RESULTS AND DATA FOR EXPERIMENTS IN BASIC ELECTRONICS 12/e

Lab Experiments Manual

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ANSWERS for INTRODUCTION I-1:

Electronics Math Review

NOTE: Math problems only - no questions or report are required for this review of mathematics.

I-1.1 Power of 10 Notation

1.	**7.29**	x 10^{3}		9.	**1.21**	x 10^{6}		17.	**19.203**	x 10^{3}
2.	**8.69**	x 10^{9}		10.	**26.3**	x 10^{6}		18.	**3.8308**	x 10^{-6}
3.	**57.83**	x 10^{3}		11.	**402**	x 10^{0}		19.	**2.18**	x 10^{-2}
4.	**1.59**	x 10^{3}		12.	**495**	x 10^{6}		20.	**4.00**	x 10^{0}
5.	**1.86**	x 10^{6}		13.	**2**	x 10^{7}		21.	**15.00**	x 10^{-7}
6.	**25.74**	x 10^{6}		14.	**25.085**	x 10^{2}		22.	**3.20**	x 10^{-1}
7.	**32.99**	x 10^{9}		15.	**367.83**	x 10^{-1}		23.	**4.2**	x 10^{5}
8.	**660.3**	x 10^{0}		16.	**44.856**	x 10^{-9}		24.	**8.88**	x 10^{7}

I-1.2 Scientific Notation

1.	**3.4 x 10^{1}**		11.	**5.30 x 10^{1}**		21.	**1.83 x 10^{8}**
2.	**139 x 10^{2}**		12.	**1.92 x 10^{9}**		22.	**1.67 x 10^{0}**
3.	**1.296 x 10^{3}**		13.	**2.30 x 10^{3}**		23.	**1.70 x 10^{-10}**
4.	**1.265 x 10^{1}**		14.	**5.53 x 10^{-2}**		24.	**1.62 x 10^{5}**
5.	**6.7 x 10^{-2}**		15.	**1.96 x 10^{1}**		25.	**1.54 x 10^{9}**
6.	**2,040,000**		16.	**3.48 x 10^{7}**		26.	**3.00 x 10^{1}**
7.	**0.000,000,034,5**		17.	**4.98 x 10^{3}**		27.	**4.71 x 10^{-8}**
8.	**724**		18.	**3.02 x 10^{-3}**		28.	**7.71 x 10^{8}**
9.	**0.000,000,377,9**		19.	**2.71 x 10^{-3}**		29.	**3.11 x 10^{0}**
10.	**3,660,000**		20.	**5.73 x 10^{2}**		30.	**3.28 x 10^{-5}**

I-1.3 Engineering Notation

1.	**794×10^{0}**		9.	**56.83×10^{-3}**		17.	**19.20×10^{9}**
2.	**32.1×10^{6}**		10.	**505×10^{3}**		18.	**4.20×10^{-6}**
3.	**53.5×10^{3}**		11.	**1.06×10^{-3}**		19.	**14.50×10^{18}**
4.	**728×10^{0}**		12.	**247.00765×10^{-9}**		20.	**16.00×10^{-6}**
5.	**6.55 M**		13.	**900×10^{0}**		21.	**15.00×10^{-6}**
6.	**98.1 m**		14.	**-2.25×10^{-3}**		22.	**3.00×10^{-3}**
7.	**32.7 k**		15.	**-16.08×10^{12}**		23.	**4.2×10^{6}**
8.	**9.24 n**		16.	**-1.67733×10^{0}**		24.	**8.88×10^{9}**

I-1.4 Significant Figures, Accuracy, Precision

1.	**4**		9.	**4**		17.	**130**
2.	**3**		10.	**33.4**		18.	**410**
3.	**3**		11.	**16794**		19.	**12**
4.	**One hundredth**		12.	**113**		20.	**8.71**
5.	**One tenth**		13.	**12.3**		21.	**1.72**
6.	**One ten-thousandth**		14.	**139**		22.	**764**
7.	**4**		15.	**890**		23.	**64.8**
8.	**4**		16.	**7.66**		24.	**1.28**

EXPERIMENT 1-1: Lab Safety, Equipment, Components

Answers to Questions:

Fill in the blanks (1-15) with the letter of the correct answer:

_**d**_ 1. An instrument used to measure potential difference.	**a**. ammeter
_**a**_ 2. An instrument used to measure current.	**b**. resistor symbol
_**g**_ 3. An instrument used to measure resistance.	**c**. power supply
_**j**_ 4. A passive component that opposes the flow of current.	**d**. voltmeter
_**i**_ 5. An instrument used to heat solder and join components.	**e**. battery symbol
_**c**_ 6. A source of dc voltage other than a battery	**f**. black
_**e**_ 7. A symbol for dc voltage source.	**g**. ohmmeter
_**b**_ 8. A symbol for resistance.	**h**. breadboard
_**f**_ 9. A color used to represent negative polarity.	**i**. soldering iron
_**h**_ 10. An item used to temporarily build circuits on.	**j**. resistor
_**n**_ 11. A Greek letter used to represent a unit of resistance.	**k**. DMM, DVM VOM
m_12. An English letter used to represent 1000.	**l**. m
_**l**_ 13. An English letter used to represent 0.001	**m**. k
_**k**_ 14. An instrument used as an ohmmeter, voltmeter, ammeter.	**n**. Ω
_**o**_ 15. A symbol for infinity.	**o**. ∞

TABLES FOR EXPERIMENT 1-1

TABLE 1-1.1 Resistor Color Codes

First Digit Band 1	**Second Digit Band 2**	**Multiplier Band 3**	**Tolerance Band 4**	**Resistor Value**
Red	Brown	Brown	Gold	**210 Ω, 5%**
Brown	Brown	Black	Gold	**11 Ω, 5%**
Green	Blue	Red	Silver	**5.6 kΩ**
Blue	Green	Yellow	Silver	**650 kΩ, 10%**
Red	Red	Orange	Silver	**22 kΩ, 10%**
Orange	White	Brown	Gold	**390 Ω, 5%**
Blue	Green	Black	Silver	**65 Ω, 10%**
Brown	Black	Red	Gold	**1 kΩ, 5%**
Yellow	Violet	Green	Gold	**4.7 MΩ, 5%**
Brown	Black	Orange	Silver	**10 kΩ, 10%**
Orange	Orange	Orange	Silver	**330 kΩ, 10%**
Brown	Black	Gold	Gold	**1 Ω, 5%**
White	Blue	Red	Silver	**9.6 kΩ, 10%**
Brown	Black	Yellow	Silver	**100 kΩ, 10%**
Brown	Green	Green	Gold	**1.5 MΩ, 5%**

TABLE 1-1.2 Resistor Color Codes

Band 1 Color	**Band 2 Color**	**Band 3 Color**	**Band 4 Color**	**Resistor Value**
__Blue__	**__Gray__**	**__Yellow__**	**__Gold__**	**680 kΩ, 5%**
__Brown__	**__Black__**	**__Orange__**	**__Silver__**	**10 kΩ, 10%**
__Brown__	**__Black__**	**__Yellow__**	**__Gold__**	**100 kΩ, 5%**
__Orange__	**__Orange__**	**__Green__**	**__Gold__**	**3.3 MΩ, 5%**
__Brown__	**__Red__**	**__Red__**	**__Silver__**	**1.2 kΩ, 10%**
__Gray__	**__Red__**	**__Brown__**	**__Silver__**	**820 Ω, 10%**
__Yellow__	**__Violet__**	**__Red__**	**__Gold__**	**47 kΩ, 5%**
__Orange__	**__Orange__**	**__Brown__**	**__Silver__**	**330 Ω, 10%**
__Yellow__	**__Violet__**	**__Yellow__**	**__Gold__**	**470 kΩ, 5%**
__Green__	**__Blue__**	**__Brown__**	**__Silver__**	**560 Ω, 10%**
__Brown__	**__Green__**	**__Green__**	**__Silver__**	**1.5 MΩ, 10%**
__Red__	**__Red__**	**__Brown__**	**__Gold__**	**220 Ω, 5%**
__Green__	**__Blue__**	**__Black__**	**__Silver__**	**56 Ω, 10%**
__Brown__	**__Red__**	**__Orange__**	**__Gold__**	**12 kΩ, 5%**
__Green__	**__Blue__**	**__Yellow__**	**__Gold__**	**560 kΩ, 5%**

EXPERIMENT 2-1: Resistance Measurements

Answers to Questions:

Answer TRUE (T) or FALSE (F) to the following:

__**T**__ 1. It is always necessary to allow VTVMs to warm up prior to use.
__**F**__ 2. The DMM can measure current.
__**F**__ 3. An ohmmeter will show zero ohms when the leads are note connected together (open circuit).
__**F**__ 4. Linear scales are used for resistance measurements.
__**T**__ 5. It is necessary to adjust infinity (∞) and zero ohms whenever changing ranges on an ohmmeter.
__**F**__ 6. A continuity check gives the value in ohms.
__**T**__ 7. Shorting the leads together on an ohmmeter results in zero ohms.
__**T**__ 8. Parallax is an error resulting from reading meter scales from an angular view.
__**F**__ 9. An ohmmeter cannot be damaged by measuring voltage.
__**F**__ 10. The range switch is only used for voltage measurements.

11. Refer to Appendix C and write an explanation of the differences between 4-Band and 5-Band resistors.

ANSWER: **Four-Band resistors provide <u>two</u> significant digits, a multiplier and a tolerance value. Five-Band resistors provide <u>three</u> significant digits, a multiplier and a tolerance value. A greater range and precision of values are available with Five-Band resistors.**

TABLES FOR EXPERIMENT 2-1

TABLE 2-1.1 Resistance Measurements Using the Ohmmeter

Student answers (measured) should be close to the Nominal Values shown here:

Nominal Value, Ω	Measured Value, Ω	Nominal Value, Ω	Measured Value, Ω
10 Ω		**10 kΩ**	
56 Ω		**10 kΩ**	
100 Ω		**10 kΩ**	
220 Ω		**22 kΩ**	
390 Ω		**33 kΩ**	
470 Ω		**47 kΩ**	
680 Ω		**47 kΩ**	
820 Ω		**68 kΩ**	
1 kΩ		**86 kΩ**	
1.2 kΩ		**100 kΩ**	
1.5 kΩ		**100 kΩ**	
2.2 kΩ		**220 kΩ**	
3.3 kΩ		**470 kΩ**	
4.7 kΩ		**1.2 MΩ**	
5.6 kΩ		**3.3 MΩ**	

EXPERIMENT 2-2: Resistor V & I Measurements

Answer to Question:

In your own words, describe the different ways an ohmmeter, an ammeter, and a voltmeter are connected to make measurements.

ANSWER:
- Ohmmeters take resistance measurements and are connected across a component with no power applied.
- Ammeters are connected in series with components.
- Voltmeters are connected in parallel (across) components.

