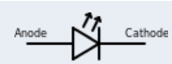
Exam #2, Chapters 3 and 4 Solutions

I. Vocabulary/Symbols

A. Anode	H. Dopant	O. Rectification	V. 
B. Bipolar	I. Drift	P. Scale or Saturation	W. 
C. Boron	J. Intrinsic	Q. Thermal Voltage	X. 
D. Carbon	K. Mobility	R. Transfer Characteristic	Y. 
E. Cathode	L. Phosphorus	S. Transfer Function	Z. 
F. Depletion Region	M. Platinum	T. Tunnel Diode	
G. Diffusion	N. Quiescent	U. 	

Definitions:

__J__ Term for an undoped semiconductor.

__G__ Type of current flow in a semiconductor due to variations in carrier concentration.

__I__ Type of current flow in a semiconductor due to electric field.

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Definitions:

__C__ Most common type of p-type dopant in silicon.

__L__ Most common type of n-type dopant in silicon.

__F__ Name of the region that is generated at the interface of a pn junction.

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Definitions:

__O__ Process of converting an AC signal into a DC signal.

__N__ Steady state, or DC, operating point.

__R__ The output voltage as a function of input voltage.

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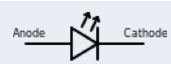
G. Diffusion	N. Quiescent	U. 	

Definitions:

__W__ Symbol for a Zener diode.

__U__ Symbol for a light emitting diode.

__V__ Symbol for a photodiode.

II. Determining the change in forward bias voltage

A diode is forward biased such that the forward current is much greater than the saturation current. Find the change in voltage, ΔV, across the diode when the current changes by a factor of 20. Use 25 mV for V_T.

$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

For case where $i \gg I_S$ the curve can be approximated by $I_D \simeq I_S e^{V_D/V_T}$

$$V_D = V_T \ln \frac{I_D}{I_S}$$

At diode voltage V_1 $\quad I_1 = I_S e^{V_1/V_T}$

At diode voltage V_2 $\quad I_2 = I_S e^{V_2/V_T}$

$$\frac{I_2}{I_1} = e^{(V_2 - V_1)/V_T}$$

$$\Delta V = V_2 - V_1 = V_T \ln \frac{I_2}{I_1} = 25\text{mV} \times \ln(20) = 74.89\text{mV}$$

$$\text{or } \Delta V = V_2 - V_1 = 2.3 V_T \log \frac{I_2}{I_1} = 57.5\text{mV} \times \log(20) = 74.81\text{mV}$$

III. Short Answer

1. Number of free carriers per cm^3 (n_i) at room temperature.
2. Number of free carriers per cm^3 (n_i) at 0 K.
3. Room Temperature in Kelvin.
4. Thermal voltage at room temperature.

1. 1.5×10^{10}
2. 0
3. 300 K
4. ~ 25 mV/25.9 mV

IV. Doped Silicon (a)

Consider doped silicon with N_D = $10^{18}/cm^3$. Find the electron and hole concentrations at T = 300 K. Calculate the resistivity and conductivity of this material. Use μ_n= 1110 cm^2/V•s and μ_p= 400 cm^2/V•s for the doped silicon.

$$n_n \simeq N_D = 10^{18}\,\mathrm{cm}^{-3}$$

Majority carrier is electrons

$$p_n \simeq \frac{n_i^2}{N_D} = \frac{\left(1.5\times10^{10}\,\mathrm{cm}^{-3}\right)^2}{10^{18}\,\mathrm{cm}^{-3}} = 225\mathrm{cm}^{-3}$$

Minority carrier is holes

$$\rho = \frac{1}{\sigma} = \frac{1}{q\left(p\mu_p + n\mu_n\right)}$$

$$= \frac{1}{1.6\times10^{-19}\,\mathrm{C}\left(\frac{225}{\mathrm{cm}^3}\left(400\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}\right)+\frac{10^{18}}{\mathrm{cm}^3}\left(1100\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}\right)\right)}$$

$$= \frac{1}{177.6\frac{\mathrm{C}}{\mathrm{V\cdot s\cdot cm}}} = 0.00563\ \Omega\cdot\mathrm{cm}$$

$$\sigma = \frac{1}{\rho} = 177.6\frac{\mathrm{S}}{\mathrm{cm}}$$

III. Doped Silicon (b)

If the temperature increases to 394.36 K, the intrinsic carrier concentration increases to 4.0 x 10^{11} cm^{-3}. What are the new carrier concentrations and the new resistivity at the higher temperature assuming the mobilities stay the same?

