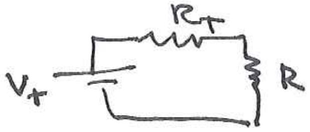
Power Transfer thm:



what value of R maximizes power transfer.

$$P = I^2 R = \left(\frac{V_T}{R_T+R}\right)^2 R = \frac{V_T^2}{R_T}\,\frac{x}{(1+x)^2} \quad \text{where } x = \frac{R}{R_T}$$

$$\partial_x\left(\frac{x}{(1+x)^2}\right) = \frac{1}{(1+x)^2} - 2\,\frac{x}{(1+x)^3} = \frac{1-x}{(1+x)^3} = 0 \rightarrow x = 1$$

In general max power transfer with $Z = Z_T^*$

Note: $R \gg R_T$ (to get <u>voltage</u> transfer) is most common

Note: Power in AC circuits: instantaneous power $= V * I \; \overset{W}{\overset{\shortparallel}{\left[\frac{J}{C}\cdot\frac{C}{s}\right]}}$

average power $= \frac{1}{T}\int_0^T V(t)\,I(t)\,dt$ if $I = I_0\cos(\omega t)$

$V = V_0\cos(\omega t+\phi)$

$$= \frac{1}{T} I_0 V_0 \int_0^T \overbrace{\cos(\omega t+\phi)}^{\cos(\omega t)\cos\phi\, -\, \sin(\omega t)\sin\phi}\cos(\omega t)$$

Note: average of $\cos^2(\omega t) = \frac{1}{2}$; average $\cos(\omega t)\sin(\omega t) = 0$

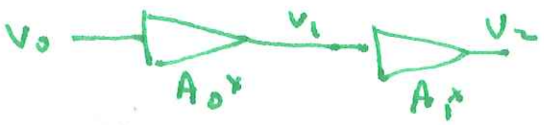
$$= \frac{I_0 V_0}{2}\cos\phi = I_{rms} V_{rms} \underbrace{\cos\phi}_{\text{"power factor"}}$$

Note: for complex I_0 & V_0 : $|I_0||V_0|\cos\phi = \mathrm{Re}\left[V_0 I_0^*\right]$

$dB = 20\log_{10}\left(\frac{V_1}{V_0}\right)$ → used where <u>ratios</u> matter as in amplification

Note: why "20" yet "deci" → $20\log\left(\frac{V_1}{V_0}\right) = 10\log\left(\frac{V_1^2}{V_0^2}\right)$ – idea is power $\propto V^2$ so this is "10" for power ratio

Note: if have a series of amplifiers

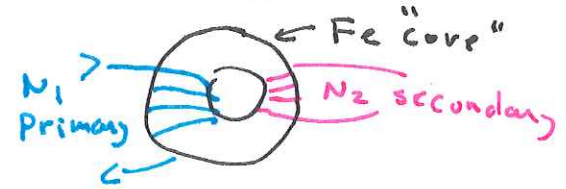


$$20\log\left(\frac{V_2}{V_0}\right) = 20\log\underset{\underset{A_1}{\uparrow}}{\left(\frac{V_2}{V_1}\right)} + 20\log\underset{\underset{A_0}{\uparrow}}{\left(\frac{V_1}{V_0}\right)}$$

so "decibels add"

Note $\log_{10}(2) = .301$ so "3dB" is a power gain of a factor of 2 (and a voltage gain of $\sqrt{2}$)

Transformer



per turn emf = $\mathcal{E}_2 \propto N_1 \dot{I}_1$

total secondary $\mathcal{E}_2 \propto N_1 N_2 \dot{I}_1$

$\mathcal{E}_1 \propto N_1^2 \dot{I}_1$

B in core $\propto N_1 I_1$

ϕ = flux in core $\propto N_1 I_1$ Area

$$\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{N_1 N_2 \dot{I}_1}{N_1^2 \dot{I}_1} = \frac{N_2}{N_1}$$

"step up" if $N_2 > N_1$; "step down" if $N_2 < N_1$

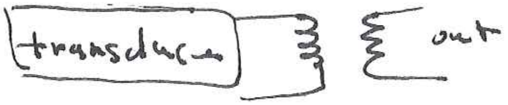
Note power gain [hope for near 100% power transfer]

so $\frac{I_2}{I_1} = \frac{N_1}{N_2}$

Note: real transformers are much more complex than above

Use transformer to ...

- step down line voltage to more usable levels "power transformer"
- to "amplify" small signals – really change apparent output impedance:



$$\frac{V_2}{I_2} = \left(\frac{N_2}{N_1}\right)^2 \frac{V_1}{I_1}$$

↖ output impedance of transducer

← apparent impedance as seen thru transformer

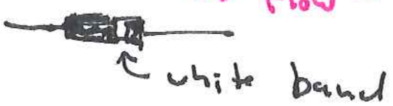
- to "free up" ground
- to insert a signal at a "floating" location (ie a location with a DC offset)

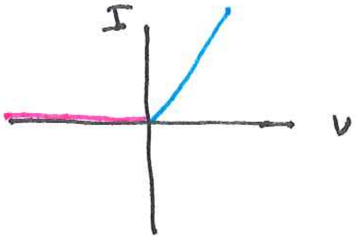
Note: "variac" – variable transformer : 120 VAC → smaller

