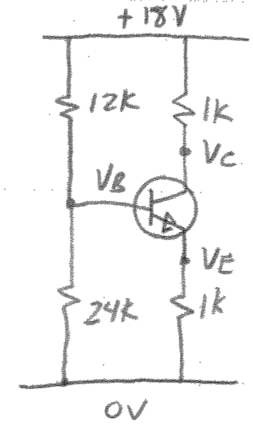
PROBLEM #1a.

Q1 Note: in each case you can start by assuming any of the modes, if you get a self-consistent solution you can stop. All cases are shown here.



ⓐ Assume cutoff. Then $I_C = I_E = I_B = 0$.

Then $V_C = 18 - (0)(1K) = 18V$

$V_E = 0(1K) = 0V$

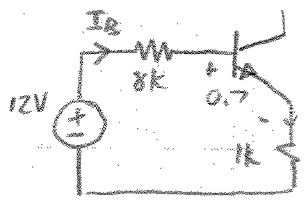
$V_B = \frac{24K}{24K + 12K} 18V = 12V.$

But $V_B > V_E$ means forward biased base-emitter. ⇒ Not cutoff.

ⓑ Assume active. Then $V_{BE} = 0.7V$, and $I_C = \beta I_B$.

Reduce left-half of circuit to Thevenin equivalent.

$V_{oc} = \frac{24K}{24K+12K} 18V = 12V$ $R_{TH} = 12k \| 24k = 8K$



$I_E = I_C + I_B$
$= (\beta+1) I_B$

Loop analysis

$-12 + 8K\, I_B + 0.7 + (101) I_B (1k) = 0.$

$I_B = 103.7\,\mu A.$

Then $I_C = \beta I_B = (100)(103.7\,\mu A) = 10.37mA$

$I_E = I_C + I_B = 10.47mA$

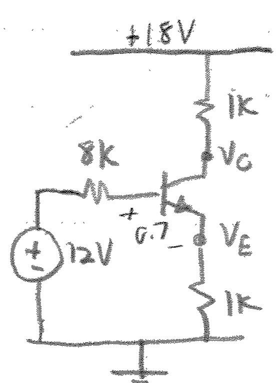
$V_C = 18 - (10.37m)(1k) = 7.63V$

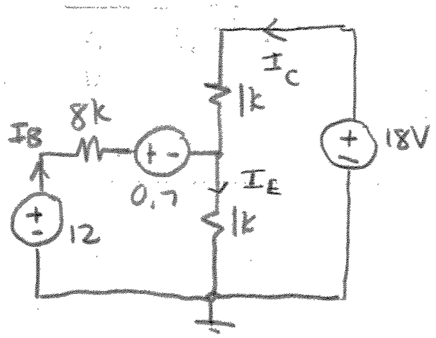
$V_E = (10.47mA)(1k) = 10.47V$

$V_B = V_E + 0.7 = 11.17V$

But $V_B > V_C$ means forward-biased collector-base ⇒ Not active

ⓒ Assume saturation. $V_{BE} = 0.7$, $V_{CE} = 0.7$ ⇒ $V_C = V_E$





Left loop

$-12 + 8k(I_B) + 0.7 + 1k(I_E) = 0$

$-12 + 8k(I_B) + 0.7 + 1k(I_B + I_C) = 0$

Right loop

$-18 + 1k(I_C) + 1k(I_E) = 0$

$-18 + 1k(I_C) + 1k(I_C + I_B) = 0.$

PROBLEM #1a continued.

Simplify: left loop $9k I_B + 1k I_C = 11.3$; right loop $1k I_B + 2k I_C = 18$ $\Rightarrow$ $I_B = 0.271\,mA$, $I_C = 8.865\,mA$

Then $I_E = I_B + I_C = 9.136\,mA$

$V_C = 18 - (8.865m)(1k) = 9.135V$

$V_E = (9.136m)(1k) = 9.136V$

(same: rounding error)

