Section 22
PN Diode Large Signal Response

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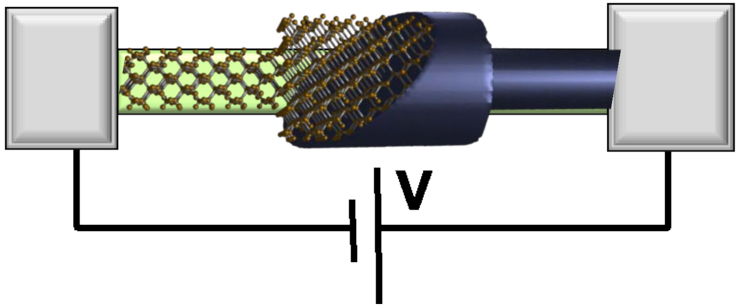
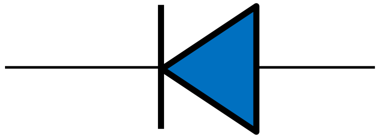


$I = G \times V$

$= q \times n \times v \times A$

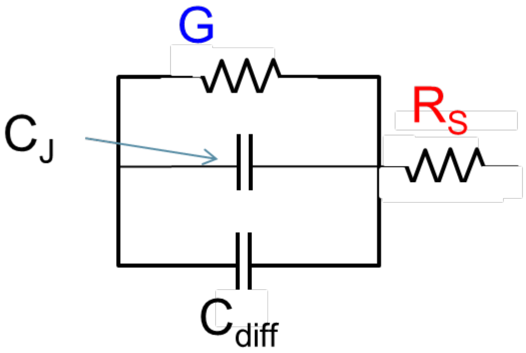
charge density velocity area



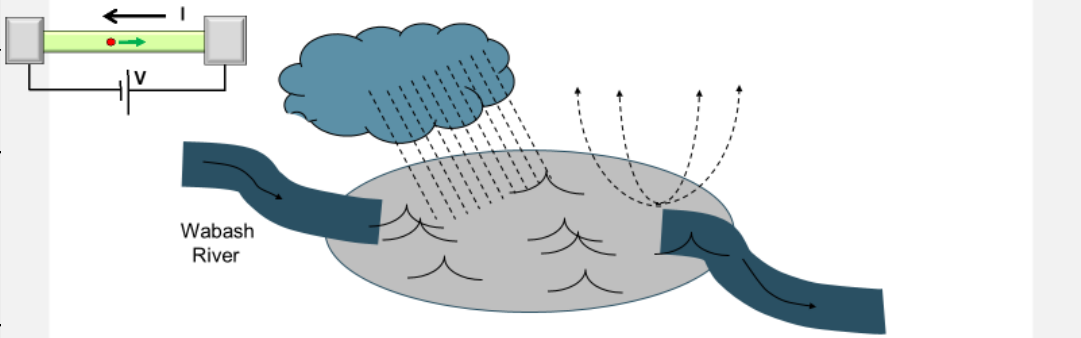
	Equilibrium	DC	Small signal	Large Signal	Circuits
PN Diode					

Diode in **Non-**Equilibrium
(External DC+AC voltage applied)

Digital Signals: switch on and off



Continuity Equation prequel: A Good Analogy



Rate of increase of water level in lake = (in flow - outflow) + rain - evaporation

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N$$

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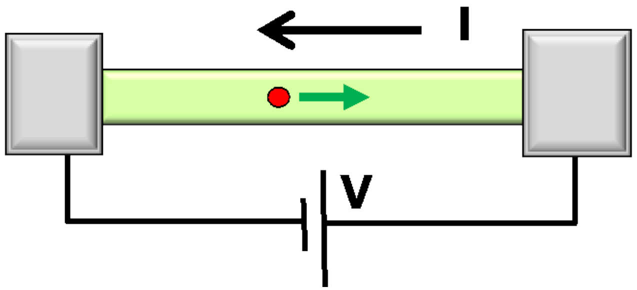

