Lecture6: Diode

Sung-Min Hong (smhong@gist.ac.kr)

Semiconductor Device Simulation Lab.
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

GIST On-Line Lecture on April 1, 2020 (Internal use only)

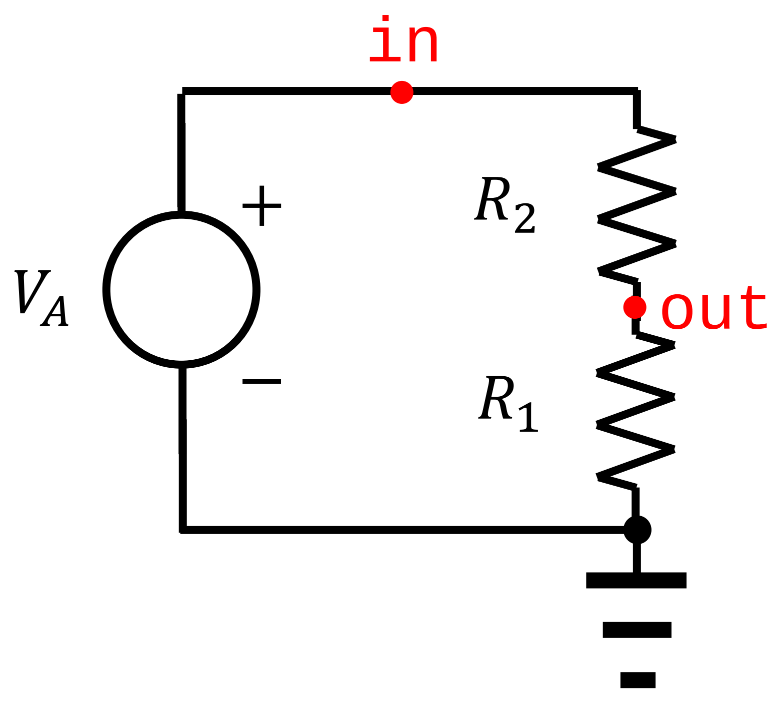
A circuit with two resistors

- Analyze the following circuit.
  - Two equations from the KCL (Let's avoid nested subscripts.)

$$I_{VA} + I_{R2} = 0$$
$$-I_{R2} + I_{R1} = 0$$

  - Three equations from elements

$$V_{in} = V_A$$
$$I_{R2} = \frac{V_{in} - V_{out}}{R_2}$$
$$I_{R1} = \frac{V_{out}}{R_1}$$



