Learning Objective: PN Junction Diode Physics

Problem 1. A Silicon ($n_i = 1.5 \times 10^{-10}$ cm^{-3}) PN junction diode is designed to operate at $T = 300$ K such that the diode current is 10 mA at a forward bias diode voltage of 0.65 V. The current density is 20 A/cm^2 under this operating condition.

(a) Suppose $N_D = 5 \times 10^{17}$ cm^{-3}, $N_A = 5 \times 10^{15}$ cm^{-3}, calculate the **build-in potential barrier** of the PN junction diode.

$$\begin{aligned} V_{bi} &= \frac{kT}{q} \ln\left(\frac{N_D N_A}{n_i^2}\right) \\ &= (0.026) \ln\left[\frac{(5 \times 10^{17})(5 \times 10^{15})}{(1.5 \times 10^{10})^2}\right] \\ &= 0.781\,\text{V} \end{aligned}$$

(b) Calculate the **power consumption** of this PN junction diode.

$$P_D = V_D I_D = (0.65)(10) = 6.5\,\text{mW}$$

(c) Determine the **cross sectional area** of this diode.

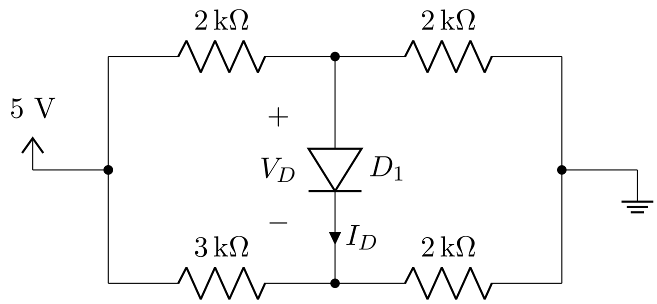
$$A = \frac{I_D}{J_D} = \frac{10 \times 10^{-3}}{20} = 5 \times 10^{-4}\,\text{cm}^2$$

(d) Determine the **reverse saturation current density** of this diode.

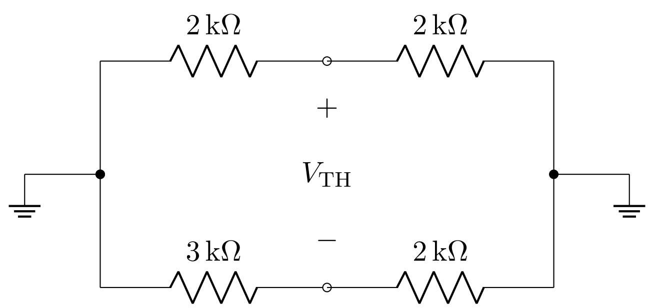
$$\begin{aligned} J_D &= J_S \left[\exp\left(\frac{V_D q}{kT}\right) - 1\right] \cong J_S \exp\left(\frac{V_D q}{kT}\right) \\ 20 &= J_S \exp\left(\frac{0.65}{0.026}\right) \\ J_S &= 2.78 \times 10^{-10}\,\frac{\text{A}}{\text{cm}^2} \end{aligned}$$

Learning Objective: PN Junction Diode DC Analysis

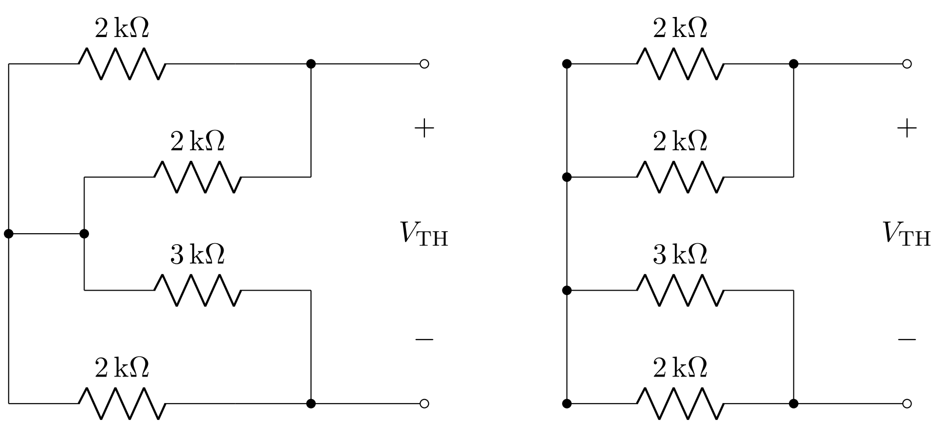
Problem 2. Calculate the **diode current** and **diode reverse saturation current** at $T = 300$ K from the circuit shown below, under diode voltage of (a) $V_D = 0.6$ V, (b) $V_D = 0.7$ V.



Solution:
Separate the load (diode) from the circuit, then apply Thevenin Theorem to reduce the circuit. The voltage source in this circuit is independent, so Thevenin resistance R_{TH} can be calculated by finding the equivalent resistance from V_{TH} port with voltage source shorted:



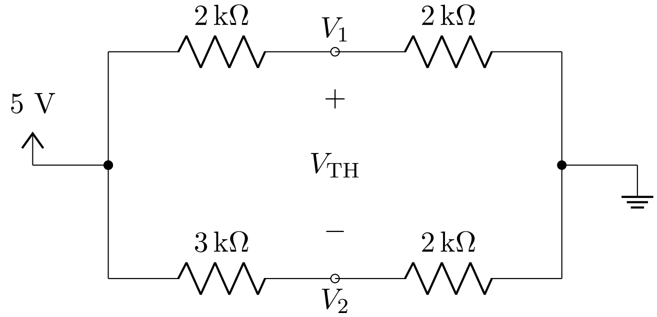
Remap this circuit by folding two 2 kΩ resistors on the right-hand side to the left, getting the following circuit:



