Modeling the Diode Forward Characteristic

- Simple circuit consisting of a source, a resistor, and a diode.
- For forward bias we have 2 models for the diode.

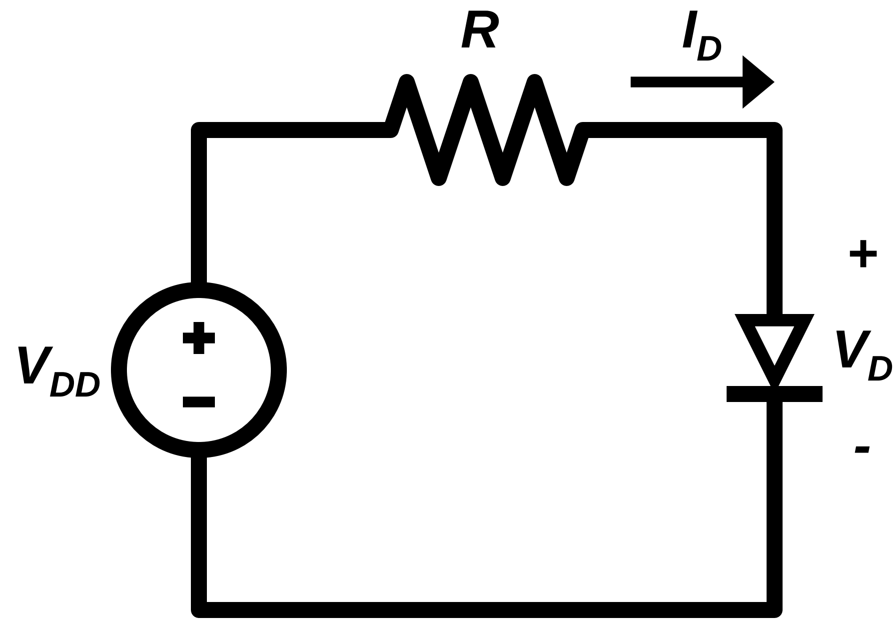
  1) Ideal Diode: Short Circuit

$$V_D = 0$$

$$I_D > 0$$

  2) Exponential Model

$$I_D = I_S e^{V_D / nV_T}$$



- In this section, we will:

  1) Address the suitability of these two models.

  2) Develop new models.

- This will help us to:

  1) Analyze diode circuits efficiently.

  2) Provide a foundation for modeling trasistor operation.

Modeling the Diode Forward Characteristic

A) The Exponential Model

1) The most accurate model.

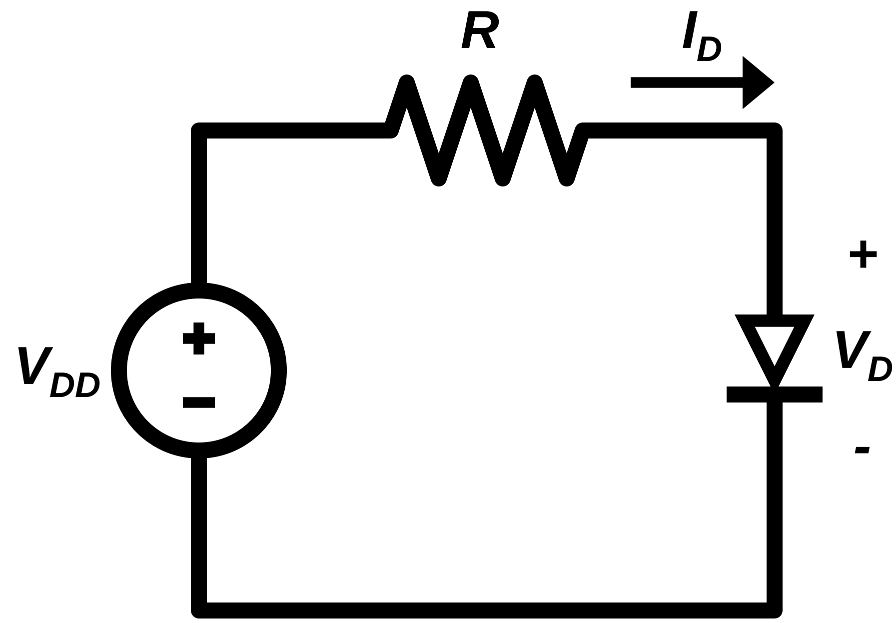
2) The hardest to analyze.

Let's analyze a circuit using the exponential model.

$$I_D = I_S e^{V_D / nV_T}$$

$$I_D = I_R = \frac{V_{DD} - V_D}{R}$$

$$I_D = -\frac{1}{R} V_D + \frac{V_{DD}}{R}$$



I_S, n, V_T are know quantities.
We have two equaition with two unknowns.