$$n_i = BT^{3/2}e^{-E_g/2kT} = 4.0\times10^{11}\,\mathrm{cm}^{-3} \text{ at } 349.36\text{ K}$$

$$n_n \simeq N_D = 10^{18}\,\mathrm{cm}^{-3} \qquad p_n \simeq \frac{n_i^2}{N_D} = \frac{\left(4.0\times10^{11}\,\mathrm{cm}^{-3}\right)^2}{10^{18}\,\mathrm{cm}^{-3}} = 1.6\times10^{5}\,\mathrm{cm}^{-3}$$

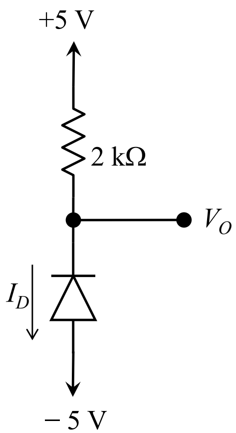
$$\rho = \frac{1}{\sigma} = \frac{1}{q\left(p\mu_p + n\mu_n\right)}$$

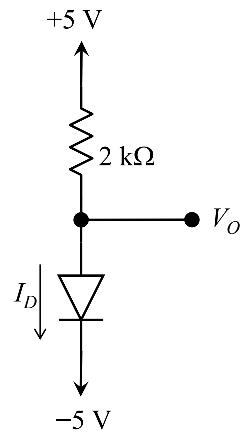
$$= \frac{1}{1.6\times10^{-19}\,\mathrm{C}\left(\frac{1.6\times10^{5}}{\mathrm{cm}^3}\left(400\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}\right) + \frac{10^{18}}{\mathrm{cm}^3}\left(1100\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}\right)\right)}$$

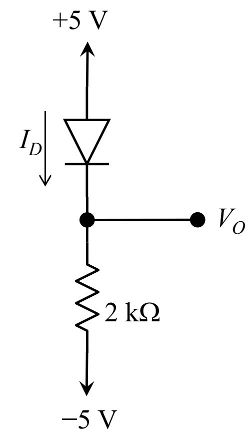
$$= \frac{1}{177.6\,\frac{\mathrm{C}}{\mathrm{V\cdot s\cdot cm}}} = 0.00563\ \Omega\cdot\mathrm{cm}$$

V. Ideal and Constant Voltage Diodes

For the circuits shown below, find the values of the voltages and currents indicated using the ideal diode model and the constant voltage (0.7 V) model. **Make sure you include units**.



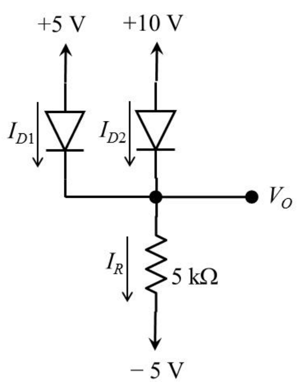




	Ideal diode	constant voltage model	Ideal diode	constant voltage model	Ideal diode	constant voltage model
V_O:	+5 V	+5 V	-5 V	-4.3 V	5 V	4.3 V
I_D:	0 mA	0 mA	5 mA	4.65 mA	5 mA	4.65 mA

VI. Ideal Diodes

For the circuits shown below, find the values of the voltages and currents indicated using the ideal diode model. **Make sure you include units**.

