n nodes, e.g., $n=3$

$n-1$ linearly KCL eqn, $n-1=2$ eqn

b branches, e.g., $b=4$

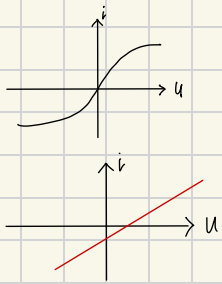
$b-(n-1)$ linearly ind. KVL eqns, e.g., $b-(n-1)=4-(3-1)=2$ eqns

pn-Junction Diode

$i_D = I_S\left(e^{\frac{u_D}{u_T}} - 1\right)$

$u_D = U_T \ln\left(\frac{i_D}{I_S} + 1\right)$

bilateral



not-bilateral

$U = Ri$

$i = Gu$

$i = 0 \Rightarrow$ open circuit OC

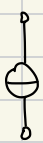
$U = 0 \Rightarrow$ short circuit SC

$U_i = 0 \Leftrightarrow$ lossless

$U_i \geq 0 \Leftrightarrow$ passive

$U_i < 0 \Leftrightarrow$ active

$U_i \neq 0 \Leftrightarrow$ lossy



independent current source

independent voltage source

Duality

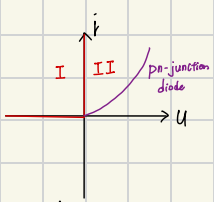
$u^d = R^d i$ $\quad i^d = \frac{1}{R^d} u^d$

eg $U = r(i)$ $\quad i = g(u)$

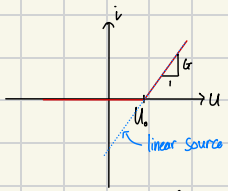
$\downarrow R^d$ $\quad \downarrow R^d$

$R^d i^d = r\left(\frac{1}{R^d} u^d\right)$ $\quad \frac{1}{R^d} u^d = g(R^d i^d)$

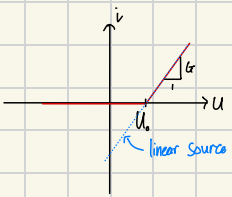
$i^d = g^d(u^d)$ $\quad u^d = R^d i^d$



ideal diodes



concave resistors



convex resistors

real negative resistors has N-type & S-type

Linearization

$\beta_{lin}(a) = \left.\frac{d\beta(a)}{da}\right|_{a=A} \cdot (a-A) + B$