Q. How do we solve for I_D and V_D?

Modeling the Diode Forward Characteristic

Graphically

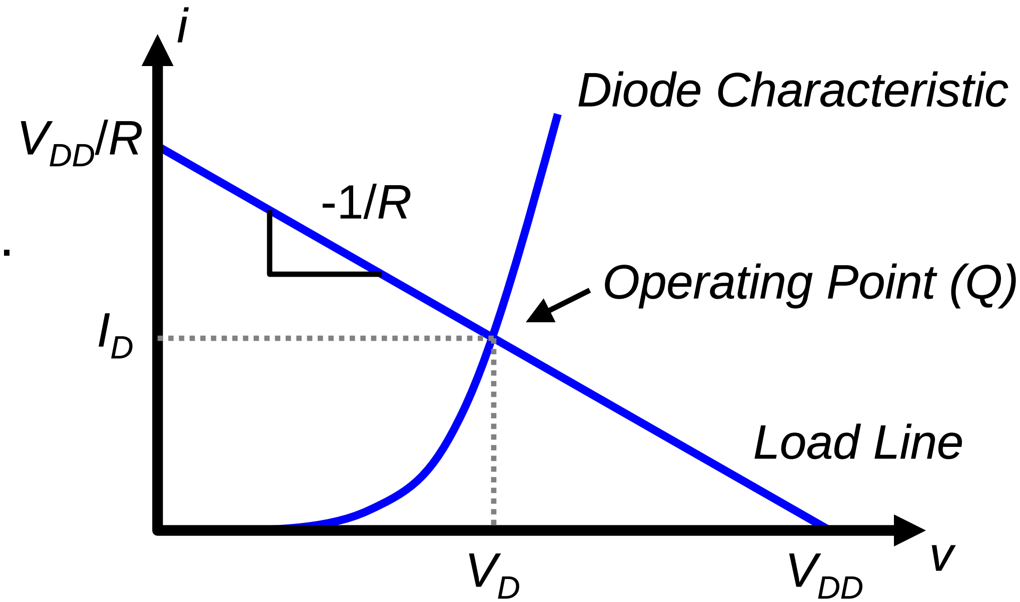
a) Plot the two equations on the *i*-*v* plane.

Eq. 1: diode characteristic curve.

$$I_D = I_S e^{V_D / nV_T}$$

Eq. 2: load line.

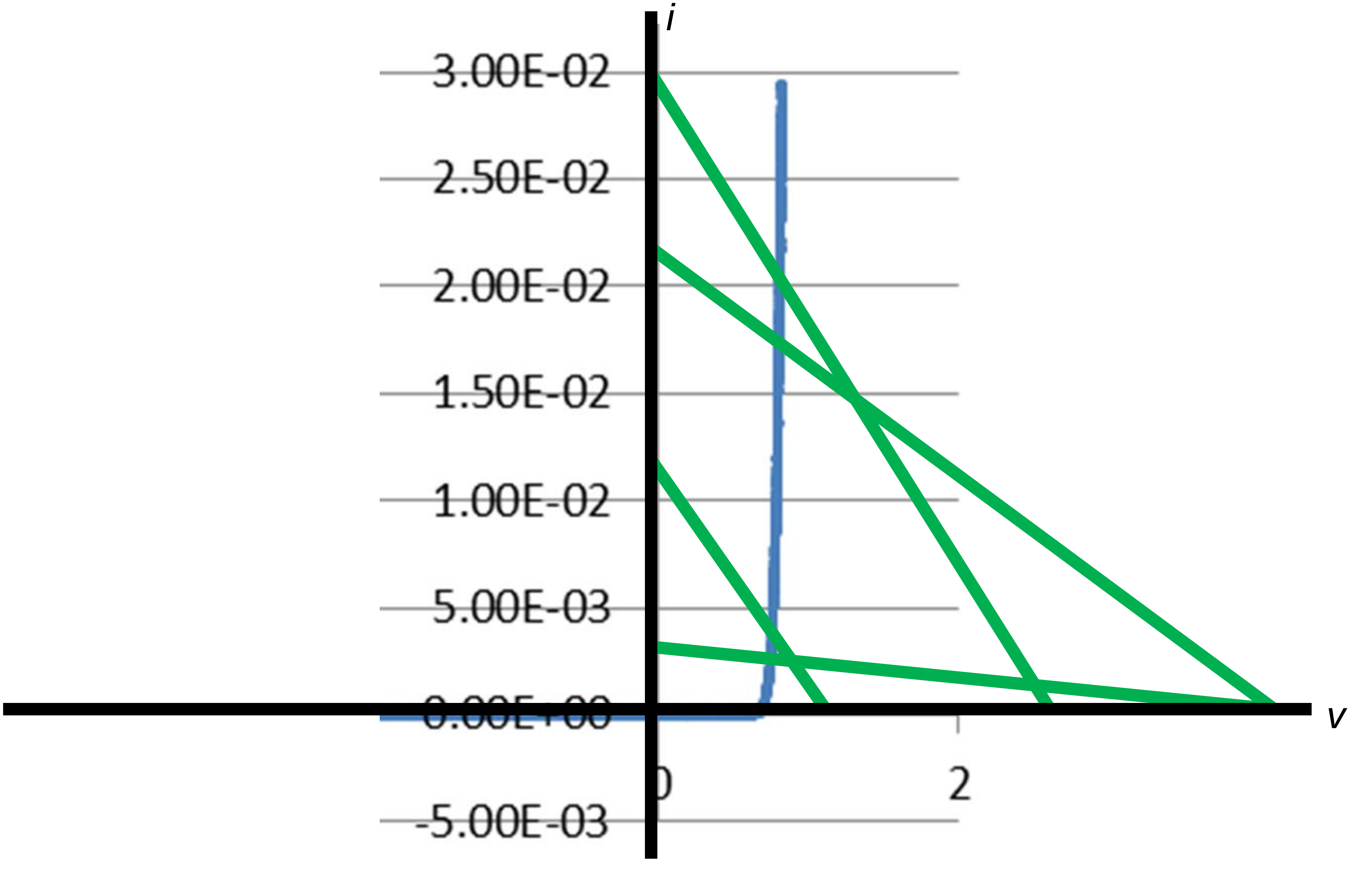
$$I_D = -\frac{1}{R} V_D + \frac{V_{DD}}{R}$$