Therefore:

$$\begin{aligned} R_{\text{TH}} &= 2\,\text{k}\Omega // 2\,\text{k}\Omega + 2\,\text{k}\Omega // 3\,\text{k}\Omega \\ &= \boxed{2.2\ \text{k}\Omega} \end{aligned}$$

Next, use node analysis to help find V_{TH}. I named the plus and minus port of V_{TH} as V_1 and V_2:



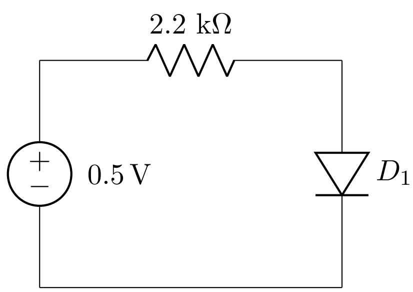
The node voltages V_1 and V_2 can be found using voltage divider:

$$V_1 = 5 \times \frac{2 \times 10^3}{2 \times 10^3 + 2 \times 10^3} = 2.5\ V$$
$$V_2 = 5 \times \frac{2 \times 10^3}{3 \times 10^3 + 2 \times 10^3} = 2\ V$$

The Thevenin voltage V_{TH} can be expressed as

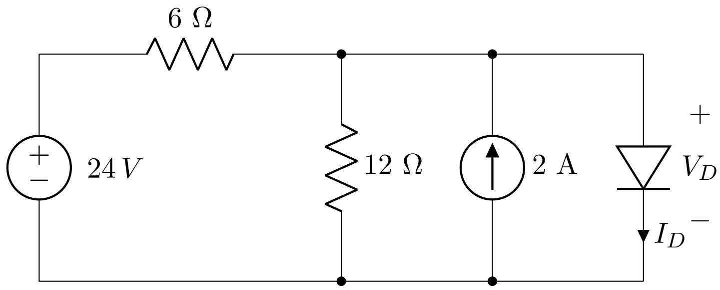
$$V_{\text{TH}} = V_1 - V_2 = \boxed{0.5\ \text{V}}$$

We get the following Thevenin equivalent circuit:

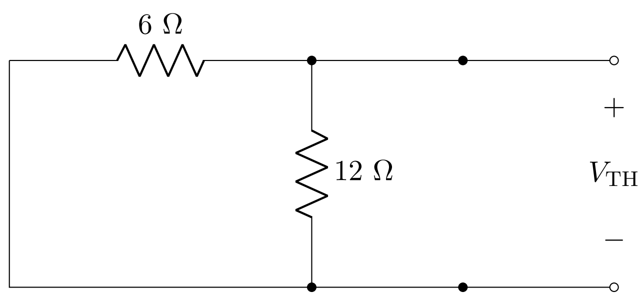


Because the Thevenin voltage is lower than the diode turn on voltage for both part (a) $V_D = 0.6$ V and (b) $V_D = 0.7$ V, the diode current for both case is $\boxed{I_D = 0\ \text{A}}$, and reverse saturation current $\boxed{\text{can't determined}}$.

Problem 3. Calculate the **diode current $\mathbf{I_D}$** and **diode voltage $\mathbf{V_D}$** at $T = 300$ K from the circuit shown below. Assume the diode D_1 is ideal. (Use $I_s = 10^{-12}$ A)



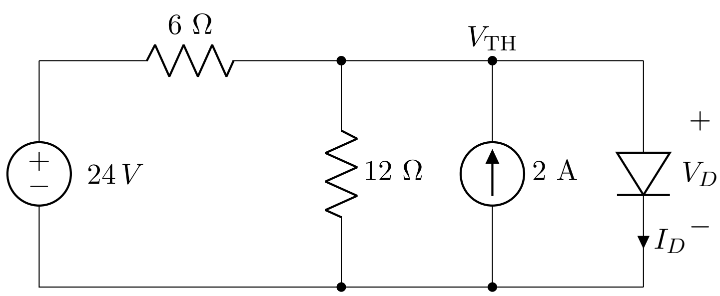
Solution:
Separate the load (diode) from the circuit, then apply Thevenin Theorem to reduce the circuit. The voltage source and current source in this circuit are independent, so Thevenin resistance R_{TH} can be calculated by finding the equivalent resistance from V_{TH} port with voltage source shorted and current source removed:



Therefore:

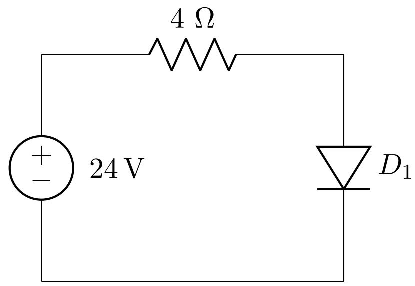
$$R_{\text{TH}} = 6\,\Omega//12\,\Omega = \boxed{4\ \Omega}$$

Then mark the node between 6 Ω and 4 Ω resistor V_{TH}, and perform KCL:



$$\begin{aligned}
\frac{V_{\text{TH}} - 24}{6} + \frac{V_{\text{TH}}}{12} &= 2 \\
2(V_{\text{TH}} - 24) + V_{\text{TH}} &= 24 \\
V_{\text{TH}} &= \boxed{24\ \text{V}}
\end{aligned}$$

We get the following Thevenin equivalent circuit:



Applying both KVL and diode current equation to solve for V_D and I_D:

$$I_D = \frac{24 - V_D}{4}$$
$$I_D = \times 10^{-12} \exp\left(\frac{V_D}{0.026}\right)$$

By solving the system of equation get: $\boxed{V_D = 0.764\,V,\ I_D = 5.809\,A}$.