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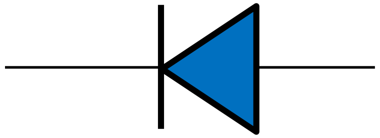
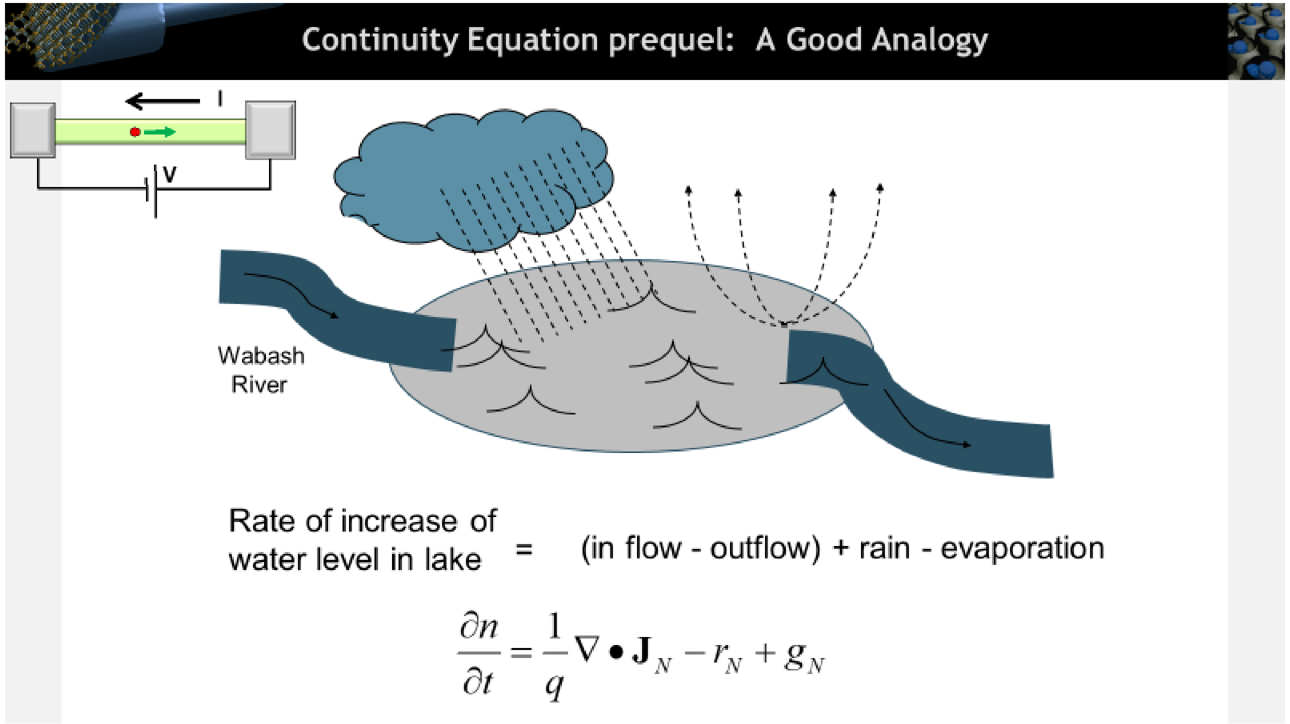
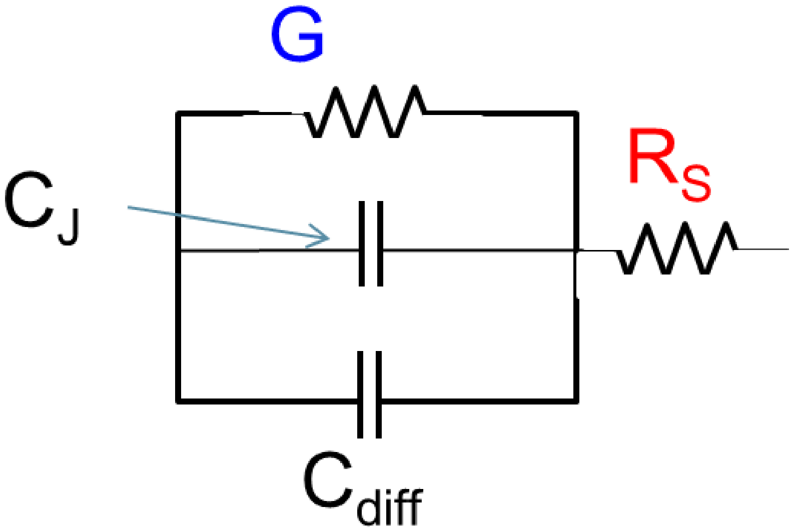
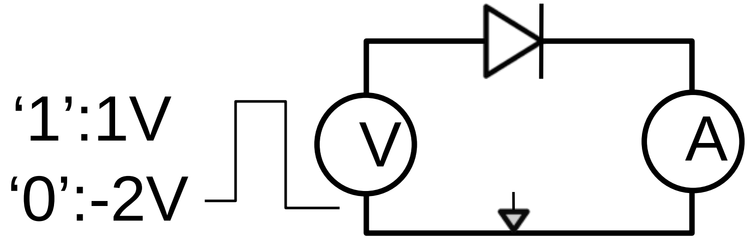


- 22.1 Charge control model
- 22.2 Turn-off and Turn-on characteristics
- 22.3 Steady-State expression from Charge Control





