Part 1

Electronic Principles

Chapter 1 Introduction

SELF-TEST

1. a	**7. b**	**13. c**	**19. b**
2. c	**8. c**	**14. d**	**20. c**
3. a	**9. b**	**15. b**	**21. b**
4. b	**10. a**	**16. b**	**22. b**
5. d	**11. a**	**17. a**	**23. c**
6. d	**12. a**	**18. b**	

JOB INTERVIEW QUESTIONS

Note: The text and illustrations cover many of the job interview questions in detail. An answer is given to job interview questions only when the text has insufficient information.

2. It depends on how accurate your calculations need to be. If an accuracy of 1 percent is adequate, you should include the source resistance whenever it is greater than 1 percent of the load resistance.

5. Measure the open-load voltage to get the Thevenin voltage V_{TH}. To get the Thevenin resistance, reduce all sources to zero and measure the resistance between the *AB* terminals to get R_{TH}. If this is not possible, measure the voltage V_L across a load resistor and calculate the load current I_L. Then divide $V_{TH} - V_L$ by I_L to get R_{TH}.

6. The advantage of a 50 Ω voltage source over a 600 Ω voltage source is the ability to be a stiff voltage source to a lower value resistance load. The load must be 100 greater than the internal resistance in order for the voltage source to be considered stiff.

7. The expression *cold-cranking amperes* refers to the amount of current a car battery can deliver in freezing weather when it is needed most. What limits actual current is the Thevenin resistance caused by chemical and physical parameters inside the battery, not to mention the quality of the connections outside.

8. It means that the load resistance is not large compared to the Thevenin resistance, so that a large load current exists.

9. Ideal. Because troubles usually produce large changes in voltage and current, so that the ideal approximation is adequate for most troubles.

10. You should infer nothing from a reading that is only 5 percent from the ideal value. Actual circuit troubles will usually cause large changes in circuit voltages. Small changes can result from component variations that are still within the allowable tolerance.

11. Either may be able to simplify the analysis, save time when calculating load current for several load resistances, and give us more insight into how changes in load resistance affect the load voltage.

12. It is usually easy to measure open-circuit voltage and shorted-load current. By using a load resistor and measuring voltage under load, it is easy to calculate the Thevenin or Norton resistance.

PROBLEMS

1-1. *Given:*

$V = 12$ V

$R_S = 0.1\ \Omega$

Solution:

$R_L = 100R_S$

$R_L = 100(0.1\ \Omega)$

$R_L = 10\ \Omega$

Answer: The voltage source will appear stiff for values of load resistance of $\geq 10\ \Omega$.

1-2. *Given:*

$R_{L\text{min}} = 270\ \Omega$

$R_{L\text{max}} = 100\ \text{k}\Omega$

Solution:

$R_S < 0.01\ R_L$ (Eq. 1-1)

$R_S < 0.01(270\ \Omega)$

$R_S < 2.7\ \Omega$

Answer: The largest internal resistance the source can have is 2.7 Ω.

1-3. *Given:* $R_S = 50\ \Omega$

Solution:

$R_L = 100R_S$

$R_L = 100(50\ \Omega)$

$R_L = 5\ \text{k}\Omega$

Answer: The function generator will appear stiff for values of load resistance of $\geq 5\ \text{k}\Omega$.

1-4. *Given*: $R_S = 0.04\ \Omega$

Solution:

$R_L = 100R_S$

$R_L = 100(0.04\ \Omega)$

$R_L = 4\ \Omega$

Answer: The car battery will appear stiff for values of load resistance of $\geq 4\ \Omega$.

1-5. *Given*:
$R_S = 0.05\ \Omega$
$I = 2$ A

Solution:
$V = IR$ (Ohm's law)
$V = (2\text{ A})(0.05\ \Omega)$
$V = 0.1$ V

Answer: The voltage drop across the internal resistance is 0.1 V.

1-6. *Given*:
$V = 9$ V
$R_S = 0.4\ \Omega$

Solution:
$I = V/R$ (Ohm's law)
$I = (9\text{ V})/(0.4\ \Omega)$
$I = 22.5$ A

Answer: The load current is 22.5 A.

