HW#3

- It will be posted soon.
  - Simulation of a pn junction

Lecture9:
Diode models and circuits (1)

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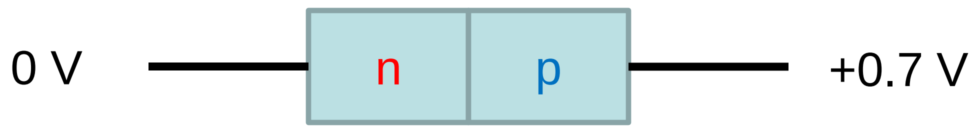
Forward/reverse

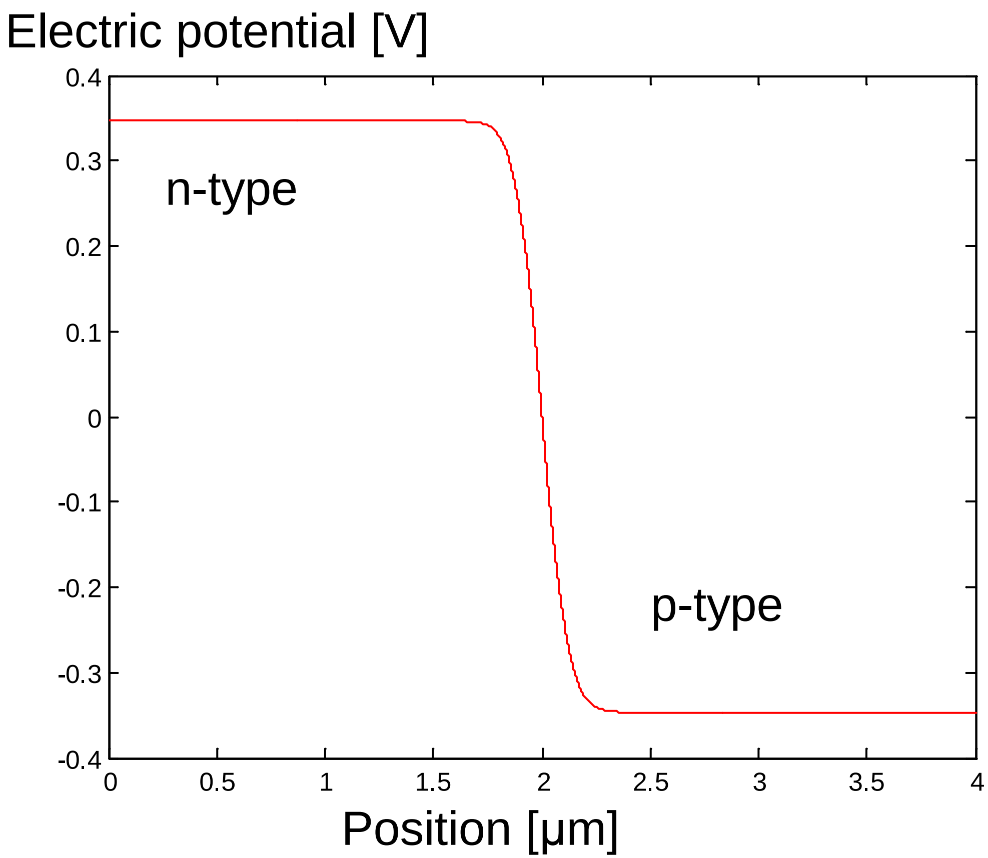
- A diode shows a strong polarity.
  - Does a resistor have a polarity?
  - In diodes, the following two cases are completely different.
- Forward bias
  - The voltage at the n-type side is higher than the p-type one.



- Reserve bias
  - The voltage at the p-type side is lower than the n-type one.

Reverse bias

- Electric field
  - Now, the magnitude of the electric becomes larger.



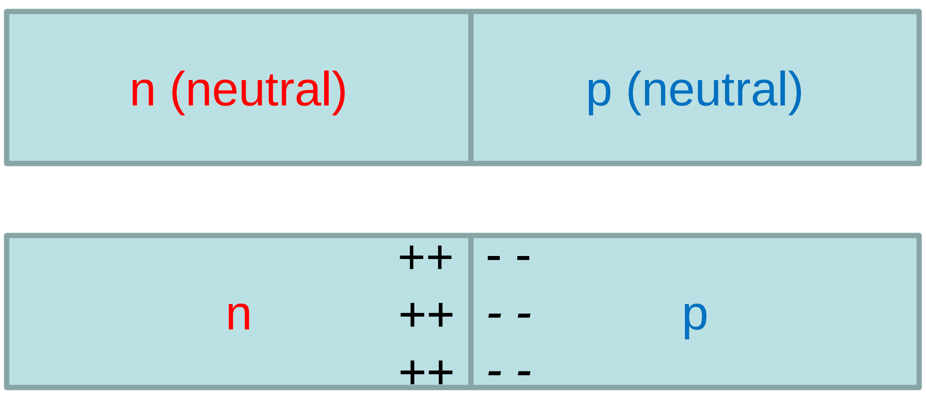
🡐 This is the equilibrium solution. What happens when the n-type region is positively biased?

Higher electric field?

- How can the pn junction generate the higher electric field?
  - At equilibrium, how did it generate the built-in electric field?

$$\nabla \cdot \mathbf{D} = \rho$$

  - Higher electric field means more space charges!



🡐 Which one can provide nonzero electric field?

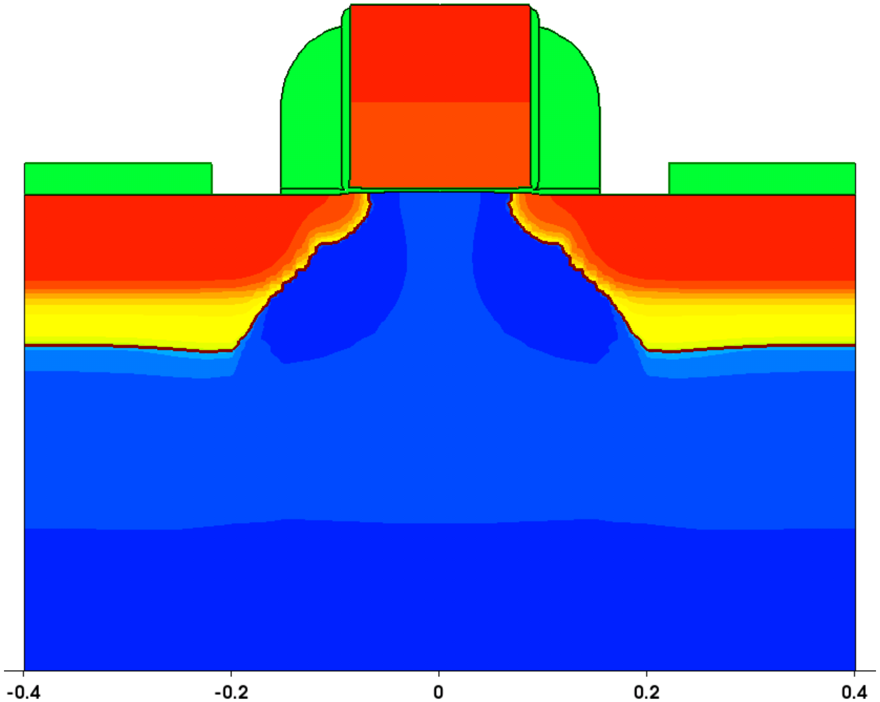
- Therefore, the depletion region becomes wider.
  - Even higher potential barrier!