TABLES FOR EXPERIMENT 2-2

TABLE 2-2.1 Voltage Measurements

Resistor Value	Voltage
1 kΩ	**3 V**
100 Ω	**3 V**
10 kΩ	**3 V**

TABLE 2-2.2 Current Measurements

Resistor Value	Voltage	Current, I
100 Ω	**1 V**	**10 mA**
330 Ω	**1 V**	**3 mA**
560 Ω	**1 V**	**1.8 mA**

EXPERIMENT 3-1: Ohm's Law

Answers to Questions:

_C__ 1. If the circuit of Fig. 3-1.1 had 10 kΩ of resistance, the amount of applied voltage necessary to produce 1 mA would be:
A. 1000V **B.** 100 V **C.** 10 V **D.** 1 V

__B__ 2. In the circuit of Fig. 3-1.1, if the applied voltage was increased, the amount of power would:
A. Decrease **B.** Increase **C.** Stay the same

__B__ 3. Compared to a voltmeter, the ammeter in Fig. 3-1.1 is:
A. Drawn differently and connected differently **B.** Drawn the same and connected differently **C.** Drawn differently and connected the same **D.** Drawn the same and connected the same

__D__ 4. Referring to the circuit of Fig. 3-1.2, if the voltage was doubled for each step but the resistance was halved, the current (Table 3-1.2) would:
A. Increase by twice as much **B.** Decrease by one-half **C.** Decrease by one-fourth **D.** Increase by four times as much

__C__ 5. According to Ohm's law and the data gathered in the experiment:
A. The more resistance, the more current with constant voltage **B.** The more current, the less voltage with constant resistance **C.** The less resistance, the more current with constant voltage **D.** The less current, the more voltage with constant resistance

__B__ 6. If the terminals (negative and positive) of the power supply in Fig. 3-1.2 were reversed, it would be necessary to:
A. Reverse the terminals of the ammeter and the resistor **B.** Reverse the terminals of the voltmeter and the ammeter **C.** Reverse the terminals of the voltmeter and the resistor **D.** Reverse the terminals of the resistor only

__B__ 7. Because the ammeter is connected in the same path as the resistor, would you expect the ammeter's resistance to be:
A. Very large **B.** Very small **C.** Medium value

B or C 8. To obtain a current value of 30 mA, the amount of voltage and resistance necessary would be:
A. V = 100 V, R = 333 Ω **B.** V = 15 V, R = 400 Ω **C.** V = 3 V, R = 100 Ω **D.** A, B, and C

TABLE 3-1.1 Ohm's Law

Applied Voltage V	Nominal Resistance Ω	Measured Current, mA	Calculated Current,* mA	Calculated Power
1.5	100	**14.2**	**15.0**	**225 mW**
2.5	100	**24.5**	**25.0**	**625 mW**
3.5	100	**33.8**	**35.0**	**1.225 W**
4.5	100	**42.8**	**45.0**	**2.025 W**
6.0	100	**59.0**	**59.0**	**3.6 W**
7.0	100	**69.5**	**70.0**	**4.9 W**
8.0	100	**79.8**	**80.0**	**6.4 W**
9.0	100	**89.2**	**90.0**	**8.1 W**

*Formula: Applied voltage/nominal resistance

TABLE 3-1.2 Ohm's Law

Applied Voltage, V	Nominal Resistance, Ω	Measured Resistance, Ω	Measured Current, mA	Calculated Current, * mA
5.0	1000		**5.1**	**5.0**
5.0	820		**5.8**	**6.1**
5.0	560		**9.05**	**8.93**
5.0	330		**15.6**	**15.2**
5.0	100		**51.6**	**50.0**

*Formula: Applied voltage/measured resistance

EXPERIMENT 3-2: Applying Ohm's Law

Answers to Questions:

1. In the circuits of Fig. 3-2.2a and b, what aspects of Ohm's law were validated?
   The circuits validate that I = V/R and that there are proportional relationships between V, I, and R.

2. Describe any difference between the power calculations using the measured values and the calculated values. Refer to the percentage of error values.
   Some difference in power calculations can result when measured values differ from calculated values, but not more than 10 percent.

3. Explain why you think an ammeter can be connected in the circuit and not affect the flow of current. **An ammeter has practically zero resistance.**

4. Explain why the voltage measured across the resistor is the same as the applied voltage. **They are connected across the same points.**

5. In the circuit you designed, explain how you could reduce the dissipated power by one-half. **Increase R by 2X, or reduce V_a or I by one-fourth.**

TABLES FOR EXPERIMENT 3-2

TABLE 3-2.1 Approximate Values Are Acceptable

Circuit	Measured Value, R	Measured Value, V	Measured Value, I	Calculated Value, I	Calculated Value $P = V^2/R$	Measured Value $P = I^2R$	% Error P
a (470Ω)	470 Ω	10 V	21 mA	21 mA	210 mW	200 mW	<10%
b (330Ω)	330 Ω	7 V	21 mA	21 ma	150 mW	145 mW	<10%

TABLE 3-2.2

Measured Value, R	Measured Value, V	Measured Value, I	Calculated Value, $P = V^2/R$*	Measured Value, $P = I^2R$	% Error P
220 Ω	**5 V**	**23 mA**	**115 mW**	**115 mW**	**<10%**

EXPERIMENT 4-1: Series Circuits

Answers to Questions:

__C__ 1. In a series circuit, total current I_T is equal to:
A. R_T x I_T **B.** V_T x R_T **C.** V_T/R_T **D.** R_T/V_T

__B__ 2. In a series circuit, the current is:
A. Different through every resistor in series **B.** Always the same through every resistor in series **C.** Calculated by using Ohm's law as I = V x R **D.** Found only by using the voltmeter

__C__ 3. The total voltage in a series circuit is:
A. Equal to total resistance **B.** Found by adding the current through each resistor **C.** Equal to the sum of the series IR voltage drops **D.** Found by using an ohmmeter

__D__ 4. In a series circuit with 10 V applied:
A. The greater the total resistance, the greater the total current **B.** The greater the total current, the greater the total resistance **C.** The IR voltage drops will each equal 10 V **D.** The sum of the IR voltage drops will equal 10 V

__D__ 5. When an IR voltage drop exists in a series circuit:
A. The polarity of the resistor is equal to positive **B.** The polarity of the resistor is equal to negative **C.** The polarity of the resistor is less than the total current on both sides **D.** The polarity of the resistor is positive on one end and negative on the other because of current flowing through it

WRITE A SHORT ANSWER FOR THE FOLLOWING QUESTIONS

6. Does $V_T = I_{R1} + I_{R2} + I_{R3}$?
ANSWER: No. The sum of the currents does not equal the total voltage V_T.

7. Is the measurement current the same at all parts of the series circuit?
ANSWER: Yes. Measured currents will be the same in all parts of a simple series circuit.

8. Does $R_T = R_1 + R_2 + R_3$?
ANSWER: Yes. The sum of the resistances equals the total resistance in a simple series circuit.

TABLES FOR EXPERIMENT 4-1

TABLE 4-1.1

Nominal Resistance, Ω	Measured, Ω
R_1 = 150	**149 Ω**
R_2 = 15	**15.7 Ω**
R_3 = 10	**9.5 Ω**
R_T = 175	**174.2 Ω**

TABLE 4-1.2

	Calculated	Measured	% Error
R_T	**175 Ω**	**174.2 Ω**	**0.46%**
I_T	**57.14 mA**	**58.5 mA**	**-2.38%**
V_{R1}	**8.57 V**	**8.5 V**	**0.82%**
V_{R2} V_{R2}	**0.857 V**	**0.92 V**	**7.35%**
V_{R3} V_{R3}	**0.571 V**	**0.56 V**	**1.93%**

TABLE 4-1.3

Point	Current, mA
A	**58.5 mA**
B	**58.5 mA**
C	**58.5 mA**
D	**58.5 mA**

EXPERIMENT 4-2: Series Circuits - Resistance

Answers to Questions:

1. Write the formula that determines the total resistance R_T that is found in a series resistance string.
   $R_T = R_1 + R_2 + R_3 + \ldots R_m$

2. Write the formula that determines the amount of current flow for the circuit shown in Fig. 4-2.5 if the potential difference is 85 V.
   $R_T = R_1 + R_2 + R_3$
   $= 100\ \Omega + 150\ \Omega + 220\ \Omega$
   $= 570\ \Omega$

   $$I_T = \frac{V_A}{R_T} = \frac{85\text{ V}}{570\ \Omega} = 0.149\text{ A}$$

3. In your estimation would $V_T = IR_1 + IR_2 + IR_3 + \ldots$ be true for all series resistive strings? Explain.
   Yes. Current I is the same throughout all parts of a series circuit.

4. Do you believe that the measured current is the same at all points of a series resistive string when a potential difference is present across the circuit? Explain.
   Yes. If the circuit is not open, the total is determined so that $I_T = \frac{V_A}{R_T}$

5. Could you always expect that $R_T = R_1 + R_2 + R_3 + \ldots$ in a series resistive circuit? Explain.
   Yes, unless there is an open in the series resistive string.

CRITICAL THINKING QUESTIONS

Note: The following questions are designed to help you analyze the previous lab experiment in a complete and in-depth fashion. To answer these questions, you should review the related material in Grob/Schultz, Basic Electronics.

1. Explain where "sources" of error exist in this experiment. How could these sources of error be reduced?
   In this experiment, sources of error could be components, equipment, tolerance, and human error. NOTE: Answers will vary.

2. The purpose of a series circuit is to connect different components that need the same current. After reviewing your results for this experiment, explain how this purpose supports, or agrees with, your findings.
   Based upon measurements taken, the experiment supports the concept that the current is the same at different parts of the circuit.

3. Explain why the current is the same in all parts of a series circuit.
   The value of current flow is the same value in all parts of a series circuit because The resistance is the same value in all parts of a series circuit.

4. Is it the case that the mathematical calculations of the measured values of a series circuit are such that the amount of current between two points in a circuit equals the potential difference divided by the resistance between these points? Explain.
   Yes, as defined by Ohm's law.

5. Explain what is meant by the term series string.
   Series string is another name for resistors that are connected in series.

TABLES FOR EXPERIMENT 4-2

TABLE 4-2.1 Individual Resistor Values

Resistors **Ω**	Measured	% Tolerance
100	**98.9**	**5%**
150	**152.7**	**5%**
220	**222**	**5%**
390	**392**	**5%**
560	**564**	**5%**

TABLE 4-2.2 Total Resistance R_T and Percentage of Error

	Calculated **Ω**	Measured **Ω**	% Error
Total Resistance	**470**	**467**	**0.63**

TABLE 4-2.3 Series Circuit Measurements

Resistors **Ω**	Value	Measured*	Measured Voltage	Calculated Current
R_1	**100**	**98.9**	**3.17**	**0.032**
R_2	**150**	**152.7**	**4.80**	**0.031**
R_3	**220**	**222**	**7.04**	**0.031**

*Values are from the previous table.

TABLE 4-2.4 Series Circuit Measurements and Percentage of Error

Resistance	Expected	Measured	Measured Voltage	Calculated Current	% Error
X to Y	**660 Ω**	**662.9 Ω**			
Current Y		**0.020 A**			
R_5			**1.9 V**	**0.019 A**	**5.3%**
R_6			**10.6 V**	**0.019 A**	**5.3%**

EXPERIMENT 4-3: Series Circuits – Analysis

Answers to Questions

1. Explain the significance of the following statement: In a series resistive circuit, in order to calculate I, the total V_T can be divided by the total R_T, or an individual IR drop can be divided by its resistance.
   According to Ohm's law, the current I is the same in all parts of a series resistive circuit so either formula is correct.

2. Describe what a zero voltage drop could be.
   Either no supply voltage or a shorted component.

3. Describe the nature of the IR drop and current value of a component which displays the characteristics of a short.
   The IR drop displays practically 0 V. The current value increases to compensate for the shorted component.

4. In a series circuit, if the IR voltage drop is measured to be the same across two resistors, what can be said about these two resistors?
   They are the same ohmic value.

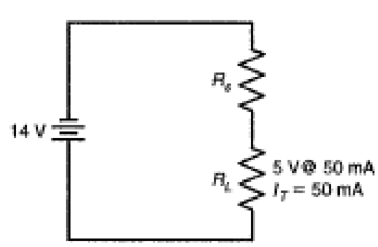
5. In a series circuit, if the current is measured to be 0 mA and is the same in all resistances, what would you suspect is taking place in this circuit?
   Either there is no supply voltage or there is an open in the circuit.

