Introduction to Diodes

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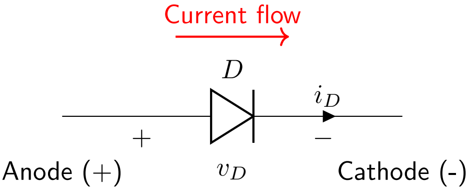
What is a Diode?

The Basic Idea:

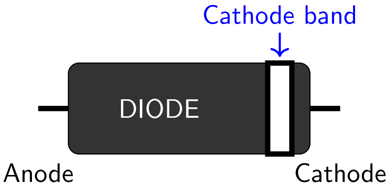
- Two-terminal semiconductor device
- Conducts current in one direction
- Blocks current in the other direction

Symbol and Terminals:



Triangle points in direction of current flow

Physical Device:



Key Applications:

- Rectification (AC to DC)
- Voltage regulation
- Signal clipping and protection
- Logic circuits

The Shockley Diode Equation

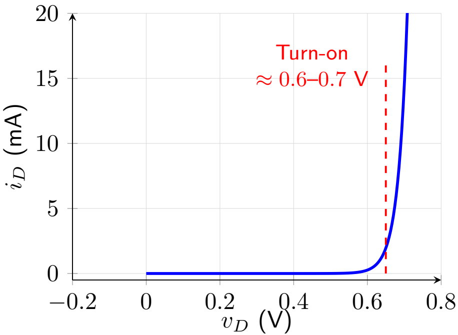
The relationship between voltage and current in a diode is described by the **Shockley equation**:

$$i_D = I_S \left(e^{v_D/nV_T} - 1 \right)$$

Parameters:

- i_D = diode current
- v_D = voltage across diode
- I_S = saturation current ($\approx 10^{-14}$ A)
- n = ideality factor (1-2)
- $V_T = kT/q$ = thermal voltage (about 25 mV at room temperature)
- k = Boltzmann's constant
- T = absolute temperature (K)
- q = elementary charge

Exponential Behavior:



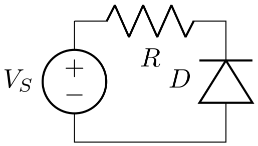
Current increases exponentially with voltage

Forward Bias Operation

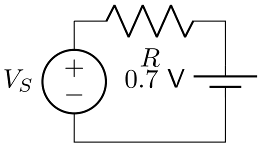
Forward Bias: Positive voltage applied to anode relative to cathode ($v_D > 0$)

Behavior:

- Little current until $v_D \approx 0.5$–0.6 V
- Current increases rapidly above this
- $v_D \approx 0.7$ V when conducting
- Voltage stays about constant once "on"

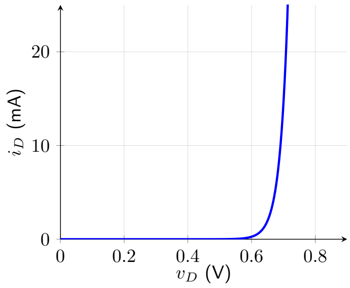


Actual diode



Simplified model

I-V Characteristic:



Small voltage change → Large current change

Reverse Bias Operation

Reverse Bias: Negative voltage applied to anode ($v_D < 0$)

Behavior:

- Small current magnitude
- Current $\approx -I_S$ (saturation current)
- Typically nanoamperes (nA)
- Diode is approximated as open circuit

From the Shockley Equation:

For $v_D < 0$ and $|v_D| >> V_T$:

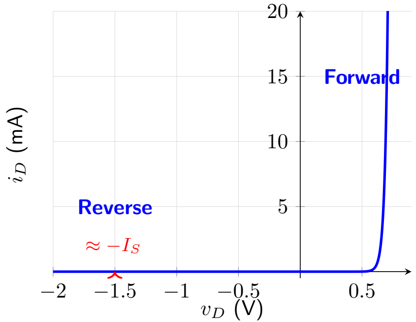
$$e^{v_D/nV_T} \approx 0$$

$$i_D \approx I_S(-1) = -I_S$$

Warning

Excessive reverse voltage causes breakdown and will damage diode

Complete I-V Characteristic:



One-way current flow

Small-Signal Resistance r_d

Two types of resistance:

DC Resistance:

$$R_D = \frac{V_D}{I_D}$$

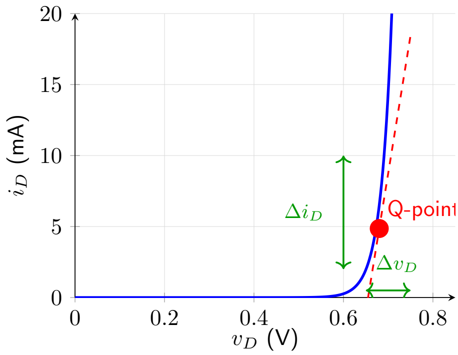
- Total voltage divided by total current

