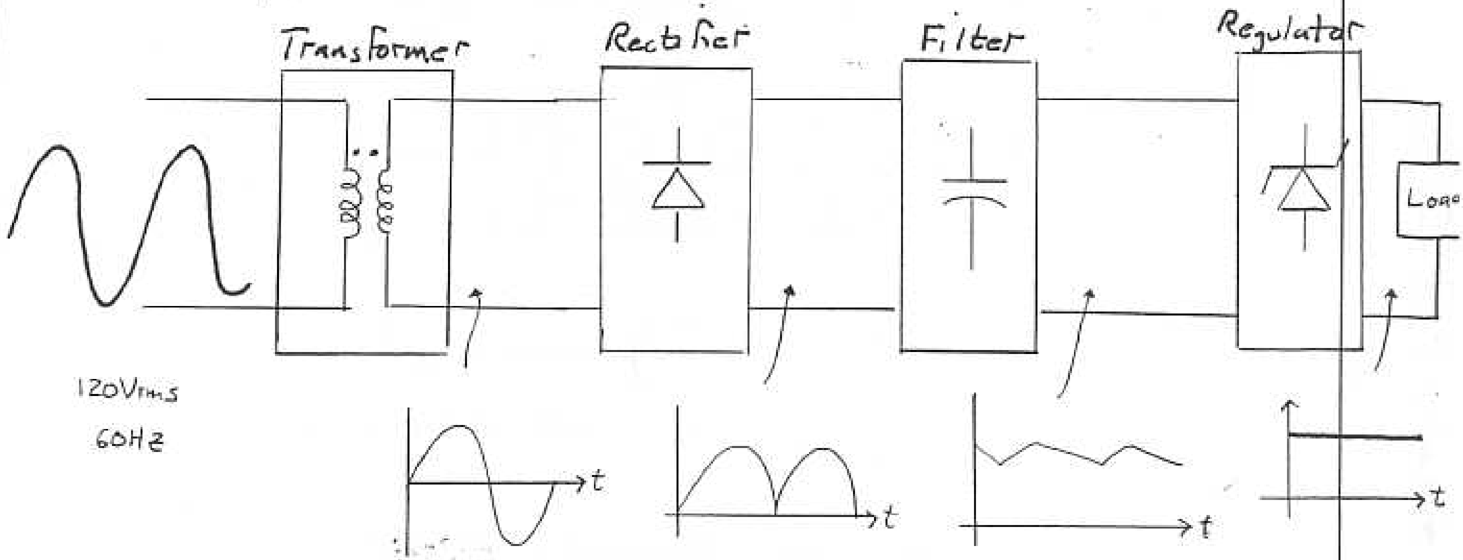
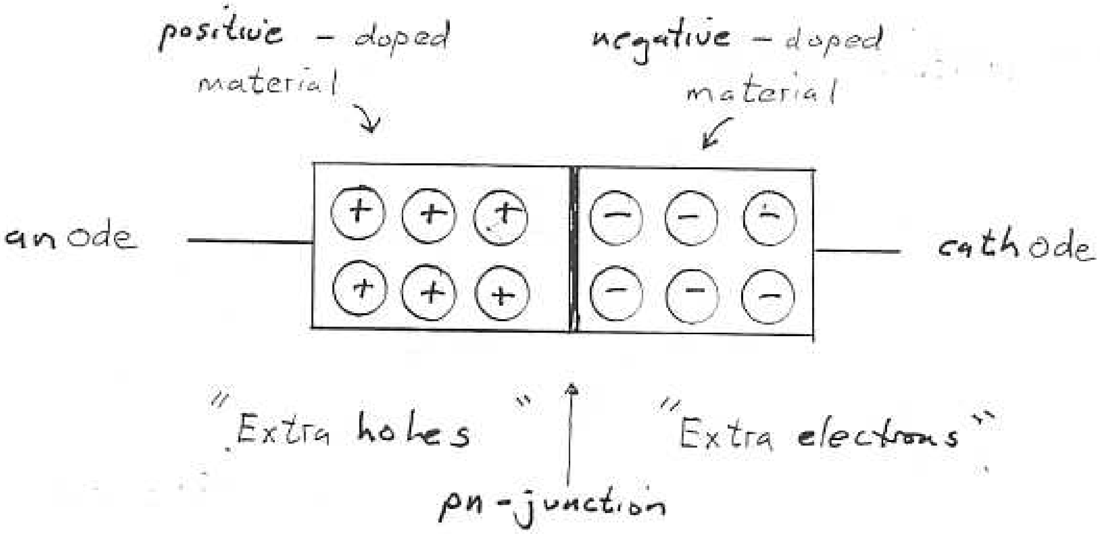
Power Supplies