CRITICAL THINKING QUESTIONS

1. As described in the introduction of this experiment, a common application of series circuits is to use a resistance to drop the voltage from the voltage source to a lower value. Design a series-dropping resistor R_s so that the load requires 5 V at 50 mA, while the supply voltage is limited to 14 V_{DC}.

$$V_{R_s} = 14\ \text{V} - 5\ \text{V} = 9\ \text{V}$$

$$R_s = \frac{V_{R_s}}{I_T} = \frac{9\ \text{V}}{50\ \text{mA}} = 180\ \Omega$$



$$V_{R_s} = 14\ \text{V} - 5\ \text{V} = 9\ \text{V}$$

$$R_s = \frac{V_{R_s}}{I_T} = \frac{9\ \text{V}}{50\ \text{mA}} = 180\ \Omega$$

2. Determine the resistor's wattage rating for the design problem as described in critical thinking question 1. Using manufacturer's specification sheets and/or supplier catalogs, select a resistor that closely matches your component design. Using this value, and assuming that your design is not a perfect match, how will the voltage drops and circuit current values be affected? Explain.

   P = IV **A typical value could be 180 Ω at 0.5 W.**
   = (50 mA) (9 V)
   = 0.45 W

3. The purpose of a series circuit is to connect different components that need the same current. After reviewing your results for this experiment, explain how this purpose supports or agrees with your findings.
   This experiment, based upon measurements, supports this conclusion.

4. Explain why the current is the same in all parts of a series circuit.
   In all parts of a series circuit, the value of current (electron flow) is the same because the resistance is the same value.

5. Explain where the sources of errors exist within this experiment. How could these sources of error be reduced?
   In this experiment, sources of error could be components, equipment, tolerance, and human error. Answers will vary.

TABLES FOR EXPERIEMNT 4-3

TABLE 4-3.1 Individual Resistor Values

Resistors	Measured Ω	% Tolerance
100	**100**	**5**
150	**150**	**5**
220	**220**	**5**
390	**390**	**5**
560	**560**	**5**

TABLE 4-3.2 Total Resistance R_T and Percentage of Error

	Calculated	Measured	% Error
Total Resistance	**1420 Ω**	**1415 Ω**	**0.35**

TABLE 4-3.3 Current and Voltage Measurements
Current = __0.014 A__ at point A.

Point A Resistors	Value Ω	Measured*	Measured Voltage	Calculated Current
R_1	100	**100 Ω**	**1.4**	**1.4**
R_2	150	**150 Ω**	**2.1**	**2.1**
R_3	220	**220 Ω**	**3.1**	**3.1**
R_4	390	**390 Ω**	**5.5**	**5.5**

*Values from previous table.

TABLE 4-3.4 The Total Voltage IR Drops and Percentage of Error
Voltage = __20 V__

	Measured IR Drops*	Calculated IR Drops	% Error
IR_1	**1.4**	**1.4**	**0**
IR_2	**2.1**	**2.1**	**0**
IR_3	**3.1**	**3.1**	**0**
IR_4	**5.5**	**5.5**	**0**
Sum of IR Drops	**12.1**		
V_T – sum = IR_5	**7.9**		

*Values from previous table.

TABLE 4-3.5 Analyzing IR Drops

Explain: The values are comparable.

Calculated IR_5*	**7.9 V**
Measured IR_5	**7.8 V**

*Use value of IR_5 from Table 4-3.4

EXPERIMENT 4-4: Series Circuits with Opens

Answers to Questions

1. Define, in your own words, what the unique characteristics of a series resistive circuit are.
   The sum of the resistances equals the total resistance. The sum of the voltage drops equals the total voltage. The current is the same throughout the circuit.

2. Describe what happens to the current in a series resistive circuit if an open in the circuit path occurs.
   The current would be measured at zero.

3. Describe what happens to the voltage drops in a series resistive circuit if an open in the circuit path occurs.
   The voltage drops would be zero, except across the open; then the voltage drop would be the same as the applied voltage.

4. In a series resistive circuit that provides a given amount of current flow, when the resistors are compared why does the resistor with a higher ohmic value also have a larger voltage drop across it? Is this also true for a circuit with an open?
   Because of Ohm's law ($V = IR$), the larger resistance, the greater the voltage drop. Yes. The resistance across the open is infinite and because of Ohm's law all the supply voltage will be dropped there.

5. Give an application of a series circuit.
   Many answers are possible. Students could mention AND gates.

CRITICAL THINKING QUESTIONS

Note: The following questions are designed to help you analyze the previous lab experiment in a complete and in-depth fashion. To answer these questions, you should review the related material in Grob/Schultz, Basic Electronics.

1. Explain where the sources of error exist in this experiment. How could these sources of error be reduced?
   In this experiment, sources of error could be components, equipment, tolerance, and human error. Answers will vary.

2. How could the idea of open circuits apply to the 120 V AC from the power line in your home?
   A wall outlet would have 120 V AC across its open terminals.

3. Explain why the current is the same in all parts of a series circuit. Further, describe why the IR drops are zero in an open series resistive circuit.
   If there is no current flowing, there will be no IR drops in an open circuit except across the open where the applied voltage will be found.

4. Demonstrate mathematically why the current of an open circuit is practically zero.
   $I = \frac{V_A}{R}$ if $R = \infty$; therefore, $I = \frac{V_A}{\infty} = 0$ A.

5. Why is the source voltage in an open series resistive circuit present with or without current flow in the external circuit?
   The potential difference from the source is unaffected by the open and does not need current to flow to be able to maintain a potential difference.

TABLES FOR EXPERIMENT 4-4

TABLE 4-4.1 Individual Resistor Values

Resistors **Ω**	Measured	% Tolerance
100	**98**	**5**
150	**147**	**5**
220	**220**	**5**
390	**389**	**5**

TABLE 4-4.2 Total Resistance R_T and Percentage of Error

	Calculated	Measured	% Error
Total Resistance	**860 Ω**	**854 Ω**	**0.7**

TABLE 4-4.3 Current and Voltage Measurements

Circuit without Open					Circuit with Open		
Resistor Values	Measured Voltage	Circuit Points	Measured Current		Measured Voltage	Circuit Points	Measured Current
R_1	**2.3 V**	A	**0.02 A**		**0 V**	A	**0 A**
R_2	**3.4 V**	B	**0.02 A**		**0 V**	B	**0 A**
R_3	**5.1 V**	C	**0.02 A**		**0 V**	C	**0 A**
R_4	**9.0 V**	D	**0.02 A**		**0 V**	D	**0 A**

EXPERIMENT 4-5: Series-Aiding and Series-Opposing Voltages

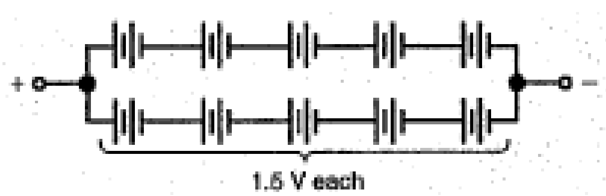
Answers to Questions

1. Name four precautions which must be observed in measuring voltages.
   Polarity and adequate range are two precautions. The other two should be reviewed in lecture class.

2. What would happen to a dry cell or battery if the positive and negative terminals were short-circuited?
   There would be maximum current flow. The battery might explode.

3. What arrangement of six dry cells gives the maximum voltage?
   Series-aiding arrangement.

4. Draw a practical arrangement of ten 1.5-V dry cells to get a battery of 7.5 V.
   NOTE: student drawings will vary.



5. Explain the difference in connection between two dry cells connected in series-aiding and in series-opposing.
   Series-aiding voltages are additive. Series-opposing voltages are subtracted.

TABLES FOR EXPERIMENT 4-5

TABLE 4-5.1

Battery	Measured Voltages
1	**1.42 V**
2	**1.44 V**
3	**1.45 V**
4	**1.39 V**

TABLE 4-5.2

Series-Aiding Battery	Measured Voltages
1 + 2	**2.86 V**
1 + 2 + 3	**4.32 V**
1 + 2 + 3 + 4	**5.7 V**

TABLE 4-5.3

Parallel-Arrangement Battery	Measured Voltages
1 + 2	**1.45 V**
1 + 2 + 3	**1.45 V**
1 + 2 + 3 + 4	**1.45 V**

TABLE 4-5.4

Circuit	Voltages	Terminals
Fig. 4-5.2	**2.9 V**	A to B
Fig. 4-5.3	**1.45 V**	C to D

TABLE 4-5.5

Circuit	Voltages	Terminals
Fig. 4-5.4a	**0.025 V**	E to F
Fig. 4-5.4b	**1.4 V**	G to H
Fig. 4-5.4c	**2.8 V**	I to J

EXPERIMENT 4-6: Positive and Negative Voltages to Ground

Answers to Questions

1. Explain the circuit function of a voltage divider.

Voltage dividers are used to deliver part of the supply voltage in a specific amount. They also function to deliver a specific amount of current. Functionally, this allows a complex circuit to share one supply or source. As the name implies, the applied voltage is divided among the resistors across its potential.

2. What is the purpose of a circuit ground ?

For circuits, the ground is a return path for current to the supply source and is sometimes connected to the chassis. In a home or building that uses AC voltage, one side is connected to a metal conductor in the ground for safety against large spikes of voltage or current.

3. Draw an example of a circuit where a voltage is negative with respect to ground.

NOTE: Student drawings will vary.

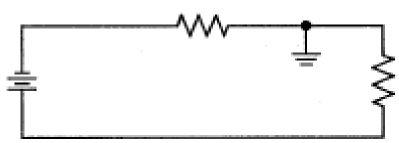


TABLE 4-6.1 (steps 2 – 7)

	Measured	Calculated	Polarity*
R_1	**10 k Ω**		
R_2	**4.7k Ω**		
R_3	**4.7k Ω**		
R_T	**19.5k Ω**	**19.5k Ω**	
I_T	**1 mA**	**1mA**	
V_{A-C}	**10.3V**	**10.3 V**	**+**
V_{B-C}	**4.8 V**	**4.8 V**	**+**
V_{D-C}	**-4.8 V**	**-4.8 v**	**-**
V_T	20 V		

*Note: Polarity with respect to common ground.

TABLE 4-6.2 (steps 8 and 9)

	Measured	Calculated	Polarity*
R_1	**10 k Ω**		
R_2	**4.7k Ω**		
R_3	**4.7k Ω**		
R_T	**19.5k Ω**	**19.5k Ω**	
I_T	**1 mA**	**1mA**	
V_{A-C}	**-10.3V**	**10.3 V**	**-**
V_{B-C}	**-4.8 V**	**4.8 V**	**-**
V_{D-C}	**4.8 V**	**-4.8 v**	**+**
V_T	20 V		

EXPERIMENT 5-1: Parallel Circuits

Answers to Questions

1. What is a parallel circuit? What circuit characteristics indicate that a parallel circuit condition exists?
   A parallel circuit has more than one current path connected across common voltage points.

2. In the circuit of Fig. 5-1.2, determine the power being dissipated by each resistor using the values of current determined in procedure step 7. Use the formula I^2R = power (watts).
   P_{R1} = 255 mW P_{R3} = 108 mW
   P_{R2} = 110 mW

3. Are the voltages the same across each resistor in a parallel circuit?
   Yes.

4. Are the currents the same through each resistor in a parallel circuit?
   No.

5. Suppose in procedure step 7 that R_3 developed a short-circuited condition. How would the current flowing through each resistor change? Would the voltage drops across each resistor change? How?
   The current through each R_1 and R_2 would be practically zero. Current through R_3 would be very high. With no current, R_1 and R_2 have little or no voltage drop. R_3 is drawing all the power from the source.