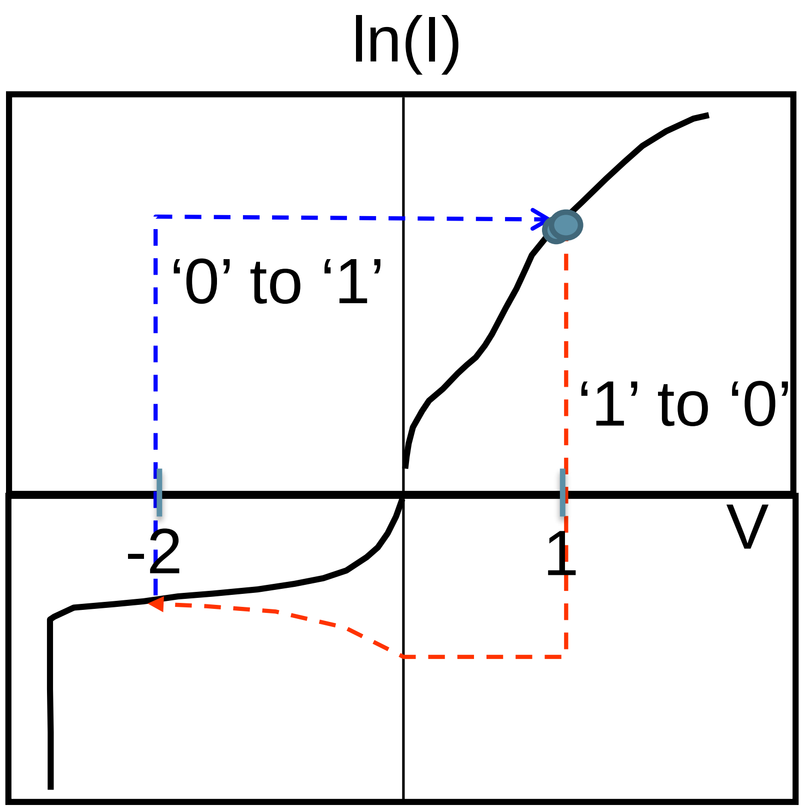
Digital, Large Signal Applications

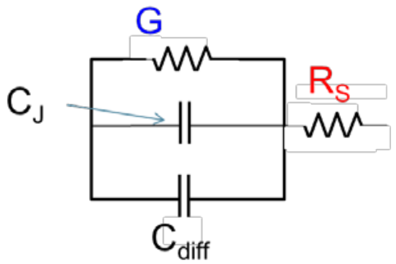


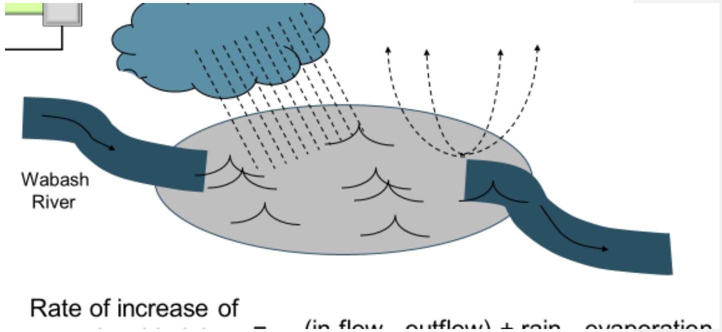
———— :If transition is slow,
every point is in quasi-equilibrium
→treat them like DC