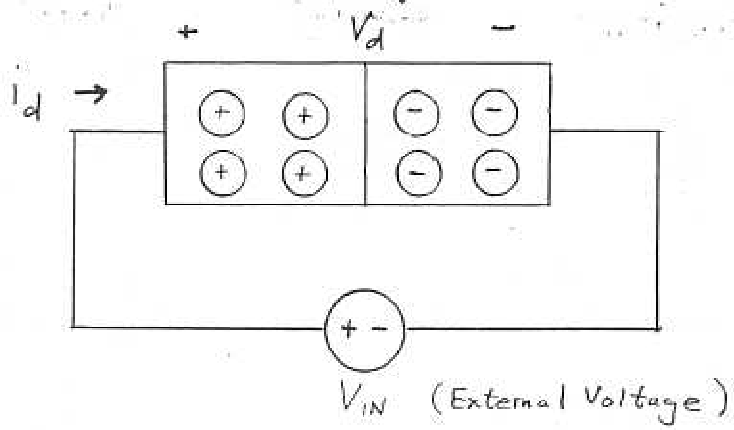
(*) Almost all **electronic** equipment that plugs into the wall **outlet** contains a power supply in which fixed **AC** is converted into well-**regulated** DC

Rectifiers

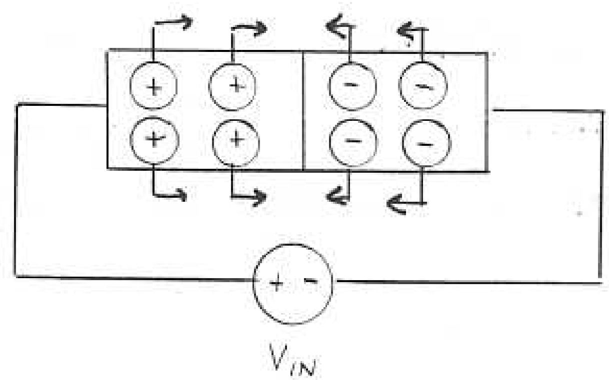
(*) To explain rectifiers we need to introduce a **semi**-conductor device called the **diode**, in which we have



(*) To get an appreciation for how the diode works, consider applying a DC voltage across it. Define the voltage across and current through the diode

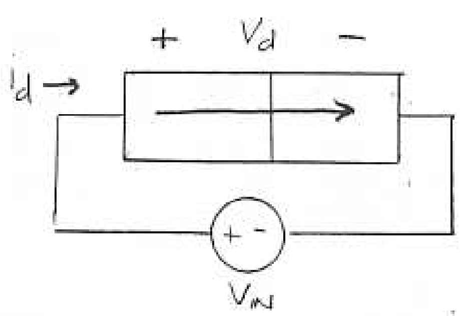


→ LIKE CHARGES REPEL



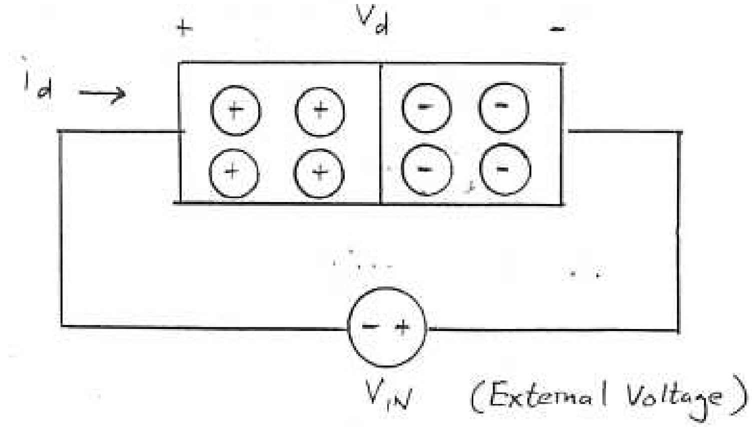
some recombine

and so since we keep track of hole flow (or positive charge), the net current flow is