Small-Signal Resistance:

$$r_d = \frac{dv_D}{di_D} = \frac{nV_T}{I_D}$$

- Slope of I-V curve at operating point
- Used for small AC signal analysis
- Inversely proportional to DC current

Visualization:



Slope at Q-point $= 1/r_d$

Calculating Small-Signal Resistance r_d

Formula:

$$r_d = \frac{nV_T}{I_D}$$

At room temperature with $n = 1$ and $V_T = 25$ mV:

$$r_d \approx \frac{25 \text{ mV}}{I_D}$$

Examples:

I_D	r_d
1 mA	25 Ω
5 mA	5 Ω
10 mA	2.5 Ω
100 μA	250 Ω

Higher current $\rightarrow$ Lower resistance

Practical Measurement:
From measurements, use:

$$r_d \approx \frac{\Delta V_D}{\Delta I_D}$$

1. Measure V_D and I_D at operating point
2. Make small change in V_D
3. Measure new I_D
4. Calculate r_d

Why It Matters:

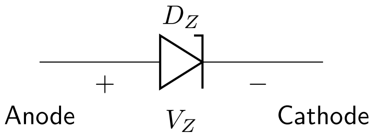
- Essential for AC circuit analysis
- Determines circuit impedance
- Used in small-signal models

Zener Diodes: Reverse Breakdown by Design

What's Different?

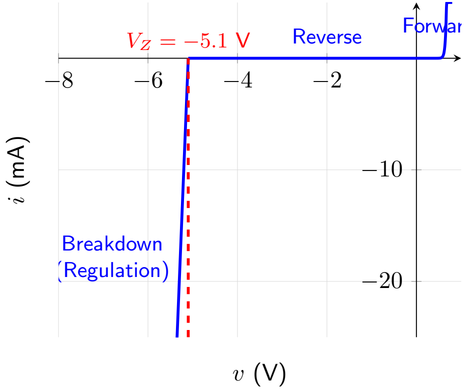
- Designed to operate in reverse breakdown
- Has a specific breakdown voltage (V_Z)
- Maintains near constant voltage in breakdown
- Used for voltage regulation

Symbol:



Bent line distinguishes from regular diode

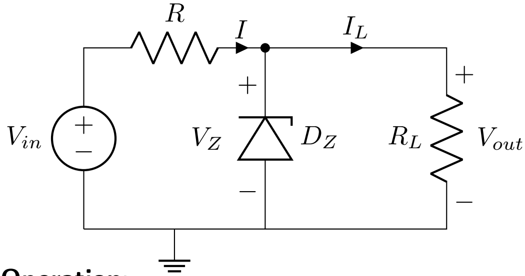
I-V Characteristic:



Voltage stays near V_Z as current varies

Zener Voltage Regulation

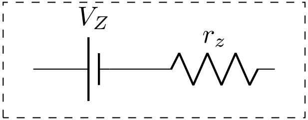
Simple Voltage Regulator:



Operation:

- V_{in} must be greater than V_Z
- Zener maintains $V_{out} \approx V_Z$
- Works even if V_{in} or I_L varies
- Series resistor R limits current

Zener Model in Breakdown:



Zener model

$$V_{actual} = V_Z + r_z \cdot I_Z$$

Small-Signal Resistance (r_z):

- Smaller r_z = better regulation
- Measure as $r_z = \Delta V_Z / \Delta I_Z$

Important

$P_Z = V_Z \times I_Z$ must be within power rating

What You'll Do in Lab

Experiment 1: Forward Bias

- Measure I-V characteristics
- Observe exponential behavior
- Identify turn-on voltage

Experiment 2: Small-Signal Resistance

- Calculate r_d from measurements
- Verify theoretical predictions
- Compare at different operating points
- Understand slope of I-V curve

Experiment 3: Reverse Bias

- Measure reverse current
- Verify saturation current behavior
- Understand one-way conduction

Experiment 4-5: Zener Diodes

- Measure breakdown characteristics
- Determine Zener voltage
- Calculate Zener resistance r_z
- Verify voltage regulation

Summary: Diode Fundamentals

Key Concepts:

- Diodes are one-way current devices
- Forward bias: conducts at ≈ 0.7 V
- Reverse bias: blocks current ($\approx -I_S$)
- Exponential I-V relationship

Important Equations:

- Shockley: $i_D = I_S(e^{v_D/nV_T} - 1)$
- Small-signal: $r_d = nV_T/I_D$
- Thermal voltage: $V_T \approx 25$ mV

Zener Diodes:

- Operate in reverse breakdown
- Maintain constant voltage V_Z
- Used for voltage regulation
- Model: V_Z + small resistance r_z

Next Topics:

- Diode circuit analysis
- Rectifier circuits (AC to DC)
- Bridge rectifiers

Prepare for Lab

Review Shockley equation, understand forward/reverse bias, and complete pre-lab questions