1-7. *Given:*
$I_S = 10$ mA
$R_S = 10\text{ M}\Omega$

Solution:
$R_L = 0.01\ R_S$
$R_L = 0.01(10\text{ M}\Omega)$
$R_L = 100\text{ k}\Omega$

Answer: The current source will appear stiff for load resistance of $\leq 100\text{ k}\Omega$.

1-8. *Given:*
$R_{L\min} = 270\ \Omega$
$R_{L\max} = 100\text{ k}\Omega$

Solution:
$R_S > 100\ R_L$ (Eq. 1-3)
$R_S > 100(100\text{ k}\Omega)$
$R_S > 10\text{ M}\Omega$

Answer: The internal resistance of the source is greater than 10 MΩ.

1-9. *Given:* $R_S = 100\text{ k}\Omega$

Solution:
$R_L = 0.01R_S$ (Eq. 1-4)
$R_L = 0.01(100\text{ k}\Omega)$
$R_L = 1\text{ k}\Omega$

Answer: The maximum load resistance for the current source to appear stiff is 1 kΩ.

1-10. *Given:*
$I_S = 20$ mA
$R_S = 200\text{ k}\Omega$
$R_L = 0\ \Omega$

Solution:
$R_L = 0.01R_S$
$R_L = 0.01(200\text{ k}\Omega)$
$R_L = 2\text{ k}\Omega$

Answer: Since 0 Ω is less than the maximum load resistance of 2 kΩ, the current source appea rs stiff; thus the current is 20 mA.

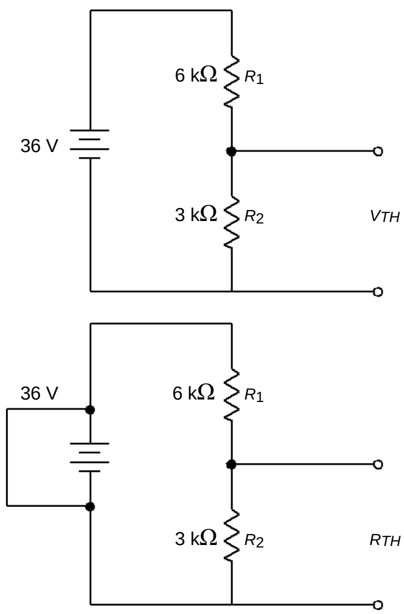
1-11. *Given:*
$I = 5$ mA
$R_S = 250\text{ k}\Omega$
$R_L = 10\text{ k}\Omega$

Solution:
$R_L = 0.01R_S$ (Eq. 1-4)
$R_L = 0.01(250\text{ k}\Omega)$
$R_L = 2.5\text{ k}\Omega$
$I_L = I_T\,[(R_S)/(R_S + R_L)]$ (Current divider formula)
$I_L = 5\text{ mA}\,[(250\text{ k}\Omega)/(250\text{ k}\Omega + 10\text{ k}\Omega)]$
$I_L = 4.80$ mA

Answer: The load current is 4.80 mA, and, no, the current source is not stiff since the load resistance is not less than or equal to 2.5 kΩ.

1-12. *Solution:*
$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 36\text{ V}[(3\text{ k}\Omega)/(6\text{ k}\Omega + 3\text{ k}\Omega)]$
$V_{R2} = 12$ V
$R_{TH} = [R_1R_2/R_1 + R_2]$ (Parallel resistance formula)
$R_{TH} = [(6\text{ k}\Omega)(3\text{ k}\Omega)/(6\text{ k}\Omega + 3\text{ k}\Omega)]$
$R_{TH} = 2\text{ k}\Omega$

Answer: The Thevenin voltage is 12 V, and the Thevenin resistance is 2 kΩ.

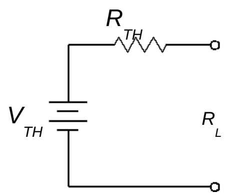


(*a*) Circuit for finding V_{TH} in Prob. 1-12. (*b*) Circuit for finding R_{TH} in Prob. 1-12.