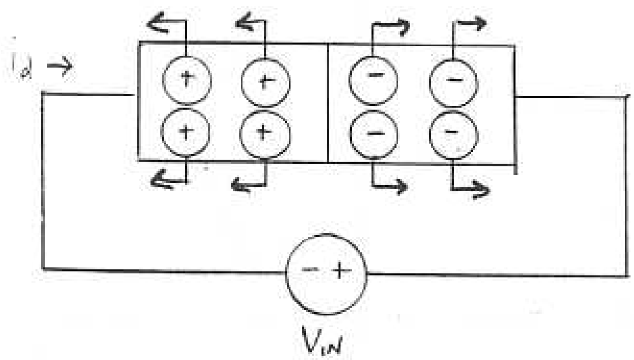


so $i_d > 0$, $V_d > 0$ and we are said to be **Forward** biased.

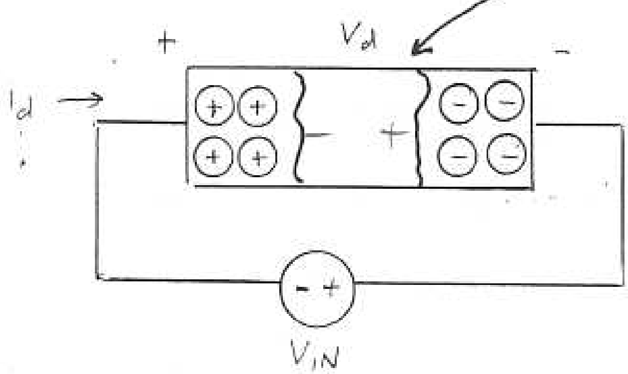
(*) IF we reverse the polarity of V_{IN}



→ UNLIKE CHARGES ATTRACT

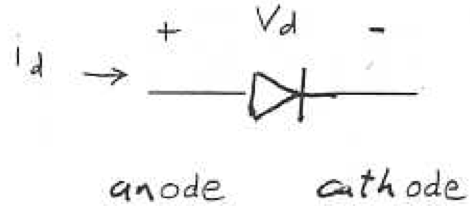


and we create what is called a depletion region and NO current Flows

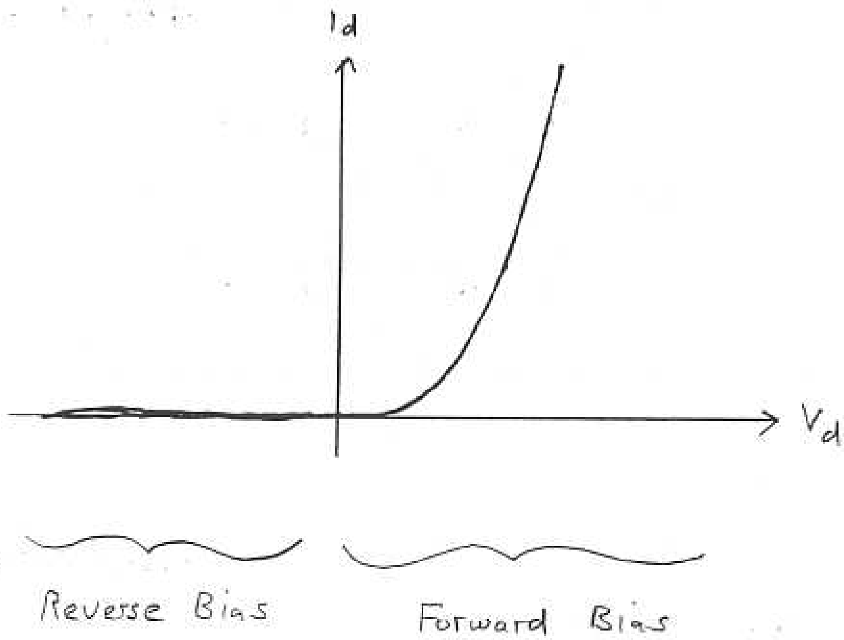


here with $i_d \approx 0$, $V_d < 0$ we are said to be **Reverse** biased

(*) We soon tire of drawing the p-type and n-type materials and replace our diode by a circuit symbol