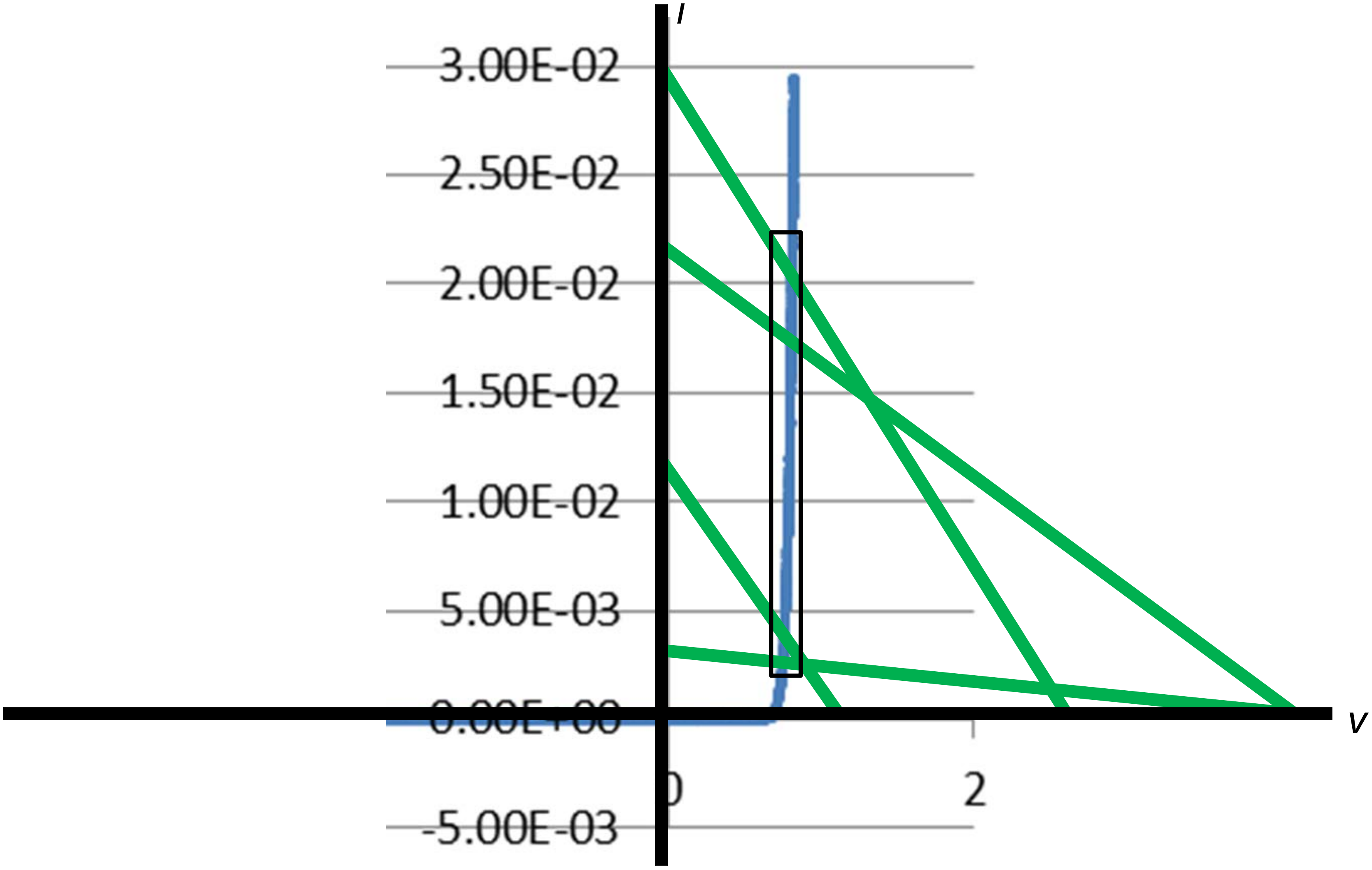
b) The solution is the intersection, *Q*, of the two curves and is referred to as the operating point.

- Graphical analysis becomes very difficult for complex circuits.
- Too difficult to be justified for practical use.