Variable capacitance

- Capacitor? Why do we care about it?

$$Q = CV \text{ and } I = C\frac{dV}{dt}$$

  - Where can you find capacitance in the following structure?
  - Why is it important?



Doping profile of a typical planar MOSFET

Charge

- Charge stored in a pn junction

$$Q = A\sqrt{2\epsilon_s q \frac{N_A N_D}{N_A + N_D}(V_0 + V_R)}$$

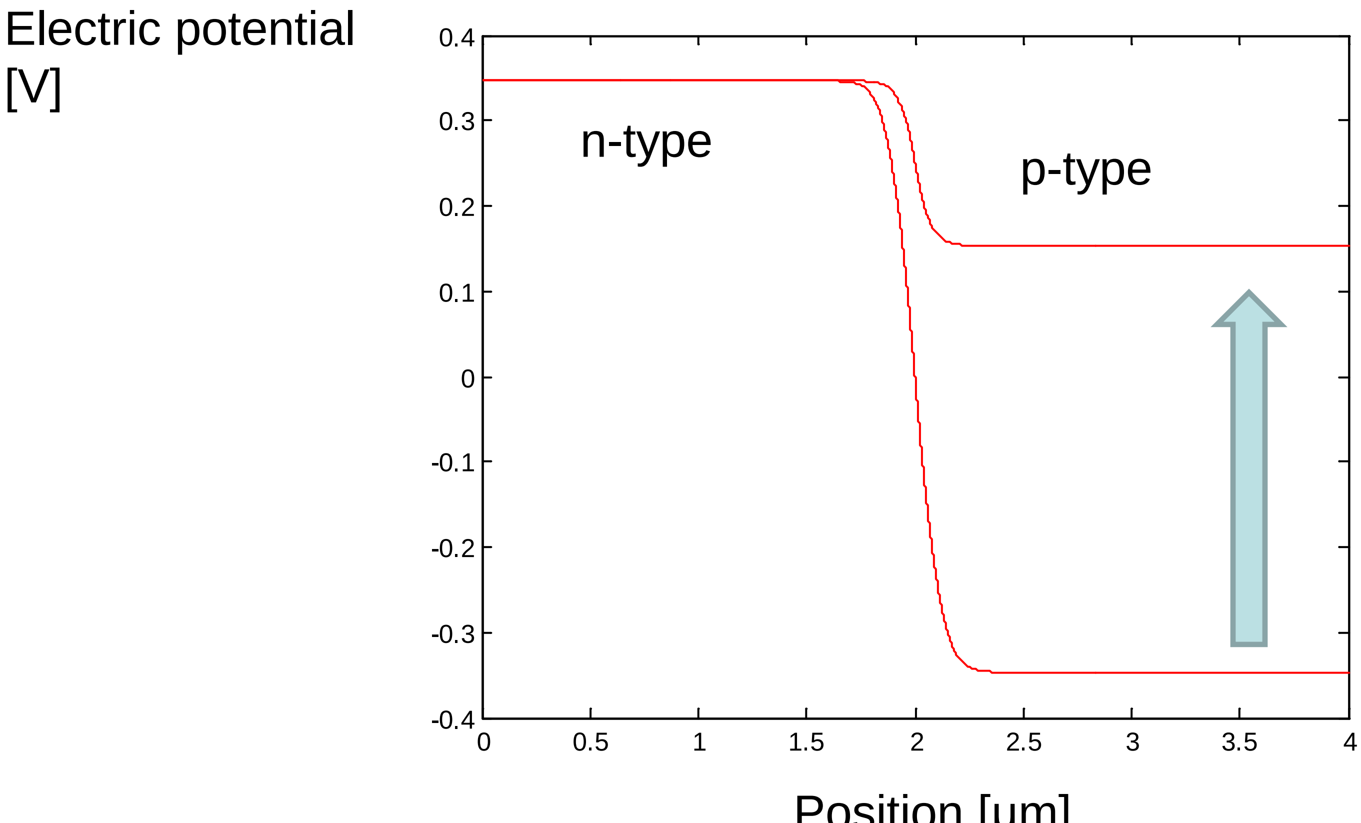
  - Then, what is the capacitance at a given value of the reverse bias, V_R?

Summary of reverse bias

- Reverse bias
  - Larger electric field
  - Wider depletion region
  - (Almost) no current flow
  - Variable capacitance