TABLES FOR EXPERIMENT 5-1

TABLE 5-1.1

	Measured	Calculated
R_1	**990 Ω**	
R_T		**990 Ω**
V_{R1}	**10 V**	
I_a	**10.5 mA**	**10.1 mA**
I_b	**10.5 mA**	**10.1 mA**

TABLE 5-1.2

	Measured	Calculated
R_1	**990 Ω**	
R_2	**997 Ω**	
R_T		**496.7 Ω**
V_{R1}	**10 V**	
V_{R2} V_{R2}	**10 V**	
I_a	**20.8 mA**	**20.1 mA**
I_b	**10.6 mA**	**10.1 mA**
I_c	**10.5 mA**	**10.0 mA**

TABLE 5-1.3

	Measured	Calculated
R_1	**990 Ω**	
R_2	**997 Ω**	
R_3	**2.175 Ω**	
R_T		**404.4 Ω**
V_{R1}	**10 V**	
V_{R2}	**10 V**	
V_{R3}	**10 V**	
I_a	**25.5 mA**	**24.7 mA**
I_b	**11.0 mA**	**10.1 mA**
I_c	**10.8 mA**	**10.0 mA**
I_d	**5.2 mA**	**4.6 mA**

EXPERIMENT 5-2: Parallel Circuits – Resistance Branches

Answers to Questions

1. Write the formula that determines the total resistance R_T of the circuit depicted in Fog. 5-2.3.

$$R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$$

2. Mathematically determine the branch current passing through R_1, as shown in Fig. 5-2.3. Show all calculations.

$$I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{15\text{ V}}{1000\text{ W}} = 0.015\text{ A}$$

Note: $V_A = V_{R_1} = 15$ V

3. In your estimation, would $V_T = IR_1 = IR_2 = IR_3 = \ldots$ be true for all parallel resistive branches? Explain.
   Yes, since the voltage applied (V_T) is connected across each resistor directly and the voltage drop is also determined by Ohm's law, so that $V_T = IR$.

4. In a parallel circuit, the amount of current in each separate branch depends upon what factor?
   The total applied voltage and the ohmic value of the individual branch resistor.

5. Could you always expect that $R_T = R_1 + R_2 + R_3 + \ldots$ in a series resistive circuit? Explain.
   Yes, but this would not be true of a parallel resistive circuit.

CRITICAL THINKING QUESTIONS

Note: The following questions are designed to help you analyze the previous lab experiment in a complete and in-depth fashion. To answer these questions, you should review the related material in Grob/Schultz, Basic Electronics.

1. Explain where the sources of errors exist in this experiment. How could these sources of error be reduced?
   In this experiment, sources of error could be components, equipment, tolerance, and human error. Answers will vary.

2. The purpose of a parallel circuit is to connect different components that need the same voltage. After reviewing your results for this experiment, explain how this purpose supports, or agrees with, your findings. Explain.
   The results support the concept that the voltages are the same across the components connected in parallel.

3. Explain why the voltage is the same across all branches in a parallel circuit.
   The voltage is the same across all branches in a parallel circuit since the components are connected directly across the supply voltage.

4. Explain why, for a parallel resistive circuit, each branch current equals the applied voltage divided by the branch resistance.
   This is because Ohm's law states that

$$I_{branch} = \frac{V_A}{R_{branch}}$$

5. How is it possible for current to be different in various parts of parallel circuits when the applied voltage is found to be the same across all branches?
   Current divides in a parallel circuit.

TABLES FOR EXPERIMENT 5-2

TABLE 5-2.1 Individual Resistor Values

	Nominal Value	Measured Value
R_1 =	1 kΩ	**980 Ω**
R_2 =	2.2 kΩ	**2150 Ω**
R_3 =	390 Ω	**390 Ω**
R_4 =	1.2 kΩ	**1200 Ω**
R_5	3.9 kΩ	**3800 Ω**

TABLE 5-2.2 Total Resistance R_T and Percentage of Error

	Nominal Calculated Total Resistance $R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_5$	Total Resistance Measured	% Error
R_T =	**195.7 Ω**	**190 Ω**	**2.9**

TABLE 5-2.3 Recording Voltage, Current, and Error Measurements

	Part A				Part B		Part C	
	Measured Voltage		Tables 5-2.1 And 5-2.2 Measured Resistance		Calculated I = V/R		Measured I	% Error
V_A	**15 V**	R_T	**190 Ω**	I_T	**0.079 A**	Point A	**0.080 A**	**13**
V_{R1}	**15 V**	R_1	**980 Ω**	I_{R1}	**0.015 A**	Point B	**0.012 A**	**20**
V_{R2}	**15 V**	R_2	**2150 Ω**	I_{R2}	**0.007 A**	Point C	**0.008 A**	**14.3**
V_{R3}	**15 V**	R_3	**390 Ω**	I_{R3}	**0.038 A**	Point D	**0.041 A**	**7.9**
V_{R4}	**15 V**	R_4	**1200 Ω**	I_{R4}	**0.013 A**	Point E	**0.010 A**	**23**
V_{R5}	**15 V**	R_5	**3800 Ω**	I_{R5}	**0.004 A**	Point F	**0.004 A**	**0**

EXPERIMENT 5-3: Parallel Circuits – Analysis

Answers to Questions

1. Why is it true that the combined resistance of a parallel branch circuit equals the value of one branch resistance divided by the number of branches?
   When all branch resistances are equivalent, this is true because of the reciprocal resistance formula.

2. Define the term *bank* with regard to the parallel resistive circuit.
   A combination of parallel branches is often referred to as a bank.

3. In your estimation would $V_T = I_{R_1} = I_{R_2} = I_{R_3} = ...$, be true for all parallel resistive branches? Explain.
   Yes, since the voltage applied (V_T) is connected across each resistor directly and the voltage drop is also determined by Ohm's law, so that V_T = IR.

4. Does the formula $I_T = I_1 + I_2 + I_3 + I_4 + \ldots$, apply for any number of parallel branches? What if the individual branch resistances were equal or unequal? Explain.
   Yes. It makes no difference whether the resistances are equal or unequal. Total current is always equal to the sum of the individual branch currents.

5. What is meant by total-current method?
   The total-current method can be used in determining the total equivalent resistance of a parallel branch circuit.

CRITICAL THINKING QUESTIONS

Note: The following questions are designed to help you analyze the previous lab experiment in a complete and in-depth fashion. To answer these questions, you should review the related material in Grob/Schultz, Basic Electronics.

1. Explain where the sources of errors exist in this experiment. How could these sources of error be reduced?
   In this experiment, sources of error could be components, equipment, tolerance, and human error. Answers will vary.

2. One purpose of this experiment is to validate that the formula for the total current I_T in the main line of a parallel resistive circuit is $I_T = I_1 + I_2 + I_3 + I_4 + \ldots$. After reviewing your results for this experiment, explain how this purpose supports, or agrees with, your findings.
   The results support this purpose.

3. Explain why the voltage is the same across all branches in a parallel circuit.
   All branches in a parallel circuit are connected across the supply voltage.

4. Describe the two methods of analyzing main-line current flow as demonstrated in Fig. 5-3.2.
   The two methods utilized are (a) The reciprocal resistance formula, and (b) Ohm's law.

5. Explain what is meant by the statement "When a circuit provides more current with the same applied voltage, the greater value of current corresponds to less resistance because of Ohm's law inverse relationship between current and resistance." Show an example of this statement.

   $I = \frac{V}{R}$ R = 100 Ω R = 1000 Ω R = 10 Ω

   V = 100 V $I = \frac{100\text{ V}}{100\ \Omega} = 1\text{ A}$ $I = \frac{100\text{ V}}{1000\ \Omega} = 0.1\text{ A}$ $I = \frac{100\text{ V}}{10\ \Omega} = 10\text{ A}$

   As the resistance decreases, when the voltage is held constant, the current increases.

TABLES FOR EXPERIMENT 5-3

TABLE 5-3.1 Individual Resistor Values

	Nominal Value	Measured Value	% Error
R_1 =	680 Ω	**680**	**0**
R_2 =	1.2 kΩ	**1200**	**0**
R_3 =	1.0 kΩ	**1000**	**0**
		Step 1	*Step 2*
		Sum Measured	% Error
Sum =	302.7 Ω	**302.7**	**0**
		Step 2	

TABLE 5-3.2 Voltage Measurements

V_A	15 V		I_A	0.049 A
V_{R1}	15 V		I_B	0.022 A
V_{R2}	15 V		I_C	0.013 A
V_{R3}	15 V		I_D	0.015 A
Step 3			*Step 4*	

TABLE 5-3.3 Comparison of Calculated and Measured Currents

	Voltage Measurements from Table 5-3.2		Resistance Measurements from Table 5-3.1		Calculated Currents Columns 1 and 2		Measured Currents From Table 5-3.2	Current % Error
V_{R1}	**15 V**	R_1	**679 Ω**	I_1	**0.022 A**	I_1	**0.022 A**	0
V_{R2}	**15 V**	R_2	**1.184 kΩ**	I_2	**0.012 A**	I_2	**0.012 A**	0
V_{R3}	**15 V**	R_3	**1.000 kΩ**	I_3	**0.014 A**	I_3	**0.015 A**	1

TABLE 5-3.4 Tabulations for Three Equal Resistances in Parallel

	Nominal Values		Measured Values		Calculated by Reciprocal Method		Calculated by other method Described in Introduction
R_4 =	22 kΩ		**22.5 kΩ**				
R_5 =	22 kΩ		**22.2 kΩ**				
R_6 =	22 kΩ		**22.1 kΩ**				
		R_T =	**7.41 kΩ**	R_T =	**7.42 kΩ**	R_T =	**7.333 kΩ**

EXPERIMENT 5-4: Parallel Circuits – Opens and Shorts

Answers to Questions

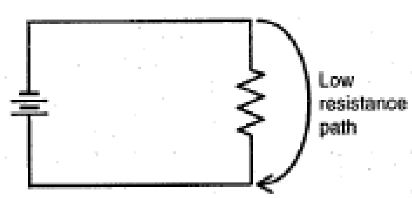
1. What is the result of an open circuit? Explain what happens to the levels of voltage and current in a basic parallel branch circuit.
   There is no current flow with an open circuit. In a basic parallel branch circuit, there is maximum voltage drop at the source of the open.

2. How will an open in a parallel branch affect the main-line current?
   An open in a parallel branch will result in no change in its drop. Current will be zero through this branch.

3. What is the main advantage of wiring a circuit in a parallel fashion?
   An open in one branch does not affect the operation of another branch.

4. Why does a short display practically no resistance? Provide a schematic drawing explaining your answer.

   NOTE: Student drawings will vary, showing a wire around a component or a wire to ground. Either way, the explanation should focus on the wire (short) as a zero resistance path.



5. What limits the current resulting from a short?
   Usually, the main-line circuit breaker or a fuse.

Critical Thinking Questions / Answers

1. Ask your laboratory instructor for two fuses, one that functions and one that does not. After studying these components, describe how they are similar and how they are different. Explain how you think these components operate.
   An open or blown fuse does not have its terminals connected internally. A functioning fuse has its terminals connected by a fine wire that will burn open with excessive current flow or demand.

2. Explain in your own words why short-circuited components are rarely damaged.
   Excessive current that could damage a component is bypassed around the component.

3. If any individual resistor is shorted in a parallel circuit, why are all other resistive branches shorted as well?
   All resistors are connected across one another. When one is shorted, they are all shorted.

4. Explain what is meant by the term *bypass* with reference to a shorted circuit.
   Current follows an alternative path around a component.

5. When a parallel circuit develops a shorted component, the voltage source cannot usually maintain its voltage level. Explain.
   The power supply or voltage source is usually limited in some way as to the amount of current it can supply. A short draws a maximum, infinite amount of current from its source which usually trips a circuit breaker.

