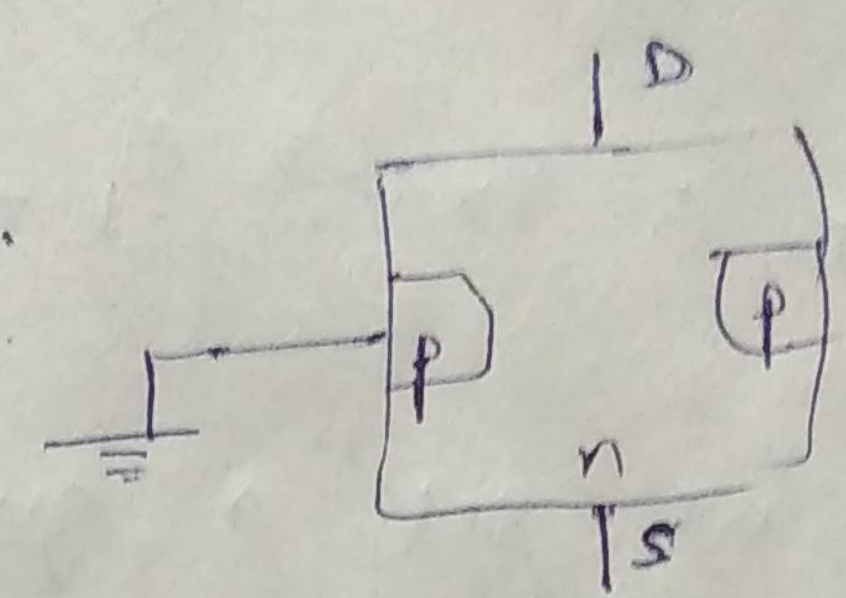
Here source and gate are not at same potential.



$V_G = 0$

$V_S = ?$ ← not equal to zero

↳ V_S = drop across R_S



Assuming that gate is reverse biased.

⇒ Assuming $V_{GS} \leq 0\ V$

This is a pretty valid assumption — because if you see the o/p loop — the top node is at +18 volt and bottom at 0 V — so every point in b/w these two nodes will have a voltage b/w +18 volt and 0 volt

⇒ V_S will be a +ve value

$$\Rightarrow V_{GS} = V_G - V_S = 0 - V_S = -V_S$$

$$\Rightarrow V_{GS} \leq 0\ V$$ (we only know $V_{GS} \leq 0$. We don't know the exact value.)

$$i_D = \frac{18 - V_D}{500}$$ or $$i_D = \frac{V_S}{1000}$$

$V_{GS} = -V_S$

$V_S = -V_{GS}$

$$\Rightarrow i_D = \frac{-V_{GS}}{1000}$$

$$\Rightarrow V_{GS} = -1000\ i_D$$

Assuming that JFET is in active region, then

$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\Rightarrow i_D = 8m\left(1 - \frac{V_{GS}}{-4}\right)^2 = 8\times10^{-3}\left(1 - \frac{V_{GS}}{-4}\right)^2$$

$$\Rightarrow i_D = 8\times10^{-3}\left(1 - \frac{-1000\, i_D}{-4}\right)^2$$

$$i_D = 8\times10^{-3}\left(1 - \frac{1000\, i_D}{4}\right)^2$$

So we get a quadratic in i_D —

$$i_D^2 - (10\times10^{-3})\, i_D + 16\times10^{-6} = 0$$

The solutions to this equation are —

$i_{D_1} = 2\times10^{-3}$ Amp $\qquad i_{D_2} = 8\times10^{-3}$ Amp

But only one value of current can exist in the circuit. So which is the correct value?