Modeling the Diode Forward Characteristic

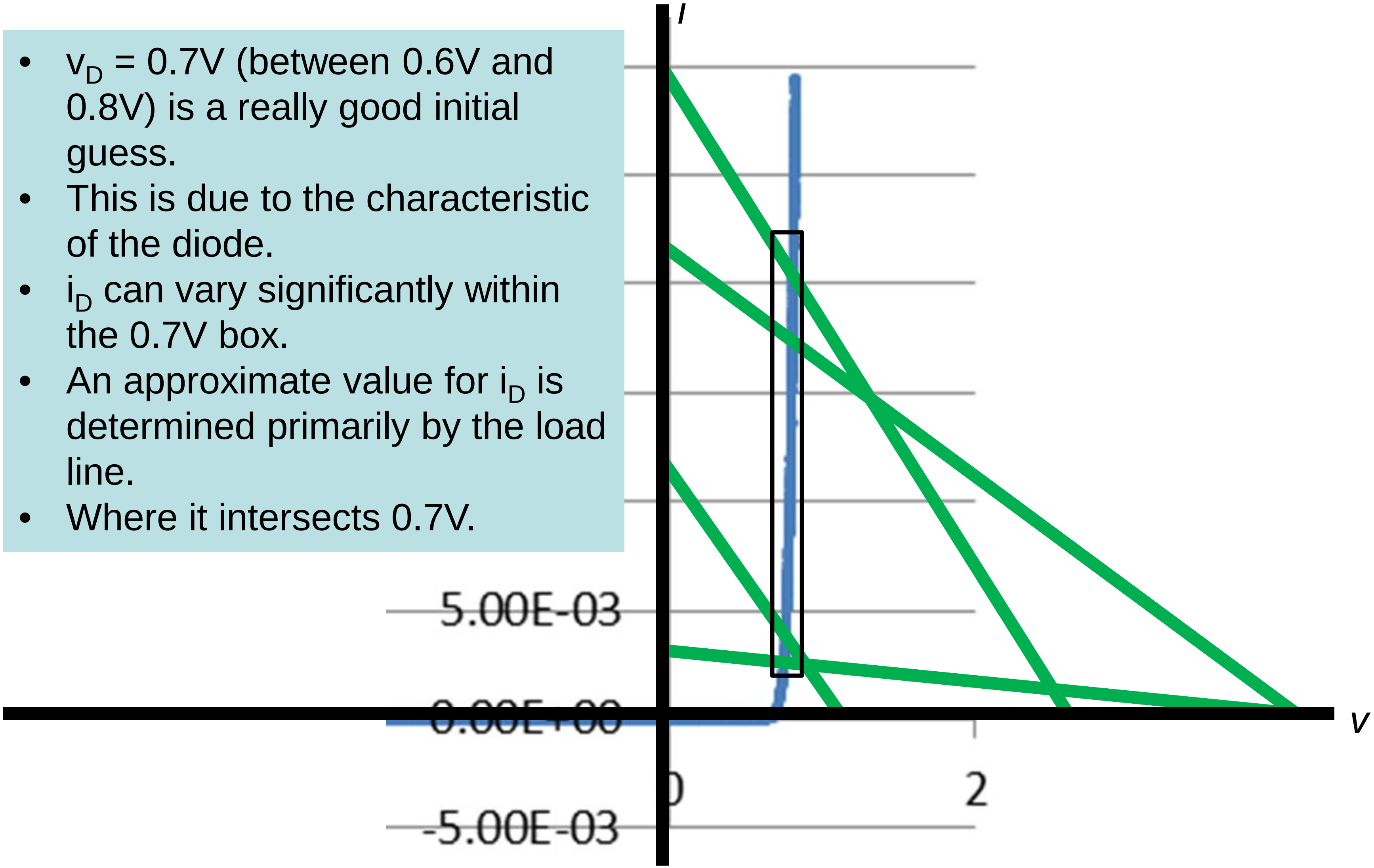


Modeling the Diode Forward Characteristic



Modeling the Diode Forward Characteristic

- v_D = 0.7V (between 0.6V and 0.8V) is a really good initial guess.
- This is due to the characteristic of the diode.
- i_D can vary significantly within the 0.7V box.
- An approximate value for i_D is determined primarily by the load line.
- Where it intersects 0.7V.



Modeling the Diode Forward Characteristic

Iterative analysis

Remember the two equations: $I_D = I_S e^{V_D / nV_T}$ Diode Characteristic

$$I_D = -\frac{1}{R} V_D + \frac{V_{DD}}{R}$$ Load Line

What do we know about a diode in forward bias?
The voltage across the diode is between 0.6 and 0.8 Volts.

Approach:

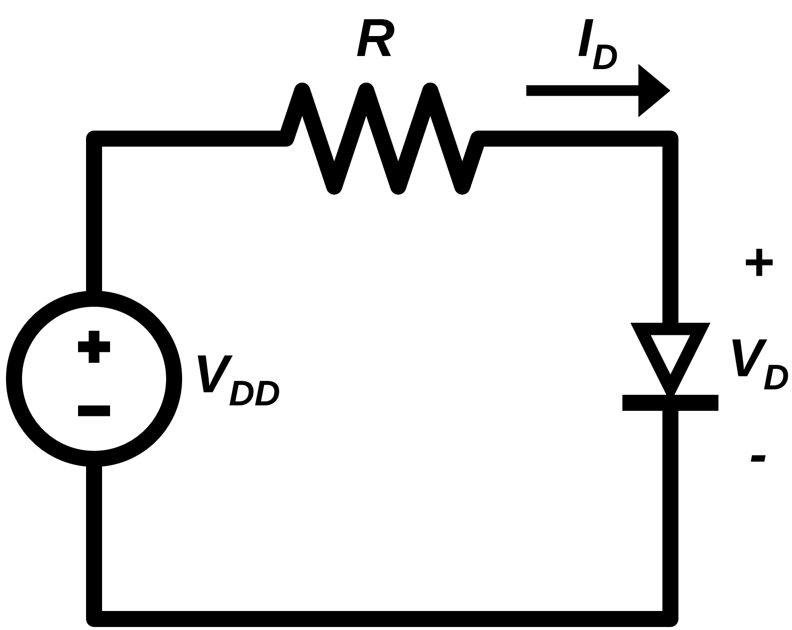
1) Assume V_D is 0.7 Volts.
2) Solve for I_D using circuit equation (load line).
3) Calculate new value of V_D or ΔV_D using the Diode Characteristic curve.

$$V_D = nV_T \ln\left(I_D / I_S \right) \quad \text{or} \quad \Delta V_D = nV_T \ln\left(I_{D2} / I_{D1} \right)$$

4) Go back to step 2 and repeat until the answer converges.

Modeling the Diode Forward Characteristic

From the measurements:
nV_T = .05 V, $I_S = 1 \times 10^{-8}$ A
V_{DD} = 5 V, and R=1 kΩ.