1-13. *Given:*
$V_{TH} = 12$ V
$R_{TH} = 2\text{ k}\Omega$

Solution:
$I = V/R$ (Ohm's law)
$I = V_{TH}/(R_{TH} + R_L)$
$I_{0\Omega} = 12\text{ V}/(2\text{ k}\Omega + 0\ \Omega) = 6$ mA
$I_{1\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 1\text{ k}\Omega) = 4$ mA
$I_{2\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 2\text{ k}\Omega) = 3$ mA
$I_{3\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 3\text{ k}\Omega) = 2.4$ mA
$I_{4\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 4\text{ k}\Omega) = 2$ mA
$I_{5\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 5\text{ k}\Omega) = 1.7$ mA
$I_{6\text{k}\Omega} = 12\text{ V}/(2\text{ k}\Omega + 6\text{ k}\Omega) = 1.5$ mA

Answers: 0 Ω 6 mA; 1 kΩ, 4 mA; 2 kΩ, 3mA; 3 kΩ, 2.4 mA; 4 kΩ, 2 mA; 5 kΩ, 1.7 mA; 6 kΩ, 1.5 mA.



Thevenin equivalent circuit for Prob. 1-13.

1-14. *Given*:

$V_S = 18$ V
$R_1 = 6$ kΩ
$R_2 = 3$ kΩ

Solution:

$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 18$ V[(3 kΩ)/(6 kΩ + 3 kΩ)]
$V_{R2} = 6$ V
$R_{TH} = [(R_1 \times R_2)/(R_1 + R_2)]$ (Parallel resistance formula)
$R_{TH} = [(6$ kΩ × 3 kΩ)/(6 kΩ + 3 kΩ)]
$R_{TH} = 2$ kΩ

Answer: The Thevenin voltage decreases to 6 V, and the Thevenin resistance is unchanged.

1-15. *Given:*

$V_S = 36$ V
$R_1 = 12$ kΩ
$R_2 = 6$ kΩ

Solution:

$V_{TH} = V_{R2}$
$V_{R2} = V_S[(R_2)/(R_1 + R_2)]$ (Voltage divider formula)
$V_{R2} = 36$ V[(6 kΩ)/(12 kΩ + 6 kΩ)]
$V_{R2} = 12$ V
$R_{TH} = [(R_1R_2)/(R_1 + R_2)]$ (Parallel resistance formula)
$R_{TH} = [(12$ kΩ)(6 kΩ)/(12 kΩ + 6 kΩ)]
$R_{TH} = 4$ kΩ

Answer: The Thevenin voltage is unchanged, and the Thevenin resistance doubles.

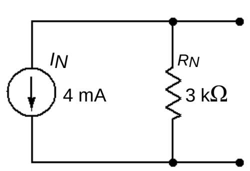
1-16. *Given:*

$V_{TH} = 12$ V
$R_{TH} = 3$ kΩ

Solution:

$R_N = R_{TH}$
$R_N = 3$ kΩ
$I_N = V_{TH}/R_{TH}$
$I_N = 12$ V/3 kΩ
$I_N = 4$ mA

Answer: $I_N = 4$ mA, and $R_N = 3$ kΩ



Norton circuit for Prob. 1-16.

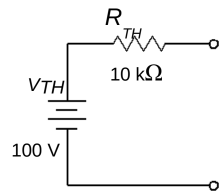
1-17. *Given:*

$I_N = 10$ mA
$R_N = 10$ kΩ

Solution:

$R_N = R_{TH}$ (Eq. 1-10)
$R_{TH} = 10$ kΩ
$I_N = V_{TH}/R_{TH}$ (Eq. 1-12)
$V_{TH} = I_NR_N$
$V_{TH} = (10$ mA)(10 kΩ)
$V_{TH} = 100$ V

Answer: $R_{TH} = 10$ kΩ, and $V_{TH} = 100$ V



Thevenin circuit for Prob. 1-17.