$V_B = V_E + 0.7 = 9.836V$

$V_C = V_E$, $V_B > V_C$, $V_B > V_E$ — OK for saturation

$V_E = 9.136V$	$I_E = 9.136\,mA$
$V_B = 9.836V$	$I_B = 0.271\,mA$
$V_C = 9.136V$	$I_C = 8.865\,mA$

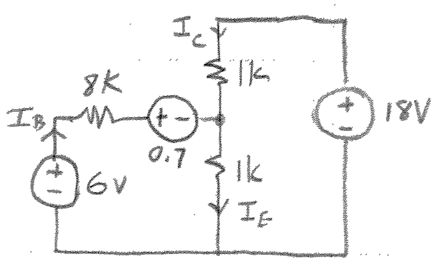
Q2 (a) Assume cutoff

$$I_C = I_E = I_B = 0 \Rightarrow V_C = 18V,\ V_E = 0V,\ V_B = \frac{12k}{12k+24k} 18V = 6V.$$

but then $V_B > V_E$, which means not cutoff

(b) Assume saturation. $V_{BE} = 0.7$, $V_{CE} = 0.7$, $V_C = V_E$.

$$V_{oc} = \frac{12k}{12k+24k} 18V = 6V, \quad R_{TH} = 12k \| 24k = 8k.$$



Left loop: $-6 + 8k I_B + 0.7 + 1k(I_E) = 0$

$-6 + 8k I_B + 0.7 + 1k(I_B + I_C) = 0$

$9k I_B + 1k I_C = 5.3$

Right loop: $-18 + 1k I_C + 1k I_E = 0$

$-18 + 1k I_C + 1k(I_B + I_C) = 0$

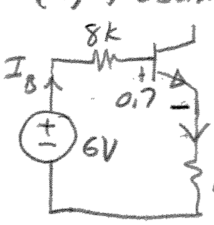
$1k I_B + 2k I_C = 18$

Solve: $9k I_B + 1k I_C = 5.3$; $1k I_B + 2k I_C = 18$ $\Rightarrow$ $I_B = -0.435\,mA$ ← problem already $I_B < 0$. $I_C = 9.218\,mA$

Current can't flow backward (unless breakdown) through BE junction.

Not saturation

(c) Assume active. $V_{BE} = 0.7$, $I_C = \beta I_B$.



$-6 + 8k I_B + 0.7 + 1k(I_E) = 0$

$-6 + 8k I_B + 0.7 + 1k(\beta+1)(I_B) = 0.$

$I_B = 48.62\,\mu A$

then $I_C = \beta I_B = 4.862\,mA$

$I_E = 4.911\,mA$

PROBLEM #1a. Continued.

Then $V_C = 18 - (4.862m)(1K) = 13.138V$

$V_E = (4.911m)(1K) = 4.911V$

$V_B = V_E + 0.7 = 5.611V$

$V_C > V_B$, $V_B > V_E$ } OK for active.

$V_E = 4.911V$	$I_E = 4.911mA$
$V_B = 5.611V$	$I_B = 48.62\mu A$
$V_C = 13.138V$	$I_C = 4.862mA$

Q3 (a) Assume cutoff. $I_E = I_C = I_B = 0$.

Then $V_E = 12$, $V_C = 0$, $V_B = 0$. But $V_E > V_B$ which is forward-bias for PNP transistor.

Not cutoff

(b) Assume active. $V_{EB} = 0.7$, $I_C = \beta I_B$.

~~Then $V_E = 12$, $V_B = V_E - 0.7 = 11.3$.~~ $I_B = 11.3/24k = 470.8\mu A$

$I_C = \beta I_B = 47.08mA \rightarrow V_C = (47.08m)(1K) = 47.08V$.

47.08V is not possible, also $V_C > V_B$ is forward bias collector-emitter

Not active.

(c) Assume saturation $V_{EB} = 0.7$, $V_C = V_E$.

$V_C = V_E = 12V$. $V_B = V_E - 0.7 = 11.3$. $I_B = 11.3/24k = 470.8\mu A$.

$I_C = 12/2k = 6mA$. $I_E = I_C + I_B = 6.471mA$

$V_E > V_B$ and $V_C = V_E$. OK for saturation.

$V_E = 12V$	$I_E = 6.471mA$
$V_B = 11.3V$	$I_B = 470.8\mu A$
$V_C = 12V$	$I_C = 6mA$

Q4 (a) Assume cutoff. $I_E = I_C = I_B = 0$.

Then $V_E = 12$, $V_C = 0$, $V_B = 0$. But $V_E > V_B$, forward-bias for PNP.

Not cutoff.

(b) Assume saturation. $V_{EB} = 0.7$, $V_C = V_E$. Need $I_C < \beta I_B$.