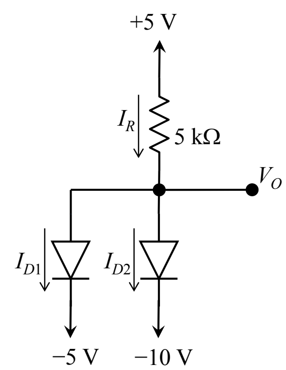


V_O: 10 V

I_{D1}: 0 mA

I_{D2}: 3 mA

I_R: 3 mA

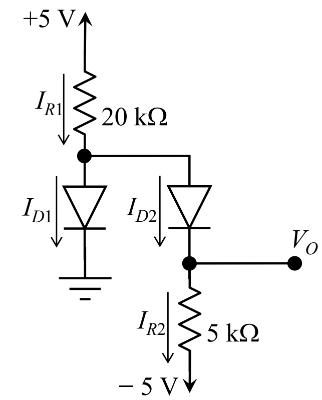


V_O: -10 V

I_{D1}: 0 mA

I_{D2}: 3 mA

I_R: 3 mA



V_O: -3.0 V

I_{D1}: 0 mA

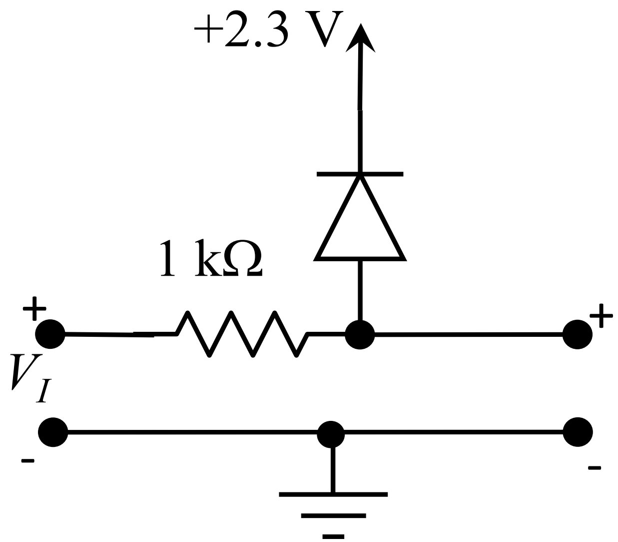
I_{D2}: 0.4 mA

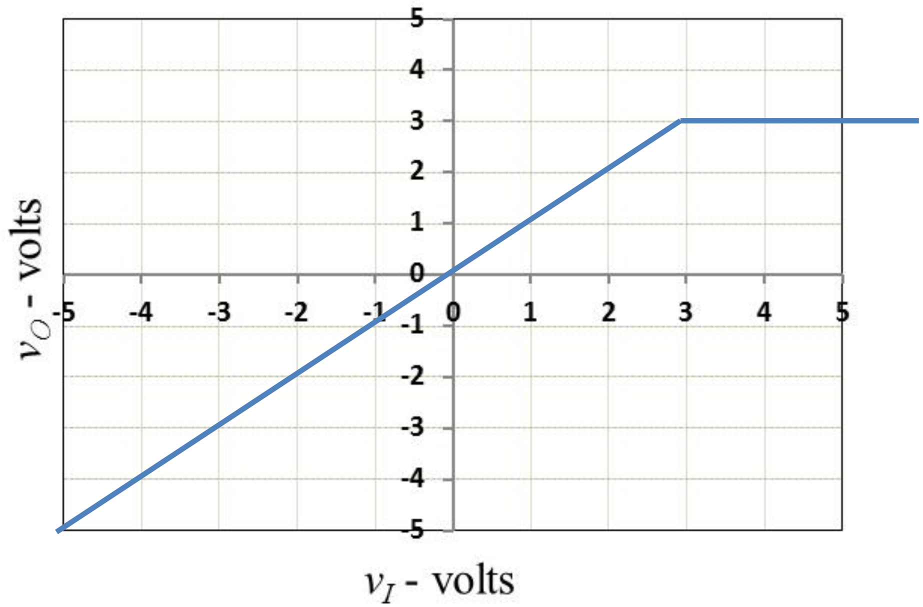
I_{R1}: 0.4 mA

I_{R2}: 0.4 mA

VII. Limiting and Clamping Circuits

Sketch the transfer characteristic v_O versus v_I, for the limiter circuit shown below. All diodes begin conducting at a forward voltage drop of 0.5 V and have voltage drops of 0.7 V when conducting a current $i_D \geq$ 1 mA.





