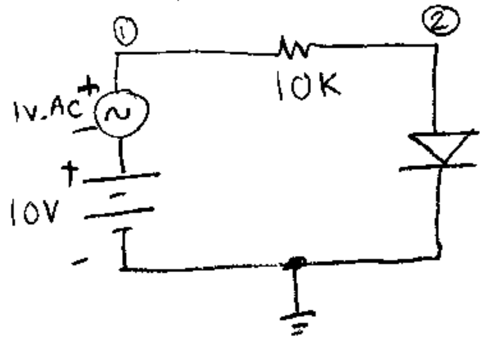
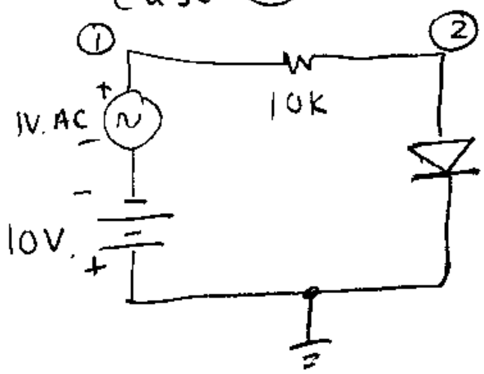
Diodes in AC (small signal) analysis (1.4)

(Intro to small signal models)

Idea: for "small" signals,
we can make a linear equivalent circuit:

Consider this:

Case ① 

Case ② 

What are AC and DC voltages at node ②?
(Diode, $V_\gamma = .7$ $r_d = 100\Omega$)

Terminology: The DC voltage is called "quiescent".
The AC voltage is called "signal".

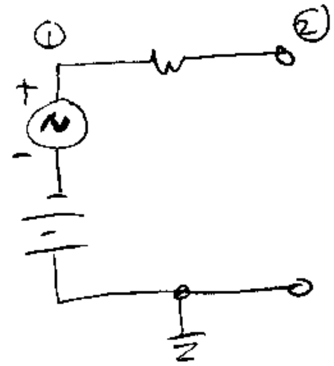
The "voltage swing" at the input here is 2 volts. (or ± 1 volt)

Exercises - (not to hand in)

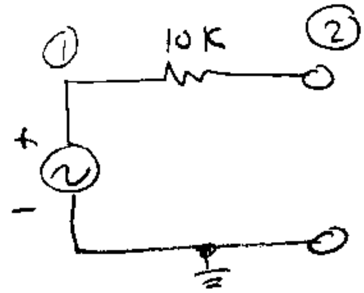
Page	Ex.	
35	17, 18	
39	19, 20	Not discussed in class. You should get it from reading.
40	21, 22	
46	35	
47	41, 43	

Look at case 2 first, it's easier.

Diode is off, so circuit is:



For the "small signal" model, consider only the AC components:



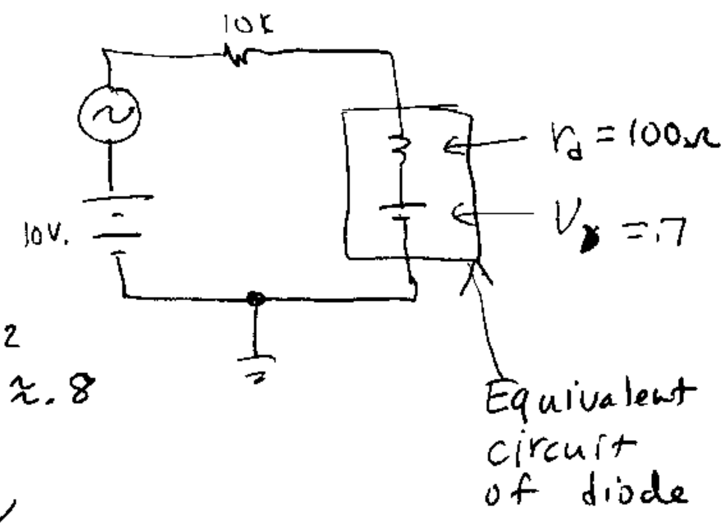
So, the AC voltage at ② is the same as ①.