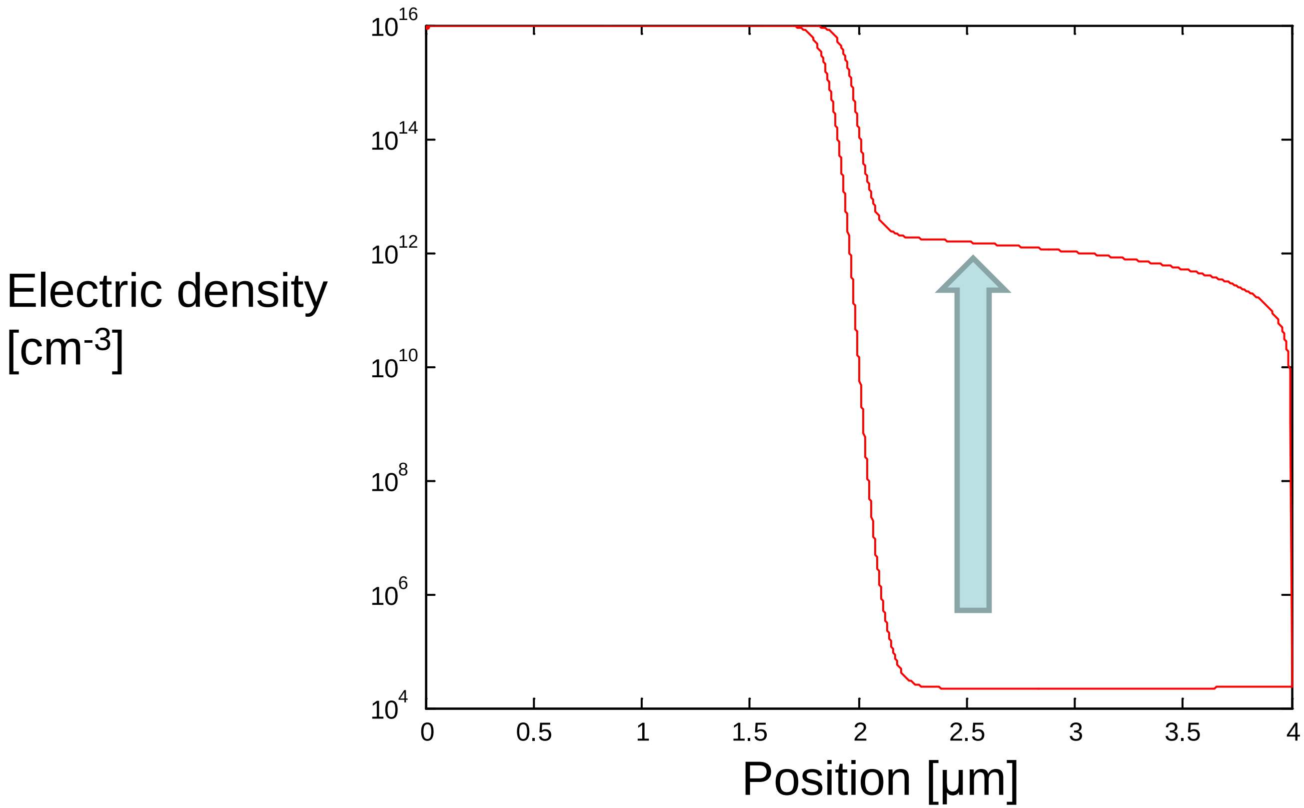
Forward bias

- Forward bias
  - We can easily guess that the depletion width will be reduced.
  - Potential barrier is lowered. (Equilibrium and 0.5 V)



Density @ forward bias

- Electron concentration (similar for hole concentration)
  - Equilibrium and 0.5 V
  - Exponential increase of electron density!



IV characteristics

- In forward bias,
  - The external voltage opposes the built-in potential, raising the diffusion currents substantially.
- In reverse bias,
  - The applied voltage enhances the field, prohibiting current flow.

$$I_D = I_S\left(\exp\frac{V_D}{V_T} - 1\right)$$

  - Here, the "reverse saturation current" is given by

$$I_S = Aqn_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right)$$

  - L_n and L_p are electron and hole "diffusion lengths," respectively.

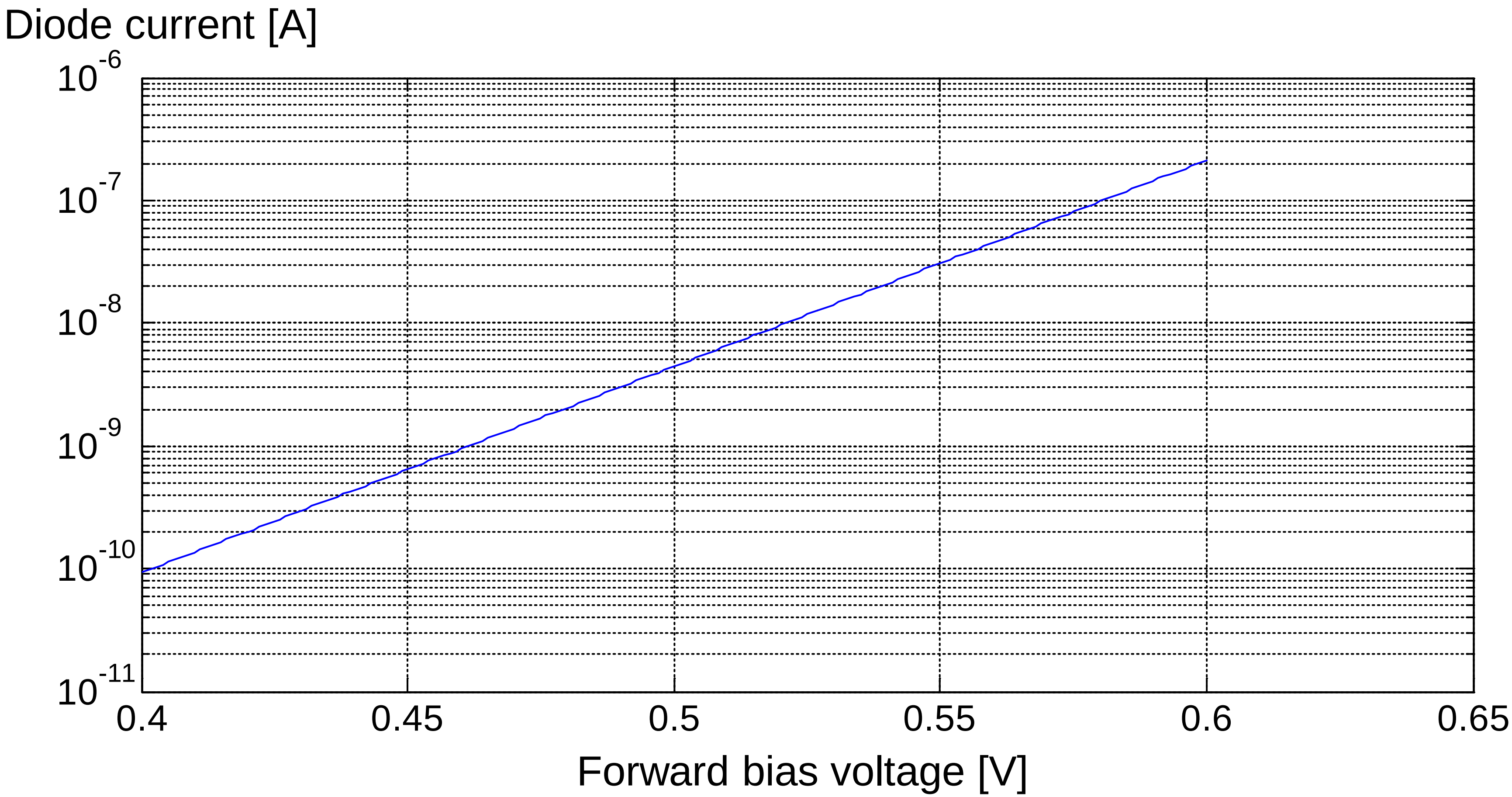
An example

- Determine I_S.
  - The cross section of 100 μm^2
  - L_n and L_p are 20 μm and 30 μm, respectively.
  - L_n and L_p are 20 μm and 30 μm, respectively.

- When $I_S = 1.77 \times 10^{-17}$ A,
  - Determine the forward bias current.
  - For $V_D = 300$ mV, $I_s\left(\exp\frac{V_D}{V_T} - 1\right)$ = 3.63 pA
  - For $V_D = 800$ mV, 820 μA