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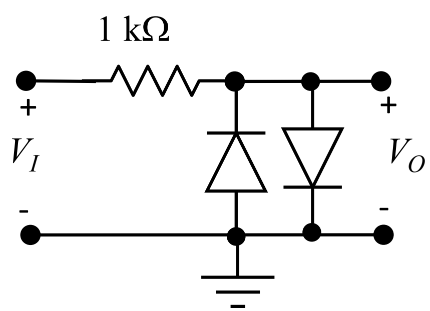
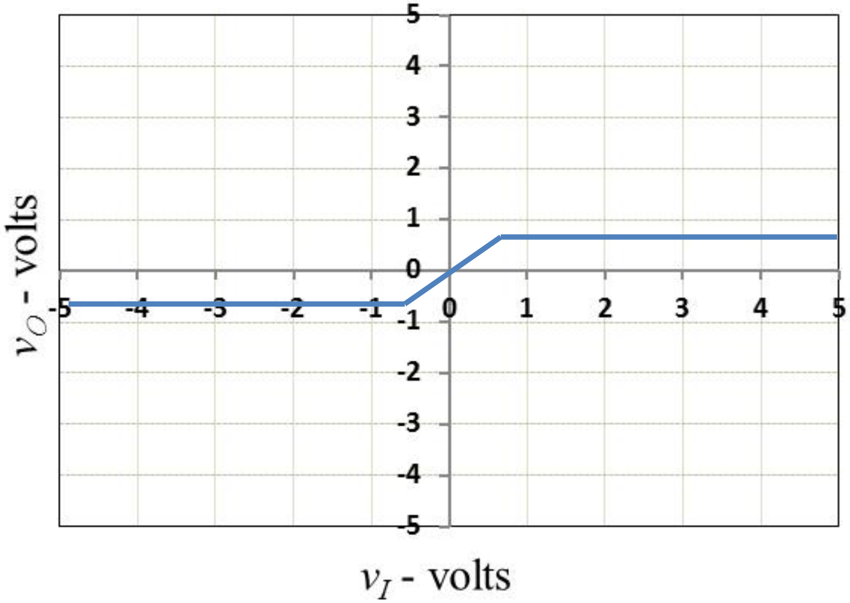
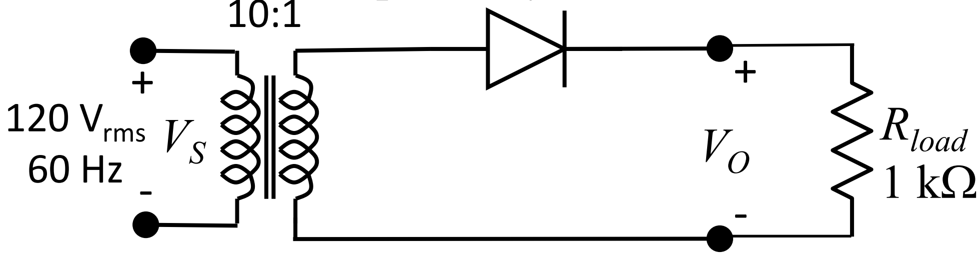




VIII. Rectification

A half-wave rectifier circuit with a 10-kΩ load operates from a 120-V (rms) 60-Hz household supply through a 10-to-1 step-down transformer. It uses a silicon diode that can be modeled to have a 0.7-V drop for any current. Answer the following:



$$V_{rms} = \frac{120V_{rms}}{10} = 12V_{rms}$$

$$V_{opeak} = \sqrt{2}(12V_{rms}) - V_D$$

$$V_{opeak} = 16.97 - 0.7 = 16.27V$$

$$V_s = 16.97\text{V} \times \sin\theta$$

$V_s \geq 0.7V$ when

$$\theta = \sin^{-1}\left(\frac{0.7}{16.97}\right) = 2.364° \text{ or } 0.0412 \text{ rad}$$

$$\frac{\pi - 2\theta}{2\pi} = 48.68\%$$

$$I_{Lpeak} = \frac{V_{opeak}}{1k\Omega} = 16.27 \text{ mA}$$

Vrms out of transformer $12V_{rms}$

V_{Opeak}: $16.27V$

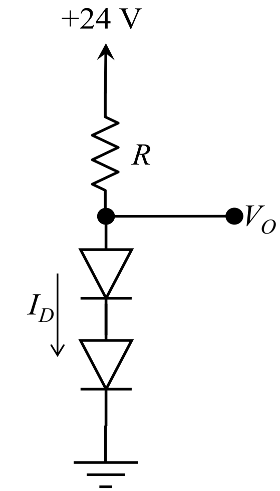
Fraction of a period diode is conducting 48.68% %