the current-voltage characteristic is given by



The net current flow under Forward Bias is governed by the "Shockley Diode Equation"

$$i_d = I_o \left(e^{\frac{V_d}{nV_T}} - 1 \right)$$

I_o: 1×10^{-14} A

$nV_T \approx 26$ mV

temp. dependent

For instance

$$V_d = 0.7V \longrightarrow i_d = 4.93mA$$

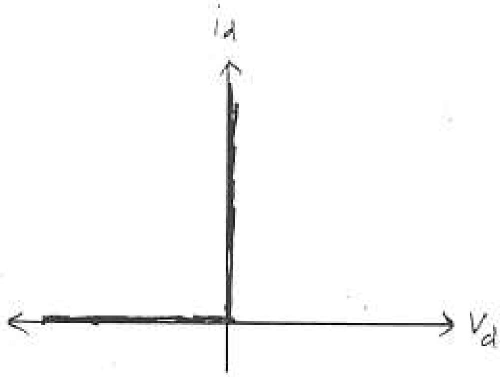
$$V_d = 0.75V \longrightarrow i_d = 33.7mA$$

$$V_d = 0.9V \longrightarrow i_d = 10.8A!!$$

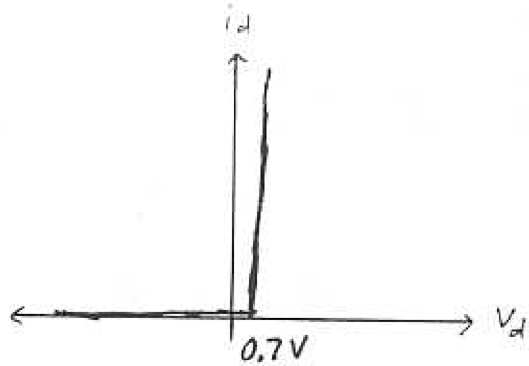
(*) Too big of voltage across → lot'sa current

→ device destroyed

(*) The Shockley Diode Equation is nice but sometimes we want to use a simpler i_d - V_d characteristic



"IDEAL MODEL"



"ALMOST IDEAL MODEL"

Q. How can we tell in a circuit whether a diode is conducting (ON) or blocking (OFF)?

ANALYSIS STRATEGY

→ Assume a state

→ Perform circuit analysis

→ Test assumption

(1) Assume ON so $V_d = 0V$ (REPLACE WITH SHORT)

Find i_d

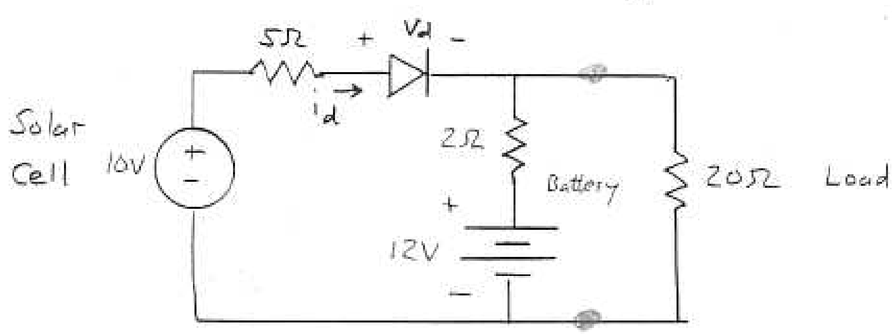
IF $i_d > 0$ TRUE $i_d < 0$ FALSE

(2) Assume OFF so $i_d = 0A$ (REPLACE WITH OPEN)

Find V_d (ACROSS OPEN CIRCUIT)