- We can solve it easily.
  - A set of linear equations

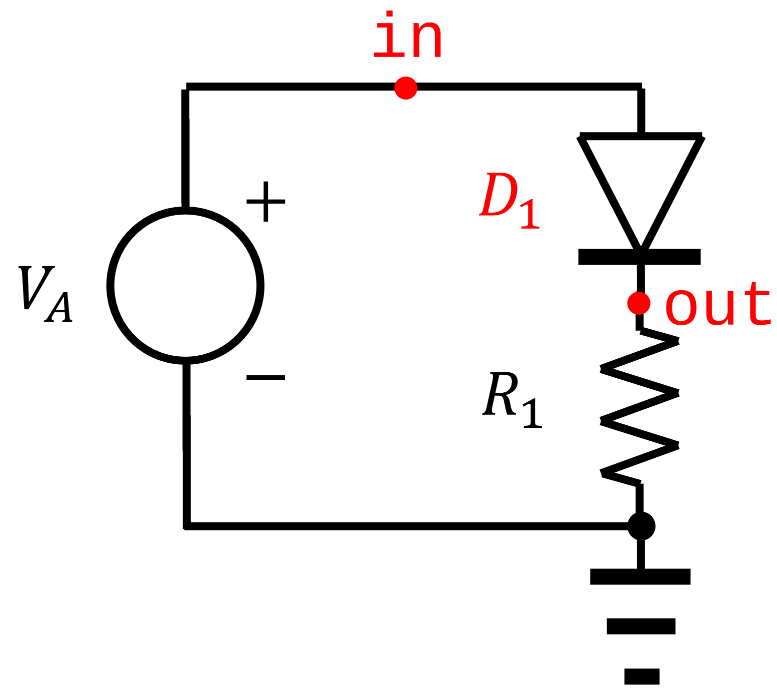
A circuit with a diode

- Then, analyze the following circuit.
  - Two equations from the KCL

$$I_{VA} + I_{D1} = 0$$
$$-I_{D1} + I_{R1} = 0$$

  - Three equations from elements

$$V_{in} = V_A$$
$$I_{D1} = I_s\left(\exp\left(\frac{V_{in} - V_{out}}{V_T}\right) - 1\right)$$
$$I_{R1} = \frac{V_{out}}{R_1}$$



- We CANNOT solve it easily.
  - A set of nonlinear equations

General solution

- Solve the set of equations.
  - After simple manipulation, it is easily found that

$$r(V_{out}) = -I_S\left(\exp\left(\frac{V_A - V_{out}}{V_T}\right) - 1\right) + \frac{V_{out}}{R_1} = 0$$