-------:If transition is very fast

------:Current flips "immediately",
voltage changes slowly





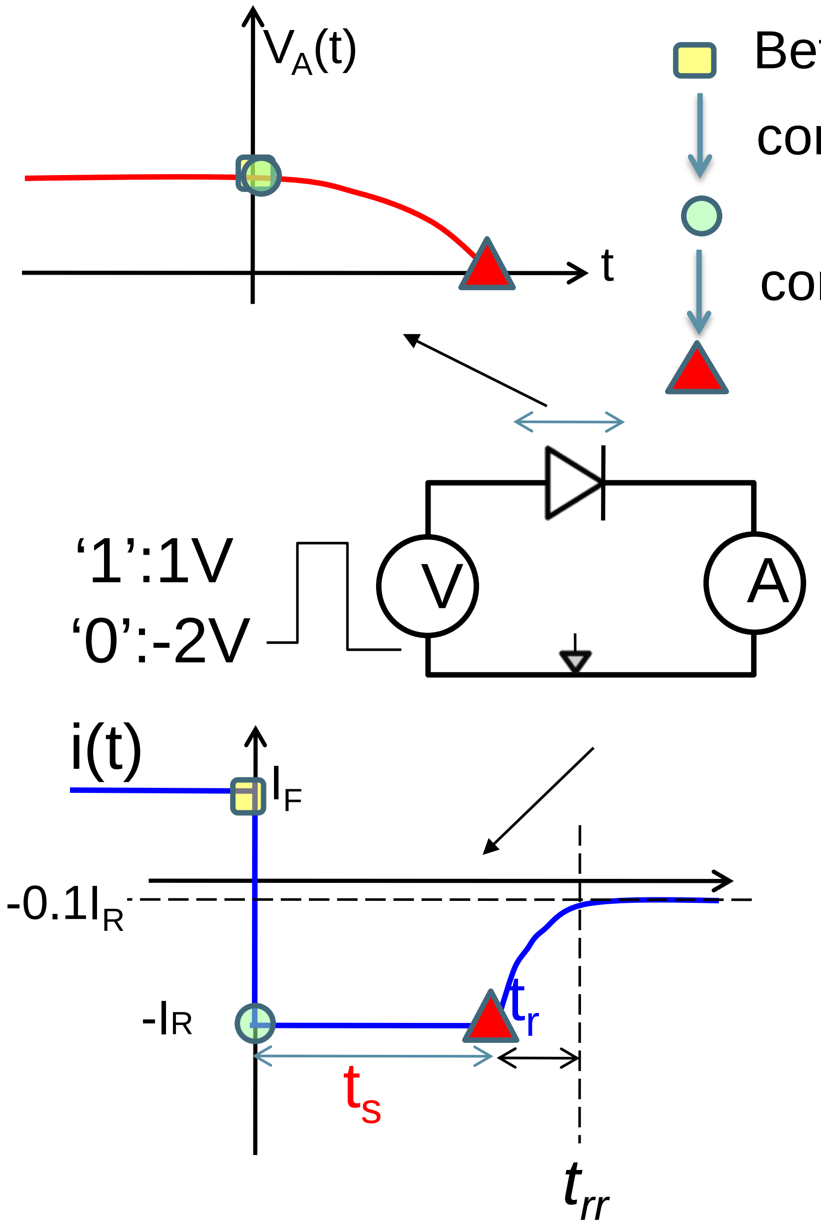


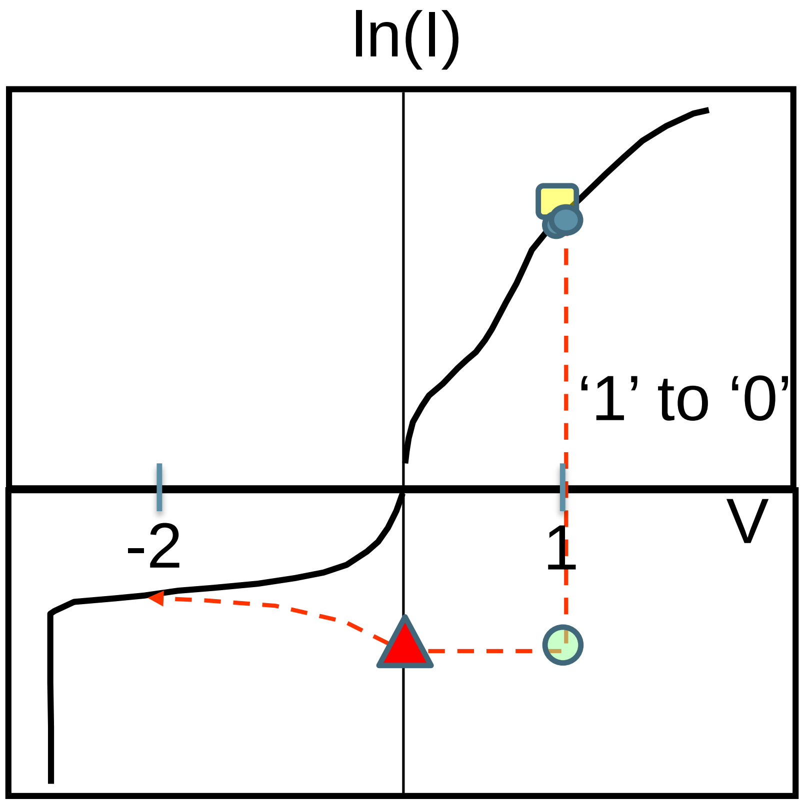
A Closer Look to Fast Transition

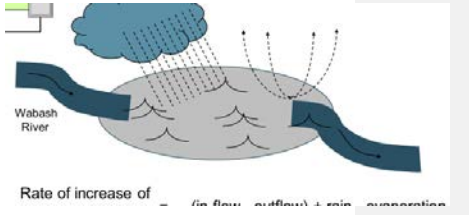
Before transition occur

constant voltage, current change from I_F to I_R

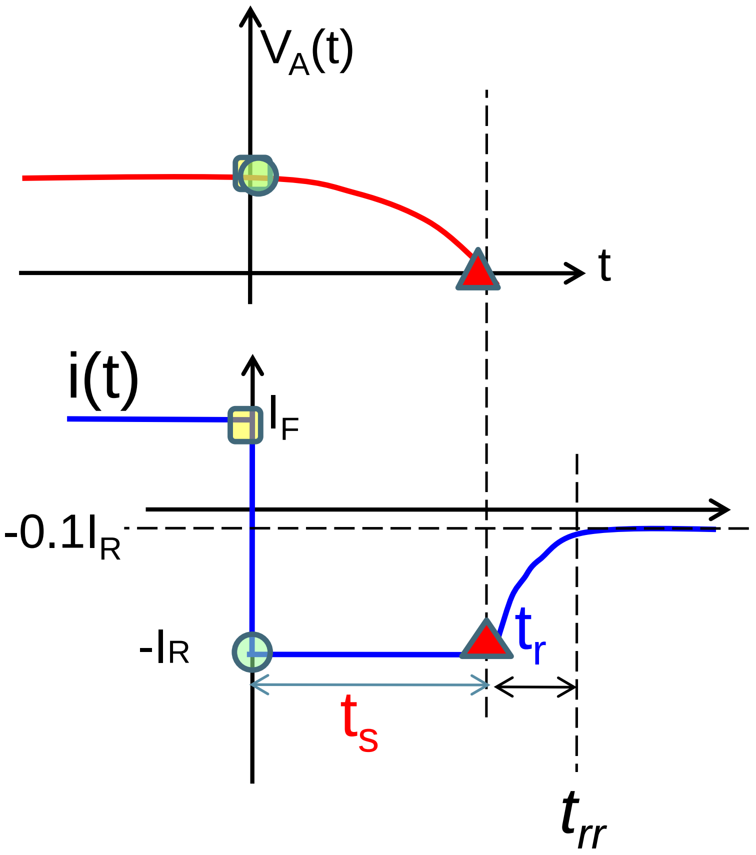
constant current, voltage change form 1V to 0V







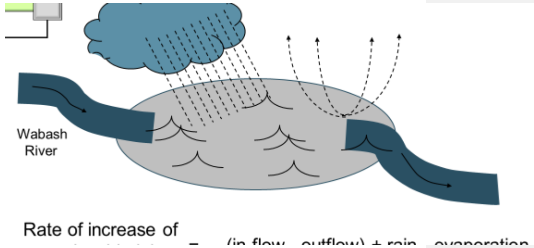
Definitions



t_s … Charge storage time

t_r … Recovery time

t_{rr} .. Reverse recovery time



Continuity Equations