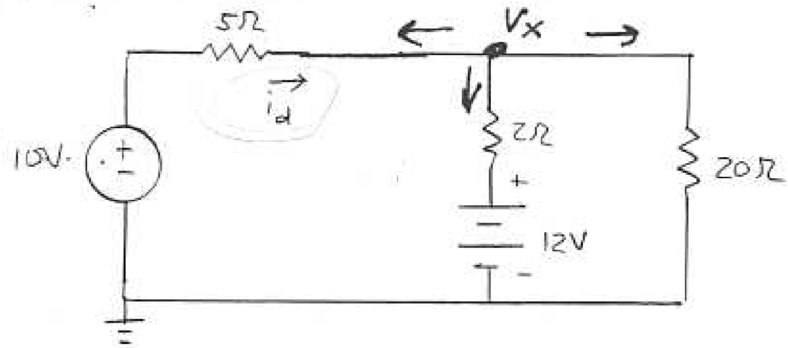
IF $V_d < 0$ TRUE $V_d > 0$ FALSE

ex. Suppose we have the following circuit. Find the diode status.



diode prevents backcharging of solar cell

(1) Assume the diode is ON : $V_d = 0V$



analyze using nodal

$$\frac{V_x - 10}{5\Omega} + \frac{V_x - 12}{2\Omega} + \frac{V_x - 0}{20\Omega} = 0$$