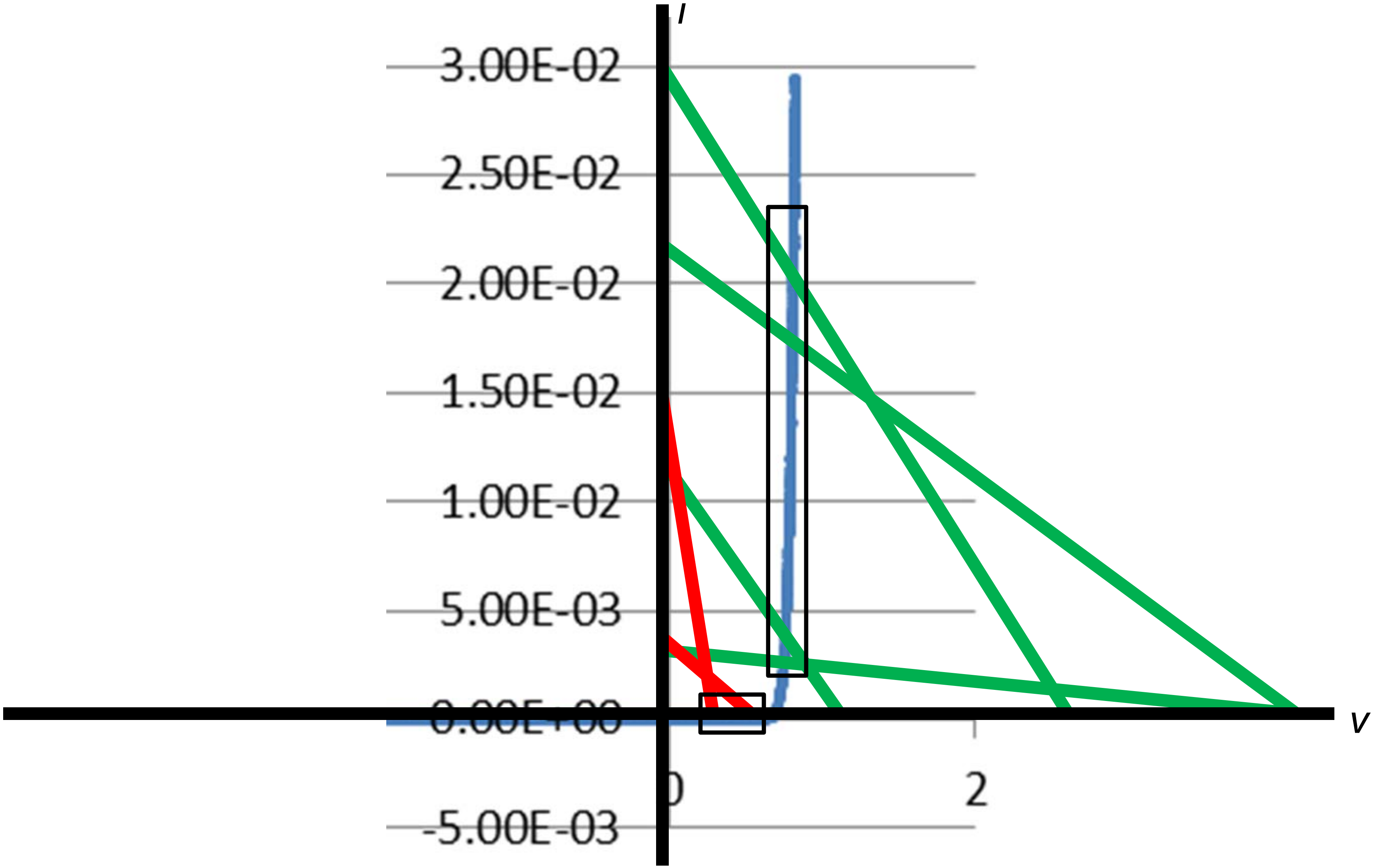
Modeling the Diode Forward Characteristic

- For complex circuits this approach is very time consuming to do by hand, because you must re-analyze the circuit for each iteration.
- However, this approach can be easily iterated using computer analysis.

Conclusions

- the graphical and iterative solution methods using the exponential model are inefficient.
- For effective circuit analysis a simple model for the junction diode is needed.

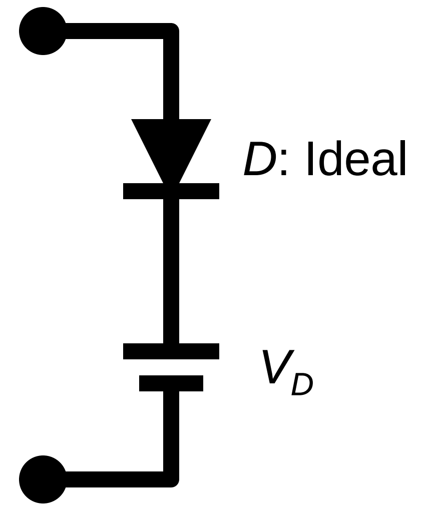
Modeling the Diode Forward Characteristic