Now, Case ①

Diode is ON

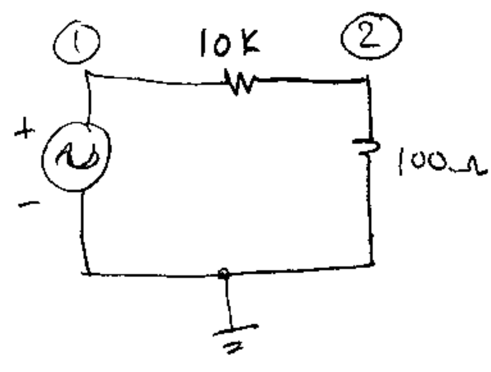
DC $I_{DQ} = \frac{10 - .7}{10100} = .92$ ma

$V_{DQ} = .7 + (.92)(.1) = .7 + .092$
$= .792 \approx .8$



For "small signal" model, consider only AC components:

So, $\frac{V_2}{V_1} = \frac{100}{10K + 100}$



Now, try it with a real diode

$I_S = 10^{-15}$, Case 1

For $R = 10K$

Hint: We know it is forward biased.

If $V_D = 0$, $I_D = 1$ ma

If $V_D = 1$, $I_D = .9$ ma

→ Assume $V_D = .5$, $I_D = .95$ ma

(or solve graphically
by iteration
with a simulator
with Maple
etc.)

(be prepared to correct it if you are wrong).

Now, find r_d

$r_d = \frac{dv}{di}$, so $\frac{1}{r_d} = \frac{di}{dv}$ = the derivative of the diode equation.

"Small signal" conductance

"Small signal" resistance

$$\frac{di}{dv} = \frac{d}{dV}\left(I_S\left(e^{\frac{V}{V_T}}-1\right)\right) = I_S\left(\frac{d}{dV}\left(e^{\frac{V}{V_T}}-1\right)\right)$$

$$= I_S\left(\frac{d}{dV}\left(e^{\frac{V}{V_T}}\right) + \underbrace{\frac{d}{dV}(-1)}_{=0}\right) = \frac{I_S}{V_T}e^{\frac{V}{V_T}}$$

$$\frac{d}{dx}e^x = e^x \quad \text{so--} \quad \frac{d}{dV}e^{\frac{V}{V_T}} = \frac{1}{V_T}e^{\frac{V}{V_T}}$$

so -- $\frac{1}{r_d} = \frac{I_S}{V_T} e^{\frac{V}{V_T}}$

but $I_{DQ} = I_S\left(e^{\frac{V}{V_T}} - 1\right) \approx I_S e^{\frac{V}{V_T}}$

-1 term is insignificant
for $\frac{V}{V_T}$ large.

Max error is $I_S \approx 10^{-15}$

so -- $\frac{1}{r_d} \approx \frac{I_{DQ}}{V_T}$

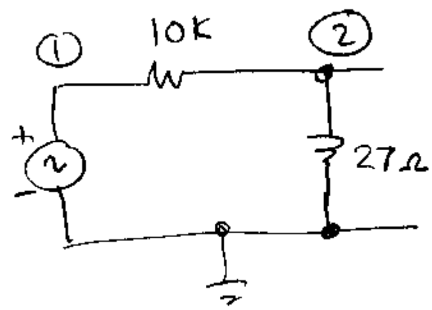
and $r_d \approx \frac{V_T}{I_{DQ}} \approx \frac{.026}{I_{DQ}}$

Back to our circuit ...

