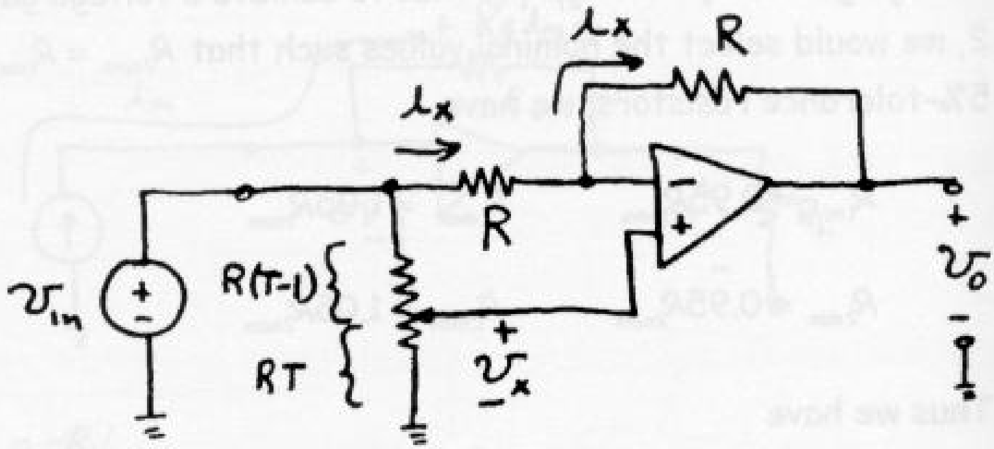
P14.11 Using the summing-point constraint, we have

$$i_D = \frac{v_{in}}{R} = I_s \exp(v_D / nV_T) \text{ and } v_o = -v_D$$

Solving, we have

$$v_o = -nV_T \ln\left(\frac{v_{in}}{RI_s}\right)$$

P14.27



By the voltage-division principle, we have

$$v_x = \frac{RT}{RT + (1-T)R} v_{in} = Tv_{in}$$

Then, we can write

$$i_x = \frac{v_{in} - v_x}{R} = \frac{v_{in}(1-T)}{R}$$

$$v_o = -Ri_x + v_x$$

$$= -v_{in}(1-T) + Tv_{in}$$

$$= v_{in}(2T - 1)$$

Thus, as T varies from 0 to unity, the circuit gain varies from -1 through to 0 to +1.

3. a) p-type

b) $v = \mu E$, p-type, so $v_p = \mu_p \cdot E$

Find μ_p from lookup table (page 36 of H&S, or Lecture 10, slide 20)

Total Dopant Concentration: $1.8 \times 10^{15}/cm^{-3}$

So $\mu_p \approx 500\ cm^2/Vs$

$4 \times 10^6 = 500 E$

$E = \frac{4 \times 10^6}{500} = 0.8 \times 10^4 = 8 \times 10^3 \frac{V}{cm}$

4a) As - Donor

B - Acceptor

P - Donor

$N_D = 10^{16} + 2.5 \times 10^{15} = 1.25 \times 10^{16}/cm^{-3}$

$N_A = 1.15 \times 10^{16}/cm^{-3}$

$n = \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2}$, $p = \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2}$

$n = \frac{1.25 \times 10^{16} - 1.15 \times 10^{16}}{2} \sqrt{\left(\frac{1.25 \times 10^{16} - 1.15 \times 10^{16}}{2}\right)^2 + (10 \times 10^{19})} = 1.0 \times 10^{15}$ electrons$/cm^3$

$p = \frac{(1.15 - 1.25) \times 10^{16}}{2} + \sqrt{\left(\frac{(1.15 - 1.25) \times 10^{16}}{2}\right)^2 + 10^{20}} = \frac{n_i^2}{1 \times 10^{15}} = 10^5$ holes$/cm^3$

slow way ↑   fast way ↑

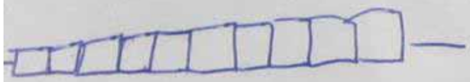
b) $R_s = \frac{\rho}{t} = \frac{1}{q p \mu_p \cdot t} = \frac{1}{1.6\times10^{-19}\cdot \mu_p \cdot p \cdot 0.0011} = 250$

Assume that $p \approx N_A$. Take a guess, $\mu_p = 500$ ($N_A \sim 10^{16}$)

$$\frac{1}{1.6\times10^{-19}\cdot 500\cdot 0.011\cdot p} = 250$$

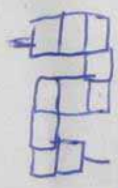
$p = 4.5\times10^{16}$ holes/cm^{-3}, $N_A = 4.5\times10^{16}$ acceptors/cm^{-3}

Mobility for $N_A = 4.5\times10^{16}$ is ~475. We could repeat finding p for $\mu_p = 475$ to get a better answer, but 475 is close to 500, so $N_A = 4.5\times10^{16}$ should be acceptable.