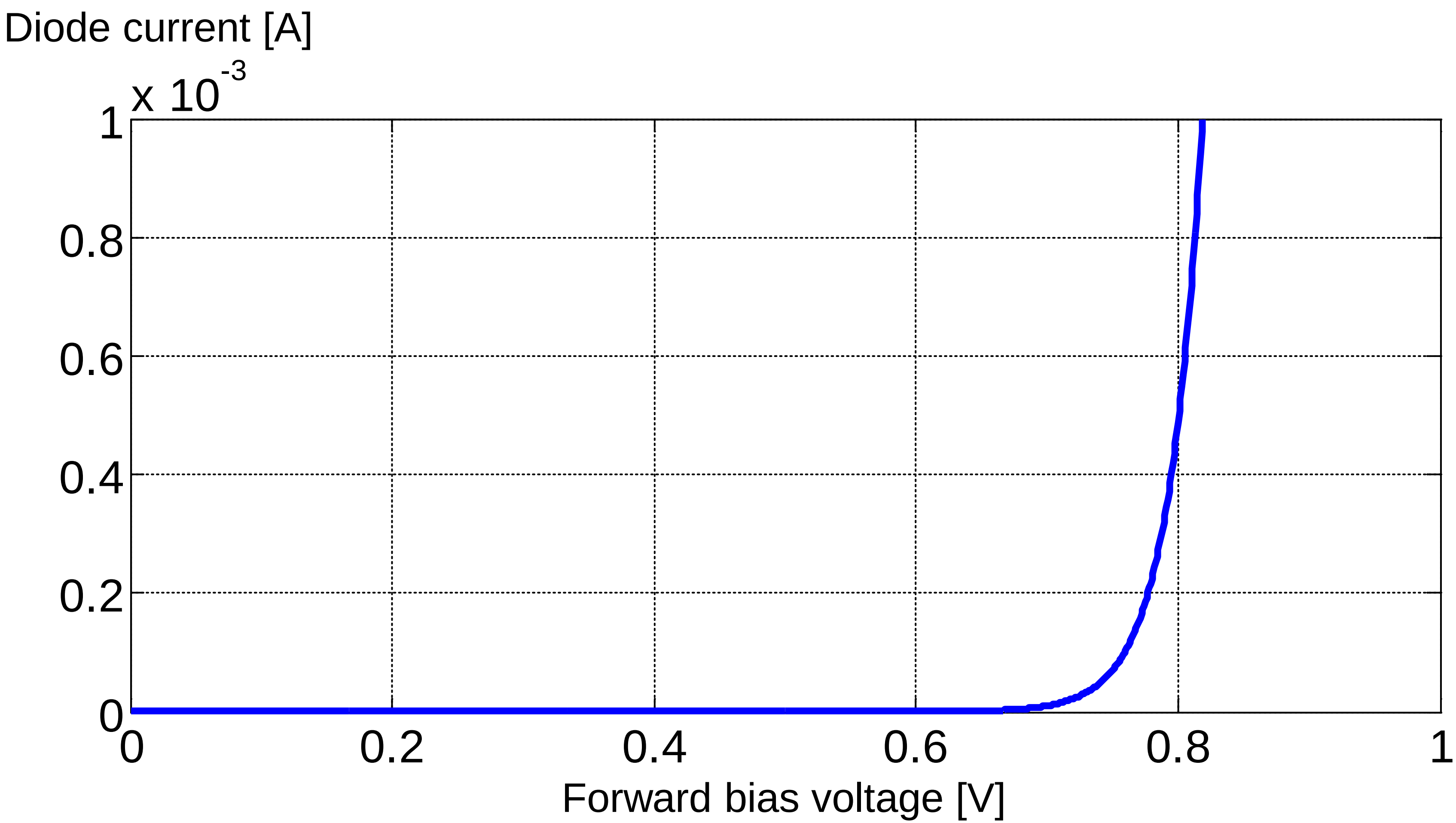
60 mV/dec, what is it?

- Calculate $V_T \ln 10$ at 300K.
  - Approximately 60 mV



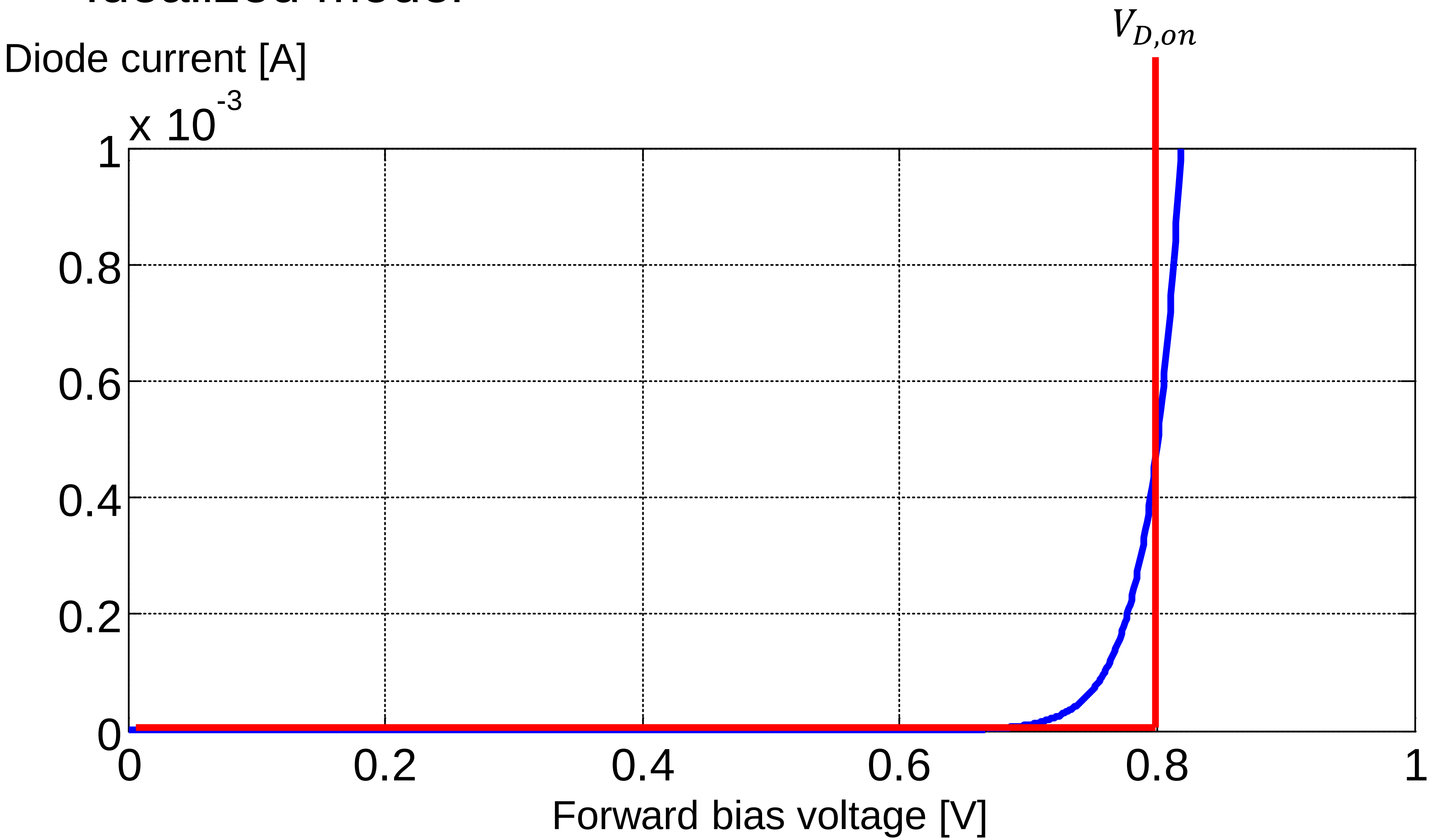
Draw it!

- In the linear scale, very steep increase of current!