  - A nonlinear equation for V_{out} is obtained.
- An example inspired by Razavi, Example 2.21
  - In this example,

$$I_S = 10^{-16}\ \mathrm{A}$$
$$R_1 = 1\ \mathrm{k\Omega}$$
$$V_A = 1\ \mathrm{V}$$

  - Assume 300 K.
  - How can we solve it?

Iterative method

- Trial-and-error
  - Try $V_{out} = 1\ \mathrm{V}$. (Of course, it is not a solution.)
  - Then, we have

$$r(V_{out} = 1\ \mathrm{V}) = \frac{1\ \mathrm{V}}{1\ \mathrm{k\Omega}} = 1\ \mathrm{mA} \neq 0$$

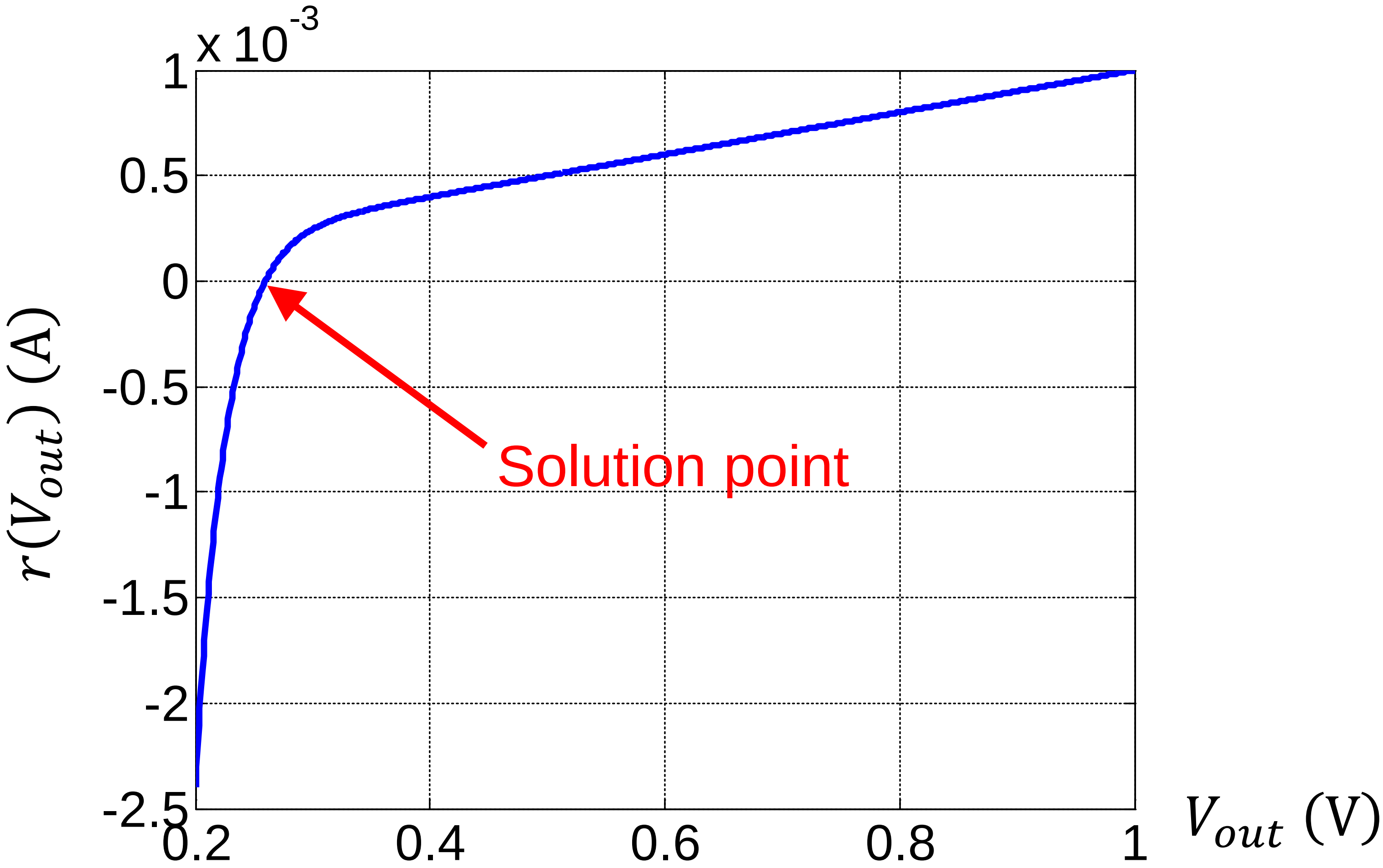
  - Okay, (as expected) it is not a solution. How about $V_{out} = 0.9\ \mathrm{V}$?
  - Then, we have