10 squares = 2.5kΩ

or:



or many other configurations.

In case you're confused about why I made a guess about the mobility:

The reason that we have to guess at the value of the hole mobility in the above problem is that to find the number of holes, we need to know the hole mobility, but to find the hole mobility, we have to know the number of acceptors (and thus the number of holes). Since there are many different values of Na which all have roughly the same mobility, I chose to guess the mobility and see what Na I got as a result, and then looked up the mobility for the Na that I found. Since the Na I found yielded a mobility close enough to my guess, then I know that my guess was fine.

5) $R_s = \frac{\rho}{t} = \frac{1}{q \cdot n \cdot \mu_n \cdot t} = \frac{1}{1.6\times10^{-19} \cdot 0.001 \cdot 10^{17} \cdot 350} = 178.57\ \Omega/\text{sq}$

$\mu_n = 350$ (H&S, page 36) (Lecture 10, slide 20)

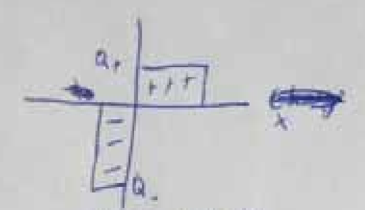
6) a) From slide 6, lecture 11:

$$\phi_0 = \frac{KT}{q} \cdot \ln\left(\frac{N_A N_D}{n_i^2}\right)$$, assume room temperature (not stated in the problem, sorry)

$$= 0.060 \ln\left(\frac{10^{17} \cdot 10^{14}}{10^{20}}\right) = 1.52\ V$$

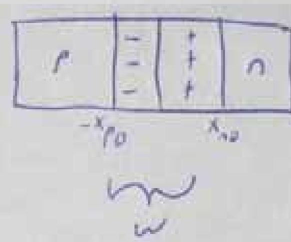
b) Slide 11, lecture 11:
$N_A >> N_D$, so: $W_j = \sqrt{\frac{2 \cdot 10^{-12}}{1.6\times10^{-19} \cdot 10^{14}}(1.52 - 0)} = 4.36\times10^{-4}$ cm

c)



Charge Density

p n

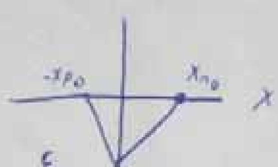


$Q_- = -1.6\times10^{-19} \cdot N_A$
$= -1.6\times10^{-2}\ C/cm^3$

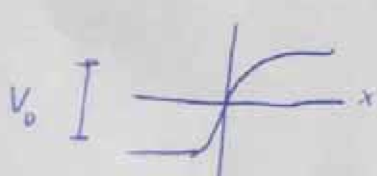
$Q_+ = 1.6\times10^{-19} \cdot N_D$
$= 1.6\times10^{-5}\ C/cm^3$

$W = 4.36\times10^{-4}$ cm

(it's possible to find $-x_{p0}$ and x_{n0}, but not necessary)