Then $V_C = 12$, $V_B = 12 - 0.7 = 11.3$, $I_B = 11.3/24k = 470.8\mu A$

$V_C = 12V$, $I_C = 12/150 = 80mA$. But then $I_C > \beta I_B$, not possible

Not saturation.

PROBLEM #1a. continued

(c) Assume active. $V_{EB} = 0.7$, $I_C = \beta I_B$.

$V_E = 12$, $V_B = 12 - 0.7 = 11.3$, $I_B = 11.3/24k = 470.8\,\mu A$

$I_C = \beta I_B = 47.08\,mA$ $I_E = I_B + I_C = 47.55\,mA$

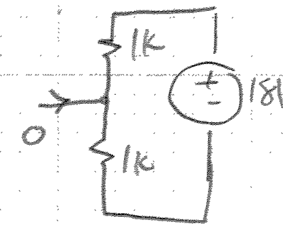
$V_C = I_C(150) = 7.062V$ $V_E > V_B$, $V_B > V_C$. OK.

$V_E = 12V$	$I_E = 47.55\,mA$
$V_B = 11.3V$	$I_B = 470.8\,\mu A$
$V_C = 7.062V$	$I_C = 47.08\,mA$

PROBLEM #1b

Repeat all using high-β approximation. Use known correct modes from previous part.

Q_1. Saturation: analysis is the same as previous part.
If you ignore I_B, then $V_C = V_E = 9V$, close.
However, this is not safe analysis because you don't know I_B is small.



Q_2 Active. Find $V_B \cong V_{OC} = \frac{12K}{12K + 24K} 18 = 6V$

Then $V_E = 6 - 0.7 = 5.3V$. $I_E = 5.3/1K = 5.3\,mA$, $I_C \approx I_E = 5.3\,mA$

$I_B = I_C/\beta = 53\,\mu A$. $V_C = 18 - (5.3)(1K) = 12.7V$, $V_E = (5.3)(1K) = 5.3V$

$V_B = V_E + 0.7 = 6.0V$.

$V_E = 5.3V$	$I_E = 5.3\,mA$
$V_B = 6.0V$	$I_B = 53\,\mu A$
$V_C = 12.7V$	$I_C = 5.3\,mA$

Q_3 Saturation: analysis is the same as previous part.

Q_4 Active: $V_E = 12$, $V_B = 12 - 0.7 = 11.3$, $I_B = 11.3/24 = 470.8\,\mu A$

$I_C = \beta I_B = 47\,mA$, $I_E \approx I_C = 47\,mA$, $V_C = (47m)(150) = 7.05V$

$V_E = 12V$	$I_E = 47\,mA$
$V_B = 11.3V$	$I_B = 471\,\mu A$
$V_C = 7.05V$	$I_C = 47\,mA$

PROBLEM #3

Q1 Current is flowing, so it is not cutoff.

Guess saturation. $\frac{V_G-(-12)}{560k}+\frac{V_G-12}{430k}=0 \Rightarrow V_G=1.576$ Volts

$I_S=25mA$, $I_D=I_S=25mA$, $V_D=12-(25m)(150)=8.25$ Volts.

Use $I_D=\frac{1}{2}k_n'(\frac{W}{L})(V_{GS}-V_t)^2 \rightarrow 25m=(4m)(V_{GS}-1)^2$

solve: $V_{GS}=\begin{cases}-1.5 \leftarrow \text{cutoff, } V_{GS}<V_t \\ (3) \leftarrow \text{pick this one}\end{cases}$

$V_S=V_G-V_{GS}=1.576-3.5=-1.924$ Volts

Check $V_{GS}>V_t$, OK $\quad V_{DS}>V_{GS}-V_t \rightarrow V_D>V_G-V_t$, OK

$\{ I_D=25mA,\ V_D=8.25\text{ Volts},\ V_G=1.576\text{ Volts},\ V_S=-1.924\text{ Volts} \}$

Q2 Guess saturation. $\frac{V_G-(-12)}{220k}+\frac{V_G-12}{680k}=0 \Rightarrow V_G=-6.133$ Volts

$I_D=\frac{1}{2}k_n'(\frac{W}{L})(V_{GS}-V_t)^2$, also $I_D=I_S=\frac{V_S-(-12)}{180}$.