Constant-voltage model

- Idealized model



A simple math

- An input voltage, $V_{in}(t) = \sin \omega t$
- A system

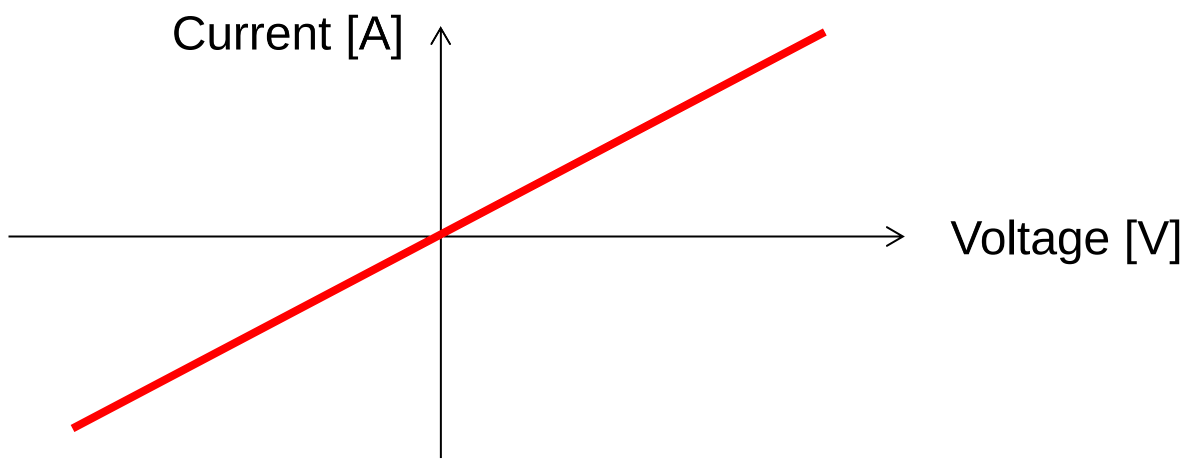
$$V_{in} \longrightarrow \boxed{V_{out} = 3 \times V_{in}} \longrightarrow V_{out}$$

- Another system

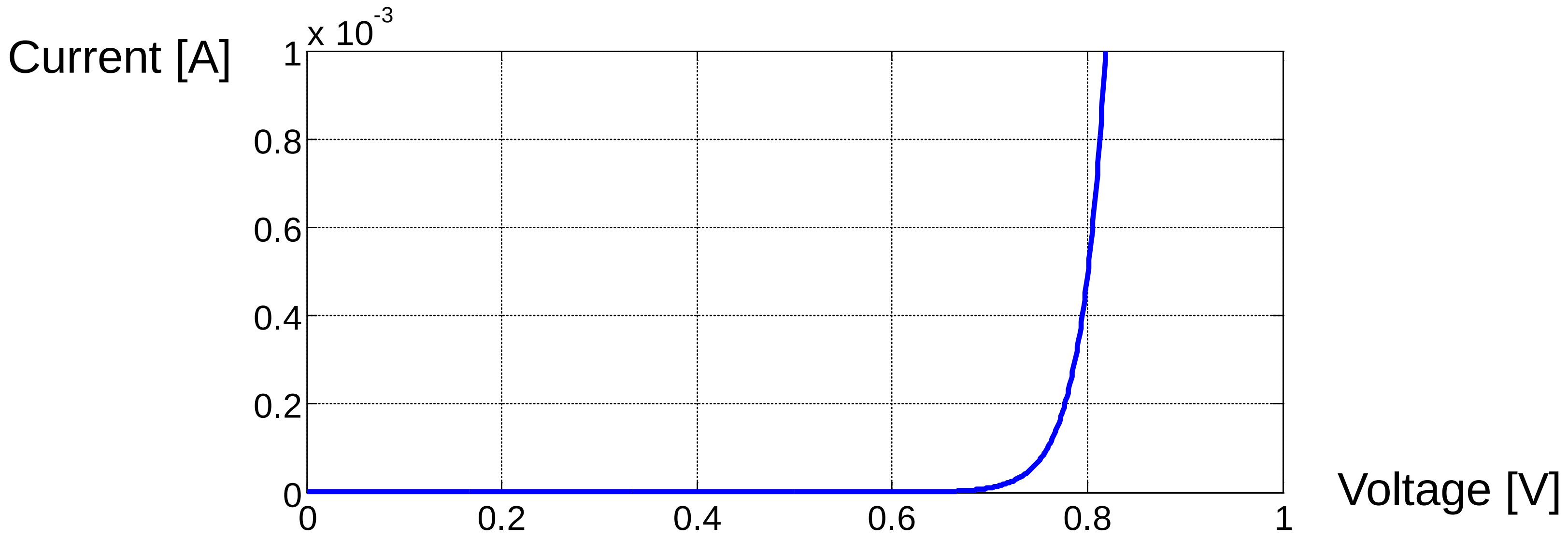
$$V_{in} \longrightarrow \boxed{V_{out} = V_{in}^2} \longrightarrow V_{out}$$

Which is nonlinear?