Full analytical solution impossible for large signal….

$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right)$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N$$

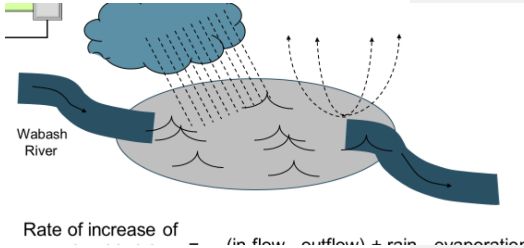
$$\mathbf{J}_N = qn\mu_N \mathcal{E} + qD_N \nabla n$$

$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_P - r_P + g_P$$

$$\mathbf{J}_P = qp\mu_P \mathcal{E} - qD_P \nabla p$$

$$\frac{\partial Q_n}{\partial t} = i_{n,diff} - \frac{Q_n}{\tau_n}$$

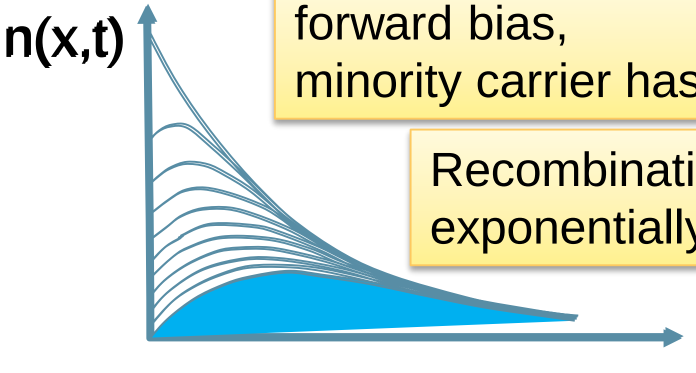
$$\frac{\partial Q_p}{\partial t} = i_{p,diff} - \frac{Q_p}{\tau_n}$$



Charge control equations:

Approximation when you have large transient response

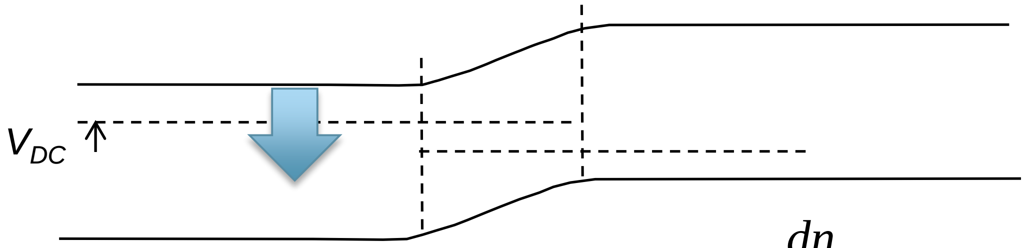
How Does Current Flip Without Voltage Flipping?

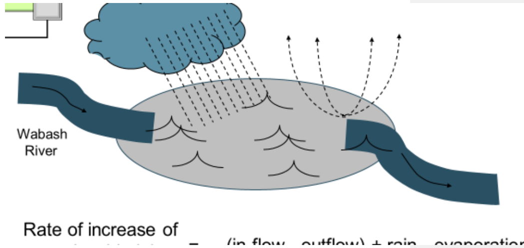


forward bias,
minority carrier has been injected

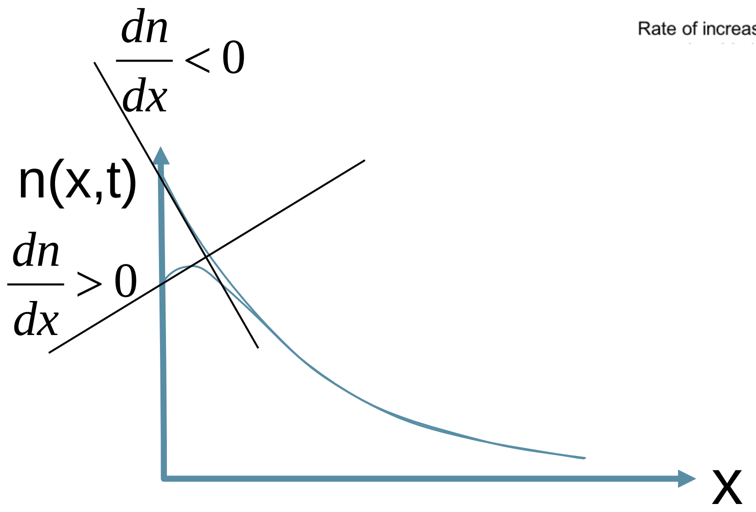
Recombination→n(x,t) exponentially dying out

Where did the charge go?
1. Back to the left-hand side
2. Recombine with the trap and the majority carrier





When voltage starts to change,
=> n(x,t) suddenly bends downwards,
⇒ dn/dx changes sign
⇒ current flips from p→n to n→p



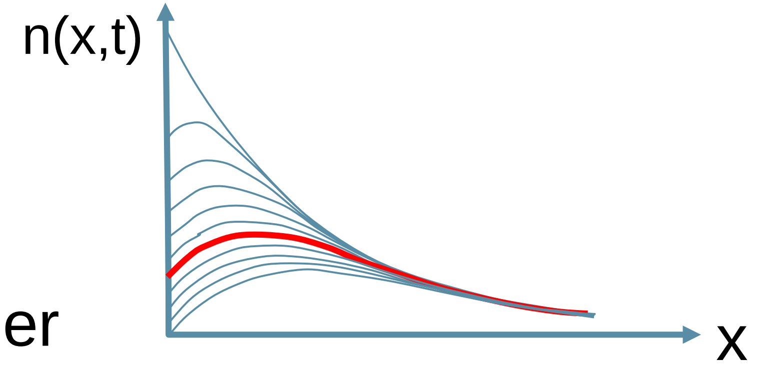
Large Signal Charge Control Model

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{dJ_n}{dx} - r_N + \cancel{g_N}$$

$$\mathbf{J}_N = q\cancel{n\mu_N\mathcal{E}} + qD_N\frac{dn}{dx}$$

$n = \cancel{n_0} + \Delta n$ minority carrier

$$\frac{\partial(\Delta n)}{\partial t} = D_N\frac{d^2(\Delta n)}{dx^2} - \frac{\Delta n}{\tau_n}$$