TABLES FOR EXPERIMENT 5-4

TABLE 5-4.1 Individual Resistor Values

		Nominal Resistance	Measured Resistance
Step 1	R_1	1500 Ω	**1.482 kΩ**
	R_2	2200 Ω	**2.20 kΩ**
	R_3	3900 Ω	**3.88 kΩ**
	R_4	5600 Ω	**5.58 kΩ**
	R_5	1000 Ω	**1.024 kΩ**

TABLE 5-4.2 Total Resistance R_T and Percentage of Error

		Calculated	Measured	% Error
Step 2	R_T	**393.26 Ω**	**393 Ω**	**0.0674**

TABLE 5-4.3 Voltage Drops and Current Measurements

	Measured R Values from Table 5-4.1	Measured Voltage Drop	Current Measured Through Resistor
R_1	**1.482 kΩ**	**1.678 V**	**1.2 mA**
R_2	**2.20 kΩ**	**8.0 V**	**1.2 mA**
R_3	**3.88 kΩ**	**8.0 V**	**3.7 mA**
R_4	**5.58 kΩ**	**6.32 V**	**2.1 mA**

TABLE 5-4.4 Voltage Drops and Current Measurements with Shorted Components

With Only R_1 Shorted				**With Only R_2 Shorted**				**With Only R_3 Shorted**				**With Only R_4 Shorted**			
V_{R1}	**0.1mA**	I_1	**1.41mA**	V_{R1}	**0.3mV**	I_1	**0.2nA**	V_{R1}	**0.3mV**	I_1	**0.2nA**	V_{R1}	**6.20V**	I_1	**4.2mA**
V_{R2}	**7.84V**	I_2	**3.6mA**	V_{R2}	**1.1mV**	I_2	**14.8nA**	V_{R2}	**1.2mV**	I_2	**0.4nA**	V_{R2}	**6.2V**	I_2	**2.9mA**
V_{R3}	**7.84V**	I_3	**2.03mA**	V_{R3}	**1.2mV**	I_3	**0.2nA**	V_{R3}	**1.1mV**	I_3	**14.7nA**	V_{R3}	6.2V	I_3	**1.6mA**
V_{R4}	**7.84V**	I_4	**1.41mA**	V_{R4}	**1.4mV**	I_4	**0.2nA**	V_{R4}	**1.0mV**	I_4	**0.2nA**	V_{R4}	0.3mV	I_4	**4.18mA**

How do the above measurements reinforce the characteristics of a short?
Circuit current increases when a component is shorted. Voltage across other components increases. (Students may compare their values.)

Verify by calculations the expected voltages and currents for this circuit when R_2 is shorted.
[Calculations should closely match measurements with R_2 shorted.]

TABLE 5-4.5 Voltage Drops and Current Measurements

	Measured R Values from Table 5-4.1	Measured Voltage Drop	Current Measured Through Resistor
R_1	**1.482 kΩ**	**15.0 V**	**10.2 mA**
R_2	**2.20 kΩ**	**4.24 V**	**1.93 mA**
R_3	**3.88 kΩ**	**15.0 V**	**3.86 mA**
R_4	**5.58 kΩ**	**10.76 V**	**1.93 mA**

TABLE 5-4.6 Voltage Drops and Current Measurements with Opens

Point A Open				Point B Open				Point C Open				Point D Open			
V_{R1}	**0**	I_1	**0**	V_{R1}	**0V**	I_1	**0mA**	V_{R1}	**15V**	I_1	**10.09mA**	V_{R1}	**15V**	I_1	**10.09mA**
V_{R2}	**0**	I_2	**0**	V_{R2}	**4.24V**	I_2	**1.93mA**	V_{R2}	**0V**	I_2	**0mA**	V_{R2}	**4.24V**	I_2	**1.93mA**
V_{R3}	**0**	I_3	**0**	V_{R3}	**15V**	I_3	**3.86mA**	V_{R3}	**15V**	I_3	**3.87mA**	V_{R3}	**15V**	I_3	**0mA**
V_{R4}	**0**	I_4	**0**	V_{R4}	**10.77V**	I_4	**1.93mA**	V_{R4}	**0V**	I_4	**0mA**	V_{R4}	**10.76V**	I_4	**1.93mA**

How do the above measurements validate the characteristics of an open circuit?
Zero volts and zero current result when the circuit is open at point A. Zero volts and zero current result only in some portions of the circuit for points B, C, and D. (Students may be more specific.)

EXPERIMENT 6-1: Series Parallel Circuits - Resistance

Answers to Questions

1. Write the formula that correctly determines the total resistance of the circuit in Fig. 6-1.6.

$$R_T = R_1 + \left(\frac{1}{1/R_2 + 1/R_3 + 1/R_4}\right) + R_5 = 390\ \Omega + \left(\frac{1}{1/100\Omega + 1/150\Omega + 1/220\Omega}\right) + 560\Omega = 997.4\Omega$$

2. With reference to Fig. 6-1.6, which resistors are parallel to, or in series with, R_3?
R_1 and R_3 are in series with the R_3 parallel bank of resistors. R_2 and R_4 are in a parallel arrangement with R_3.

3. If in Fig. 6-1.1, the voltage across R_1 was determined to be 20 V, what would the circuit supply voltage be? Explain.
The circuit supply voltage would be 20 V. Since R_1 is connected across V_A, the voltage drop across R_1 is equivalent to V_A.

4. If in Fig. 6-1.4, the current measured through R_5 was 20 mA, what would be the current through R_1? Why?
The current would be 20 mA. R_5 is in series with R_1. The current is the same in series circuits.

5. Write the formula that would give the equivalent resistance of five 22-kΩ resistors connected in parallel. Applying your formula, determine this resistive value.

$$R_{EQ} = \frac{1}{1/22k\Omega + 1/22k\Omega + 1/22k\Omega + 1/22k\Omega + 1/22k\Omega}$$
$$= 4400\Omega$$

CRITICAL THINKING QUESTIONS.

1. In analyzing series-parallel circuits, it is believed that with a parallel string across the main line, the branch currents and the total current can be found without knowing the total resistance. Explain how this principle can be true.
According to Grob/Schultz, this principle can be true if it is possible to calculate the branch currents first, or by calculating the applied voltage and then the branch currents.

2. In analyzing series-parallel circuits, it is believed that when parallel strings have series resistances in the main line, the total resistance must be calculated to find the total current, assuming no branch currents are known. Explain how this principle can be true.
   Refer to the section on analyzing series-parallel circuits in Basic Electronics, Grob/Schultz, for a schematic representation.

3. In analyzing series-parallel circuits, if the source voltage is applied across the total resistance of the entire circuit, a total current will be produced that will be found in the main line. Explain how this principle can be true.
   See the answer to critical thinking question 2.

4. In analyzing series-parallel circuits, it is believed that any individual series resistance has its own voltage drop that is less than the total applied voltage. Explain how this principle can be true.
   See the answer to critical thinking question 2.

5. In analyzing series-parallel circuits, it is believed that any individual branch current must be less than the total main-line current. Explain how this principle can be true.
   The sum of individual branch currents for a parallel circuit would equal the total current. Therefore, any individual branch current would be less than the total.

TABLES FOR EXPERIMENT 6-1

TABLE 6-1.1 Individual Resistor Values

	Nominal Resistance	Measured Value
R_1	390 Ω	**390 Ω**
R_2	100 Ω	**100 Ω**
R_3	150 Ω	**150 Ω**
R_4	220 Ω	**220 Ω**
R_5	560 Ω	**560 Ω**

TABLE 6-1.2 Measurements and Calculations for Resistance, Voltage, and Current

		Calculated	Measured	% Error
Step 2	R_T	**997.1 Ω**	**954 Ω**	**4.3**
	V_{R1}	**5.85 V**	**5.79 V**	**1.02**
	V_{R2}	**0.75 V**	**0.70 V**	**6.6**
Step 4	V_{R3}	**0.75 V**	**0.70 V**	**6.6**
	V_{R4}	**0.75 V**	**0.70 V**	**6.6**
	V_{R5}	**8.4 V**	**8.4 V**	**0**
	I_1 (Point A)	**0.015 A**	**0.014 A**	**6.7**
	I_2 (Point B)	**0.0075 A**	**0.0075 A**	**0**
Step 5	I_3 (Point C)	**0.005 A**	**0.004 A**	**20**
	I_4 (Point D)	**0.0034 A**	**0.003 A**	**11.76**
	I_5 (Point E)	**0.015 A**	**0.015 A**	**0**
				Step 6

EXPERIMENT 6-2: Series Parallel Circuits – Networks

Answers to Questions

1. In your own words, explain what a series-parallel circuit is.
   A series-parallel circuit is two circuits in one, a series circuit and a parallel circuit. The parallel circuit is in series with the series circuit.

2. In the circuit shown in Fig. 6-2.2, determine the power being dissipated by each resistor. Use the formula P/I * V = power (watts).
   R_1 = 160 mW, R_2 = 163.6 mW, R_3 = 76.6 mW.

3. In Fig. 6-2.2, are the voltages the same across each resistor?
   No; R_1 = 4 V, R_2 and R_3 = 6 V.

4. In Fig. 6-2.2, are the currents the same through each resistor?
   No; R_1 = 40 mA; R_2 = 27.8 mA; R_3 = 12.8 mA.

5. Suppose in Fig. 6-2.3 that R_3 developed a short-circuited condition. How would the current flowing through each resistor change? Would the voltage drop across each resistor change? How?
   The current would change as follows: R_1 = 100 mA; R_2 = 0 A; R_3 = 0 A
   Yes; the voltage drop would change. It would change as follows: R_1 = 10 V; R_2 = 0 V; R_3 = 0 V.

TABLES FOR EXPERIMENT 6-2

TABLE 6-2.1 (values for Fig. 6-2.3)

Nominal Resistance	Measured Resistance
R_1 = 150 Ω	**146 Ω**
R_2 = 100 Ω	**95 Ω**
R_3 = 100 Ω	**98 Ω**
R_4 = 120 Ω	**115 Ω**
R_5 = 150 Ω	**150 Ω**

TABLE 6-2.2

	Calculated	Measured	% Error
V_1	**4.00 V**	**4.05 V**	**1.3**
V_2	**6.00 V**	**5.95 V**	**0.8**
V_3	**6.00 V**	**5.95 V**	**0.8**
V_T		**10.0 V**	
I_1	**40 mA**	**43 mA**	**7.5**
I_2	**27.2 mA**	**30 mA**	**10.3**
I_3	**12.8 mA**	**15 mA**	**17.2**
I_T	**40 mA**	**43 mA**	**7.5**
R_T	**250.2 Ω**	**251 Ω**	**0.3**

TABLE 6-2.3

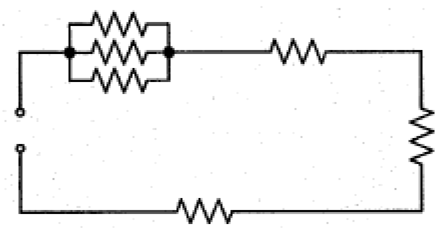
	Calculated	Measured	% Error
V_1	**10 V**	**10 V**	**0**
V_2	**2.94 V**	**2.94 V**	**0**
V_3	**2.94V**	**2.94 V**	**0**
V_4	**7.06 V**	**7.0 V**	**0**
V_5	**10 V**	**10 V**	**0**
V_T	**10V**	**10 V**	
I_1	**66 mA**	**66 mA**	**0**
I_2	**29 mA**	**29 mA**	**0**
I_3	**29 mA**	**29 mA**	**0**
I_4	**59 mA**	**59 mA**	**0**
I_5	**67 mA**	**67 mA**	**0**
I_T	**192 mA**	**192mA**	**0**
R_T	**52 Ω**	**52 Ω**	**0**

NOTE for % Error: student values will vary but should not exceed 10%.