- A resistor

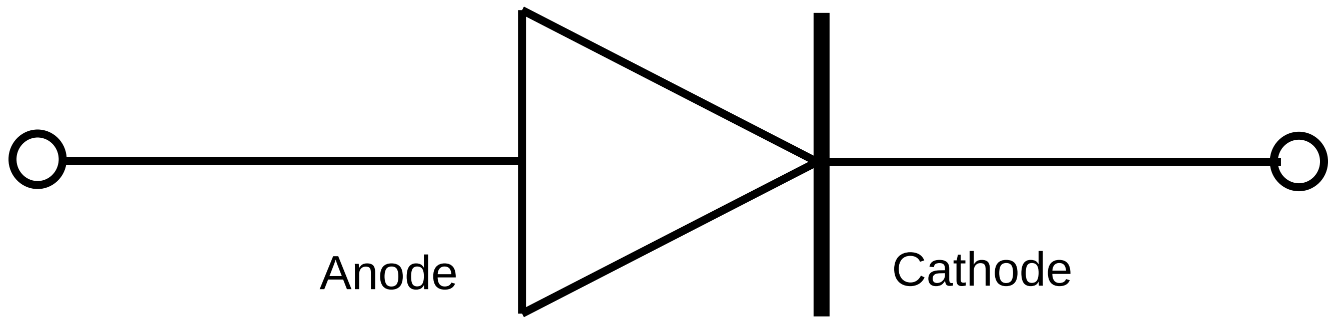


- A diode

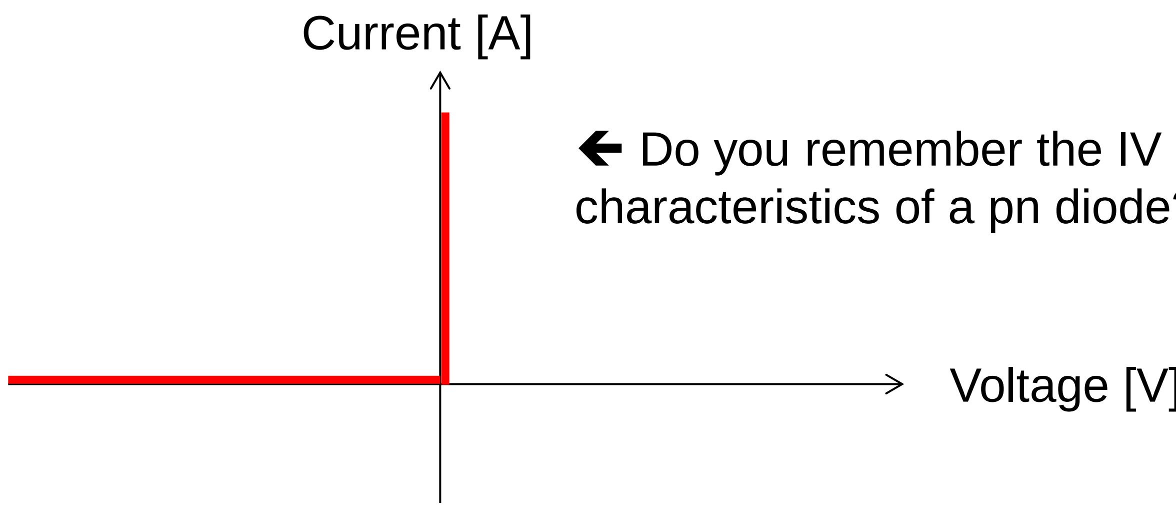


Diode

- Its symbol



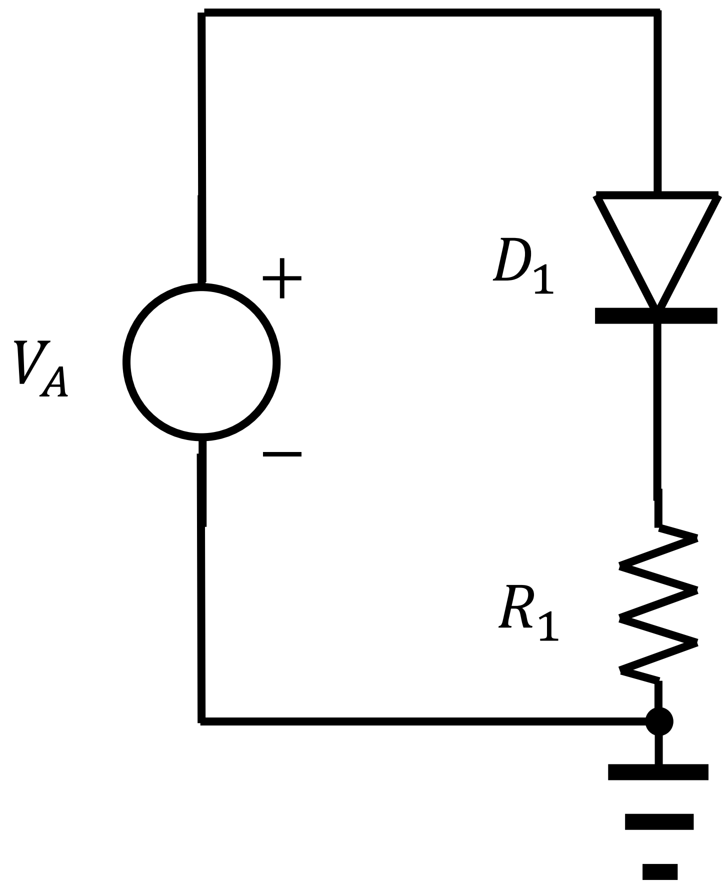
- Ideally, a perfect rectifier



← Do you remember the IV characteristics of a pn diode?

Example 3.4

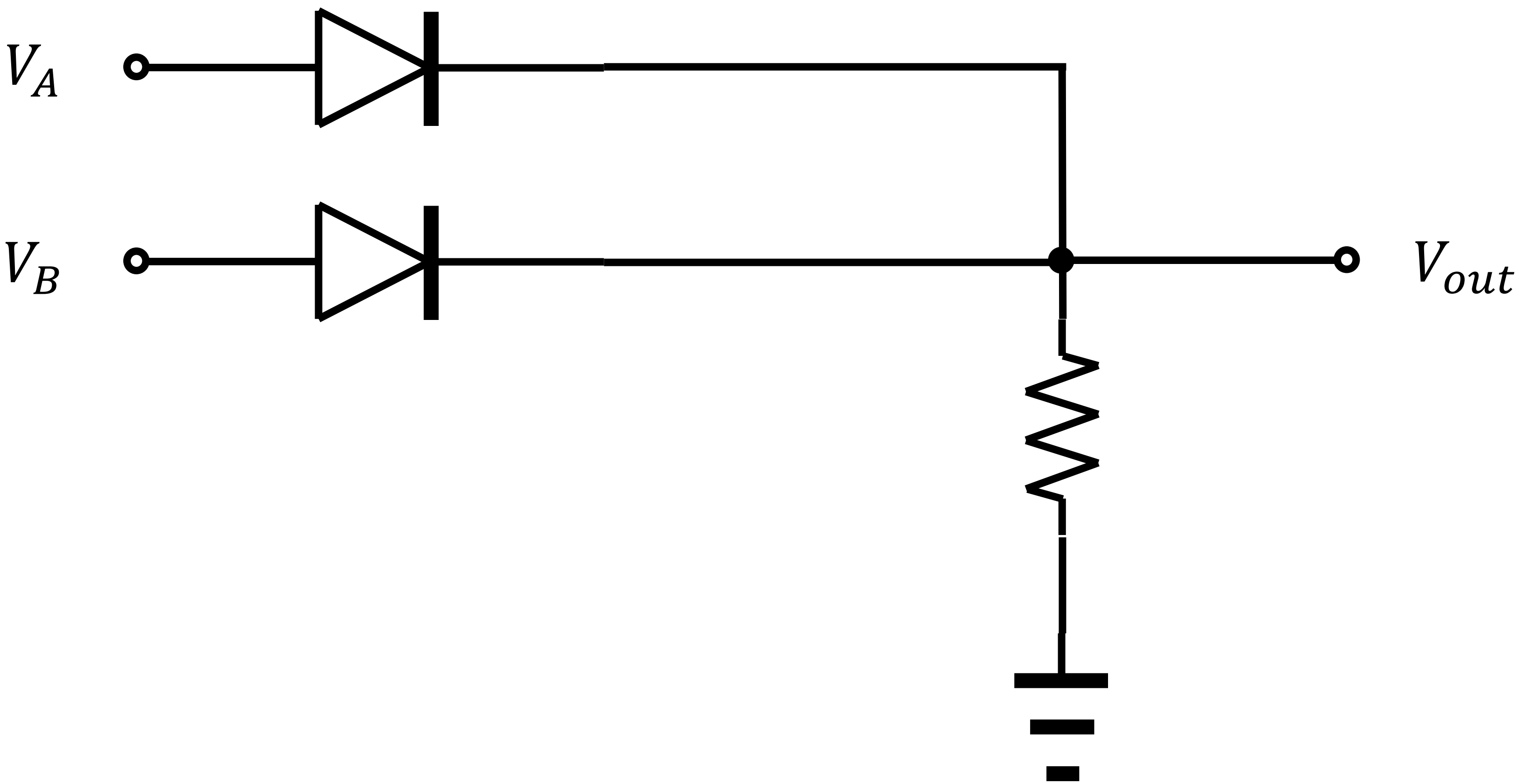
- A diode-resistor combination



🡐 Consider two cases, $V_A > 0$ and $V_A < 0$.
🡐 Draw the IV curve.

