# 5.1 Semiconductors and diode models

Name: _____ Class: _____ Date: _____ **Total: 22 marks**

**KEY WORDS** ideal model • constant-drop model • exponential model • zener diode

## Objective

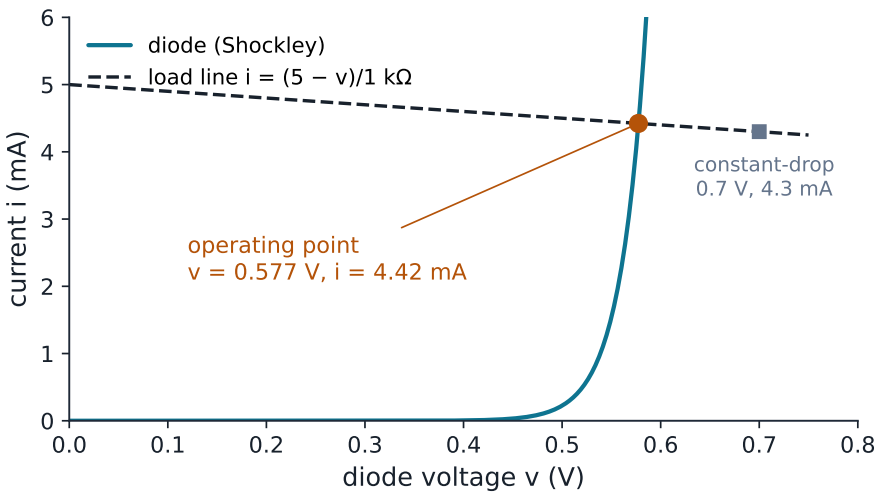
Choose among the diode's model ladder by the question, solve diode circuits each way, and quantify the model error against the exponential law.

## 1 Key knowledge and worked examples

### The model ladder

- **Ideal** : 0 V forward, open reverse – for logic-level reasoning.
- **Constant-drop** : 0.7 V forward – the default for bias arithmetic.
- **Piecewise-linear** : 0.7 V + slope $r_d = nV_T/I$ – when the load is light and the drop's variation matters.
- **Exponential** Shockley $i = I_S(e^{v/nV_T} - 1)$, $V_T = 26mV$ – when accuracy is the point.

Rule of thumb: each extra 60 mV multiplies forward current tenfold – the drop barely moves once conducting.




*The load line fixes the current; the steep diode curve barely moves the voltage.*

### Worked example: one circuit, three models, one truth

5 V source, diode, 1 kΩ. Ideal: 5 mA. Constant-drop: 4.3 mA. Shockley ($I_S = 10^{-12}A$): bisection on $I_S(e^{v/26m} - 1) = (5 - v)/1000$ gives $v = 0.578V$, $i = 4.42mA$. The constant-drop error is 2.8% – the resistor dominates the loop, which is precisely when that model earns its keep.

### The on/off discipline

Assume a diode state, solve, CHECK: forward-assumed needs `i > 0` and (for the drop models) $v_{source} > 0.7V$ available; reverse-assumed needs the actual reverse voltage below breakdown. A wrong assumption shows up as an impossible current or voltage – that is the method working, not failing.

## 2 Practice

**2.1** A 9 V source, a diode (constant-drop) and 2 kΩ in series: give the current. Repeat with the ideal model. [2]

**2.2** Two diodes in series (0.7 V each) with a 3.3 kΩ resistor across 10 V: current, and the resistor's voltage. [2]

**2.3** A 3 V source with a diode and a 100 Ω resistor: compute the current by constant-drop AND solve the Shockley equation by bisection ($I_S = 1pA$); state which model is misleading here and why. [4]

## 3 Exam-style questions

**3.1** A zener regulator: $V_{in} = 15V$, series $R = 470\Omega$, zener $V_Z = 9V$, load $R_L = 1.8k\Omega$ (zener $I_Z(min) = 2mA$ for regulation).

Compute the zener current and verify regulation holds. Then find the load resistance at which regulation just ceases, and the zener power at the load removed entirely ($R_L \to \infty$). State the safe-operating conclusion. [7]

**3.2** A clipper: two anti-series zeners (each $V_Z = 5.1V$, forward drop 0.7 V) across the output of a source with 1 kΩ series resistance.

State the clipped output levels for a ±12 V triangular input (compute the conducting path's total drop). Then sketch/describe the output for one full triangle period, and compute the current through the clipping path at the +12 V peak. Verify the zener pair's power at the peak is within 400 mW each. [7]

## Solutions

**2.1**

- Constant-drop: $(9 - 0.7)/2k = 4.15mA$.
- Ideal: $9/2k = 4.5mA$.

**2.2**

- Current: $(10 - 1.4)/3.3k = 2.61mA$.
- Resistor voltage: $2.61m \times 3.3k = 8.6V$.

**2.3**

- Constant-drop: `(3 - 0.7)/100 = 23 mA`.
- Shockley bisection on $10^{-12}(e^{v/26m} - 1) = (3 - v)/100$: $v = 0.621V$, $i = 23.8mA$.
- The two models agree within 3.3% – here the RESISTOR still dominates (100 Ω × 23 mA = 2.3 V ≫ the 60-mV-scale drop variation), so constant-drop remains honest; the trap would be a much smaller resistor.

**3.1**

- Load current: $I_L = 9/1.8k = 5mA$.
- Source current: $I_R = (15 - 9)/470 = 12.8mA$.
- Zener current: $I_Z = 12.8 - 5 = 7.8mA > 2mA$ ✓ regulation holds.
- Regulation ceases when $I_Z$ falls to $2mA$: the load then draws $I_L(max) = 12.8 - 2 = 10.8mA \rightarrow R_L(min) = 9/10.8m = 833\Omega$ (R is fixed at 470 Ω, so $I_R$ stays 12.8 mA; only the split changes).
- Load removed: $I_Z = 12.8mA$, $P_Z = 9 \times 12.8m = 115mW$.
- Conclusion: with a reasonable zener rating (≥ 150 mW) the circuit is safe at all loads from 833 Ω to open.

**3.2**

- Conducting path total drop: one zener breaks down (5.1 V) plus the other conducts forward (0.7 V) = 5.8 V. So the output clips at ±5.8 V.
- Output waveform: a triangle that follows the input within ±5.8 V and flats beyond – rising edge flattens at +5.8 V, falling at −5.8 V.
- Current at +12 V peak: $(12 - 5.8)/1k = 6.2mA$ through the clipping path.
- Zener power: the broken-down zener dissipates $5.1 \times 6.2m = 31.6mW$; the forward one $0.7 \times 6.2m = 4.3mW$ – both far below 400 mW ✓.