→ Observe, $i_{D_2} = 8\,mA = I_{DSS}$

But $i_D = I_{DSS} \Rightarrow V_{GS} = 0\,V$

But in our case $V_{GS} < 0$

$\therefore\ i_D = I_{DSS}$ can not be the answer

Hence, $i_D = i_{D_1} = 2\,mA$

Book thinks —

$V_{GS} \le 0$

But by our previous reasoning, we can write

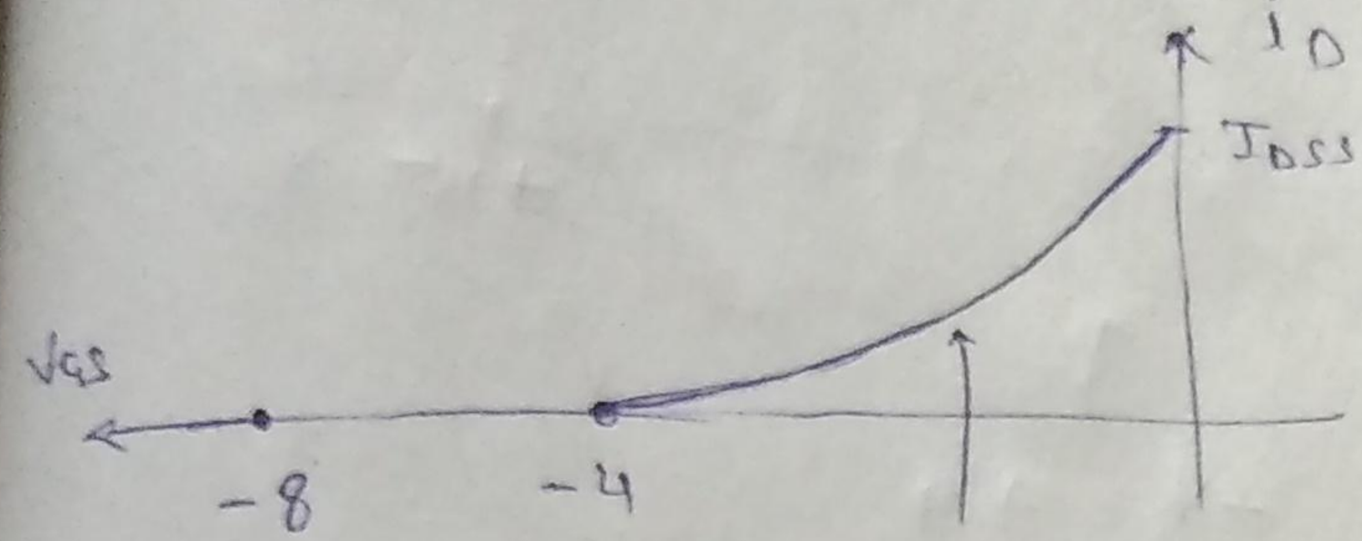
$V_{GS} < 0$

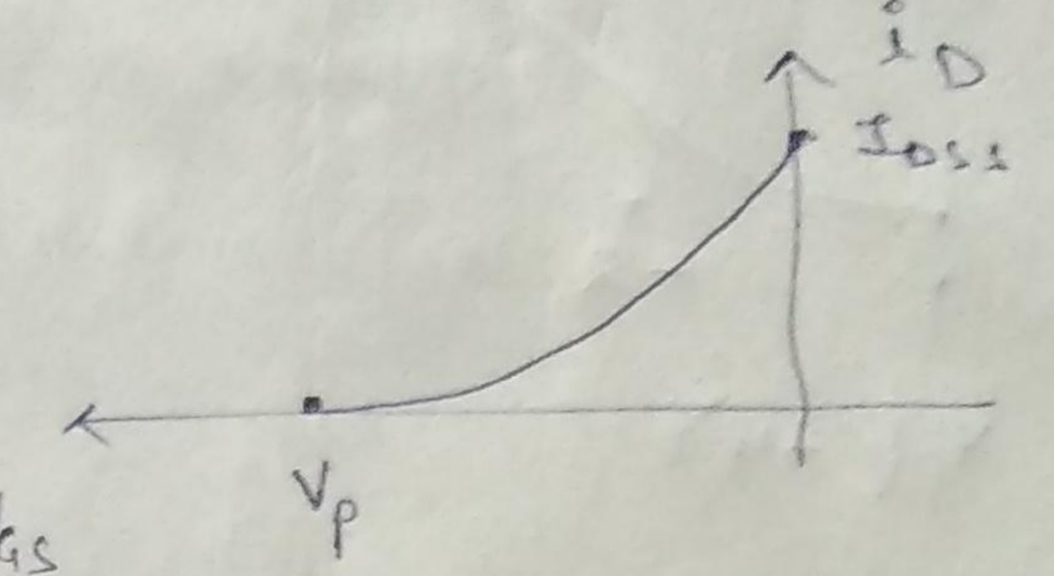
→ Book approach (more analytical)