EXPERIMENT 6-3: Series Parallel Circuits – Analysis

Answers to Questions

1. Draw a diagram showing three resistors in a bank that is in series with three resistors.



2. From Fig. 6-3.4, describe which resistors are in a parallel circuit arrangement.
   R_4 is in series with R_5; this combination is in parallel with R_2 and R_3; finally this combination is in series with R_1 and R_6.

3. From your readings in Grob/Schultz, Basic Electronics, describe three of the six characteristics of a parallel resistor circuit.
   Six possible answers are: The voltage is the same across all branches. In each branch R, I is V/R. $I_T = I_1 + I_2 + I_3 + \ldots +$ etc. R_{EQ} must be less than the least value of branch R. The largest branch I is in the smallest parallel R. An open in one branch does not prevent I in other branches.

4. From your readings in Grob/Schultz, Basic Electronics, describe three of the five characteristics of a series resistor circuit.
   The five characteristics are: The current is the same in all components. Across each series R, V is I x R. $V_T = V_1 + V_2 + V_3 + \ldots +$ etc. $R_T = R_1 + R_2 + R_3 + \ldots +$ etc. An open in one component causes the entire circuit to be open.

5. In Fig. 6-3.5, explain how you would know which resistors are in parallel with each other and which are in series.
   Follow current flow. Same currents would indicate series components; divided currents would indicate parallel components.

CRITICAL THINKING QUESTIONS

1. Determine all circuit calculations (voltage drops and currents) for the circuit shown in Fig. 6-3.5, where the applied voltage is changed to 15 V_{dc}. Determine the power dissipation required for each resistor. If the voltage were increased to 25 V DC, would the 0.25-W power rating of the resistors recommended for use in this experiment be adequate? **Yes, a 0.25-W resistor would be adequate.**

2. Determine the total resistance R_T for Fig. 6-3.3. Show all calculations.

$$R_T = \frac{V_A}{I_T} = \frac{100\text{ V}}{8.3\text{ mA}} \cong 12{,}048.2\ \Omega$$

3. Determine the power dissipation required for each resistor shown in Fig. 6-3.3. Show all calculations.

$P_{R_1} = I^2R_1 = (8.3\text{ mA})^2(1\text{ k}\Omega) = 0.069\text{ W}$, $P_{R_2 \square R_3} = I^2(R_2 \square R_3) = (8.3\text{ mA})^2(3071\ \Omega) = 0.212\text{ W}$, $P_{R_4} = I^2R_4 = (8.3\text{ mA})^2(3.9\text{ k}\Omega) = 0.269\text{ W}$, $P_{R_5 \square R_6} = I^2(R_5 \square R_6) = (8.3\text{ mA})^2(1935.5\ \Omega) = 0.133\text{ W}$, $P_{R_7} = I^2R_7 = (8.3\text{ mA})^2(2.2\text{ k}\Omega) = 0.152\text{ W}$

4. Determine the total resistance R_T for Fig. 6-3.5. Show all calculations.
R_T = 588.7 Ω

5. Determine the power dissipation required for each resistor shown in Fig. 6-3.5. Show all calculations.
P_1 = 0.109 W, P_2 = 0.066 W, P_3 = 0.029 W, P_4 = 0.036 W, P_5 = 0.006 W, P_6 = 0.172 W

TABLES FOR EXPERIMENT 6-3

TABLE 6-3.1 Individual Resistor Values

		Nominal Values	Measured Values
	R_1	150 Ω	**145 Ω**
	R_2	390 Ω	**387 Ω**
Step 1	R_3	820 Ω	**820 Ω**
	R_4	560 Ω	**568 Ω**
	R_5	100 Ω	**101 Ω**
	R_6	220 Ω	**220 Ω**

TABLE 6-3.2 Total resistance R_T and Percentage of Error

		Measured	Calculated	% Error
Step 2	R_T	**549.2 Ω**	**558.7 Ω**	**1.73**

TABLE 6-3.3 Voltage, Current Measurements, and Percentage of Error

		Measured	Calculated	% Error
	V_{R1}	**4.0 V**	**4.03 V**	**0.75**
Step 3	V_{R2}	**4.96 V**	**5.03 V**	**1.41**
	V_{R3}	**4.96 V**	**5.03 V**	**1.41**
	V_{R4}	**4.39 V**	**4.48 V**	**2.05**
	V_{R5}	**0.76 V**	**0.8 V**	**5.26**
	V_{R6}	**5.9 V**	**5.94 V**	**0.67**
	I_T (Point A)	**0.026 A**	**0.027 A**	**3.84**
	I_{R1} (Point B)	**0.026 A**	**0.027 A**	**3.84**
	I_{R2} (Point C)	**0.011 A**	**0.013 A**	**18.1**
Step 4	I_{R3} (Point D)	**0.006 A**	**0.006 A**	**0**
	I_{R4} (Point E)	**0.0075 A**	**0.008 A**	**6.66**
	I_{R5} (Point F)	**0.0075 A**	**0.008 A**	**6.66**
	I_{R6} (Point G)	**0.026 A**	**0.027 A**	**3.84**
				Step 5

EXPERIMENT: 6-4 Series Parallel Circuits – Opens and Shorts

Answers to Questions

1. What effect would a short across a resistor located in series with a parallel resistive branch have on the level of main-line current flow? Explain.
   Current flow would increase.

2. What effect would there be (on individual branch circuit levels) of a short from point A to point B within a circuit (opposite in Fig. 6-4.5)? Explain.
   Branch current levels would be zero.

3. If in Fig. 6-4.1, R_2 was shorted, what would happen to the current flow and voltage drop of R_3? What would happen to the voltage and current of R_2? Explain.
   R_3 would have no current flow or voltage drop. R_2 would have no current flow or voltage drop.

4. Calculate the needed level of power dissipation for each resistor shown in Fig. 6-4.4. How does power dissipation change for a shorted component? How would it change across an open component? Explain.
   The needed power level is as follows:
   P_{R1} = 0.02 W; P_{R2} = 0.026 W; P_{R3} = 0.031 W;
   P_{R4} = 0.002 W; P_{R5} = 0.0005 W; P_{R6} = 0.114 W.
   Shorts tend to increase power consumption. Opens tend to decrease power consumption.

5. According to Grob/Schultz, Basic Electronics, what is the potential difference across an open? Explain.
   Maximum voltage, usually the applied voltage.

CRITICAL THINKING QUESTIONS

1. For the short circuit current analysis in Step 17, the following statement is made: "Maintaining a supply voltage of 15 V, use a clip lead to short R_1 from your circuit. With an ammeter, take current measurements of I_{R2}, I_{R3}, I_{R4}, I_{R5}, and I_{R6}. Do not take the current measurement through R_1. Record this information In Table 6-4.3." Why was the current measurement I_{R1} excluded from the original measurements? What is the anticipated value for I_{R1}?
   A shunt would be created between the ammeter and R_1. This might affect the reading. $I_{R1} \approx$ 0.014 A.

2. For the open circuit voltage analysis in Step 29, the following statement is made: "Maintaining a supply voltage of 15 V, open R_1 by removing it from the circuit. Take voltage drop measurements V_{R_2}, V_{R_3}, V_{R_4}, V_{R_5}, and V_{R_6}. Do not take the voltage drop measurement across R_1. Record these measurements in Table 6-4.4." Why was the voltage measurement V_{R_1} excluded from the original measurements? What is the anticipated value for V_{R_1}?
   Because of the circuit configuration, there may be an inaccurate reading with some voltmeters. $V_{R_1} \approx 15\ \text{V}$.

3. For the open circuit current analysis in Step 41, the following statement is made: "Maintaining a supply voltage of 15 V, open R_1 by removing it from the circuit. Take current measurements I_{R_2}, I_{R_3}, I_{R_4}, I_{R_5}, and I_{R_6}. Do not take the current measurement through R_1. Record these measurements in Table 6-4.4." Why was the current measurement I_{R_1} excluded from the original measurements? What is the anticipated value for I_{R_1}?
   Because of the circuit configuration, there may be an inaccurate reading with some ammeters. $I_{R_1} \approx 0.014\ \text{A}$.

TABLES FOR EXPERIMENT 6-4

TABLE 6-4.1 Individual Resistor Values

Resistor	Nominal Value, Ω	Resistive Measurement
R_1	120	**120 Ω**
R_2	820	**820 Ω**
R_3	560	**560 Ω**
R_4	100	**95 Ω**
R_5	470	**475 Ω**
R_6	680	**697 Ω**

TABLE 6-4.2 Total Resistance R_T and Percentage of Error

	Calculated	Measurement	% Error
R_T	**1160.2 Ω**	**1148 Ω**	**1.05**

TABLE 6-4.3 Short Circuit Calculations and Measurements

	Normal Circuit Calculations	Normal Circuit Measurements		Measurements (with Each Resistor *Shorted* One at a Time) R$_1$	R$_2$	R$_3$	R$_4$	R$_5$	R$_6$
V_{R1}	**1.56V**	**1.6V**		**0V**	**2.25V**	**2.06V**	**1.43V**	**1.56V**	**3.75V**
V_{R2}	**4.67V**	**4.6 V**		**5.20V**	**0V**	**1.28V**	**5.46V**	**4.6V**	**11.25V**
V_{R3}	**4.03V**	**4V**		**4.3V**	**0V**	**0V**	**2.99V**	**4.6V**	**9.68V**
V_{R4}	**0.64V**	**0.6V**		**0.9V**	**0V**	**1.28V**	**0V**	**0V**	**1.57V**
V_{R5}	**0.64V**	**0.6V**		**0.9V**	**0V**	**1.28V**	**2.51V**	**0V**	**1.57V**
V_{R6}	**8.77V**	**8.6V**		**9.80V**	**12.75V**	**11.66V**	**8.12V**	**8.84V**	**0V**
I_{R1}	**0.013A**	**0.013A**			**0.019A**	**0.017A**	**0.012A**	**0.013A**	**0.031A**
I_{R2}	**0.005A**	**0.004A**		**0.006A**		**0.002A**	**0.007A**	**0.006A**	**0.014A**
I_{R3}	**0.007A**	**0.006A**		**0.008A**	**0A**		**0.005A**	**0.008A**	**0.017A**
I_{R4}	**0.006A**	**0.005A**		**0.009A**	**0A**	**0.013A**		**0A**	**0.016A**
I_{R5}	**0.001A**	**0.001A**		**0.002A**	**0A**	**0.003A**	**0.005A**		**0.003A**
I_{R6}	**0.013A**	**0.013A**		**0.014A**	**0.019A**	**0.017A**	**0.012A**	**0.013A**	

TABLE 6-4.4 Open Circuit Calculations and Measurements

Measurements (with Each Resistor *Opened* One at a Time)

	R$_1$	R$_2$	R$_3$	R$_4$	R$_5$	R$_6$
V_{R1}		**1.2V**	**1.11V**	**1.43V**	**1.56V**	**0V**
V_{R2}	**0V**		**7.59V**	**5.45V**	**4.6V**	**0V**
V_{R3}	**0V**	**5.6V**		**2.8V**	**4.13V**	**0V**
V_{R4}	**0V**	**1.4V**	**0V**		**0.74V**	**0V**
V_{R5}	**0V**	**1.4V**	**0V**	**2.35V**		**0V**
V_{R6}	**0V**	**6.8V**	**6.29V**	**8.12V**	**8.84V**	
I_{R1}		**0.010A**	**0.009A**	**0.012A**	**0.013A**	**0A**
I_{R2}	**0A**		**0.009A**	**0.007A**	**0.005A**	**0A**
I_{R3}	**0A**	**0.010A**		**0.005A**	**0.007A**	**0A**
I_{R4}	**0A**	**0.014A**	**0A**		**0.007A**	**0A**
I_{R5}	**0A**	**0.003A**	**0A**	**0.005A**		**0A**
I_{R6}	**0A**	**0.010A**	**0.009A**	**0.012A**	**0.013A**	

EXPERIMENT 6-5: The Wheatstone Bridge

Answers to Questions

1. In procedure steps 9 and 10, the Wheatstone bridge was balanced by matching a decade box to the unknown resistor. Thus, the Wheatstone bridge was used as what kind of meter? **Ohmmeter**

2. Explain the difference between a galvanometer and an ohmmeter.
   A galvanometer is a dual directional microammeter with the needle zeroed at top dead center; it measures current. An ohmmeter measures resistance.