Electric Field



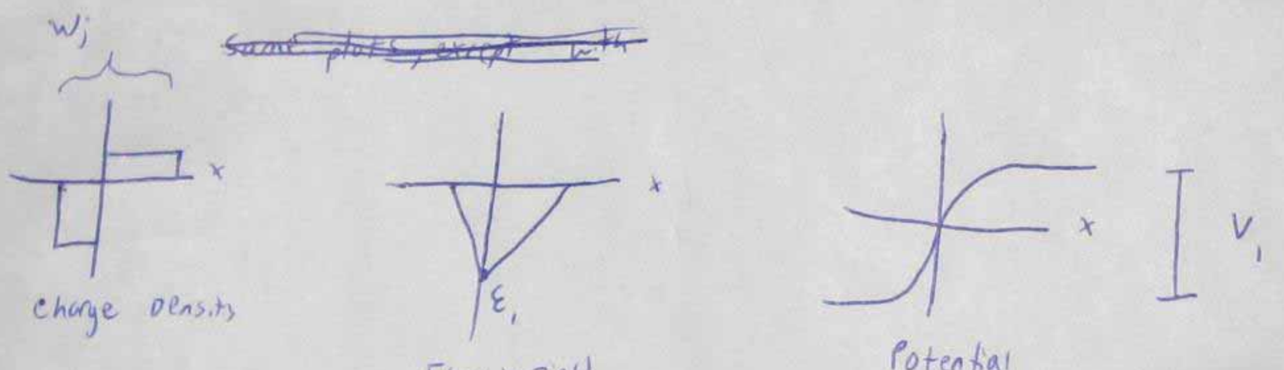
Potential

For $V_a = -0.5V$

d) $\phi_0 = 1.52V$

$$W_j = \sqrt{\frac{2\times10^{-12}}{q\cdot N_d}(1.52+0.5)} = 5.02\times10^{-4}\ cm$$

~~Same plots, except with~~



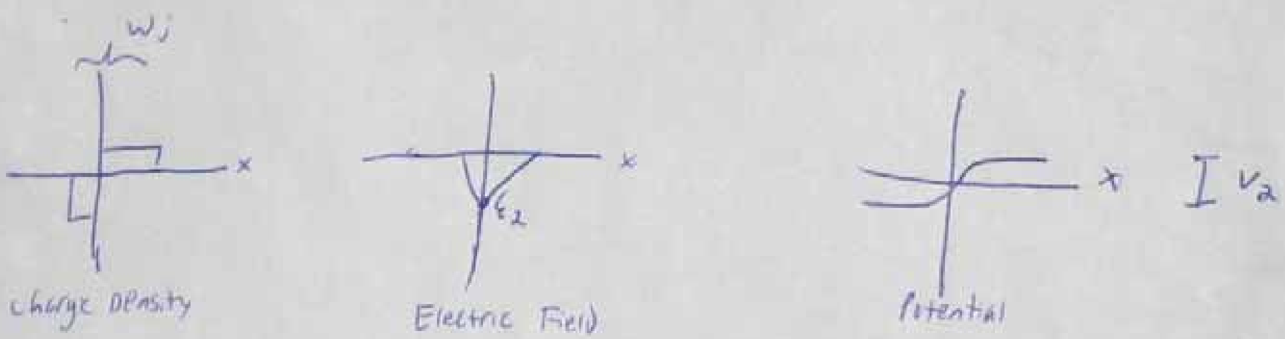
$|\varepsilon_1| > |\varepsilon_0|$

$V_1 > V_0$

For $V_a = 0.5V$

$\phi_0 = 1.52V$

$W_j = 3.57\times10^{-4}\ cm$



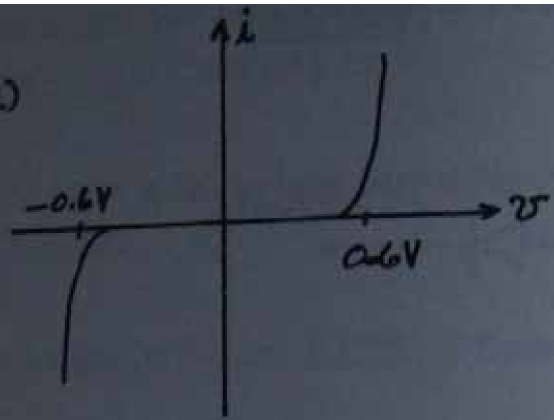
$|\varepsilon_2| < |\varepsilon_0| < |\varepsilon_1|$

$V_2 < V_0 < V_1$

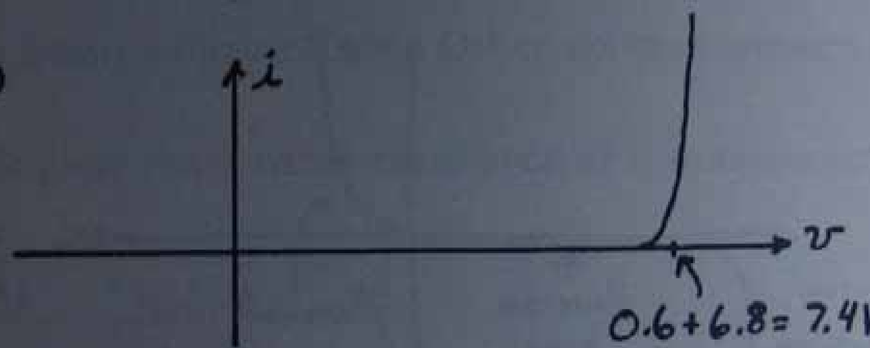
Note: The value of the charge density in all three cases has the same peak values (-q*Na, and q*nD)