We assumed that device is in active region.

Case 1 $\quad i_D = 8\,mA$

$$V_{GS} = -1000\, i_D = -1000\,(8\times10^{-3}) = -8 \text{ volt}$$





negative value $= (-4 \text{ volt})$

plot of $i_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2$

i_D(active)

As $V_{GS} = -8$ volt is less than pinch off

$\Rightarrow$ device is not in active region.

So here our assumption is contradicted.

Case 2 $\quad i_D = 2\,mA$

$$V_{GS} = -1000\, i_D = -1000\,(2\,mA) = -2 \text{ volt}$$

-2 volt $> V_P$

This supports that device is in active region.

Hence taking $i_D = 2\,mA$ as the correct answer and moving forward.

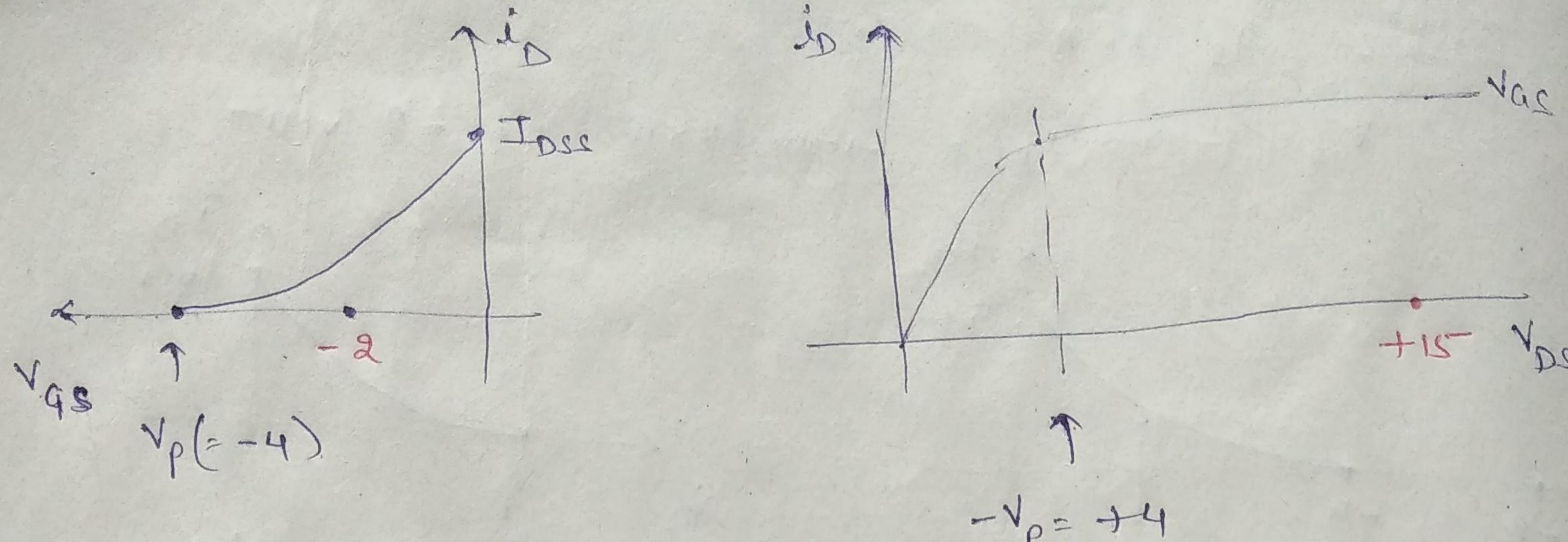
$i_D = 2\,mA \qquad V_{GS} = -2$ volt

Writing KVL in o/p loop –

$$18 - i_D R_D - V_{DS} - i_D R_S = 0$$

$$\Rightarrow 18 - 2\times10^{-3}\times 500 - V_{DS} - 2\times10^{-3}\times 1000 = 0 \quad \Rightarrow V_{DS} = 15 \text{ volt}$$

$i_D = 2mA$ $\quad$ $V_{GS} = -2$ volt $\quad$ $V_{DS} = 15$ volt



All these values are coherent, proving that device is in active region.

Depletion MOSFET

depletion mode (V_{GS} = -ive)

enhancement mode (V_{GS} = +ve)