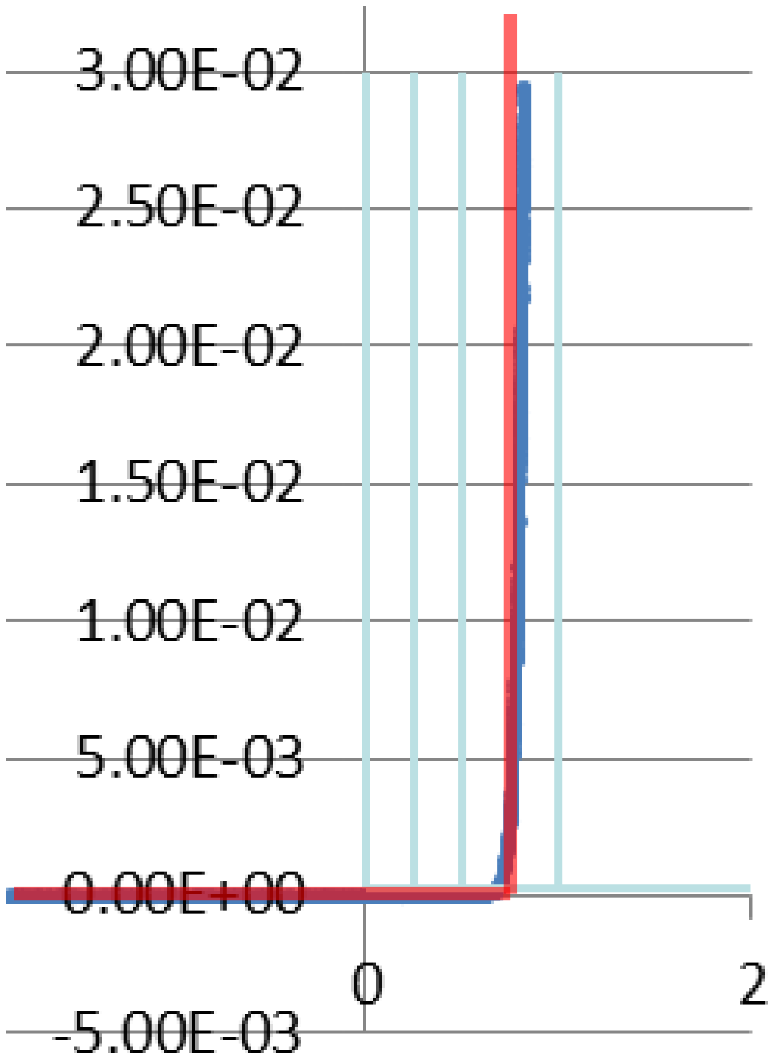
Modeling the Diode Forward Characteristic

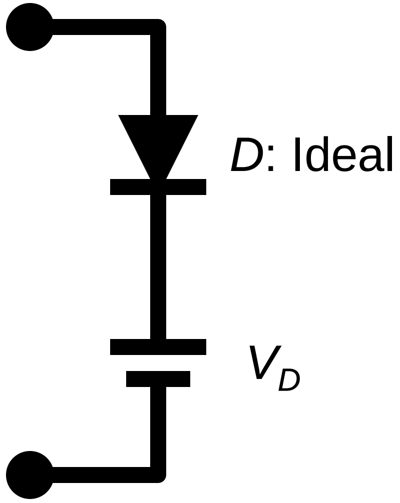
The Constant Voltage Drop Model.

- Consider the i-v relationship for the following configuration.
- An ideal diode, a battery.
- V_D uses a value between 0.6V and 0.8V (typically 0.7V).
- The battery models the small amount of potential needed to start conducting.



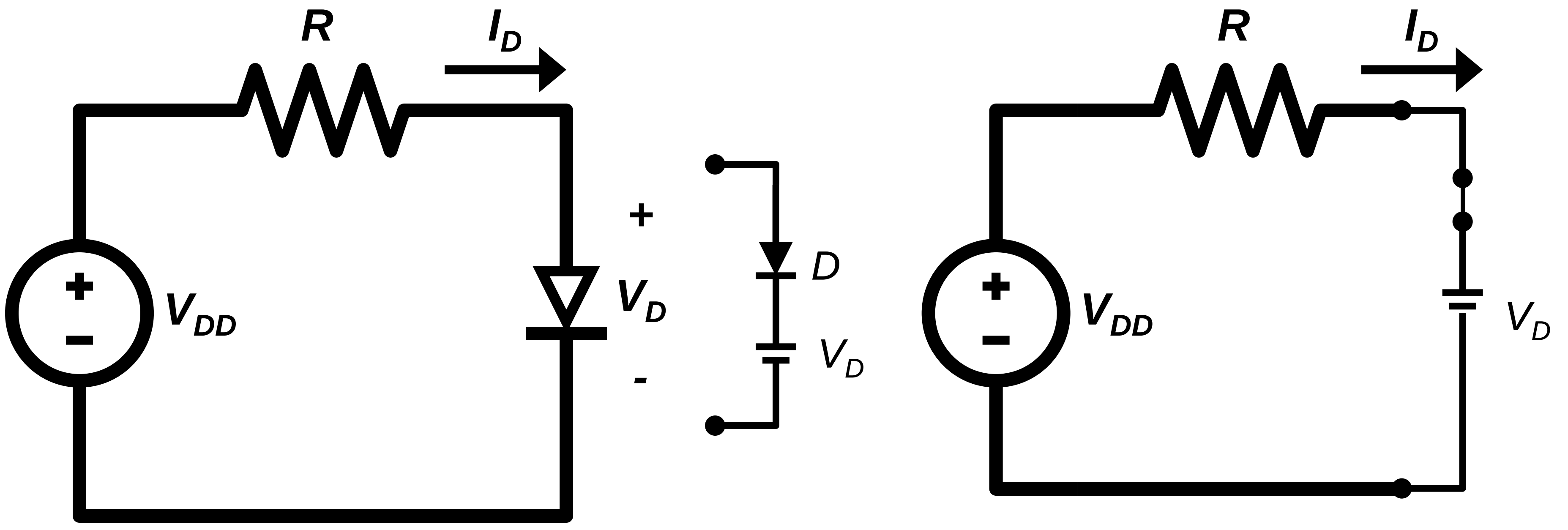
Modeling the Diode Forward Characteristic