I_{Lpeak}: 16.27 mA

Max reverse bias voltage 16.97 V

IX. Solving for the Q operating point

Assuming the availability of diodes for which $V_D = 0.75$ V at $I_D = 1.069$ mA, design a circuit that utilizes two identical diodes connected in series with a resistor R connected to a 24 V power supply. The voltage out, V_O, is to be 1.7 V. Use the exponential model to find I_D and R. Use 25 mV for V_T.



$$V_D = \frac{1.7V}{2} = 0.85V$$

$$I_D = I_S e^{V_D/V_T} \Rightarrow I_S = I_D e^{-V_D/V_T}$$

$$I_S = 1.069\text{mA}e^{-750\text{mV}/25\text{mV}} = 1\times10^{-16}\text{A} = 0.1\text{fA}$$

V_D: 850 mV

I_S: 0.1 fA

$$\frac{I_2}{I_1} = e^{(V_2-V_1)/V_T} \Rightarrow I_2 = I_1 e^{(V_2-V_1)/V_T} = 1.069\text{mA}e^{(850\text{mV}-750\text{mV})/25\text{mV}} = 58.365\text{mA}$$

$$I_D = I_S e^{V_D/V_T} = \left(1\times10^{-16}\text{A}\right)e^{850\text{mV}/25\text{mV}} = 58.365\text{mA}$$

I_D: 58.365 mA

R: 382 Ω

$$R = \frac{V_{DD} - V_O}{I_D} = \frac{24\text{V} - 1.7\text{V}}{58.365\text{mA}} = 382\Omega$$

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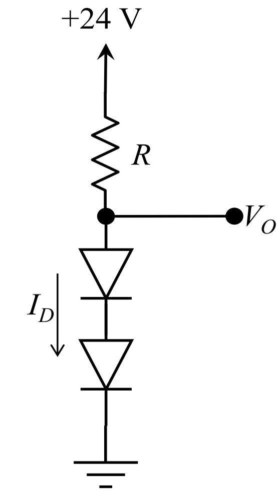


$$i_D = I_S e^{V_D/V_T} = \left(1\times10^{-16}\,\mathrm{A}\right)e^{800\mathrm{mV}/25\mathrm{mV}} = 7.9\mathrm{mA}$$

$R_{d\text{ (per diode)}}$: 0.428 Ω

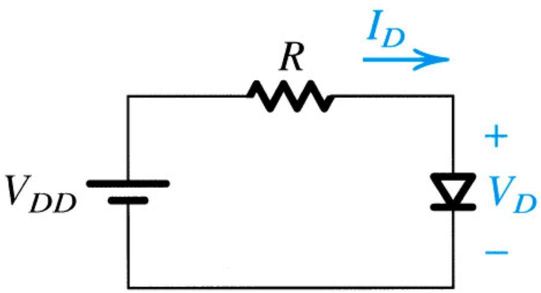
$$r_d = \frac{V_T}{I_D} = \frac{25\mathrm{mV}}{53.86\mathrm{mA}} = 0.428\ \Omega$$

$V_{op\text{-}p}$: 2.237mV

$$v_{op-p} = v_{p-p}\frac{r_{dtotal}}{r_{dtotal}+R} = 1V_{pp}\frac{2\times0.428\Omega}{2\times0.428\Omega+382\Omega}$$

$$= 1V_{pp}\frac{0.856\Omega}{382.856\Omega} = 2.237\mathrm{mV}$$

X. Solve using the iterative technique



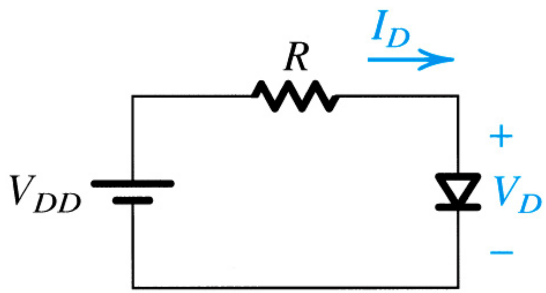
Assume that the diode in the circuit to the right has a current of 10 mA at a voltage of 0.75 V. Find the following with V_{DD} = 15 V and R = 1 kΩ using the iterative technique. Use 25 mV for V_T. Stop when there is no change > 1 mV for V_D.