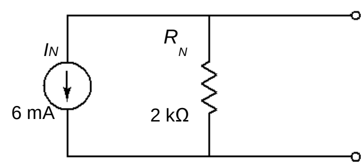
1-18. *Given (from Prob. 1-12):*

$V_{TH} = 12$ V
$R_{TH} = 2$ kΩ

Solution:

$R_N = R_{TH}$ (Eq. 1-10)
$R_N = 2$ kΩ
$I_N = V_{TH}/R_{TH}$ (Eq. 1-12)
$I_N = 12$ V/2 kΩ
$I_N = 6$ mA

Answer: $R_N = 2$ kΩ, and $I_N = 6$ mA



Norton circuit for Prob. 1-18.

1-19. Shorted, which would cause load resistor to be connected across the voltage source seeing all of the voltage.

1-20. **a.** R_1 is open, preventing any of the voltage from reaching the load resistor. **b.** R_2 is shorted, making its voltage drop zero. Since the load resistor is in parallel with R_2, its voltage drop would also be zero.

1-21. The battery or interconnecting wiring.

1-22. $R_{TH} = 2$ kΩ

Solution:

$R_{Meter} = 100R_{TH}$
$R_{Meter} = 100(2$ kΩ)
$R_{Meter} = 200$ kΩ

Answer: The meter will not load down the circuit if the meter impedance is ≥ 200 kΩ.

CRITICAL THINKING

1-23. *Given*:

$V_S = 12$ V
$I_S = 150$ A

Solution:

$R_S = (V_S)/(I_S)$
$R_S = (12$ V)/(150 A)
$R_S = 80$ mΩ

Answer: If an ideal 12 V voltage source is shorted and provides 150 A, the internal resistance is 80 mΩ.

1-24. *Given:*

$V_S = 10$ V
$V_L = 9$ V
$R_L = 75\ \Omega$

Solution:

$V_S = V_{RS} + V_L$ (Kirchhoff's law)
$V_{RS} = V_S - V_L$
$V_{RS} = 10\text{ V} - 9\text{ V}$
$V_{RS} = 1$ V
$I_{RS} = I_L = V_L/R_L$ (Ohm's law)
$I_{RS} = 9\text{ V}/75\ \Omega$
$I_{RS} = 120$ mA
$R_S = V_{RS}/I_{RS}$ (Ohm's law)
$R_S = 8.33\ \Omega$
$R_S < 0.01\ R_L$ (Eq. 1-1)
$8.33\ \Omega < 0.01(75\ \Omega)$
$8.33\ \Omega \nless 0.75\ \Omega$

Answer: **a.** The internal resistance (R_S) is 8.33 Ω. **b.** The source is not stiff since $R_S \nless 0.01\ R_L$.

1-25. *Answer:* Disconnect the resistor and measure the voltage.

1-26. *Answer:* Disconnect the load resistor, turn the internal voltage and current sources to zero, and measure the resistance.

1-27. *Answer:* Thevenin's theorem makes it much easier to solve problems where there could be many values of a resistor.

1-28. *Answer:* To find the Thevenin voltage, disconnect the load resistor and measure the voltage. To find the Thevenin resistance, disconnect the battery and the load resistor, short the battery terminals, and measure the resistance at the load terminals.

1-29. *Given:*

$R_L = 1$ kΩ
$I = 1$ mA

Solution:

$R_S > 100R_L$
$R_S > 100(1\text{ k}\Omega)$
$R_L > 100$ kΩ
$V = IR$
$V = (1\text{ mA})(100\text{ k}\Omega)$
$V = 100$ V

Answer: A 100 V battery in series with a 100 kΩ resistor.

1-30. *Given:*

$V_S = 30$ V
$V_L = 15$ V
$R_{TH} < 2$ kΩ

Solution: Assume a value for one of the resistors. Since the Thevenin resistance is limited to 2 kΩ, pick a value less than 2 kΩ. Assume $R_2 = 1$ kΩ.

$V_L = V_S[R_2/(R_1 + R_2)]$ (Voltage divider formula)
$R_1 = [(V_S)(R_2)/V_L] - R_2$
$R_1 = [(30\text{ V})(1\text{ k}\Omega)/(15\text{ V})] - 1\text{ k}\Omega$
$R_1 = 1$ kΩ
$R_{TH} = (R_1R_2/R_1 + R_2)$
$R_{TH} = [(1\text{ k}\Omega)(1\text{ k}\Omega)]/(1\text{ k}\Omega + 1\text{ k}\Omega)$
$R_{TH} = 500\ \Omega$

Answer: The value for R_1 and R_2 is 1 kΩ. Another possible solution is $R_1 = R_2 = 4$ kΩ. *Note:* The criteria will be satisfied for any resistance value up to 4 kΩ and when both resistors are the same value.