$$r(V_{out} = 0.9\ \mathrm{V}) = -10^{-16}\ \mathrm{A} \times \left(\exp\left(\frac{0.1\ \mathrm{V}}{V_T}\right) - 1\right) + \frac{0.9\ \mathrm{V}}{1\ \mathrm{k\Omega}} = 0.9\ \mathrm{mA} \neq 0$$

  - How about $V_{out} = 0.8\ \mathrm{V}$?
  - How about $V_{out} = 0.7\ \mathrm{V}$?
  - How about $V_{out} = 0.6\ \mathrm{V}$?
  - How about $V_{out} = 0.5\ \mathrm{V}$?
  - Repeat it until you get the solution…

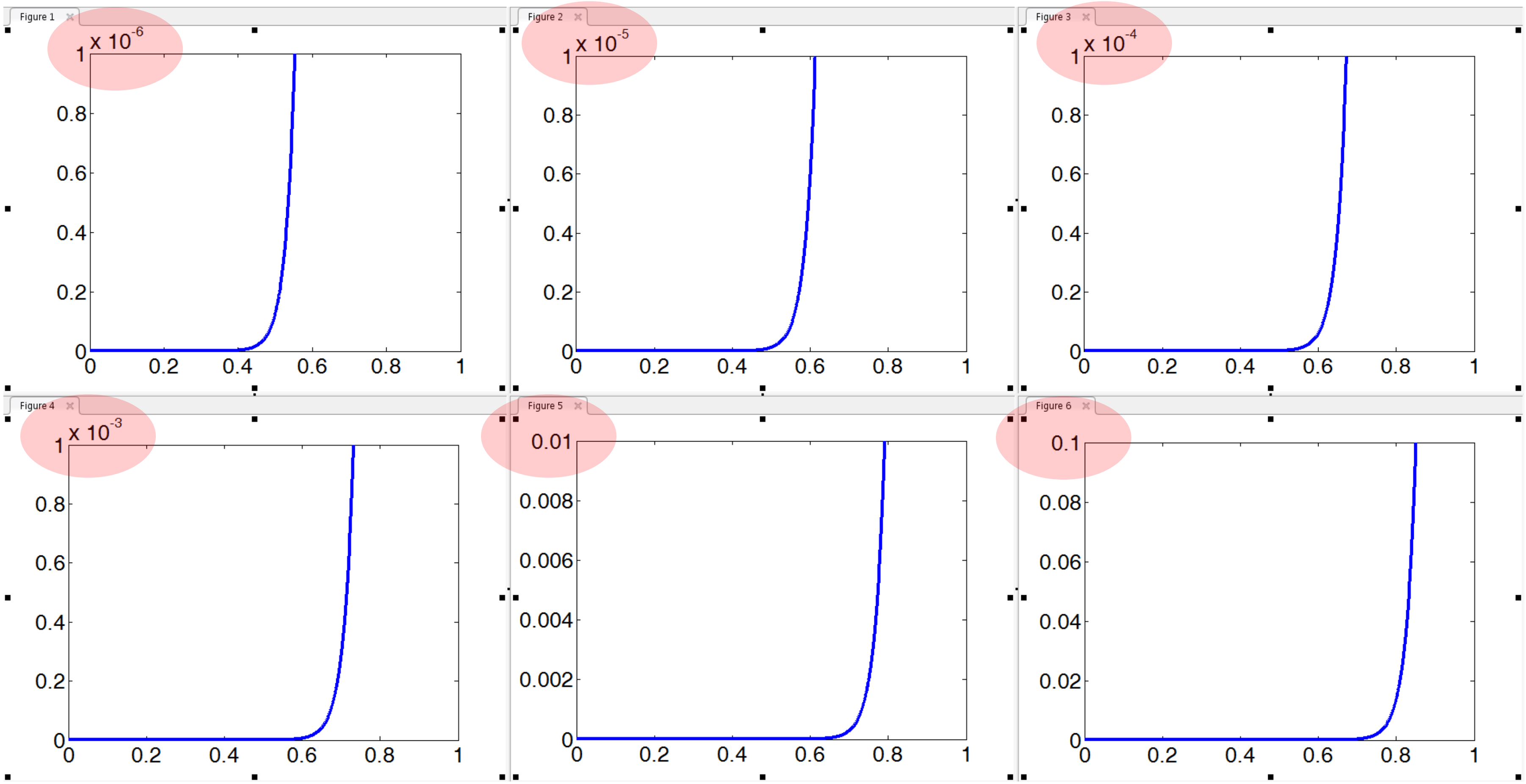
Visualization of $r(V_{out})$

- Nonlinear function



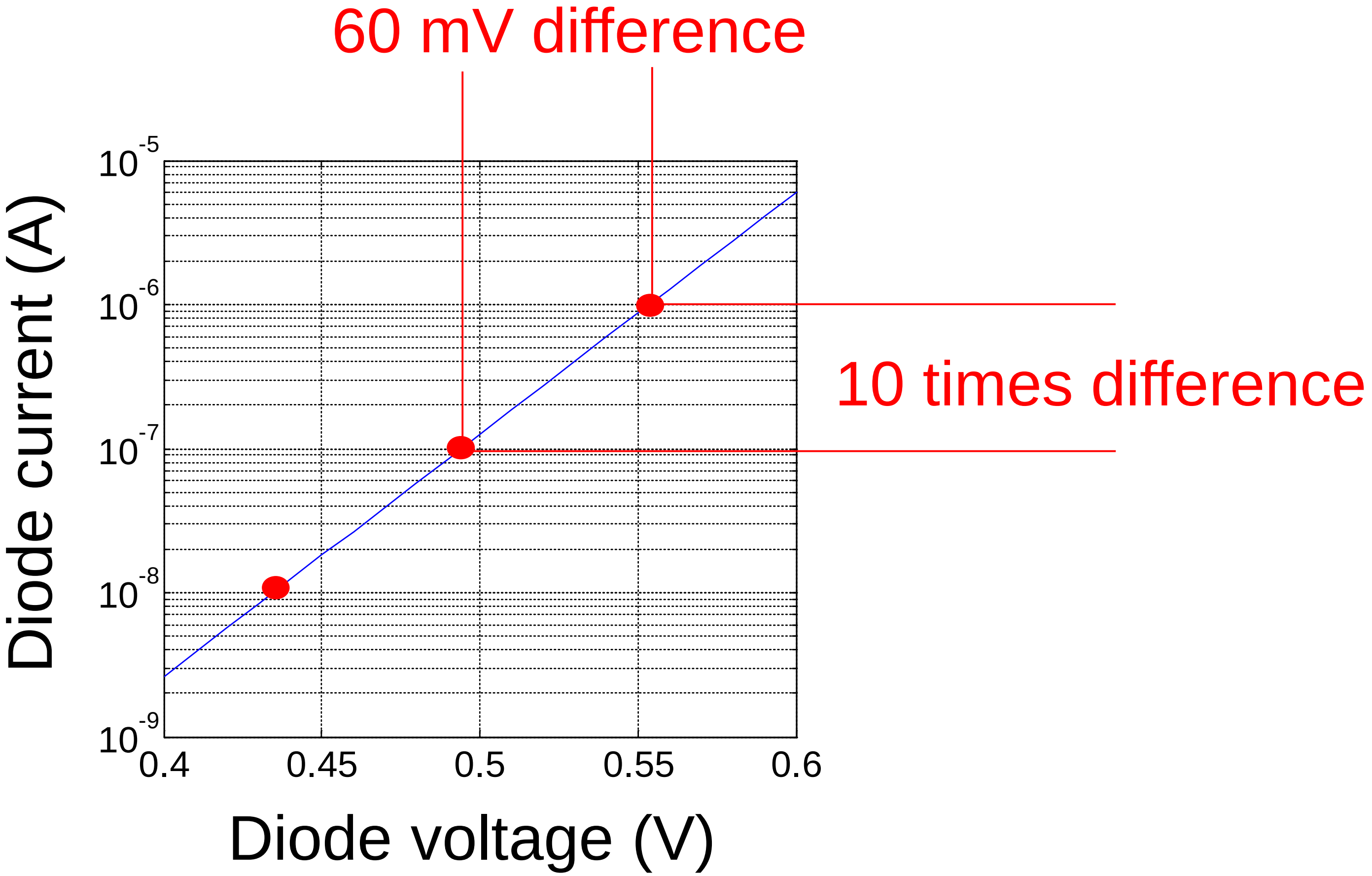
Diode I-V curves

- A diode with $I_S = 5 \times 10^{-16}$A (Only different y scales)