Modeling the Diode Forward Characteristic

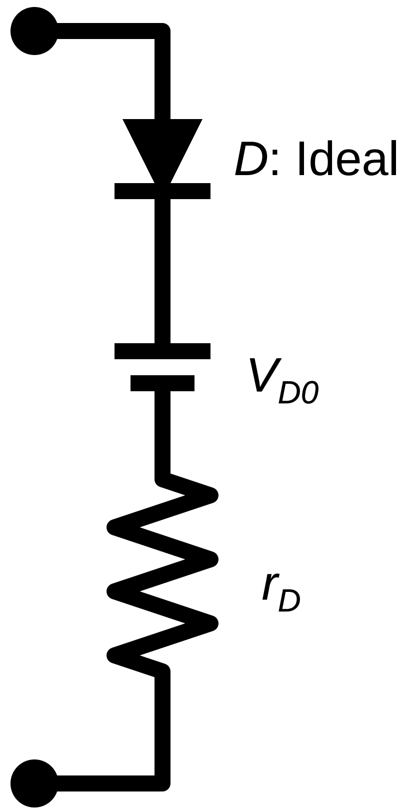
V_D=0.7



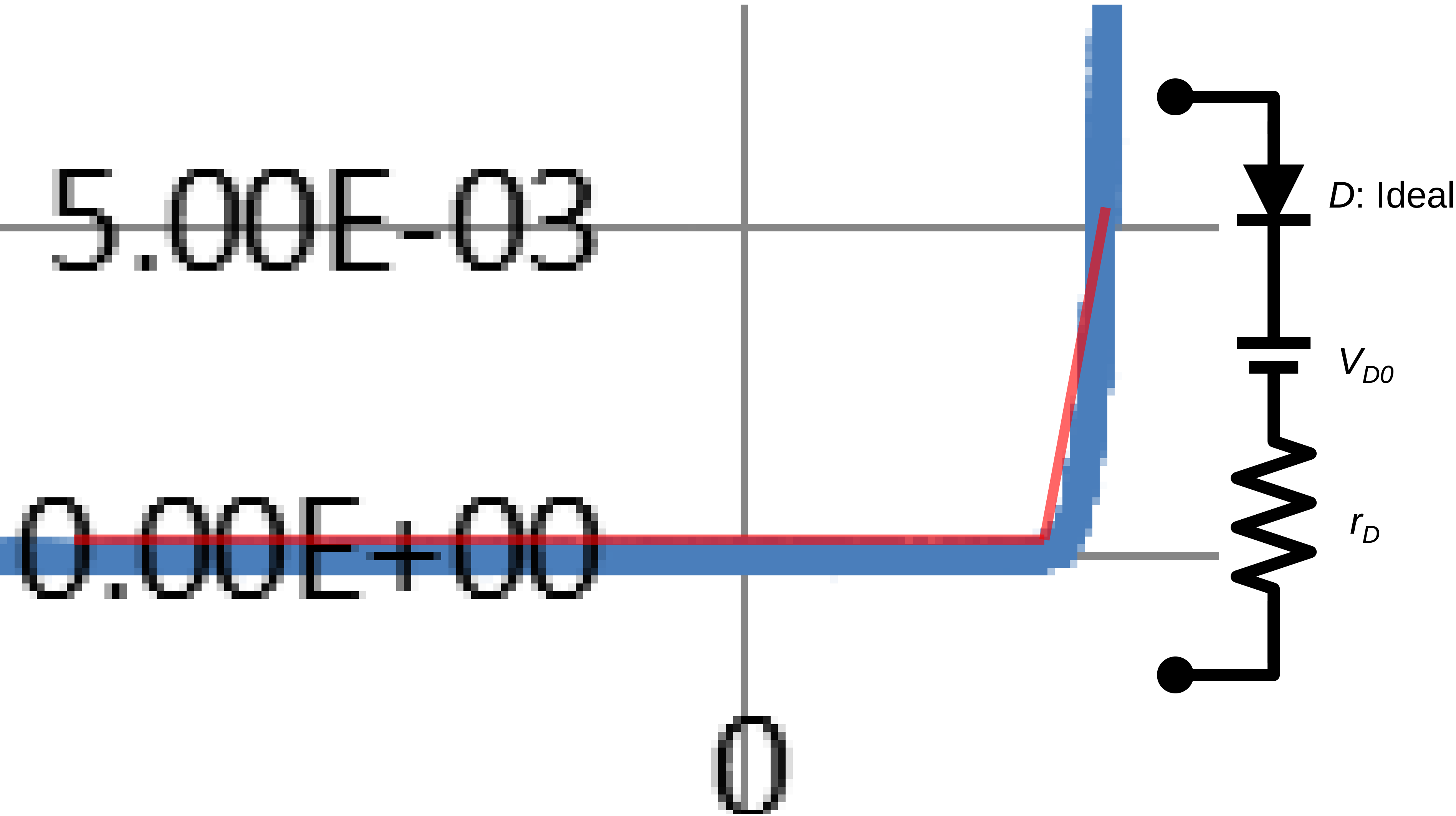
Modeling the Diode Forward Characteristic

The Constant Voltage Drop Model.

- Consider the i-v relationship for the following configuration.
- An ideal diode, a battery, and a resistor.
- V_D uses a value between 0.6V and 0.8V (typically 0.7V).
- The battery models the small amount of potential needed to start conducting.
- The resistor models the slope of the exponential curve.