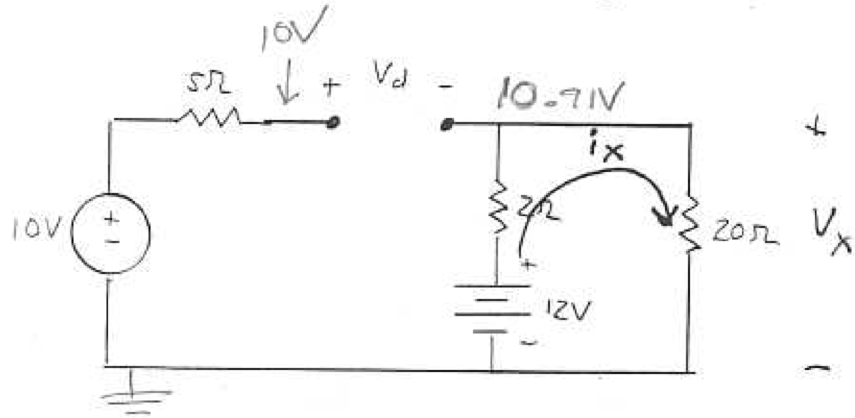
which gives $V_x = 10.667V$

so

$$i_d = \frac{10 - V_x}{5\Omega} = -0.133A$$

Since $i_d < 0$ our assumption is FALSE

(2) Assume the diode is OFF : $i_d = 0$



$$i_x = \frac{12V}{2\Omega + 20\Omega} = 0.545A$$

$$V_x = i_x \, 20\,\Omega = 10.91V$$

Since $i_d = 0$ then $V_{5\Omega} = 0$ and KVL gives

$$-10V + \cancel{V_{5\Omega}}^{\,0} + V_d + V_x = 0$$

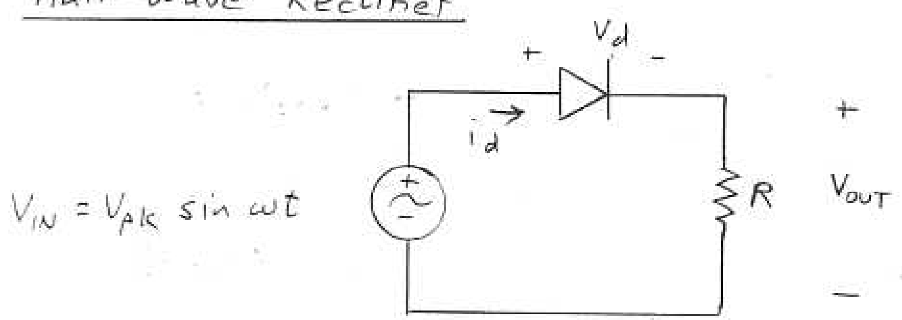
so

$$V_d = 10 - V_x = -0.91V$$

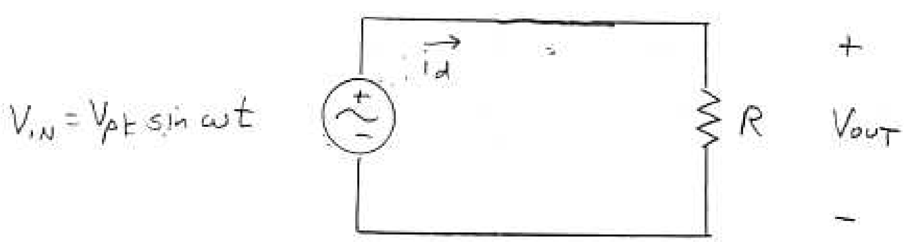
with $V_d < 0$ our assumption is TRUE

Diode is OFF

Half-Wave Rectifier

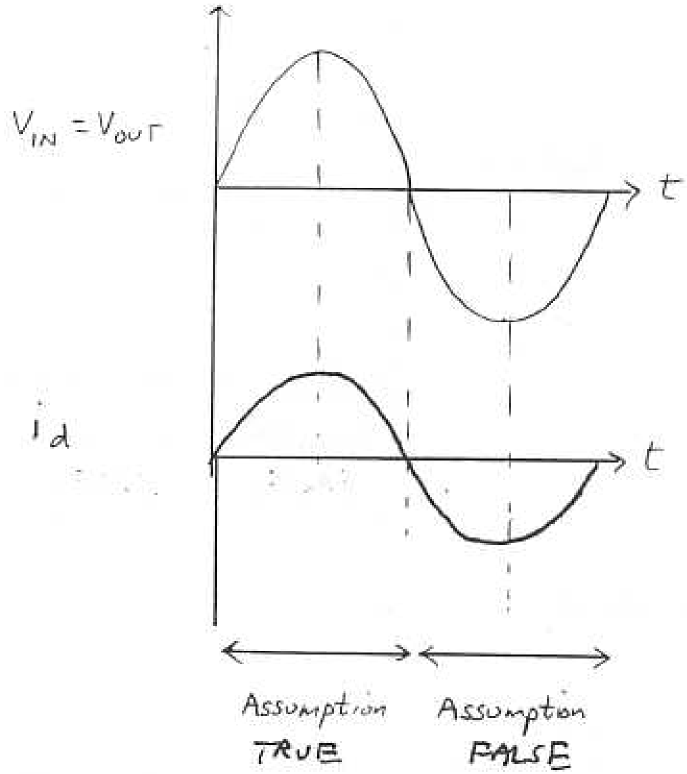


(1) Assume the diode is ON : $V_d = 0V$



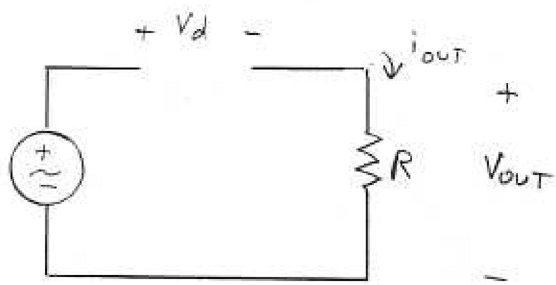
$$i_d = \frac{V_{IN}}{R} = \frac{V_{pk}}{R} \sin \omega t$$

sketching



(2) Assume the diode is OFF : $i_d = 0$

$V_{IN} = V_{pk} \sin \omega t$



With $i_{OUT} = 0 \rightarrow V_{OUT} = 0$ so KVL gives

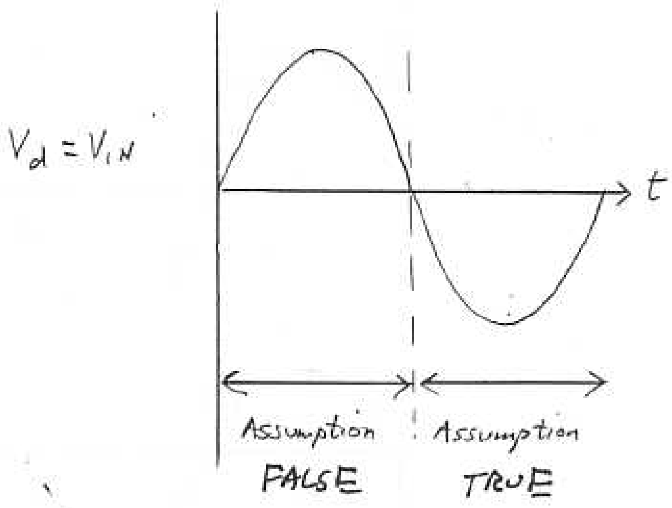
$$-V_{IN} + V_d + \cancel{V_{OUT}}^{\,0} = 0$$

