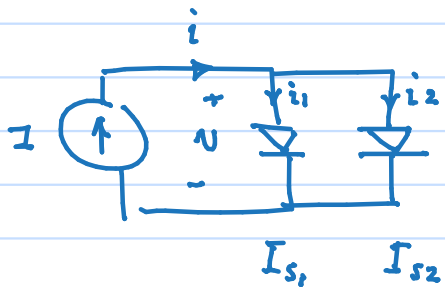


$$I_c = I_s e^{\frac{V_{BE}}{V_{Th}}}$$

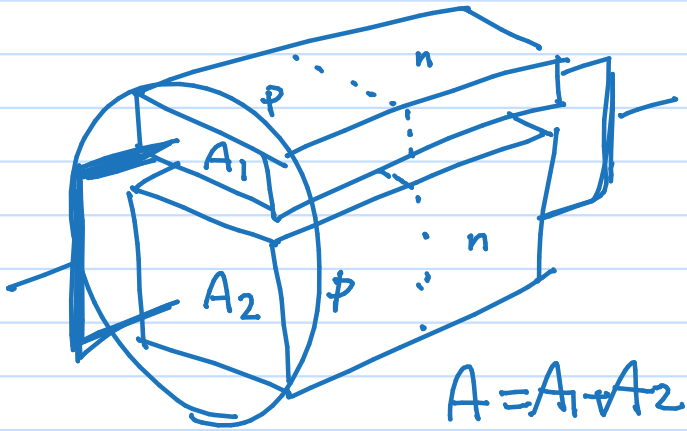
~~$$\left(1 + \frac{\beta_{CE}}{V_A} \right)$$~~



$$i_1 = I_{s1} (e^{v/v_{th}} - 1)$$

$$i_2 = I_{s2} (e^{v/v_{th}} - 1)$$

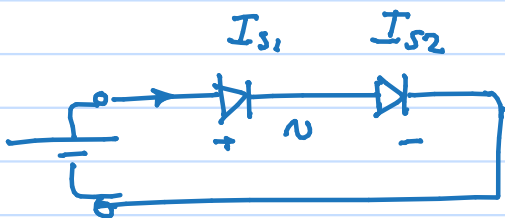
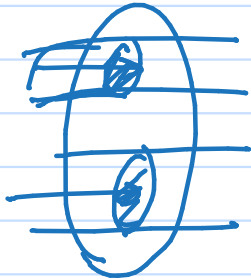
$$i = i_1 + i_2 = \underbrace{(I_{s1} + I_{s2})}_{I_s} (e^{v/v_{th}} - 1)$$