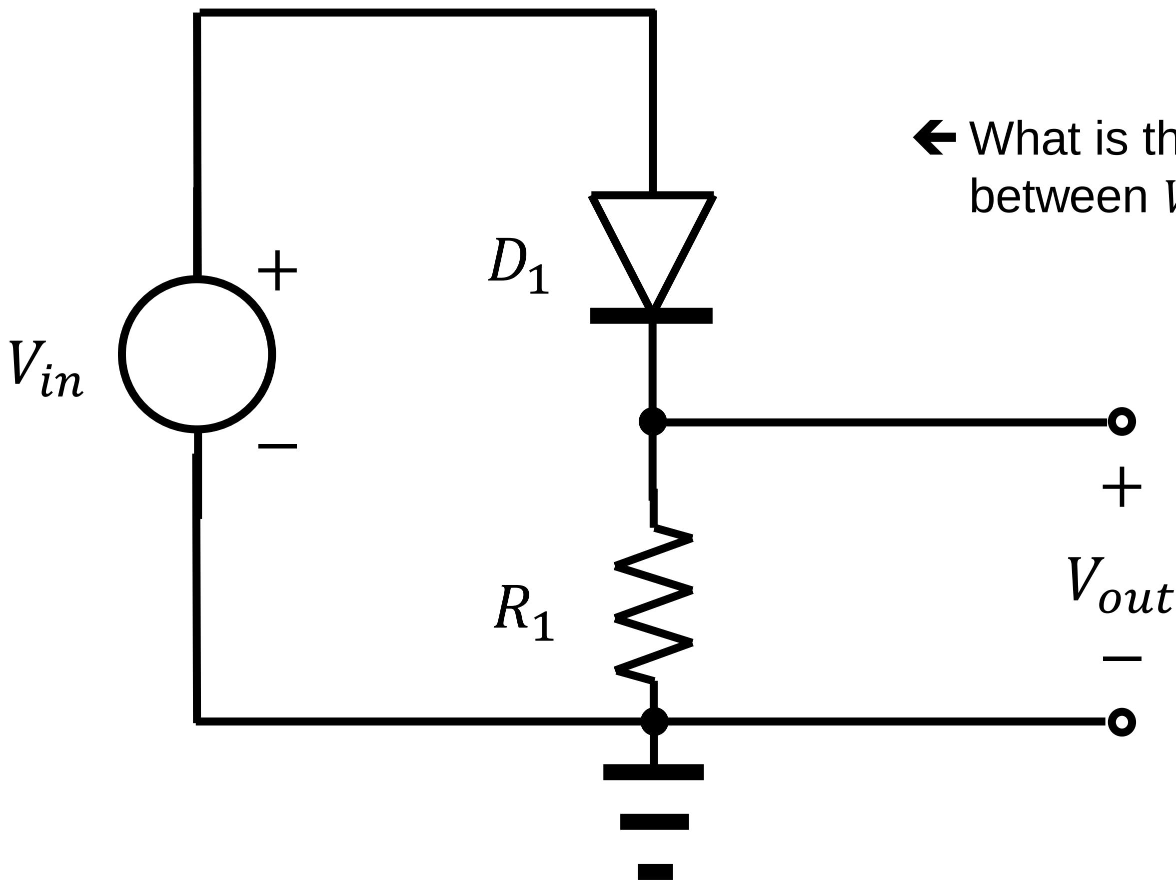
Example 3.6

- An OR gate



Rectifier

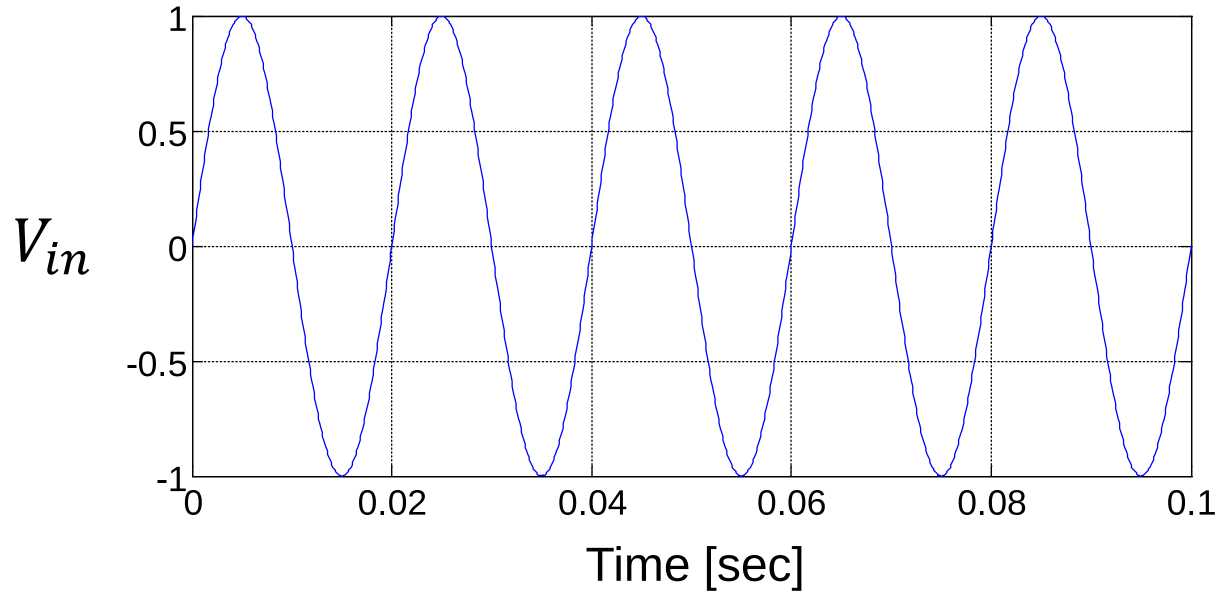
- Same circuit shown in Example 3.4.