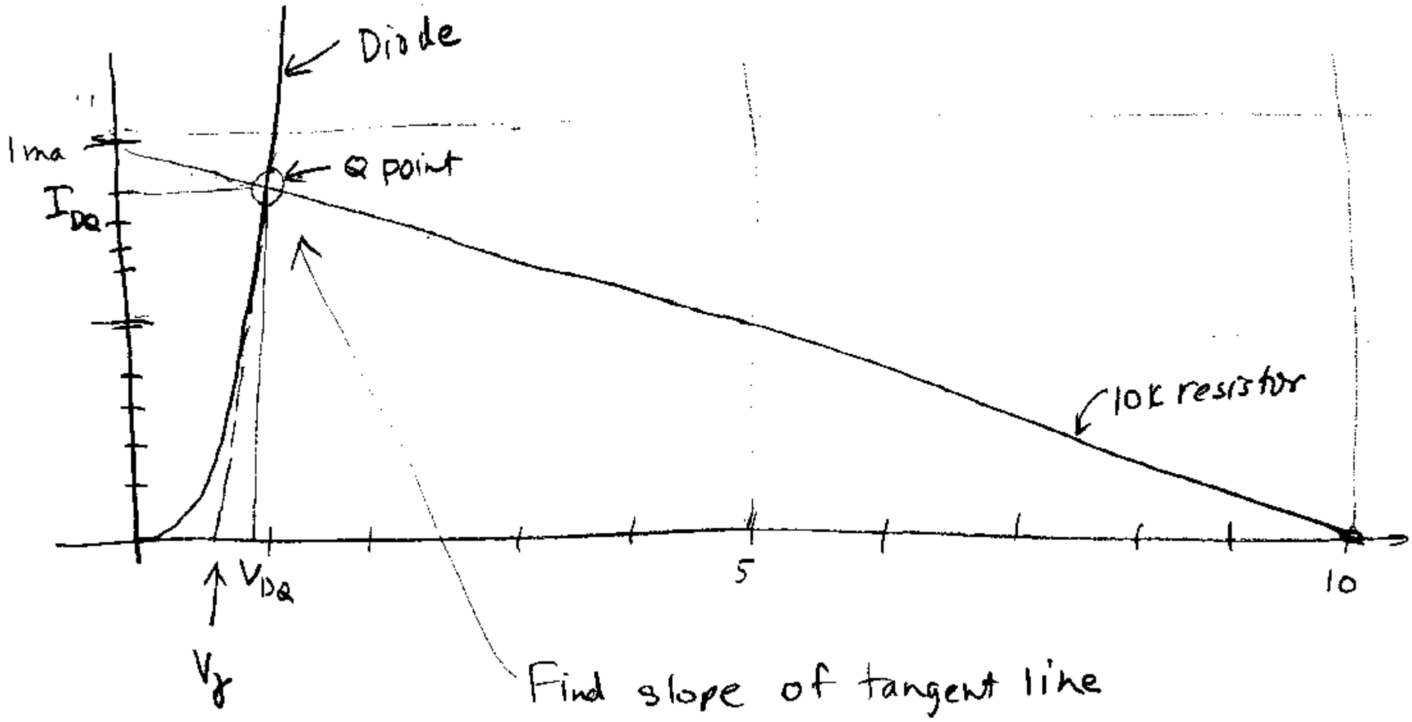
$I_{DQ} \approx .95\,ma$, $V_T \approx .026\,V = 26\,mV$.

$r_d \approx \frac{26\,mV}{.95\,ma} = 27\,\Omega$

Small signal model is :



Graphical analysis:



Find slope of tangent line

$$= g_d = \frac{1}{r_d}$$

V_γ = intercept of tangent line

If you know g_d (or have measured it ..)

$$g_d = \frac{I_{DQ} - 0}{V_{DQ} - V_\gamma}$$

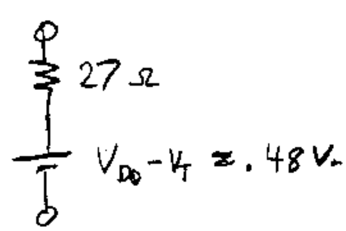
solve for V_γ

$$V_{DQ} - V_\gamma = \frac{I_{DQ}}{g_D}$$

$$V_\gamma = V_{DQ} - \frac{I_{DQ}}{g_D} = V_{DQ} - I_{DQ} r_d$$

Since $r_d = \frac{V_T}{I_{DQ}}$; $V_\gamma = V_{DQ} - V_T$

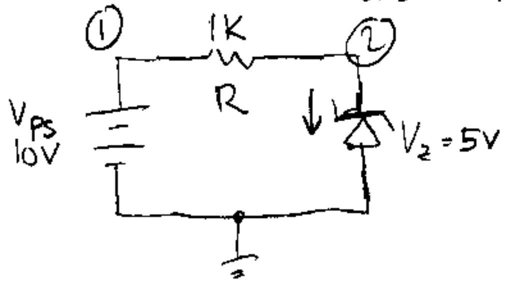
So, the equivalent circuit is:



<u>This varies with Q point.</u>

Zener diodes

We use them in the breakdown region.