P10.6*

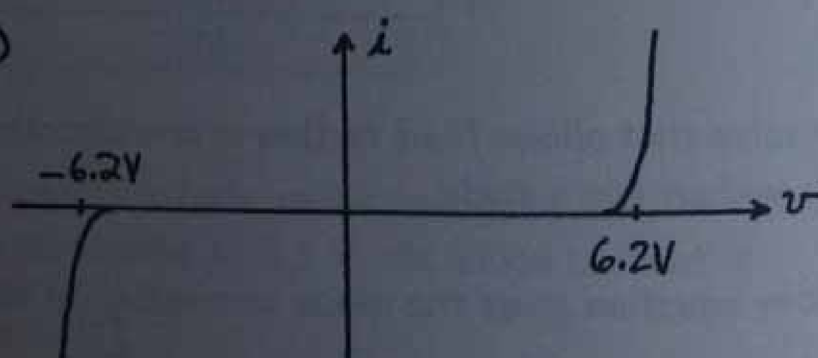
(a)



(b)



(c)



P10.8* The approximate form of the Shockley Equation is $i_D = I_s \exp(v_D / nV_T)$

Taking the ratio of currents for two different voltages, we have

$$\frac{i_{D1}}{i_{D2}} = \frac{\exp(v_{D1}/nV_T)}{\exp(v_{D2}/nV_T)} = \exp\left[(v_{D1} - v_{D2})/nV_T\right]$$

Solving for n we obtain:

$$n = \frac{v_{D1} - v_{D2}}{V_T \ln(i_{D1}/i_{D2})} = \frac{0.600 - 0.680}{0.026 \ln(1/10)} = 1.336$$

Then we have

$$I_s = \frac{i_{D1}}{\exp(v_{D1}/nV_T)} = 3.150 \times 10^{-11}\ A$$

P10.32 (a) The diode is on, $V = 0$ and $I = \frac{10}{2700} = 3.70$ mA.

(b) The diode is off, $I = 0$ and $V = 10$ V.