$$A = A_1 + A_2$$

$$I_s \propto A$$

$$\frac{i_1}{i} = \frac{I_{s1}}{I_{s1} + I_{s2}}$$

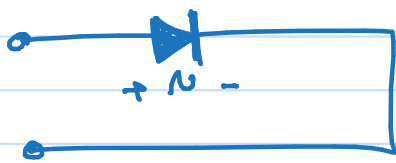


$$i = I_{s1} e^{v_1/v_{th}}$$

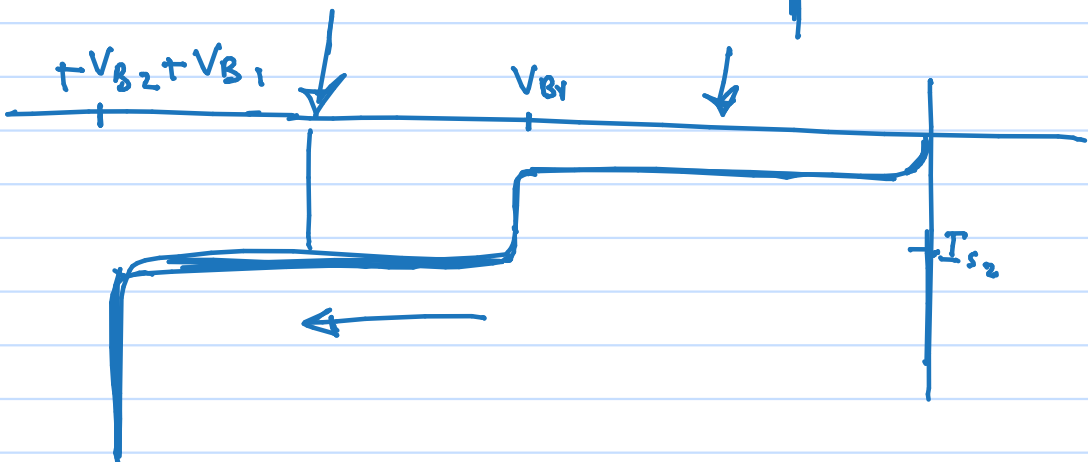
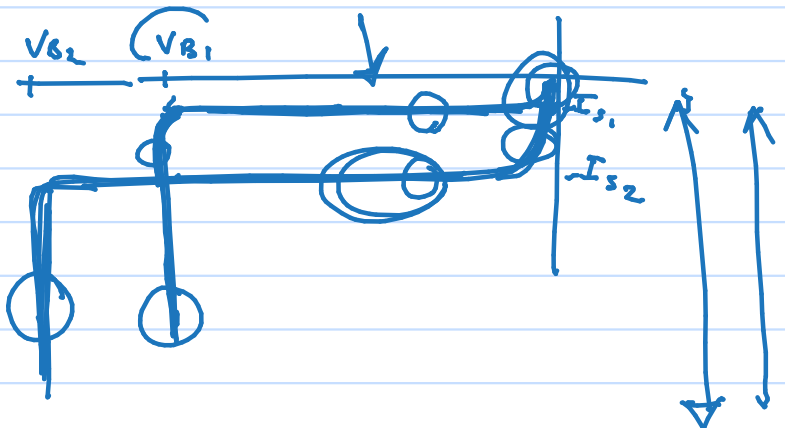
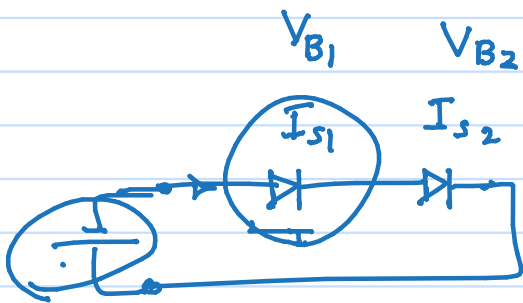
$$i = I_{s2} e^{v_2/v_{th}}$$

$$v_1 = v_{th} \ln\left(\frac{i}{I_{s1}}\right)$$

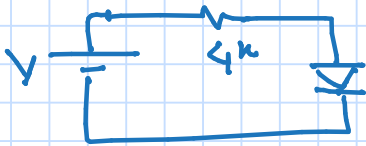
$$v_2 = v_{th} \ln\left(\frac{i}{I_{s2}}\right)$$



$$v = v_1 + v_2 = v_{th} \ln\left(\frac{i^2}{I_{s1} I_{s2}}\right) = \underline{2v_{th}} \ln\left(\frac{i}{\sqrt{I_{s1} I_{s2}}}\right)$$