Thus

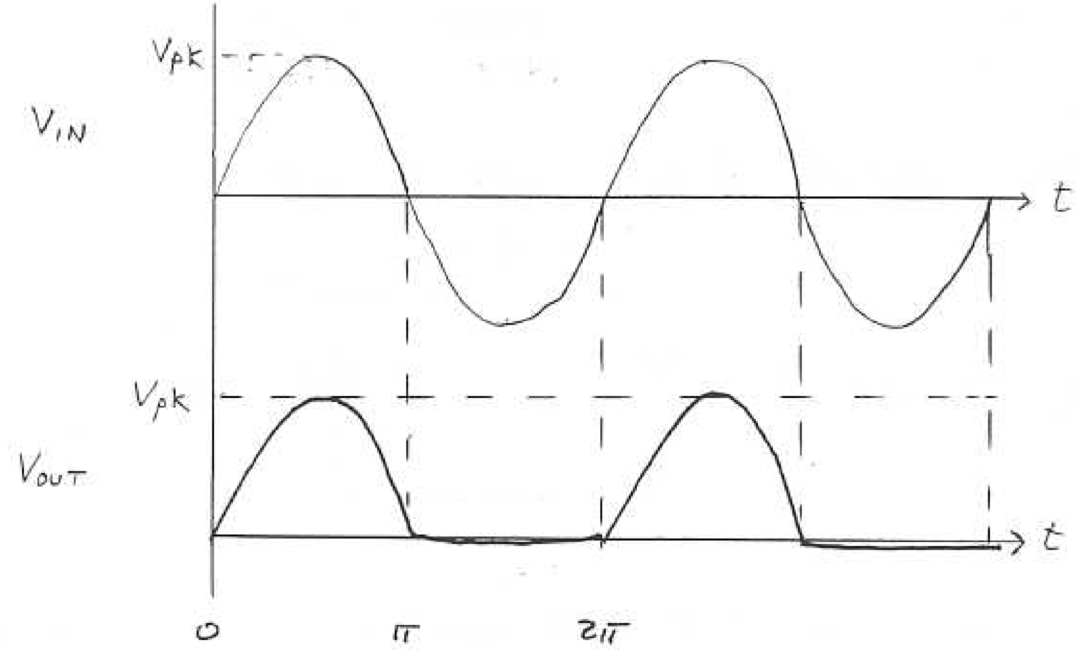
$$V_d = V_{IN}$$

When is $V_d < 0$?

sketching



Thus, we deduce that



From which we can analyze and find the average value

$$V_{OUT,ave} = \frac{1}{2\pi}\int_0^{\pi} V_{pk}\sin\theta \, d\theta$$

$$= \frac{V_{pk}}{2\pi}\left(-\cos\theta\right)\Big|_0^{\pi} = \frac{V_{pk}}{2\pi}\left(1+1\right) = \frac{V_{pk}}{\pi}$$

and the RMS value

$$V_{OUT,rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_{pk}^2 \sin^2\theta \, d\theta} \doteq \sqrt{\frac{1}{2\pi} V_{pk}^2 \left(\frac{1}{2}\theta\right)\Big|_0^{\pi}}$$

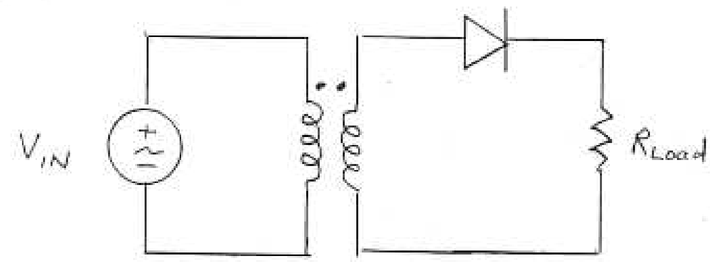
$$= \sqrt{\frac{V_{pk}^2}{4}} = \frac{V_{pk}}{2}$$