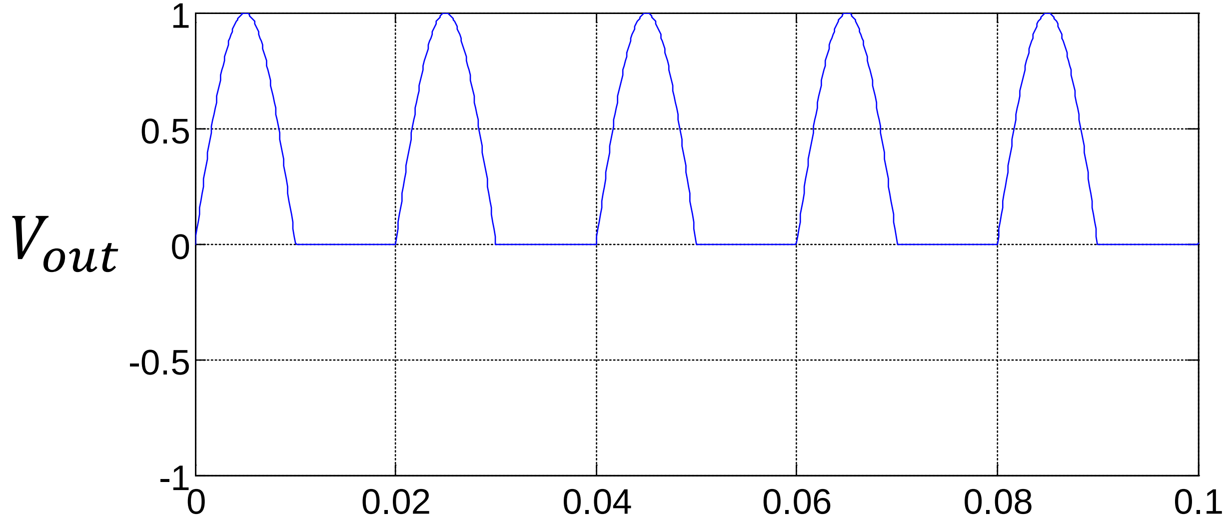
← What is the relation between V_{in} and V_{out}?

Input vs. output

- Input
  - 50 Hz
  - Pure sine
  - No dc

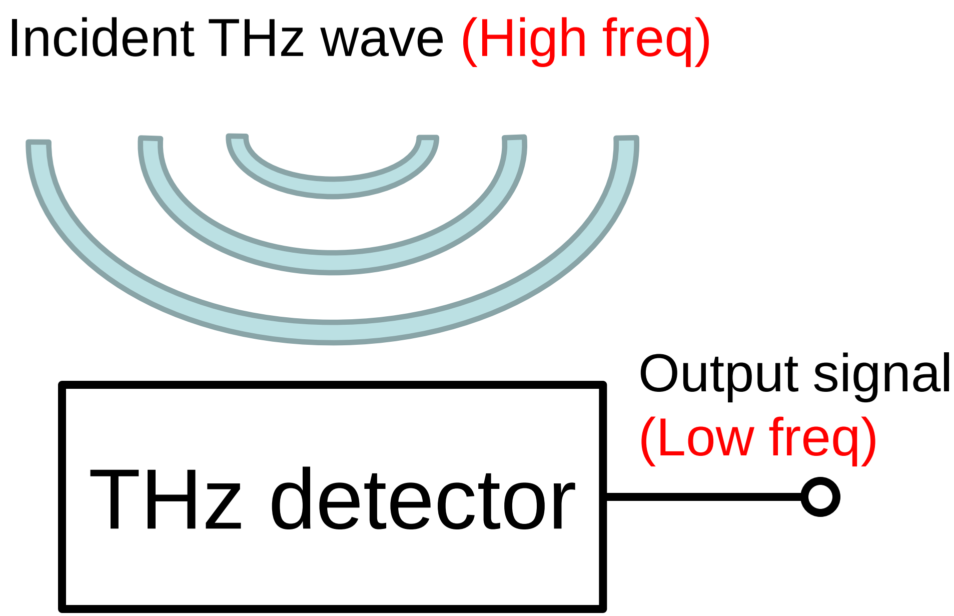


- Output
  - 0, 50, 100, … Hz
  - dc voltage: $\frac{1}{\pi}$ V



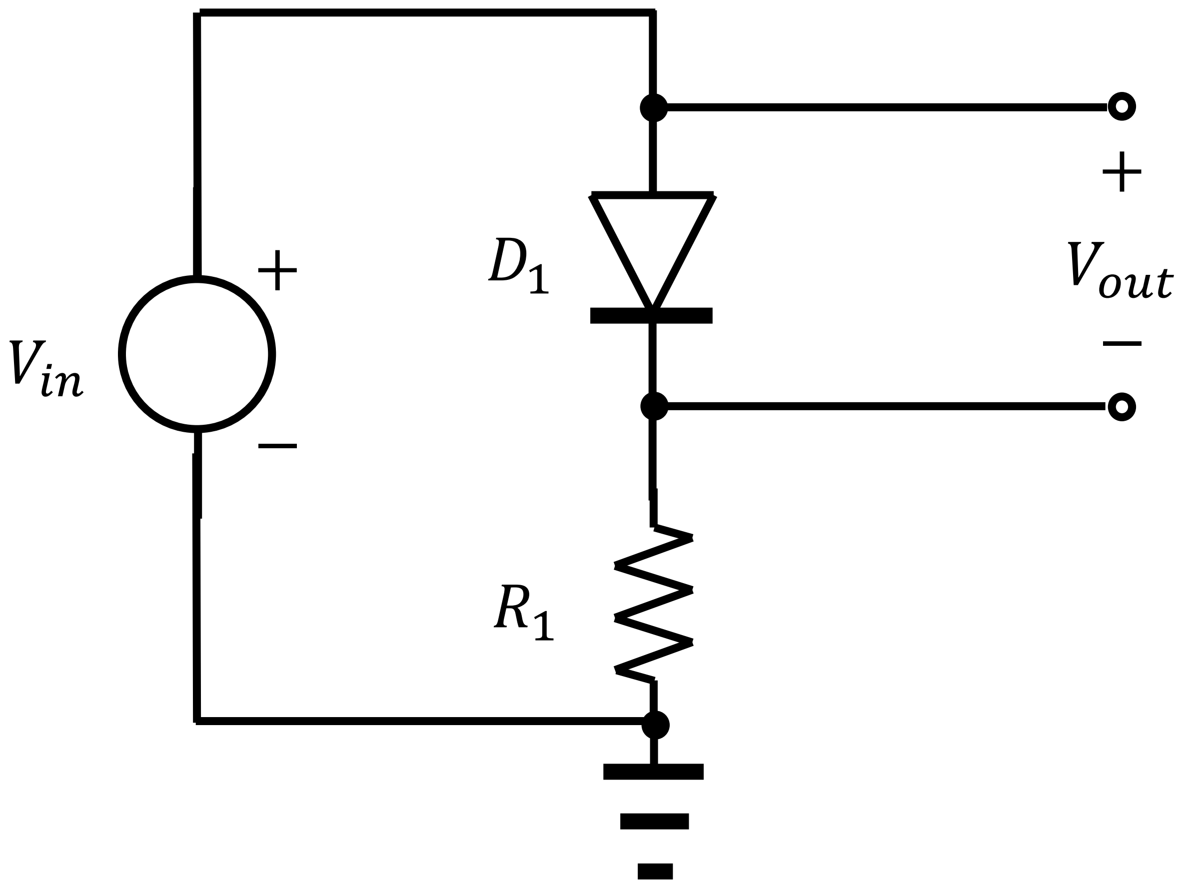
Concept!

- How to detect the electromagnetic radiation
  - Nonlinearity is required.



Rectifier, revisited

- Same circuit shown in Example 3.4.



pn junction as a diode

- Exponential model

$$I_D = I_s\left(\exp\frac{V_D}{V_T} - 1\right)$$

- Constant-voltage model
  - An "offset" voltage of $V_{D,on}$