3. In procedure step 5, suppose the schematic of Fig. 6-5.2 showed R_4 as 50 kΩ, and R_1 to R_3 remained at 10 kΩ. With power on, would the needle deflect to the right or the left? **To the right.**

4. Which circuit in Fig. 6-5.4 would be more sensitive (greater needle deflection) when attempting to balance the bridge? Why?
   Fig. 6-5.4b, because of greater voltage drops.

5. Explain any differences and/or similarities between the two circuits in Fig. 6-5.5.
   Both are balanced, and resistors are interchanged.

Differences: The resistive branch totals are different as (a) has two 60K ohm branches in parallel while (b) has a 20K ohm and a 100k in parallel. This also means circuit (b) has less total resistance and therefore the current is greater.

Similarities: Both circuits has the same basic configuration (2 parallel branches with two resistors in each branch. They also have the same applied voltage (10 V) with the same polarity.

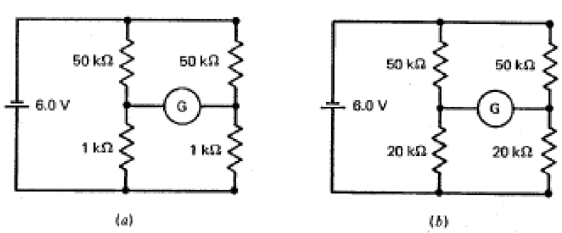
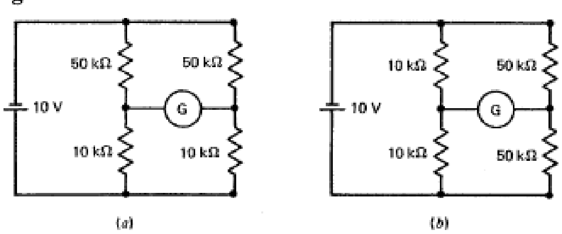


Fig. 6-5.4



TABLES FOR EXPERIMENT 6-5

TABLE 6-5.1 Data from Fig. 6-5.1

R_4 kΩ	Voltage AB	Current Direction
1	**0.71 V**	**R**
5	**0.29 V**	**R**
6	**0.22 V**	**R**
7	**0.16 V**	**R**
8	**0.10 V**	**R**
9	**0.05 V**	**R**
10	**0.005 V**	**R**
11	**0.035 V**	**L**
12	**0.072 V**	**L**
13	**0.106 V**	**L**
14	**0.138 V**	**L**
15	**0.166 V**	**L**

TABLE 6-5.2 R_1 and R_3 = 10 kΩ, R_4 = Decade Box

Voltage and Current at A and B = 0			**Needle Deflection to Right**				**Needle Deflection to Left**		
	R_4, Ω		R_4, Ω	V_{R4}	V_{R2}		R_4, Ω	V_{R4}	V_{R2}
R_2 = 10kΩ	**10kΩ**		**3.7kΩ**	**0.595**	**0.595**		**100kΩ**	**1.09**	**1.09**
R_2 = 5.6kΩ	**5.6kΩ**		**2.4KΩ**	**0.425**	**0.425**		**20.4KΩ**	**0.79**	**0.79**
R_2 = 1kΩ	**1kΩ**		**490**	**0.104**	**0.104**		**2kΩ**	**0.202**	**0.202**
R_2 = 2.2kΩ	**2.1kΩ**		**1.03kΩ**	**0.208**	**0.208**		**5kΩ**	**0.394**	**0.394**
R_2 = 2.7kΩ	**2.7kΩ**		**1.26kΩ**	**0.248**	**0.248**		**6.5kΩ**	**0.466**	**0.466**
R_2= 560Ω	**560**		**260**	**0.058**	**0.058**		**1.14kΩ**	**0.118**	**0.118**

EXPERIMENT 6-6: Additional Series Parallel Circuits

Answers to Questions

1. Which resistor in the circuit of Fig. 6-6.2 has the least effect on R_T and why?
   Resistor R_5 (100 Ω) has the least effect on R_T because it is series with R_4 (5 kΩ).

2. What would happen to the circuit of Fig. 6-2.2 if R_1 were decreased to 10 Ω?
   If R_1 were 10 Ω, then R_T would be less than 10 Ω, and the remaining resistor would have almost no effect on R_T.

3. What would happen to the circuit of Fig. 6-2.2 if R_1 were increased to 10 MΩ?
   If R_1 were 10 MΩ, then R_{eq} would have the greatest effect on R_T and R_1. In other words, R_1 would have little effect on R_T.

4. Which resistor in the circuit of Fig. 6-6.2 has the least effect on I_T?
   Resistor R_5 (100 Ω) has the least resistance, but its effect on I_T is also the least because it is in series with R4 (5 kΩ). It does not create another current path.

5. Which resistor in the circuit of Fig. 6-6.2 has the greatest effect on I_T?
   Resistor R_1 has the greatest effect on I_T because it is less than R_{eq} and allows the greatest amount of current to flow.

TABLES FOR EXPERIMENT 6-6

TABLE 6-6.1

Resistance Values Nominal or Calculated	Ω Measured	V Measured		I Calculated
R_1 = 4.7 kΩ	**4.7 kΩ**	**10 V**		**2.1 mA**
R_2 = 4.7 kΩ	**4.7 kΩ**	**10 V**		**2.1 mA**
R_3 = 1 kΩ	**1 kΩ**	**6.2 V**		**6.2 mA**
R_4 = 820 Ω	**820 Ω**	**3.8 V**		**4.6 mA**
R_5 = 2.2 kΩ	**2.2 kΩ**	**3.0 V**		**1.4 mA**
R_6 = 10 kΩ	**10 kΩ**	**0.75 V**		**0.1 mA**
R_7 = 560 Ω	**560 Ω**	**0.75 V**		**1.3 mA**
R_T = **953 Ω**	**960 Ω**		I_T =	**10.4 mA**
R_{eq} = **1.21 kΩ**	**1.2 kΩ**			
R_T with R_6 removed	**960 Ω**			
R_T with R_2 = 10 kΩ	**1.08 kΩ**			

EXPERIMENT 6-7: Additional Series Parallel Circuits – Opens and Shorts

Answers to Questions

1. What are the characteristics of a shorted circuit?
   Zero volts across the short; excessive current; practically zero resistance.

2. What are the characteristics of an open circuit?
   Infinitely high resistance; no current flow; voltage across the open circuit.

3. Compare Tables 6-7.1 and 6-7.2. What are differences and similarities?
   Differences: Opening or closing the switch changes R_T, current, and voltage drops. Similarities: The data shows that circuit Figs. 6-4.7 and 6-4.8 are the same when Fig. 4-4.7 is opened and Fig. 4-4.8 is closed.

TABLES FOR EXPERIMENT 6-7

TABLE 6-7.1 (V_A = 10 V) **TABLE 6-7.2 (V_A = 10 V)**

Unshorted Circuit, Fig. 6-7.7				**Shorted Circuit, Fig. 6-7.8**		
Component	Measured	Calculated		Component	Measured	Calculated
R_1	**150 Ω**			R_1	**150 Ω**	
R_2	**150 Ω**			R_2	**150 Ω**	
R_3	**150 Ω**			R_3	**150 Ω**	
R_T		**225 Ω**		R_T		**225 Ω**
I_{R1}	**46.5 mA**	**43.3 mA**		I_{R1}	**46.5 mA**	**43.3 mA**
I_{R2}	**23.1 mA**	**21.7 mA**		I_{R2}	**23.1 mA**	**21.7 mA**
I_{R3}	**23.4 mA**	**21.7 mA**		I_{R3}	**23.4 mA**	**21.7 mA**
V_{R1}	**6.5 V**	**6.98 V**		V_{R1}	**6.5 V**	**6.98 V**
V_{R2}	**3.25 V**	**3.46 V**		V_{R2}	**3.25 V**	**3.25 V**
V_{R3}	**3.25 V**	**3.51 V**		V_{R3}	**3.25 V**	**3.25 V**

Shorted Circuit, Fig. 6-7.7				**Opened Circuit, Fig. 6-7.8**		
R_T		**150 Ω**		R_T		**300 Ω**
I_{R1}	**68 mA**	**66.7 mA**		I_{R1}	**32 mA**	**33.3 mA**
I_{R2}	**0 mA**	**0 mA**		I_{R2}	**0 mA**	**0 mA**
I_{R3}	**0 mA**	**0 mA**		I_{R3}	**32 mA**	**33.3 mA**
V_{R1}	**10 V**	**10.2 V**		V_{R1}	**5 V**	**5.0 V**
V_{R2}	**0 V**	**0 V**		V_{R2}	**0 V**	**0 V**
V_{R3}	**0 V**	**0 V**		V_{R3}	**5 V**	**5.0 V**

EXPERIMENT 7-1: Voltage Dividers with Loads

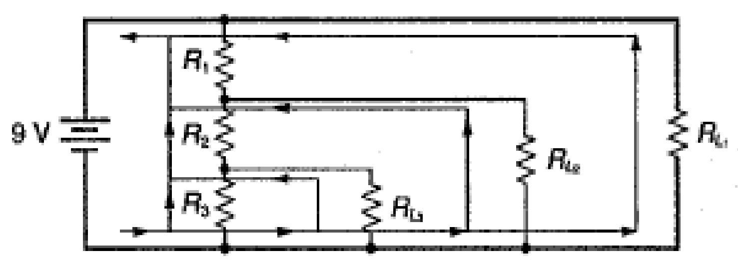
Answers to Questions

1. Explain what is meant by the term *voltage divider*.
   Total applied voltage is divided among series resistors.

2. Refer to the circuit of Fig. 7-1.4 (loaded voltage divider). Explain what would happen to the total circuit current, voltage, and resistance if R_{L2} and R_{L3} were removed.
   V_T =9 V (same) I_T = 3.2 mA R_T = 2.82 kΩ

3. If Fig. 7-1.4 were used to tap the total voltage of 9 V into three equal parts (without the loads), explain why V_{R1}, V_{R2}, and V_{R3} (with respect to ground) would not be 3 V each. Does the value of any one load greatly affect the original unloaded divider?
   They are no longer 3 V each because measurements are taken from ground reference. Yes.

4. Redraw Fig.7-1.4 and show the path of current flow by drawing arrows where necessary.



5. What effect would reversing the battery polarity have on the circuit of Fig. 7-1.4?
   Positive ground or reversing the electron current flow.