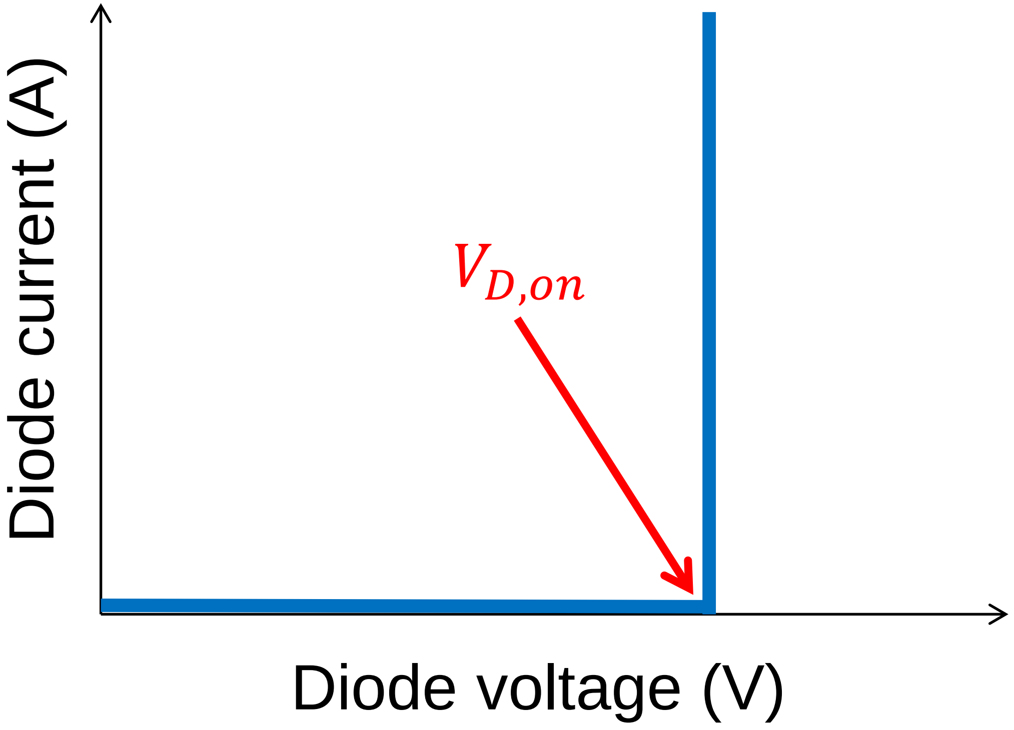
Important observation

- In order to obtain 10x larger current,
  - We must apply only 60 mV additionally. (300K)



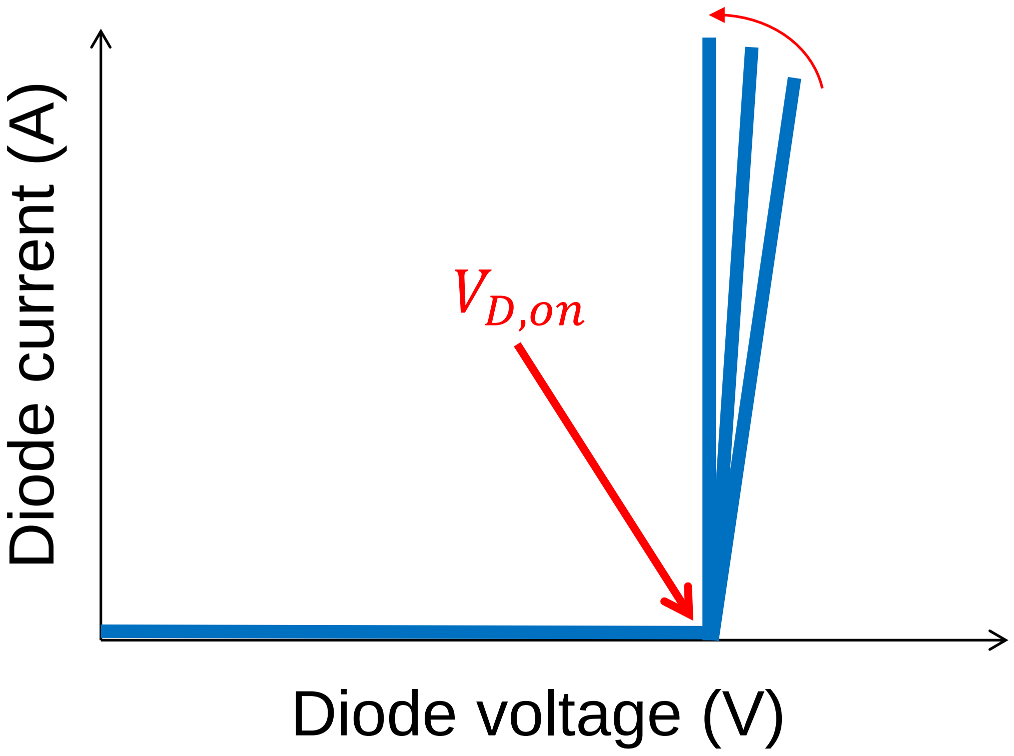
Constant-voltage model

- Two phases



Confused by abrupt increase?