1-31. *Given:*

$V_S = 30$ V
$V_L = 10$ V
$R_L > 1$ MΩ
$R_S < 0.01R_L$ (since the voltage source must be stiff) (Eq. 1-1)

Solution:

$R_S < 0.01R_L$
$R_S < 0.01(1\text{ M}\Omega)$
$R_S < 10$ kΩ

Since the Thevenin equivalent resistance would be the series resistance, $R_{TH} < 10$ kΩ.

Assume a value for one of the resistors. Since the Thevenin resistance is limited to 1 kΩ, pick a value less than 10 kΩ. Assume $R_2 = 5$ kΩ.

$V_L = V_S[R_2/(R_1 + R_2)]$ (Voltage divider formula)
$R_1 = [(V_S)(R_2)/V_L] - R_2$
$R_1 = [(30\text{ V})(5\text{ k}\Omega)/(10\text{ V})] - 5\text{ k}\Omega$
$R_1 = 10$ kΩ
$R_{TH} = R_1R_2/(R_1 + R_2)$
$R_{TH} = [(10\text{ k}\Omega)(5\text{ k}\Omega)]/(10\text{ k}\Omega + 5\text{ k}\Omega)$
$R_{TH} = 3.33$ kΩ

Since R_{TH} is one-third of 10 kΩ, we can use R_1 and R_2 values that are three times larger.

Answer:

$R_1 = 30$ kΩ
$R_2 = 15$ kΩ

Note: The criteria will be satisfied as long as R_1 is twice R_2 and R_2 is not greater than 15 kΩ.

1-32. *Answer:* First, measure the voltage across the terminals. This is the Thevenin voltage. Next, connect the ammeter to the battery terminals—measure the current. Next, use the values above to find the total resistance. Finally, subtract the internal resistance of the ammeter from this result. This is the Thevenin resistance.

1-33. *Answer:* First, measure the voltage across the terminals. This is the Thevenin voltage. Next, connect a resistor across the terminals. Next, measure the voltage across the resistor. Then, calculate the current through the load resistor. Then, subtract the load voltage from the Thevenin voltage. Then, divide the difference voltage by the current. The result is the Thevenin resistance.

1-34. *Solution:* Thevenize the circuit. There should be a Thevenin voltage of 0.148 V and a resistance of 6 kΩ.

$I_L = V_{TH}/(R_{TH} + R_L)$
$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 0)$
$I_L = 24.7\ \mu$A
$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 1\text{ k}\Omega)$
$I_L = 21.1\ \mu$A
$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 2\text{ k}\Omega)$
$I_L = 18.5\ \mu$A
$I_L = 0.148\text{ V}/(6\text{ k}\Omega + 3\text{ k}\Omega)$
$I_L = 16.4\ \mu$A

$I_L = 0.148$ V/(6 kΩ + 4 kΩ)

$I_L = 14.8$ μA

$I_L = 0.148$ V/(6 kΩ + 5 kΩ)

$I_L = 13.5$ μA

$I_L = 0.148$ V/(6 kΩ + 6 kΩ)

$I_L = 12.3$ μA

Answer: 0, $I_L = 24.7$ μA; 1 kΩ, $I_L = 21.1$ μA; 2 kΩ, $I_L = 18.5$ μA; 3 kΩ, $I_L = 16.4$ μA; 4 kΩ, $I_L = 14.8$ μA; 5 kΩ, $I_L = 13.5$ μA; 6 kΩ, $I_L = 12.3$ μA.