1-5



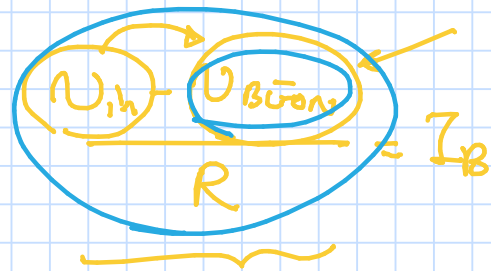
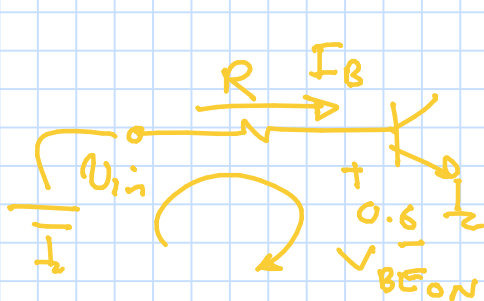
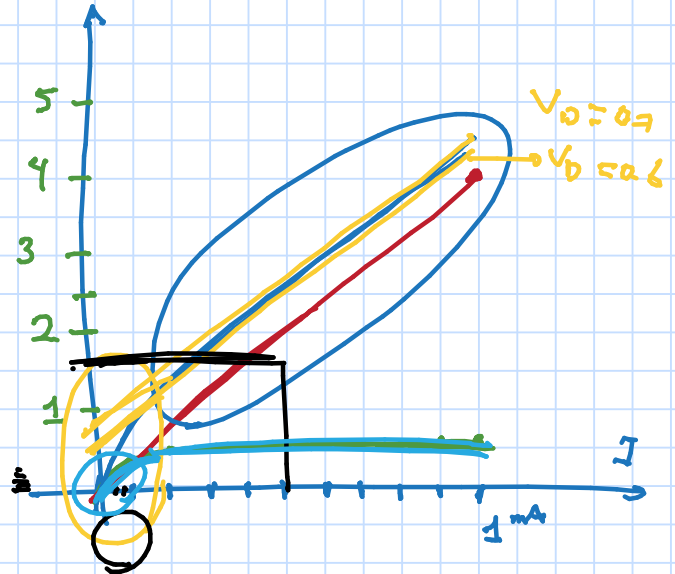
$$I_s = 5 \text{ fA} = 5 \times 10^{-15} \text{ A} = 5 \times 10^{-12} \text{ mA}$$

$$I = I_s (e^{V_D / V_{th}} - 1)$$

$$V = \underbrace{4k \times I}_{V_R} + \underbrace{V_{th} \ln \frac{I}{I_s}}_{V_D}$$