$$I_S = I_D e^{-V_D/V_T}$$

$$I_S = (10\times10^{-3}\text{A})e^{-750mV/25mV}$$

$$= 9.36\times10^{-16}\text{A}$$

X. Solve using the iterative technique



Assume that the diode in the circuit to the right has a current of 10 mA at a voltage of 0.75 V. Find the following with V_{DD} = 15 V and R = 1 kΩ using the iterative technique. Use 25 mV for V_T. Stop when there is no change > 1 mV for V_D.

$$I_D = \frac{V_{DD} - V_D}{R} = \frac{15\text{V} - 0.75\text{V}}{1\text{k}\Omega} = 14.25\text{mA}$$

But 14.25 mA is more than the 10 mA specification current

$$V_2 - V_1 = V_T \ln \frac{I_2}{I_1}$$

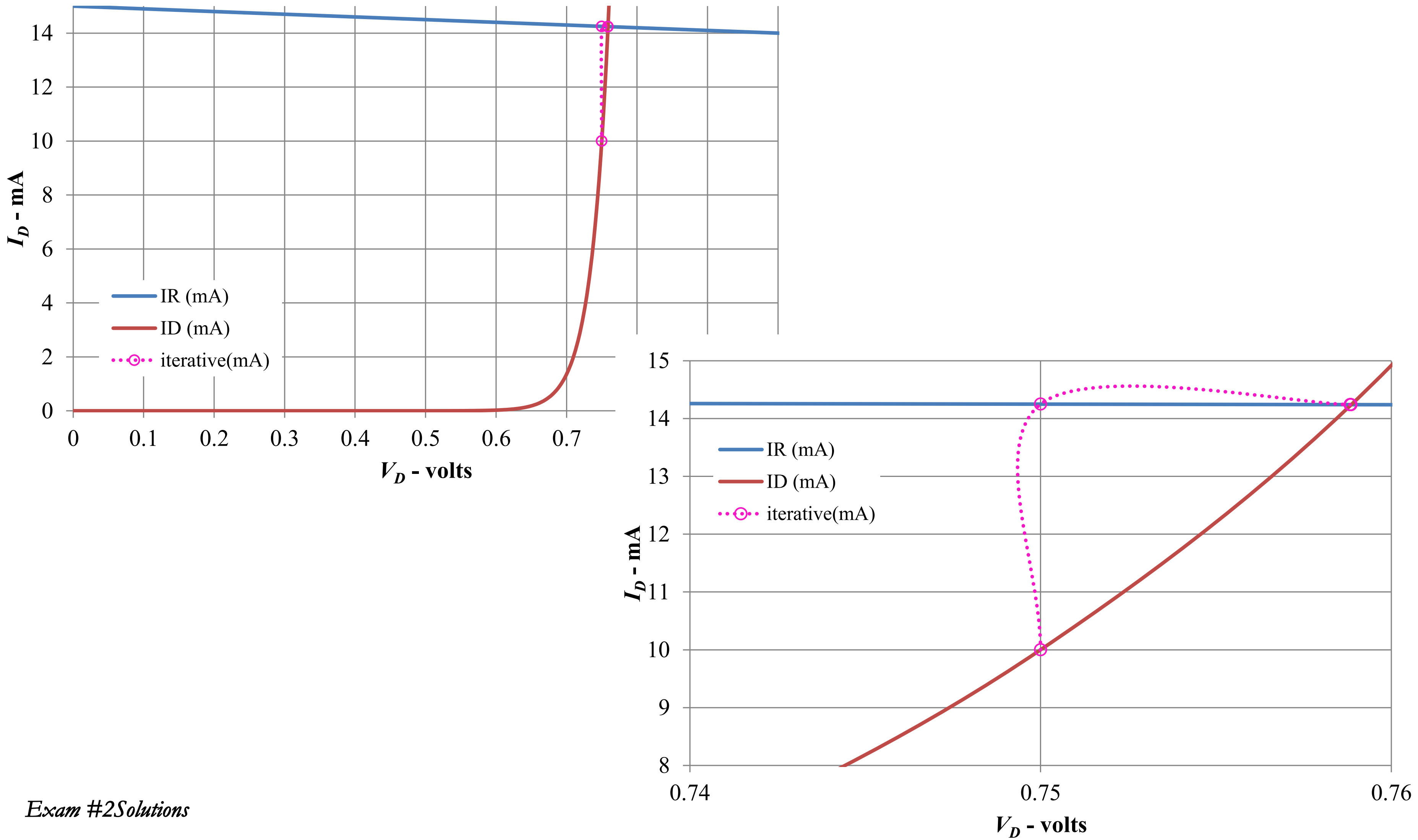
$$V_2 = V_1 + V_T \ln \frac{I_2}{I_1}$$

$$V_2 = 750\text{ mV} + (25\text{ mV}) \ln\left(\frac{14.25\text{mA}}{10\text{mA}}\right) = 758.9\text{ mV}$$

$$I_D = \frac{15\text{V} - 0.7589\text{V}}{1\text{k}\Omega} = 14.241\text{mA}$$

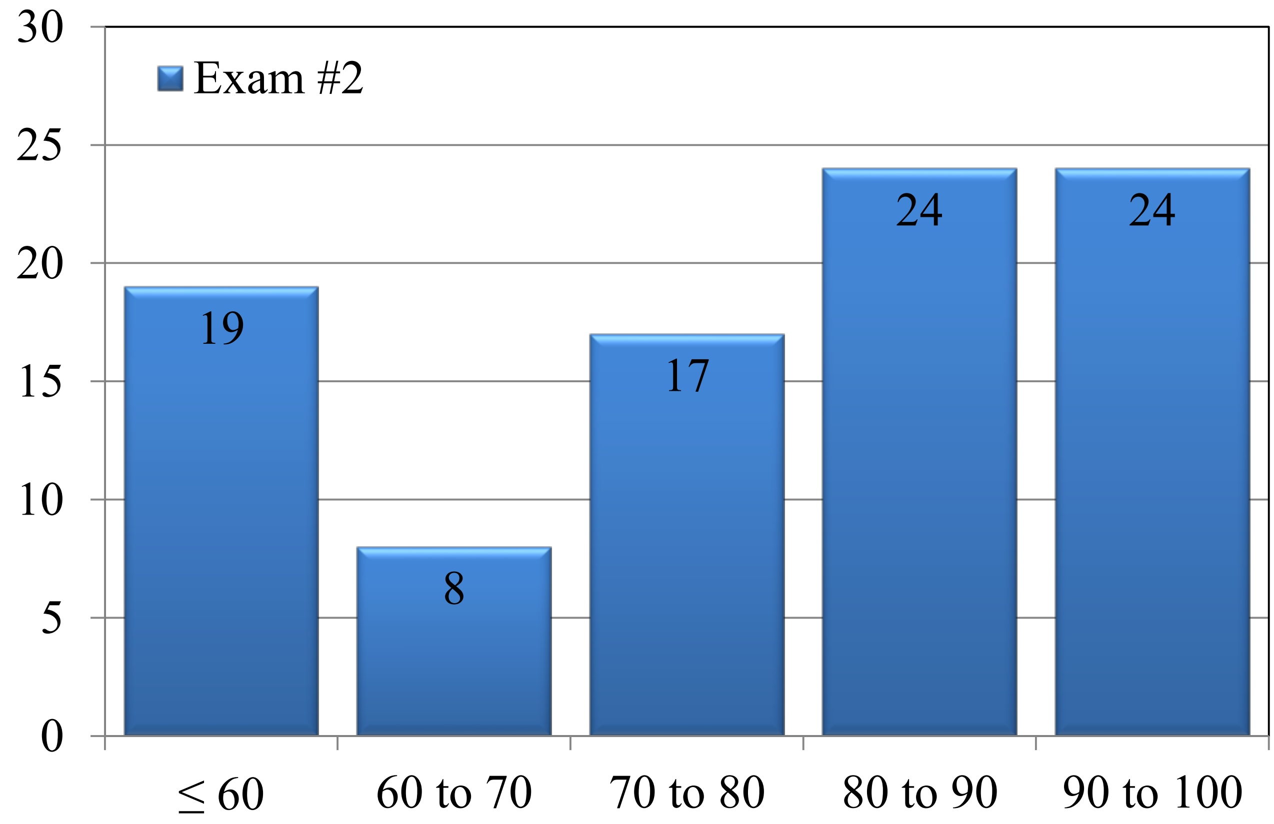
$$V_3 = 758.9\text{ mV} + (25\text{ mV}) \ln\left(\frac{14.241\text{mA}}{14.25\text{mA}}\right) = 758.9\text{ mV}$$