$\frac{V_S+12}{180}=(4m)(-6.133-V_S-1)^2$

simplify $0.72V_S^2+9.272V_S+24.633=0 \Rightarrow V_S=-6.439\pm 2.692$

$V_S=\begin{cases}(-9.131) \leftarrow \text{pick this one} \\ -3.747 \leftarrow V_G<V_S \text{ cutoff}\end{cases}$

$I_S=\frac{-9.131-(-12)}{180}=15.94mA=I_D$, $V_D=12-(250)(15.94m)=8.02$ Volts

Check $V_{GS}>V_t$, OK, $V_{DS}>V_{GS}-V_t$, OK

$\{ I_D=15.94mA,\ V_D=8.02V,\ V_G=-6.133V,\ V_S=-9.131V \}$

Q3 Guess saturation. $\frac{V_G-(-12)}{680k}+\frac{V_G-12}{220k}=0 \Rightarrow V_G=+6.133$ Volts.

$I_D=\frac{1}{2}k_n'(\frac{W}{L})(V_{GS}-V_t)^2$, also $I_D=I_S=\frac{V_S-(-12)}{250}$

$\frac{V_S+12}{250}=(4m)(6.133-V_S-1)^2$

simplify $V_S^2-11.266V_S+14.347=0 \Rightarrow V_S=5.633\pm 8.339$

$V_S=\begin{cases}13.972 \leftarrow \text{not possible, } >12V \text{ power supply.} \\ -2.704 \leftarrow \text{pick this one.}\end{cases}$

PROBLEM #3 continued.

$$I_D = \frac{V_S - (-12)}{250} = \frac{-2.704 + 12}{250} = 37.18\,mA$$

$$V_D = 12 - (37.18m)(250) = 2.704\,Volts.$$

check $V_{GS} > V_t$, ok. Check $V_{DS} > V_{GS} - V_t$, not ok. V_{DS} is $< V_{GS}$.

Guess again: triode. $V_G = +6.133$ Volts, same as above.

$$I_D = k_n'\left(\frac{W}{L}\right)\left[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}\right]^2$$

also $I_D = I_S = \dfrac{V_S - (-12)}{250} \Rightarrow V_S = -12 + 250 I_D$

$I_D = \dfrac{12 - V_D}{180} \Rightarrow V_D = 12 - 180 I_D$

$$I_D = (8m)\left[(6.133 - V_S)(V_D - V_S) - \frac{1}{2}(V_D - V_S)^2\right]$$

$$= (8m)\left[(6.133 + 12 - 250 I_D)(12 - 180 I_D + 12 - 250 I_D) - \frac{1}{2}(12 - 180 I_D + 12 - 250 I_D)^2\right]$$

Simplify

$$120.4 I_D^2 - 27.818 I_D + 1.1776 = 0 \qquad I_D = 0.1155 \pm 0.0597$$

$I_D = \begin{cases} 0.0558 \leftarrow \text{pick this one} \\ 0.1752 \leftarrow V_S \text{ is too high if you use this} \end{cases}$

$$V_S = -12 + (0.0558)(250) = 1.95\,V$$

$$V_D = 12 - (0.0558)(180) = 1.956\,V$$

Check $V_{GS} > V_t$, ok $\quad V_{DS} < V_{GS} - V_t$, ok

$\{ I_D = 55.8\,mA,\ V_D = 1.956V,\ V_G = 6.133\,V,\ V_S = 1.95\,V \}$

Q4 Guess saturation. $V_D = V_G$. $\quad I_D = \dfrac{12 - V_D}{1.5K}$. $\quad V_S = -12$.

$$I_D = \tfrac{1}{2}k_n'\left(\frac{W}{L}\right)(V_{GS} - V_t)^2 \Rightarrow \frac{12 - V_D}{1.5k} = (4m)(V_D - (-12) - 1)^2$$

Simplify $6V_D^2 + 133V_D + 714 = 0 \Rightarrow V_D = -11.0833 \pm 1.9597$

$V_D = V_G = \begin{cases} -13.043 \leftarrow \text{not possible, less than } -12V \\ -9.124 \leftarrow \text{pick this one} \end{cases}$

$I_D = \dfrac{12 - (-9.124)}{1.5k} = 14.08\,mA$. $\quad V_{GS} > V_t$, ok $\quad V_{DS} > V_{GS} - V_t$, ok

$\{ I_D = 14.08\,mA,\ V_D = -9.124V,\ V_G = -9.124V,\ V_S = -12V \}$