$$I = \frac{V_{PS} - V_Z}{R} = \frac{5}{1K} = 5\,ma$$

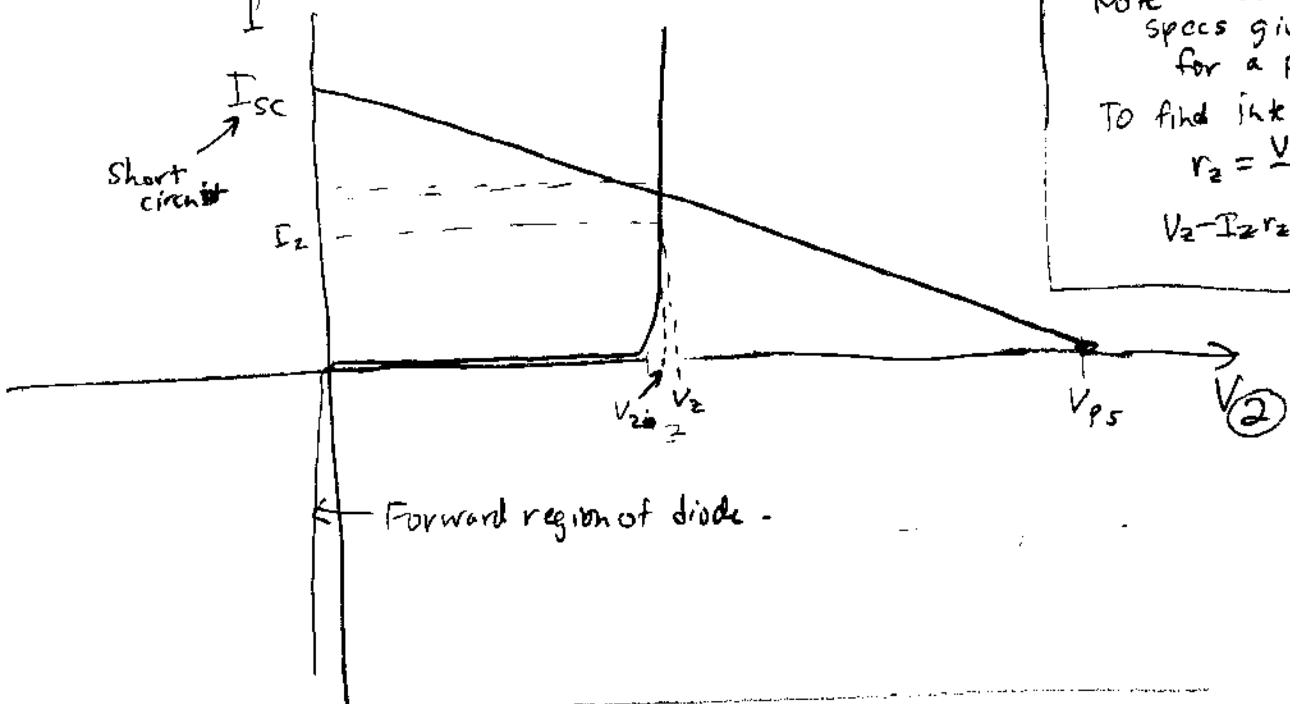
To choose R for a given I, solve for R.

$$R = \frac{V_{PS} - V_Z}{I}$$

Choose $I = 10\,ma$

$$R = \frac{10-5}{.01} = \frac{5}{.01} = 500\,\Omega$$

Load line analysis!



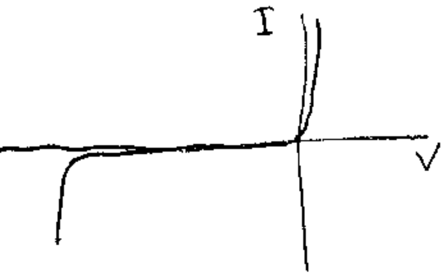
Note – Zener diode specs give V_Z for a particular I_Z.

To find intercept (V_{Z0})

$$r_z = \frac{V_Z - V_{Z0}}{I_Z}$$

$$V_Z - I_Z r_z = V_{Z0}$$

Diode curve is!



But $V_2 = -V_D$, so reverse it.

$I = -I_D$ on curve.