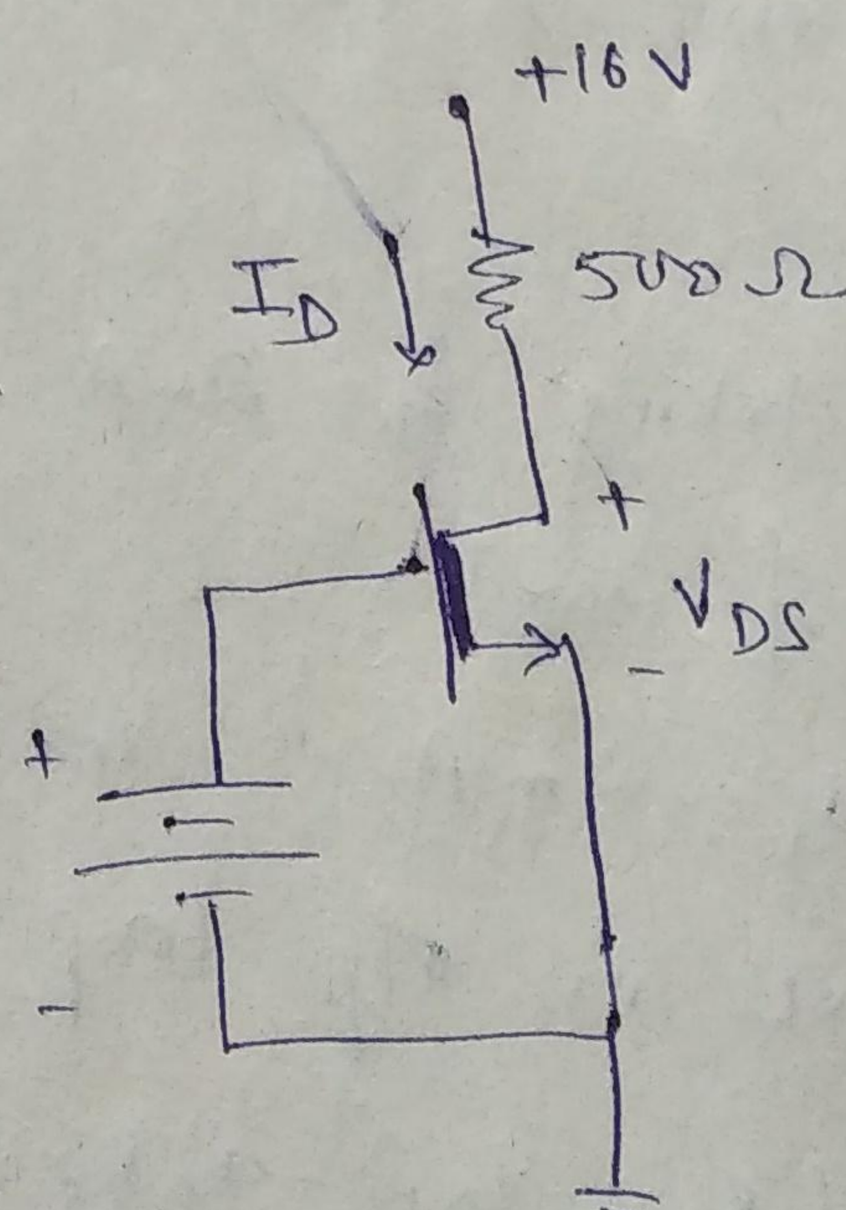
Q3 tutorial — Ex 8.3 Bobrow

Given an n type depletion MOSFET

Given: $I_{DSS} = 8\,mA$

$V_p = -2$ volt

$V_{GS} = 1$ volt



Writing KVL in o/p loop

$+16 - i_D R_D - V_{DS} = 0$

$V_{DS} = 16 - i_D(500)$

Assuming device is in active region, then

$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

$= (8\times10^{-3})\left(1 - \frac{1}{-2}\right)^2 = 18 \text{ mA}$

$\Rightarrow V_{DS} = 16 - (18)(500) = 7$ volt

V_{DS}	$V_{GS} - V_P$
7	$1-(-2) = 3$

$\Rightarrow \boxed{V_{DS} > V_{GS} - V_P}$ ← condition for depletⁿ MOS to be in active region

$\Rightarrow$ MOSFET is in active region

$\Rightarrow$ ~~thus~~ our assumption is validated.

So,

$V_{GS} = 1$ volt $i_D = 18$ mA $V_{DS} = 7$ volt

$\boxed{V_{DS} > V_{GS} - V_P}$ ← condition for depletion MOS to be in active region

and $(V_{GS} > V_P)$

$\boxed{V_{DS} < V_{GS} - V_P}$ ← condition for depletion MOS to be in ohmic region.

and $(V_{GS} > V_P)$

if $\boxed{V_{GS} < V_P}$ — device is in cut off.

→ if R_D is 750 Ω

again assuming device is in active region then

$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 18\,mA$$

$$V_{DS} = 16 - i_D(750) = 16 - 18\times10^{-3}\times750 = 2.5 \text{ volt}$$