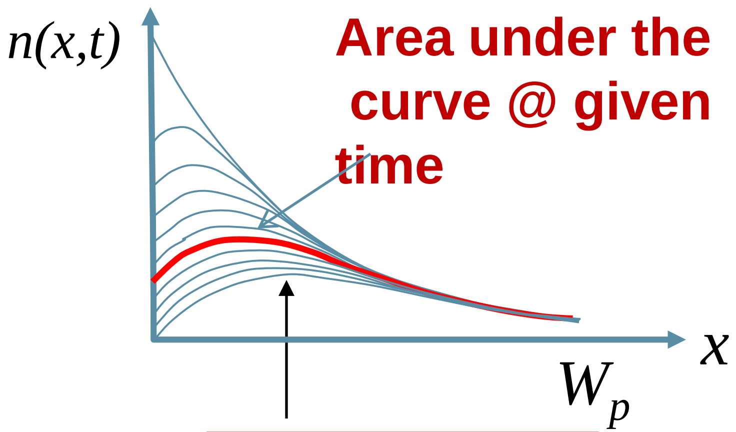


Large Signal Charge Control Model

$$\frac{\partial(\Delta n)}{\partial t} = D_N \frac{d^2(\Delta n)}{dx^2} - \frac{\Delta n}{\tau_n}$$

↓ x(qA), integrate

$$\int_0^{W_p} \frac{\partial(qA\Delta n)}{\partial t}dx = \int_0^{W_p} D_N \frac{d}{dx}\frac{d(qA\Delta n)}{dx}dx - \int_0^{W_p}\frac{qA\Delta n}{\tau_n}dx$$



$$Q \equiv \int_0^{W_p} (qA\Delta n)\,dx$$

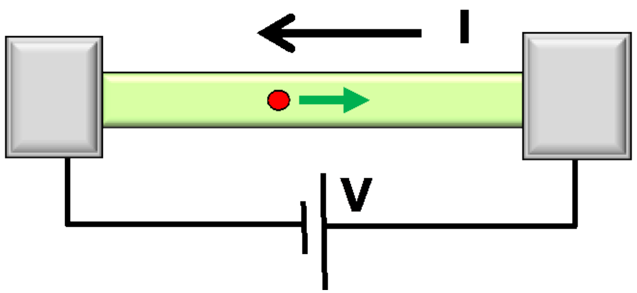
Current going out | Current coming in

$$\frac{\partial Q}{\partial t} = D_N \frac{d(qA\Delta n)}{dx}\bigg|_{x=W_p} - D_N \frac{d(qA\Delta n)}{dx}\bigg|_{x=0} - \frac{Q}{\tau_n}$$

Recombination

$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

(Total charge that is building in)=
(net electrons flowing in) – (recombination)



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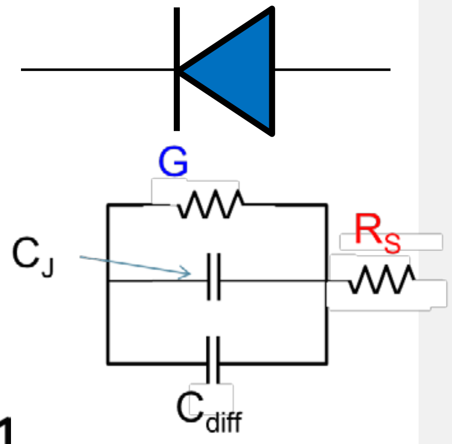

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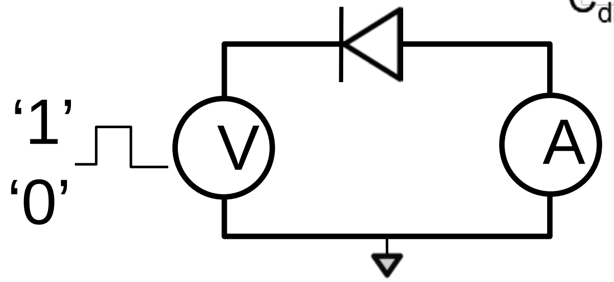
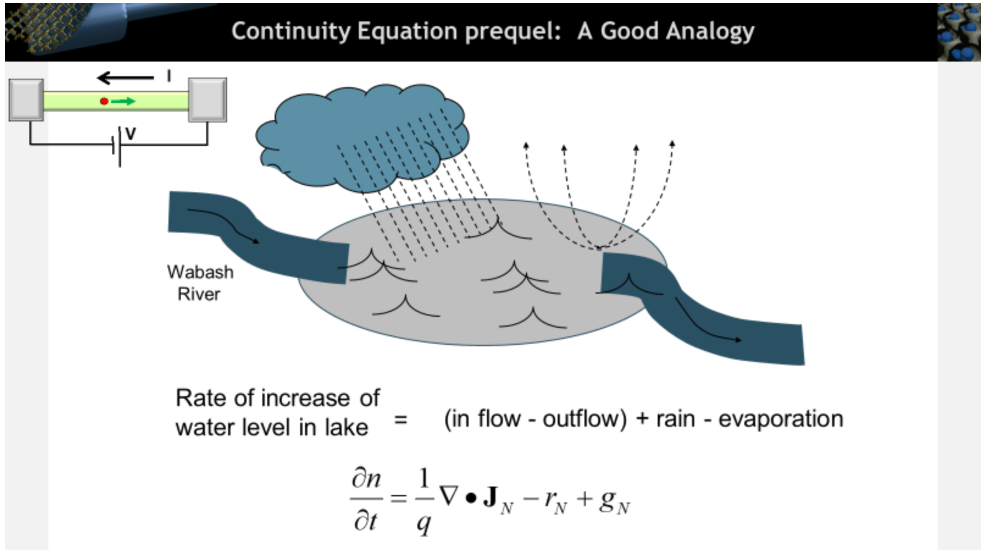
status