Diodes

→ conducts – "forward biased"

← no flow – "reverse biased"



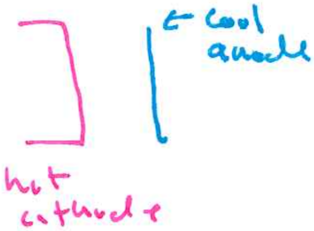


real vs ideal: the "forward" part is not linear

there is a small current in "reverse" part

for large reverse voltages there may be "breakdown" — sudden increase in reverse current: not desired (except in Zeners)

How vacuum tube diodes work: the cathode is kept quite hot (>1000K) the electrons there have lots of KE - enough to escape metal (ie KE > work function). The anode is kept at room temp - the electrons there are unable to escape metal



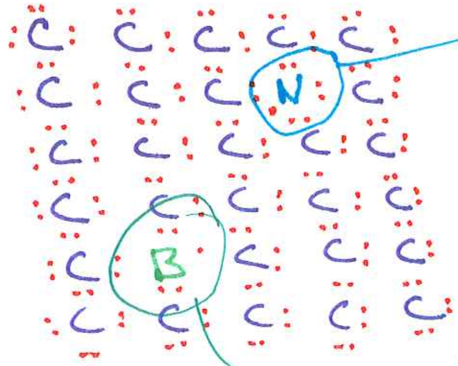
if anode is ⊕ electrons can leave cathode and travel to anode, if anode is ⊖ reverse not possible.

Long Story: solid state electronics.

III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb

"Lewis Dot"

In pure diamond each C is covalently bonded to 4 neighbors (forming a tetrahedron - but thats hard to draw on paper)



brings extra ⊕ charge - if this region is electrically neutral there will be an electron orbiting around

short ⊕ charge - if this region is electrically neutral there must be one fewer electron - a "hole"

In pure crystal Si (or diamond or Ge) thermal energy can excite a bonded e^- producing a "free" electron and "hole". Both the hole (h^+) & the electron (e^-) can move. Basic thermodynamics gives the equilibrium concentration of h & e (Notation: $[h] = \frac{\# \text{ holes}}{m^3}$)

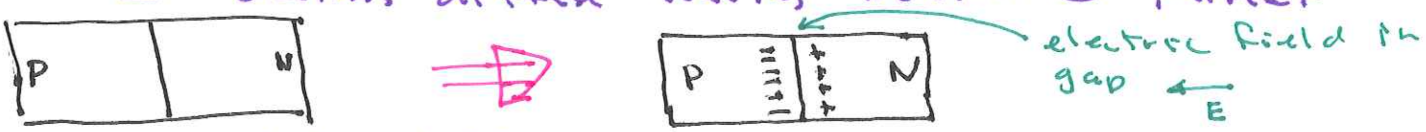
$[h][e] = K_{eq}$ (FYI: K_{eq} increases exponentially with Temp)

If we "dope" pure Si with something from column V we create lots of "extra" electrons which will be "ionized" away from parent even at "low" temps (RT). This creates N-type material where $[e] >> [h]$

If we "dope" pure Si with something from column III we create lots of "extra" holes which - at Room Temp - will roam away from parent. This creates P-type material with $[h] >> [e]$

Note: in either case there will be "minority" carriers

← electrons diffuse leaving behind ⊕ parent



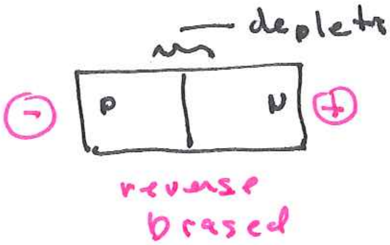
→ holes diffuse leaving behind ⊖ parent

Note: $e^- + h^+$ "recombination" & thermal ionization" are also happening all the time.

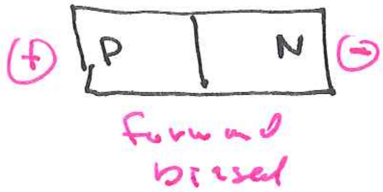
The resulting electric field pushes h to left & e^- to right. The electric field will grow until we have a net balance between diffusion & electric field induced current.

The electric field has an associated voltage with the N-type material positive.

Note: the resulting electric field pushes the minority carriers across gap.



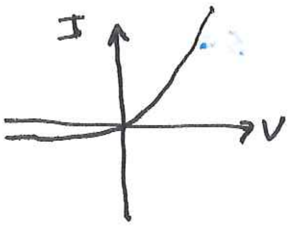
On each side of the junction the majority carriers are pushed away from junction (like vacuum tube diode)
Any minority carrier that happens into depletion zone will be pushed across gap – but that would happen even in absense of external voltage.



On each side of the junction the majority carriers are pushed across the gap. (Or at least the E field barrier in the gap is reduced) – exponentially more carriers across gap

$$I = I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

due to minority carriers



Note: there really is no "turn on" voltage. The combination of I_0 & $e^{qV/kT}$ determine when "noticeable" currents flow.

Zeners – a "spark" in the depletion region
secondary ionization if energy drop large enough