V_D	I_D mA
0.593	0.1
0.610	0.2
0.62	0.3
0.627	0.4
0.633	0.5
0.638	0.6
0.641	0.7
0.645	0.8
0.648	0.9
0.650	1

$$V_D \approx 0.6 \text{ to } 0.7$$



1-10

$$I_{S1} = 10^{-12} \text{ A}$$

$$I_{S2} = 10^{-15} \text{ A}$$

$$I_C = I_S e^{\frac{V_{BE}}{V_{Th}}}$$

$$V_{BE1} = V_{Th} \ln\left(\frac{1 \text{ mA}}{I_{S1}}\right) = 0.518$$

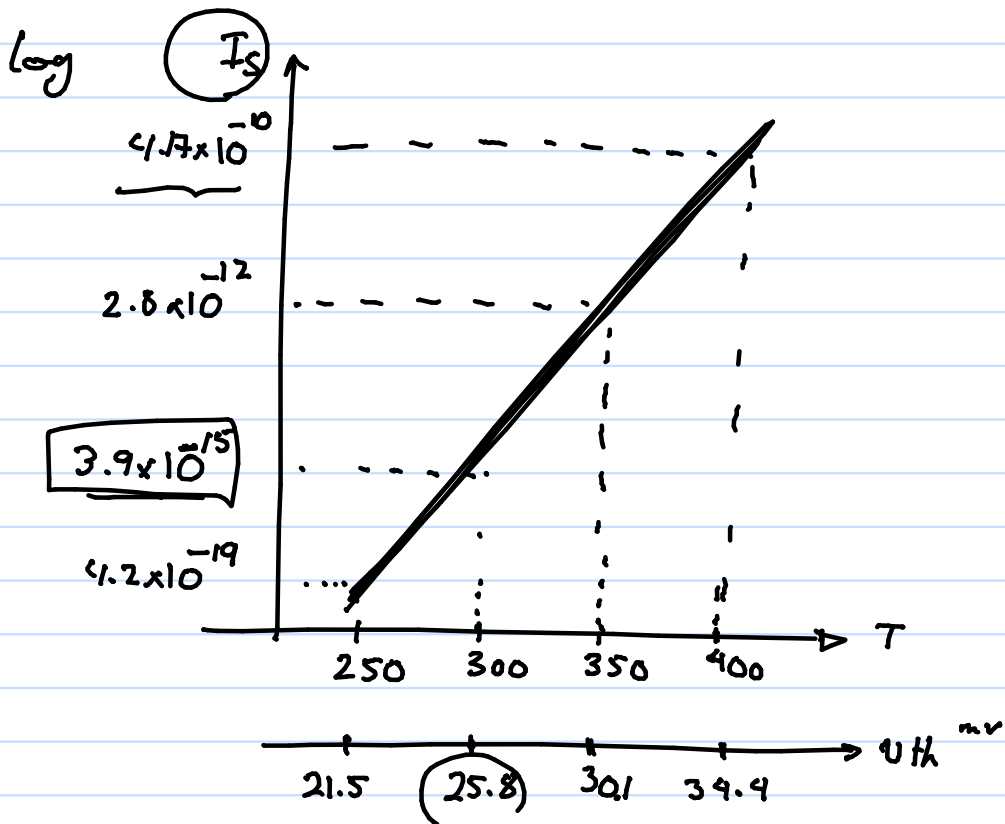
$$V_{BE2} = V_{Th} \ln\left(\frac{1 \text{ mA}}{I_{S2}}\right) = 0.691$$

V_{BE}	I_C mA
0.6	0.26
0.7	14.4

1-12

$$I_S = b T^{2.5} e^{-1.12 / (V_T)} \quad (V_T)$$

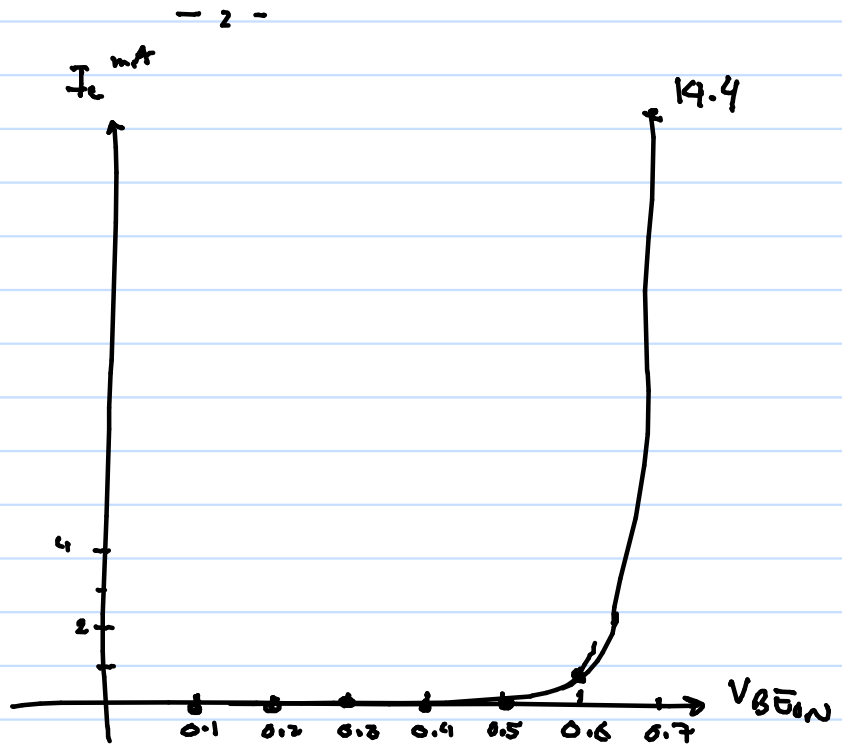
$$I_S = 10^{-15} \text{ A} \quad \left| \begin{array}{l} V_T = 25 \\ T = 300 \text{ K} \end{array} \right. \quad b = 0.018$$