- The vertical line should be interpreted as
  - A limiting case of a very steep slope

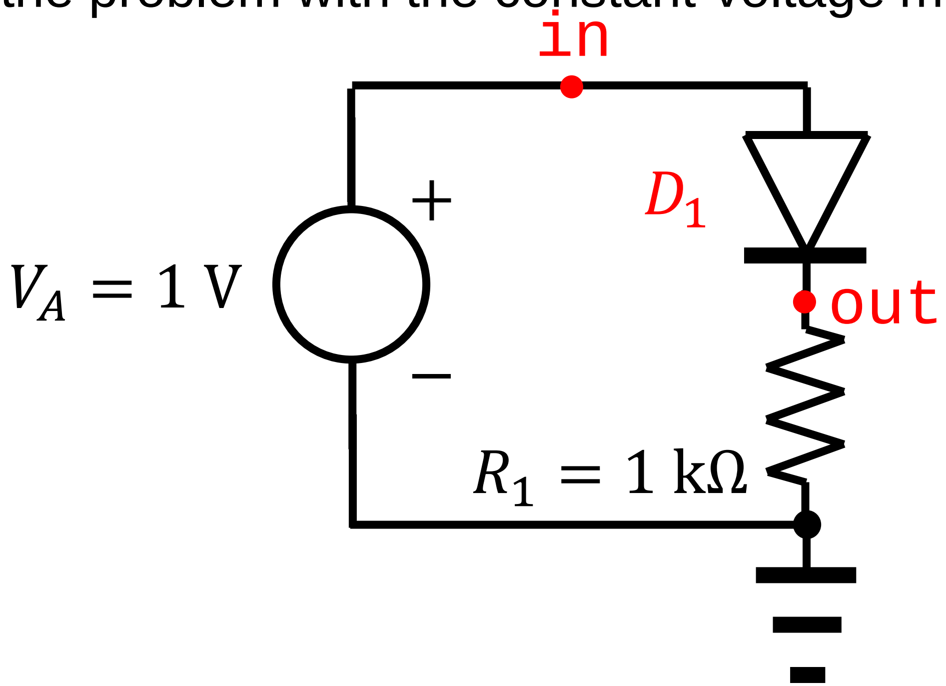


Revisiting our example

- Our previous example
  - In this example,

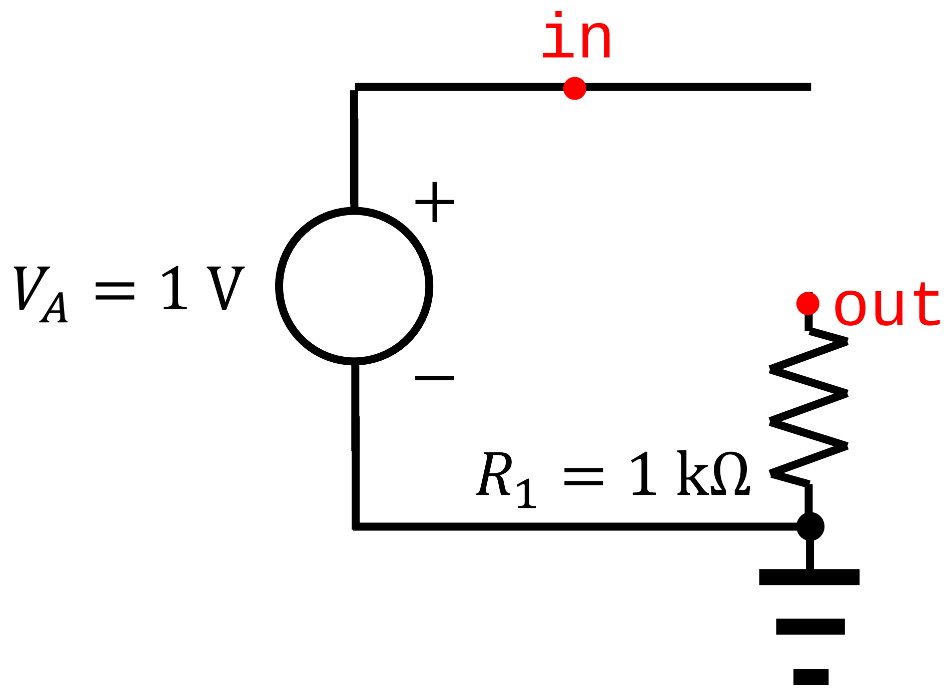
$$I_S = 10^{-16}\ \mathrm{A}$$
$$R_1 = 1\ \mathrm{k\Omega}$$
$$V_A = 1\ \mathrm{V}$$

  - Solve the problem with the constant-voltage model.



