

5.1 Semiconductors and diode models

Name: _____ Class: _____ Date: _____

Total: 22 marks

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

Objective

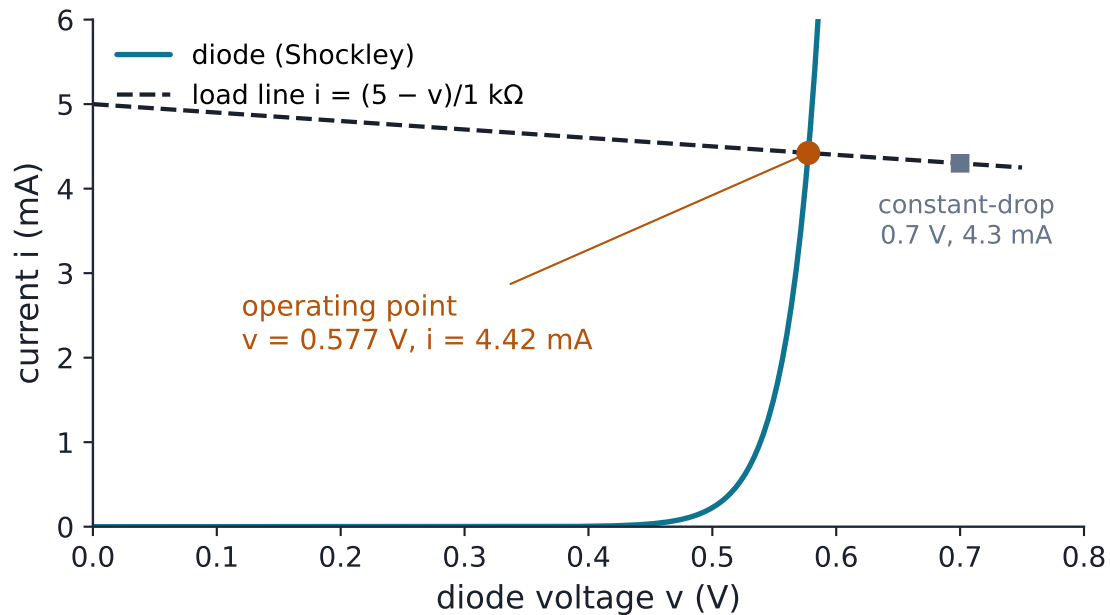
Choose among the diode's model ladder by the question, solve diode circuits each way, and quantify the model error against the exponential law.

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 k Ω . Ideal: 5 mA. Constant-drop: 4.3 mA. Shockley ($I_S = 10^{-12} \text{ A}$): bisection on $I_S(e^{v/26m} - 1) = (5 - v)/1000$ gives $v = 0.578 \text{ V}$, $i = 4.42 \text{ mA}$. 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) $v_{\text{source}} > 0.7 \text{ V}$ 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 k Ω 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 k Ω resistor across 10 V: current, and the resistor's voltage. [2]

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

3 Exam-style questions

3.1 A zener regulator: $V_{in} = 15\text{V}$, series $R = 470\Omega$, zener $V_Z = 9\text{V}$, load $R_L = 1.8\text{k}\Omega$ (zener $I_Z(\text{min}) = 2\text{mA}$ 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 ($R_L \rightarrow \infty$). 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 $1 k\Omega$ series resistance.

State the clipped output levels for a $\pm 12 V$ 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: $(3 - 0.7)/100 = 23 \text{ mA}$.
- 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 ($100 \Omega \times 23 \text{ mA} = 2.3 \text{ V} \gg$ 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: $I_Z = 12.8 - 5 = 7.8mA > 2mA \checkmark$ 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 470Ω , 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 ($\geq 150 \text{ mW}$) the circuit is safe at all loads from 833Ω 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 $\pm 5.8 \text{ V}$.
- Output waveform: a triangle that follows the input within $\pm 5.8 \text{ V}$ and flats beyond – rising edge flattens at $+5.8 \text{ V}$, falling at -5.8 V .
- Current at $+12 \text{ V}$ 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 $400 \text{ mW} \checkmark$.