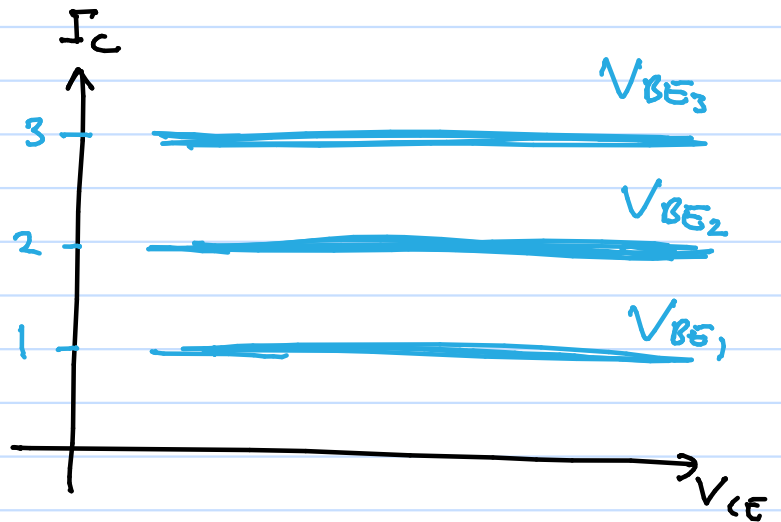
1-13

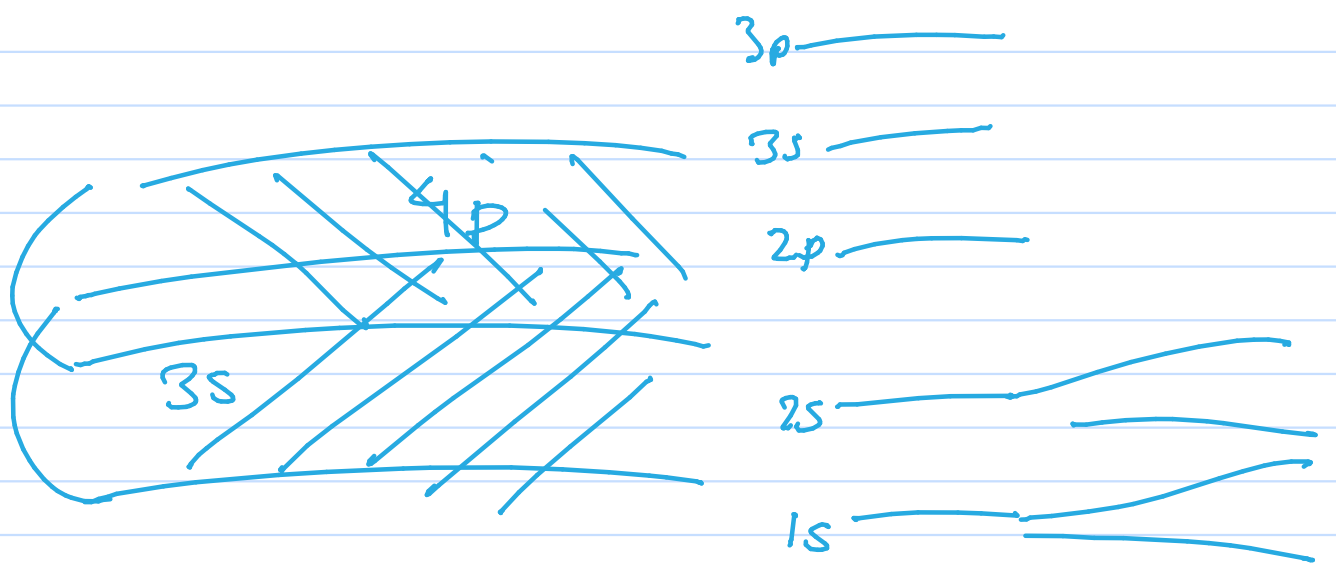
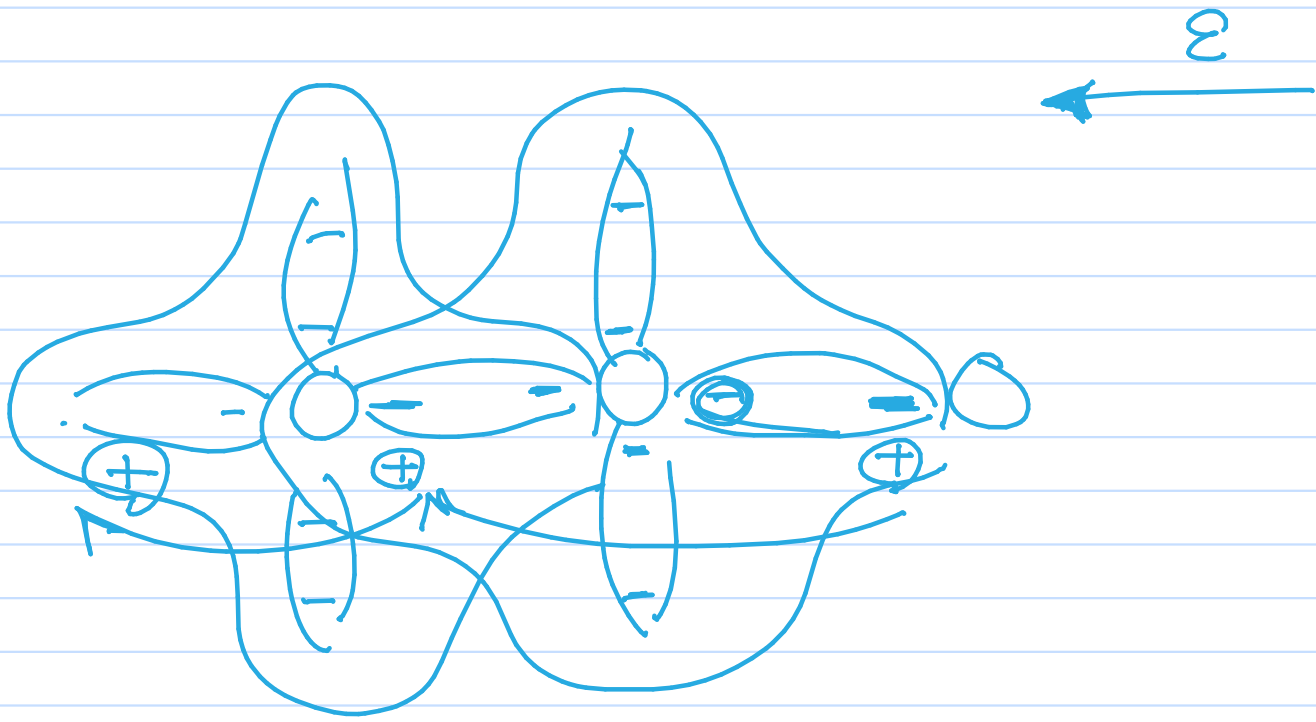
$$I_s = 10 \text{ fA} = 10 \times 10^{-12} \text{ mA} = 10^{-11} \text{ mA}$$

V_{BE}	I_C (mA)
0.1	5.4×10^{-10}
0.2	3×10^{-8}
0.3	1.6×10^{-6}
0.4	8.9×10^{-5}
0.5	0.005
0.6	0.26
0.7	14.4



I_C (mA)	$V_{BE(on)}$ (V)
1	0.6332 V_{BE1}
2	0.6505 V_{BE2}
3	0.6607 V_{BE3}





B

A