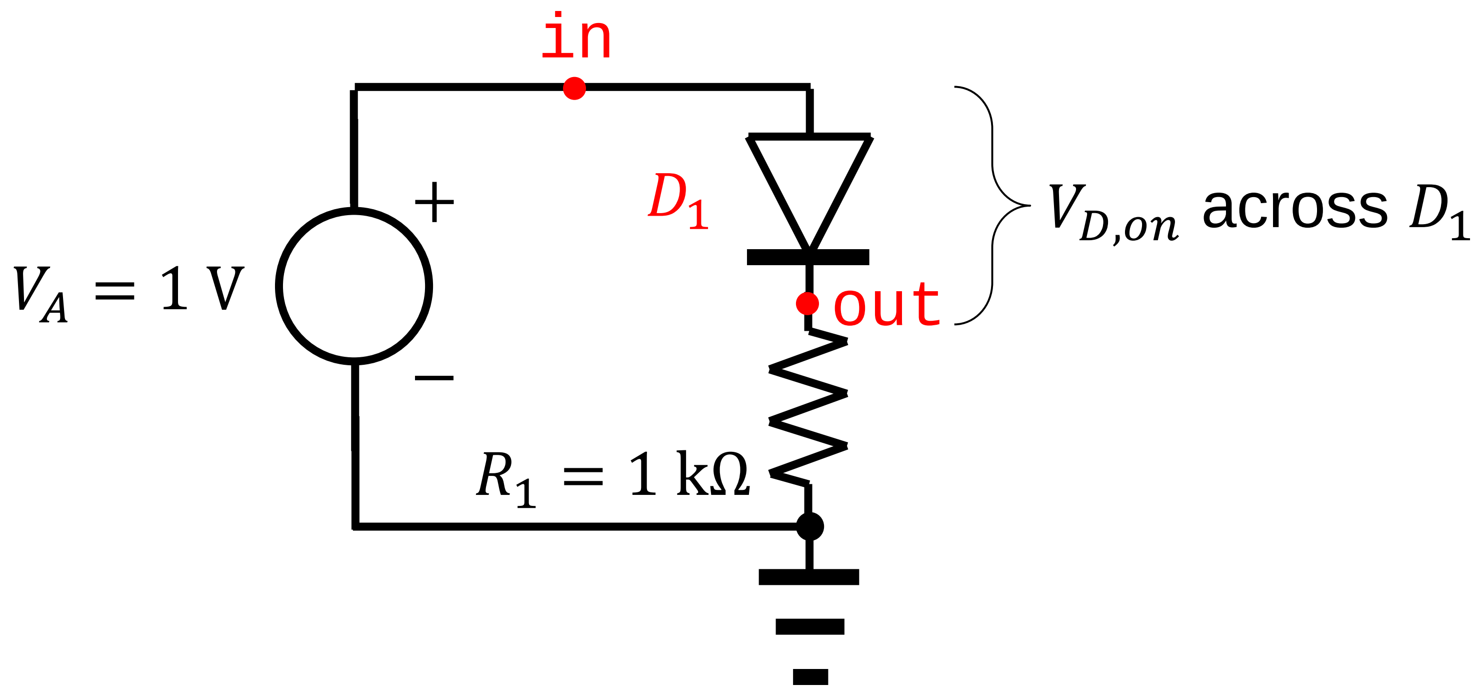
Turned off?

- Assume that the diode is turned off.
  - Then, the diode does not conduct a current.
  - Calculate V_{out}. Obviously, it must be 0 V.
  - However, it means that 1 V is applied to the diode. Since 1 V is certainly larger than $V_{D,on}$, our assumption does not hold.



Turned on?

- Assume that the diode is turned on.
  - Then, the diode can conduct a large current.
  - Calculate V_{out}. Obviously, it must be $1\ \mathrm{V} - V_{D,on}$.
  - Then, is it 0.3 V? Or 0.2 V? It depends on $V_{D,on}$.
  - The current would be around 0.2 mA ~ 0.3 mA.



Even better job?

- We know where the solution is. (You don't start from 1 V.)