$$\frac{\partial Q}{\partial t} = i_{diff} - \frac{Q}{\tau_n}$$

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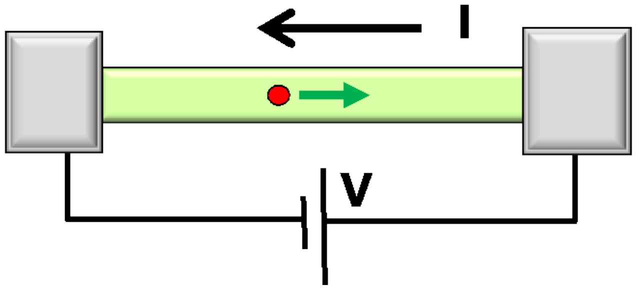

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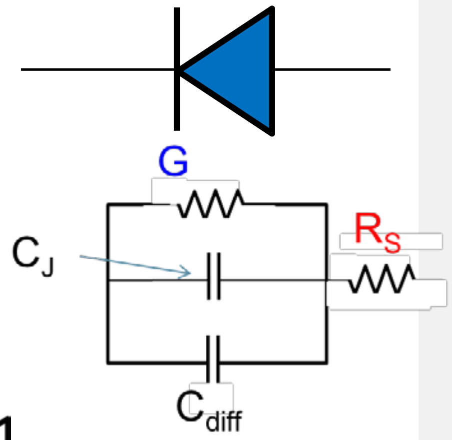

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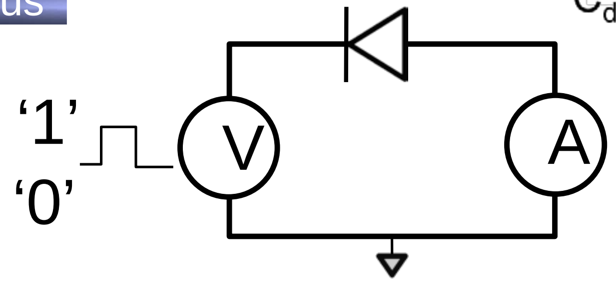

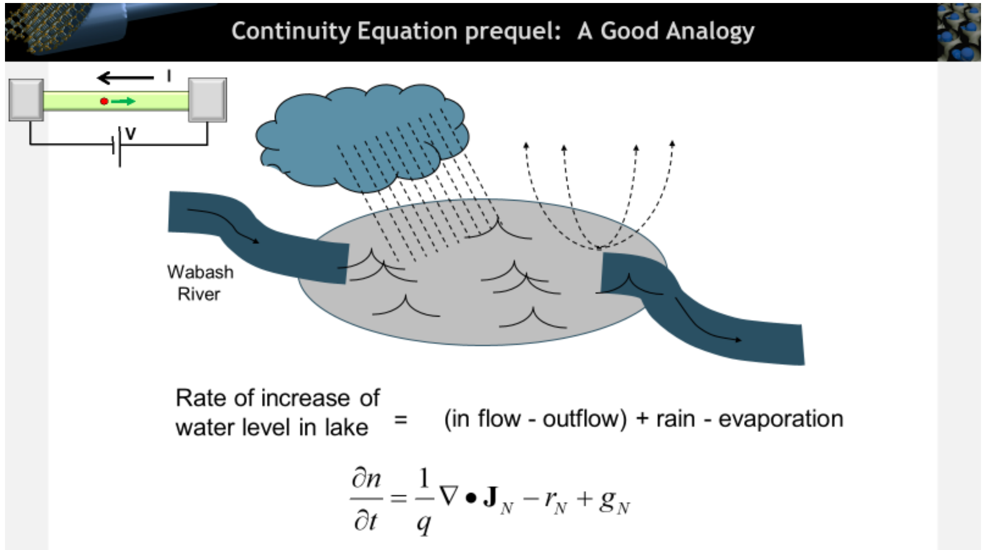

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