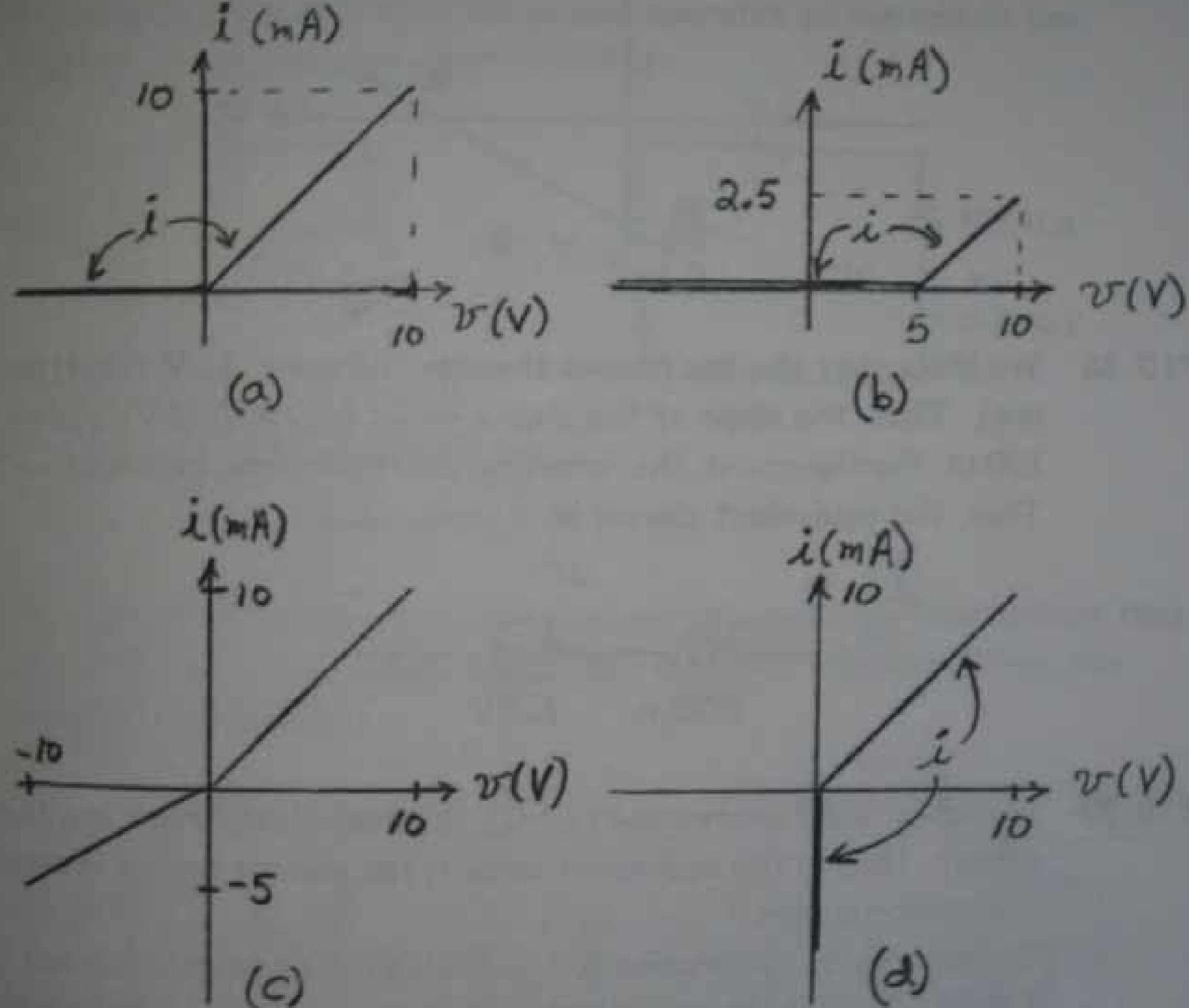
(c) The diode is on, $V = 0$ and $I = 0$.

(d) The diode is on, $I = 5$ mA and $V = 5$ V.

P10.33* (a) D_1 is on and D_2 is off. $V = 10$ volts and $I = 0$.

(b) D_1 is on and D_2 is off. $V = 6$ volts and $I = 6$ mA.

P10.35



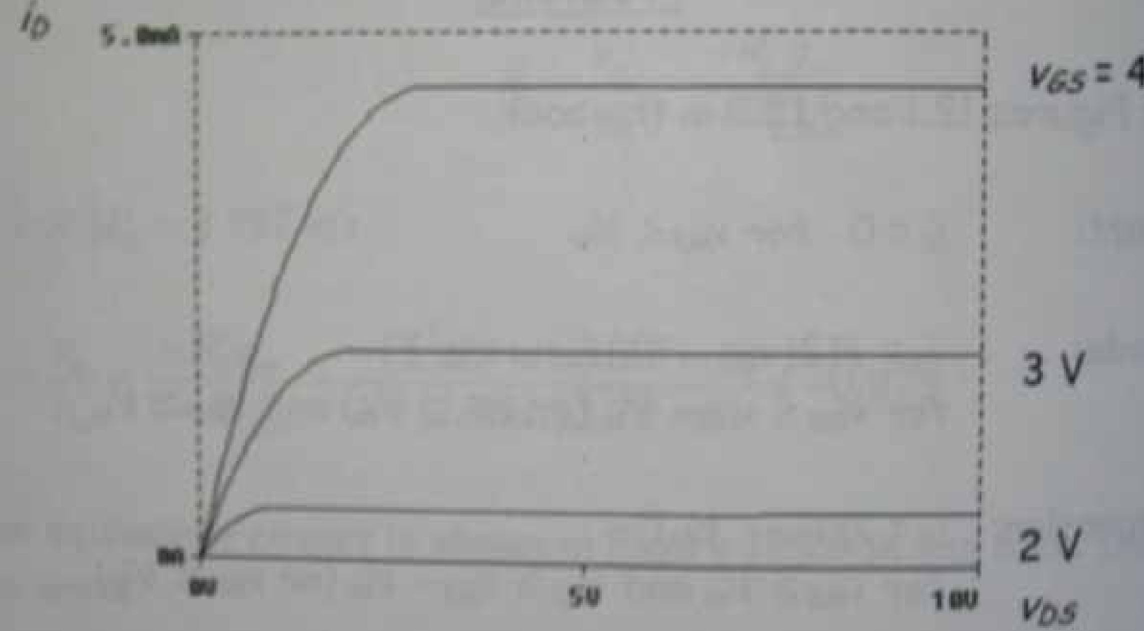
P12.3* $K = \frac{1}{2}KP(W/L) = 0.25\ \text{mA/V}^2$