V_{DS}	$V_{GS} - V_P$
2.5	$1-(-2) = 3$

$\Rightarrow$ $V_{DS} < V_{GS} - V_P$ ← condit^n^ for ohmic region

~~device is in~~

But we assumed that device is in active region.

Thus our assumption is contradicted.

So lets start all over again, by assuming that device is in ohmic region. –

$$i_D = I_{DSS}\left[2\left(1 - \frac{V_{GS}}{V_P}\right)\frac{V_{DS}}{(-V_P)} - \left(\frac{V_{DS}}{V_P}\right)^2\right]$$

$$i_D = (8\times10^{-3})\left[2\left(1 - \frac{1}{-2}\right)\frac{V_{DS}}{2} - \left(\frac{V_{DS}}{-2}\right)^2\right]$$

Also $i_D = \dfrac{16 - V_{DS}}{750}$

$$\therefore\ 8\times10^{-3}\left[2\left(1 - \frac{1}{-2}\right)\frac{V_{DS}}{2} - \left(\frac{V_{DS}}{-2}\right)^2\right] = \frac{16 - V_{DS}}{750}$$

Here we get a quadratic equation -

$$3V_{DS}^2 - 20V_{DS} + 32 = 0$$

Solut^n — $V_{DS_1} = \frac{8}{3}$ V $V_{DS_2} = 4$ V

V_{DS}	$V_{GS} - V_P$
8/3	3

$\frac{8}{3} < 3$

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

⇒ ohmic region

Coherent with the assumption ✓

V_{DS}	$V_{GS} - V_P$
4	3

$4 > 3$

$V_{DS} > V_{GS} - V_P$

condit^n for active region

contradicts the assumpt^n

ic region

device

that

$$i_D = \frac{16 - V_{DS}}{\cancel{750}} = \frac{16 - 8/3}{500}$$

$= 17.8$ mA