Iterative Solving



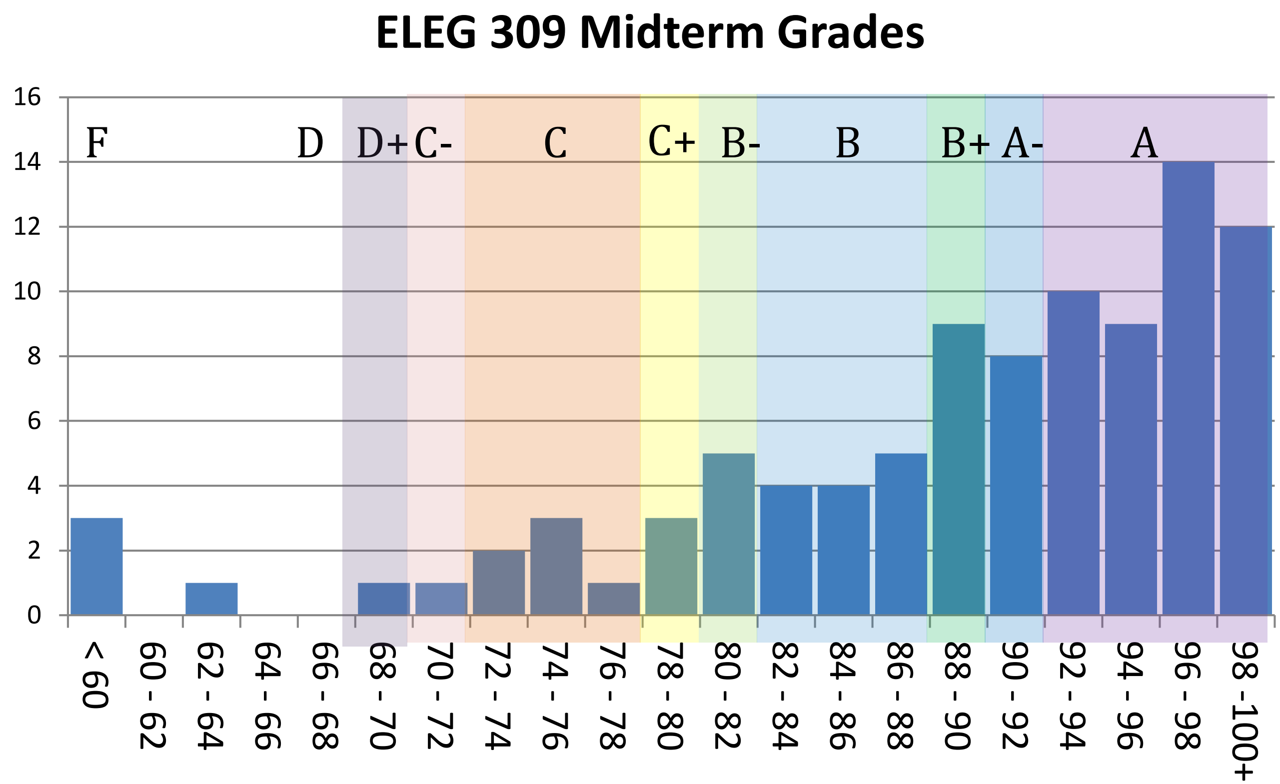
Results

# Tests	92
Average	77.1 %
High	100% (3)
Low	26.5%



Midterm Grade Distribution

Midterm Grades	*Frequency*	*Grade*
< 60	3	F
60 - 62	0	D-
62 - 64	1	D
64 - 66	0	D
66 - 68	0	D
68 - 70	1	D+
70 - 72	1	C-
72 - 74	2	C
74 - 76	3	C
76 - 78	1	C
78 - 80	3	C+
80 - 82	5	B-
82 - 84	4	B
84 - 86	4	B
86 - 88	5	B
88 - 90	9	B+
90 - 92	8	A-
92 - 94	10	A
94 - 96	9	A
96 - 98	14	A
98 -100+	12	A



Average	87.86 %
High	102.2%
Low	28.24%