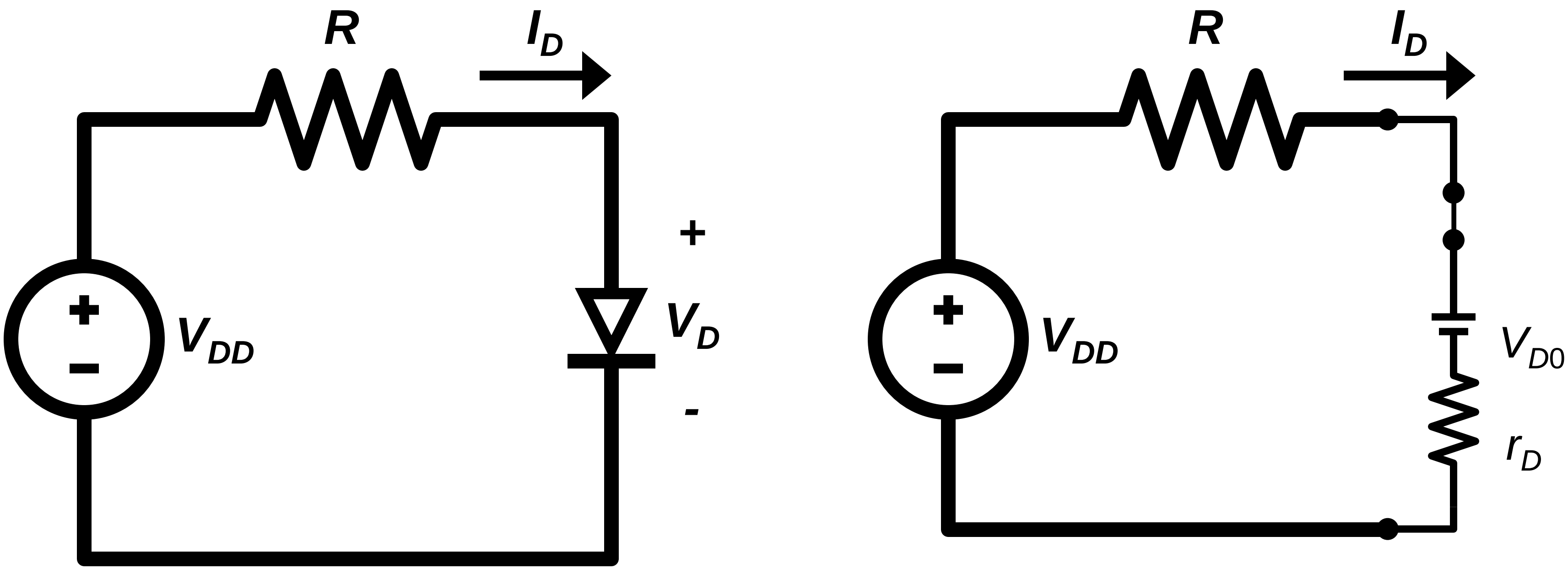


Modeling the Diode Forward Characteristic



Modeling the Diode Forward Characteristic

V_{D0}=0.6 V and r_D=20 Ω.



Modeling the Diode Forward Characteristic

Q. How are values for V_{D0} and r_D determined?
A. Minimize error within a certain range of operating conditions.

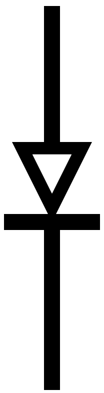
A. 1 point and a slope.

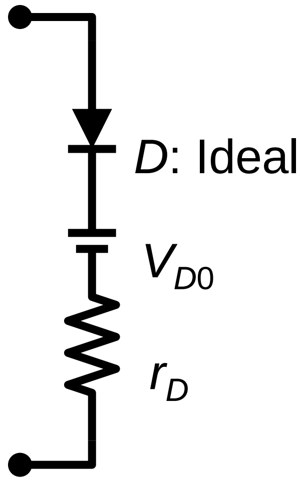
A. Given 2 points we can find a line.

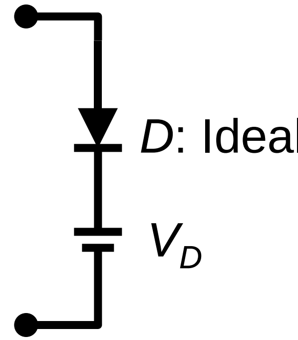
Modeling the Diode Forward Characteristic

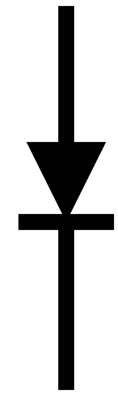
Accurate (*depends on correct model parameters*) Simple

Exponential	Battery Plus Resistance Piecewise Linear	Constant Voltage Drop	Ideal









Exponential:

$$i_d = I_S e^{v_d / nV_T}$$

Battery Plus Resistance Piecewise Linear:

$$i_d = 0, \quad v_d \le V_{D0}$$

$$i_d = \frac{v_d - V_{D0}}{r_D}, v_d \ge V_{D0}$$

Constant Voltage Drop:

$$i_d = 0, \quad v_d \le V_D$$

$$i_d = short, v_d \ge V_D$$

Ideal:

$$i_d = 0, \quad v_d \le 0$$

$$i_d = short, v_d \ge 0$$

Exponential	Battery Plus Resistance Piecewise Linear	Constant Voltage Drop	Ideal
V_D=0.649V	V_D=0.686V	V_D=0.7V	V_D=0.0V
I_D= 4.351mA	I_D= 4.314mA	I_D= 4.3mA	I_D= 5mA