(a) Saturation because we have $v_{GS} \geq V_{to}$ and $v_{DS} \geq v_{GS} - V_{to}$.
$i_D = K(v_{GS} - V_{to})^2 = 2.25$ mA

(b) Triode because we have $v_{DS} < v_{GS} - V_{to}$ and $v_{GS} \geq V_{to}$.
$i_D = K[2(v_{GS} - V_{to})v_{DS} - v_{DS}^2] = 2$ mA

(c) Cutoff because we have $v_{GS} \leq V_{to}$. $i_D = 0$.

P12.5*

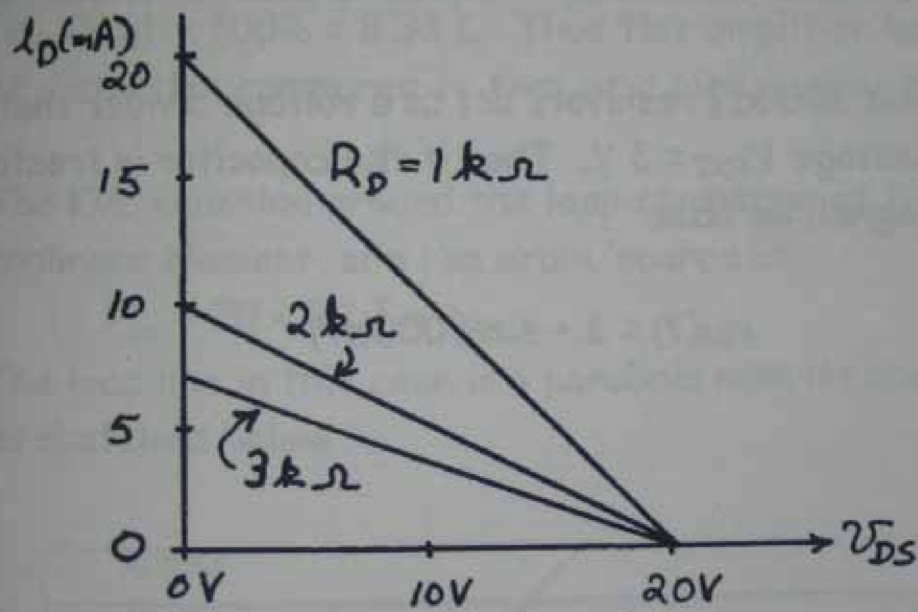


P12.9 With $v_{GS} = v_{DS} = 5$ V, the transistor operates in the saturation region for which we have $i_D = K(v_{GS} - V_{to})^2$. Solving for K and substituting values we obtain $K = 31.25\ \mu A/V^2$. However we have $K = (W/L)(KP/2)$. Solving for W/L and substituting values we obtain $W/L = 1.25$. Thus for $L = 2\ \mu m$, we need $W = 2.5\ \mu m$.

P12.13 (a) This is an NMOS transistor. We have $v_{GS} = V_{in}$ and $v_{DS} = 5$ V. With $V_{in} = 0$, the transistor operates in cutoff and $I_a = i_D = 0$. With $V_{in} = 5$, the transistor operates in satruation and $I_a = i_D = K(v_{GS} - V_{to})^2 = 8$ mA.

(b) This is a PMOS transistor. We have $v_{GS} = V_{in} - 5$ and $v_{DS} = -5$ V. With $V_{in} = 0$, the transistor operates in satruation and $I_b = i_D = K(v_{GS} - V_{to})^2 = 8$ mA. With $V_{in} = 5$, the transistor operates in cutoff and $I_b = i_D = 0$.

P12.17* The load-line equation is $V_{DD} = R_D i_D + v_{DS}$, and the plots are:



Notice that the load line rotates around the point (V_{DD}, 0) as the resistance changes.