The rms voltage allows us to find the average power consumed by the resistance via

$$P_{ave} = \frac{V_{OUT,rms}^2}{R}$$

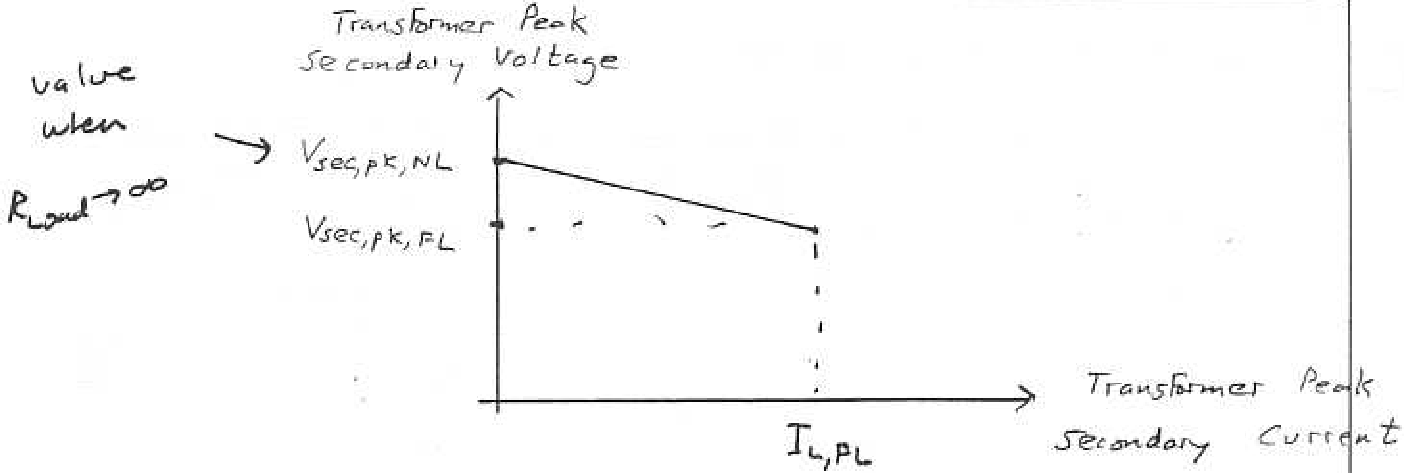
Non-Ideal Effects

(*) If we consider merging a transformer in so we can adjust the output voltage **downward**

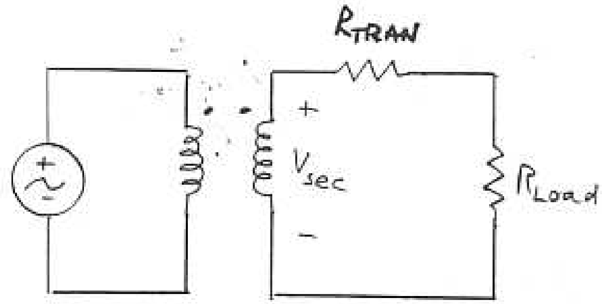


(1) Conducting diode has drop of ~ 0.7V

(2) Transformer has some output **resistance**



where NL: no load FL: Full-load



so that

$$V_{sec,pk,FL} = V_{sec,pk,NL} \frac{R_{Load,FL}}{R_{Load,FL} + R_{TRAN}}$$

But the peak secondary voltage will also be reduced by the conducting diode drop so

$$V_{sec,pk} = \left(V_{sec,pk,NL} - 0.7V \right) \frac{R_{Load}}{R_{Load} + R_{TRAN}}$$

This value can then be used in the following two equations to predict the average and rms output voltages:

$$V_{OUT,ave} = \frac{V_{sec,pk}}{\pi}$$

$$V_{OUT,rms} = \frac{V_{sec,pk}}{2}$$