1-35. *Trouble:*

1: R_1 shorted
2: R_1 open or R_2 shorted
3: R_3 open
4: R_3 shorted
5: R_2 open or open at point C
6: R_4 open or open at point D
7: Open at point E
8: R_4 shorted

1-36. R_1 shorted

1-37. R_2 open

1-38. No supply voltage

1-39. R_4 open

1-40. R_2 shorted

Chapter 2 Semiconductors

SELF-TEST

1. d	**15. a**	**29. d**	**42. b**
2. a	**16. b**	**30. c**	**43. b**
3. b	**17. d**	**31. a**	**44. c**
4. b	**18. d**	**32. a**	**45. a**
5. d	**19. a**	**33. b**	**46. c**
6. c	**20. a**	**34. a**	**47. d**
7. b	**21. d**	**35. b**	**48. a**
8. b	**22. a**	**36. c**	**49. a**
9. c	**23. a**	**37. c**	**50. d**
10. a	**24. a**	**38. a**	**51. c**
11. c	**25. d**	**39. b**	**52. b**
12. c	**26. b**	**40. a**	**53. d**
13. b	**27. b**	**41. b**	**54. b**
14. b	**28. a**		

JOB INTERVIEW QUESTIONS

9. Holes do not flow in a conductor. Conductors allow current flow by virtue of their single outer-shell electron, which is loosely held. When holes reach the end of a semiconductor, they are filled by the conductor's outer-shell electrons entering at that point.

11. Because the recombination at the junction allows holes and free electrons to flow continuously through the diode.

PROBLEMS

2-1. –2

2-2. –3

2-3. **a.** Semiconductor
b. Conductor
c. Semiconductor
d. Conductor

2-4. 500,000 free electrons

2-5. **a.** 5 mA
b. 5 mA
c. 5 mA

2-6. **a.** *p*-type
b. *n*-type
c. *p*-type
d. *n*-type
e. *p*-type

2-7. *Given:*

Barrier potential at 25°C is 0.7 V

$T_{min} = 25°C$

$T_{min} = 75°C$

Solution:

$\Delta V = (-2\text{ mV/°C})\ \Delta T$ (Eq. 2-4)
$\Delta V = (-2\text{ mV/°C})(0°C - 25°C)$
$\Delta V = 50$ mV
$V_{new} = V_{old} + \Delta V$
$V_{new} = 0.7\text{ V} + 0.05\text{ V}$
$V_{new} = 0.75$ V
$\Delta V = (-2\text{ mV/°C})\ \Delta T$ (Eq. 2-4)
$\Delta V = (-2\text{ mV/°C})(75°C - 25°C)$
$\Delta V = -100$ mV

$V_{new} = V_{old} + \Delta V$
$V_{new} = 0.7\text{ V} - 0.1\text{ V}$
$V_{new} = 0.6$ V

Answer: The barrier potential is 0.75 V at 0°C and 0.6 V at 75°C.

2-8. *Given:*

$I_S = 10$ nA at 25°C
$T_{min} = 0°C - 75°C$
$T_{max} = 75°C$

Solution:

$I_{S(new)} = 2^{(\Delta T/10)} I_{S(old)}$
$I_{S(new)} = 2^{[(0°C - 25°C)/10]} 10\text{ nA}$
$I_{S(new)} = 1.77$ nA
$I_{S(new)} = 2^{(\Delta T/10)} I_{S(old)}$
$I_{S(new)} = 2^{[(75°C - 25°C)/10)]} 10\text{ nA}$
$I_{S(new)} = 320$ nA

Answer: The saturation current is 1.77 nA at 0°C and 320 nA at 75°C.

2-9. *Given:*

$I_{SL} = 10$ nA with a reverse voltage of 10 V New reverse voltage = 100 V

Solution:

$R_{SL} = V_R/I_{SL}$
$R_{SL} = 10\text{ V}/10\text{ nA}$
$R_{SL} = 1000$ MΩ
$I_{SL} = V_R/R_{SL}$
$I_{SL} = 100\text{ V}/1000\text{ MΩ}$
$I_{SL} = 100$ nA

Answer: 100 nA.

2-10. *Answer:* Saturation current is 0.53 μA, and surface-leakage current is 4.47 μA at 25°C.

2-11. Reduce the saturation current, and minimize the RC time constants.

2-12. $R_1 = 25$ Ω