TABLES FOR EXPERIMENT 7-1

TABLE 7-1.1 No Load Values for Fig. 7-1.3

	Calculated IR Drop	Measured Current
R_1	**3.3 V**	
R_2	**3.3 V**	
R_3	**3.3 V**	
I_T		**333.3 µA**

TABLE 7-1.2 Measured Values for Fig. 7-1.3, Circuit under Load

Load at Point A			Load at Point B			Load at Point C		
R_L = 1kΩ	IR Drops	Current		IR Drops	Current		IR Drops	Current
R_1	**3.3V**			**9.17V**			**0.3V**	
R_2	**3.34V**			**0.437V**			**4.85V**	
R_3	**3.35V**			**0.439V**			**4.85V**	
R_{load}	**10V**	**10mA**		**0.877V**	**N/A**		**N/A**	**N/A**
I_T		**10.4mA**			**950µA**			**500µA**
I_B		**400µA**			**35µA**			**30µA**
R_L= 100kΩ								
R_1	**3.32V**			**3.74V**			**3.43V**	
R_2	**3.36V**			**3.15V**			**3.36V**	
R_3	**3.37V**			**3.16V**			**3.16V**	
R_{load}	**10.0V**	**100.0µA**		**6.31V**				
I_T		**500.0µA**			**400µA**			**380µA**
I_B		**400.0µA**			**350µA**			**340µA**

TABLE 7-1.3 Circuit Values for Fig. 7-1.4

	IR Drop, Measured	Current Calculated*
R_1	**4.43 V**	**4.4 mA**
R_2	**3.49 V**	**3.5 mA**
R_3	**1.12 V**	**1.1 mA**
R_{L1} R_{L3}	**1.12 V**	**2.38 mA**
R_{L2}	**1.12 V**	**981 mA**
R_{L3}	**9.04 V**	**192 mA**
R_T	**9.04 V**	**4.59 mA**

*V (IR drop measured)/R nominal = calculated current

EXPERIMENT 7-2: Current Dividers

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__F__ 1. Series circuits divide current, and parallel circuits divide voltages.

__F__ 2. Conductance G is the reciprocal of branch current.

__T__ 3. Refer to Fig. 7-2.4. If another resistor, $R_6 = 100\ \Omega$, were added in parallel to the bank, the voltage across the bank would increase.

__F__ 4. Refer to Fig. 7-2.4. If the series resistor R_1 were short-circuited, the total current would decrease.

__F__ 5. Refer to Fig. 7-2.4. If R_3 and R_4 were opened, the voltage across the series resistor R_1 would decrease.

__F__ 6. Refer to Fig. 7-2.4. If the total voltage were halved and the total circuit resistance doubled, there would be no effect upon total current.

__F__ 7. Refer to Fig. 7-2.4. If R_1 were opened, the total circuit current would increase.

__T__ 8. The voltage across any parallel bank is increased as the total conductance of the bank is increased.

__F__ 9. The total current in a parallel bank is inversely proportional to its conductance.

__T__ 10. The total current in a parallel bank is directly proportional to its total resistance.

TABLES FOR EXPERIMENT 7-2

NOTE: For Tables 7-2.1, 7-2.2, and 7-2.3, values will vary depending on information and material provided.

TABLE 7-2.1

	Nominal R, Ω	Calculated I, mA	Total Calculated V, V
R_1	100		
R_2	390		
R_T			

TABLE 7-2.2

	Nominal R, Ω	Measured I, mA	From Table 7-2.1 V, V
R_1	100		
R_2	390		
R_3	820		
R_T			

TABLE 7-2.3

	Nominal R, Ω	Calculated G, S	Calculated I, mA	Calculated V, V*	Measured I, mA
R_1	150		30.0		30.0
R_2	100				
R_3	390				
R_4	560				
R_5	820				
R_T			30.0		3.0

Note: Calculate R_T
$*V_x$ = I calculated × R nominal

EXPERIMENT 7-3: Potentiometers and Rheostats as Dividers

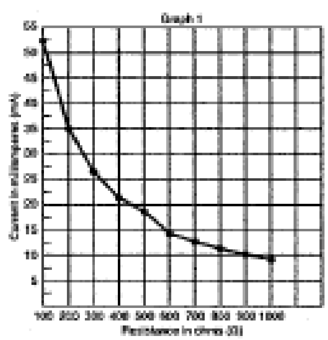
Answers to Questions

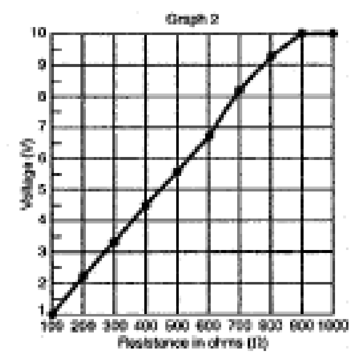
1. How many circuit connections to a potentiometer are needed? **Three.**

2. How many circuit connections to a rheostat are needed? **Two.**

3. Determine maximum power consumption from the graphs you completed in steps 5 and 10. What are the actual necessary wattages of R_1 and R_2?
   R_1 = 3 W needed. Maximum power consumption in Graph One is 2.704 W.
   R_2 = ¼ W needed. Maximum power consumption in Graph Two is 100 mW.

GRAPHS FOR EXPERIMENT 7-3





TABLES FOR EXPERIMENT 7-3

TABLE 7-3.1

Resistance, Ω	Measured Current
100	**52 mA**
200	**35 mA**
300	**27 mA**
400	**22 mA**
500	**19 mA**
600	**14.5 mA**
700	**12.8 mA**
800	**11.5 mA**
900	**10.5 mA**
1000	**9.6 mA**

TABLE 7-3.2

Resistance, Ω	Measured Voltage
100	**1.0 V**
200	**2.15 V**
300	**3.4 V**
400	**4.45 V**
500	**5.6 V**
600	**6.65 V**
700	**8.2 V**
800	**9.4 V**
900	**10.0 V**
1000	**10.0 V**

EXPERIMENT 7-4: Voltage Divider Design

Answers to Questions

1. Explain the difference between earth ground and a common reference point ground.
   "Earth ground" is a constant, whereas "common reference point ground" is a symbol of a zero reference point used in measurement.

2. Explain how a negative voltage can be obtained from a voltage divider. Explain the effects upon I, V, and R, if any.
   Negative voltage occurs by placing the common ground connection between the resistors. It has no effect on total I, V, and R.

3. Explain, in your own words, what is meant by *bleeder current.*
   A bleeder is a steady drain on the source; it has a stabilizing effect on the circuit.

4. Explain the difference, if any, between a loaded voltage divider and a series-parallel circuit.
   A loaded voltage divider is able to supply different voltages and currents to different loads from only one power source.

5. Explain how the circuit of Fig. 7-4.1 would be affected if:
   A. R_2 were short-circuited   B. R_2 were opened
   If R_2 were short-circuited, excess current would be forced through resistance. If R_2 were opened, excess current would be forced to loads.

TABLES FOR EXPERIMENT 7-4

TABLE 7-4.1

Divider	(1) Calculated R, Ω	(2) Actual R Value Ω	(3) Measured V, V	(4) Calculated I, mA
Load A	**500**	**470**	**20.04**	**42.6**
Load B	**600**	**620**	**14.87**	**24.0**
Load C	**500**	**470**	**4.97**	**10.6**
R_1	**666.7**	**666**	**5.17**	**7.2**
R_2	**571.4**	**560**	**9.90**	**17.6**
R_3	**117.65**	**117.5**	**4.96**	**46.8**

TABLE 7-4.2

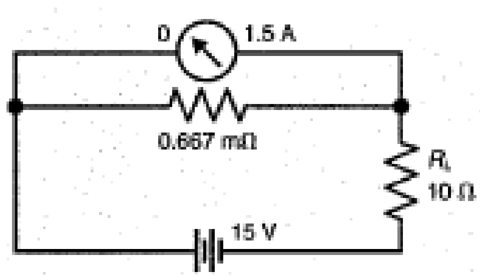
Divider	Measured V, V Common = Point C	Measured V, V Common = Point B
Load A	**15.1**	**5.5**
Load B	**9.7**	**0**
Load C	**0**	**-9.6**
R_1	**-4.8**	**-4.8**
R_2	**9.6**	**-9.6**
R_3	**15.1**	**5.6**

EXPERIMENT 8-1: Analog Ammeter Design

Answers to Questions

1. Describe how ammeters are connected in a circuit to measure current.
   They must be connected in series as a series component.
   The must be connected with the correct polarity.

2. Design an ammeter circuit that will measure 1.5 A with a 0- to 100-mA full-scale deflection meter movement.



TABLES FOR EXPERIMENT 8-1

TABLE 8-1.1

r_m	I_m	V_m
95.5 Ω	**524 µA**	**50 mV**

TABLE 8-1.2 Meter Movement

I_m, A	R_m, Ω	V_m, V
1.05 mA	**96 Ω**	**100 mV**
Shunt R_{S1} R_{S2}	**Shunt** R_{S2}	
3.36 Ω	**1 Ω**	

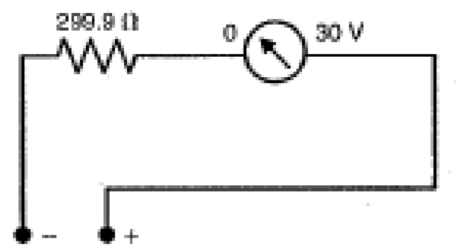
TABLE 8-1.3

Range, mA	Voltage Setting	I_1	I_2	% Accuracy
0-30	**14.25 V**	**30 mA**	**29.2 mA**	**97.3**
0-100	**32 V**	**73 mA**	**68 mA**	**93.2**

EXPERIMENT 8-2: Analog Voltmeter Design

Answers to Questions

1. Design a voltmeter that will measure 0 to 30 V dc by using a 100-mA meter movement.



TABLES FOR EXPERIMENT 8-2

TABLE 8-2.1

	0-50 µA
V_m	**36 mV**
r_m	**1.62 kΩ**
I_m	**22.3 µA**

TABLE 8-2.2 Meter Movement

I_m	**44.6 µA**
r_m	**1.62 kΩ**
V_m	**72 mV**
R_1	**111 kΩ**
R_2	**223 kΩ**

TABLE 8-2.3

Power Supply Voltages	V_1	V_2	% Accuracy
Range 1: 1-5 V			
1 V	**0.95**	**1.00**	**95**
2 V	**1.80**	**2.00**	**90**
3 V	**2.60**	**3.00**	**87**
4 V	**3.40**	**4.00**	**85**
5 V	**4.25**	**5.00**	**85**
Range 2: 1-10 V			
1 V	**1.00**	**1.00**	**100**
2 V	**2.00**	**2.00**	**100**
3 V	**2.80**	**3.00**	**93**
4 V	**3.80**	**4.00**	**95**
5 V	**4.80**	**5.00**	**96**
6 V	**5.60**	**6.00**	**93**
7 V	**6.45**	**7.00**	**92**
8 V	**7.40**	**8.00**	**93**
9 V	**8.40**	**9.00**	**93**
10 V	**9.40**	**10.00**	**94**

EXPERIMENT 8-3: Analog Ohmmeter Design

Answers to Questions

Answer TRUE (T) or FALSE (F) for each question.

__**F**__ 1. An ohmmeter is used to measure voltage and current.

__**T**__ 2. An ohmmeter has an internal battery.

__**F**__ 3. The infinity symbol (∞) on an ohmmeter indicates a short circuit.

__**T**__ 4. The ohmmeter's leads are placed across the resistance to be measured.

__**T**__ 5. When the ohmmeter leads are short-circuited, the needle will probably indicate zero.

__**F**__ 6. Ohmmeters do not require internal current-limiting resistances or shunt paths.

__**F**__ 7. The ohms or resistance scale that reads left to right is called a *back-off scale*.

__**F**__ 8. The zero-ohms adjustment should not be used when changing ranges.

__**T**__ 9. For greater values of resistance, a less-sensitive meter is required to read lesser values of current.

__**T**__ 10. An ohmmeter can be destroyed or have its fuse blown if it is used to measure resistance in a circuit where power is applied.

TABLES FOR EXPERIMENT 8-3

TABLE 8-3.1

Steps 5, 6, and 7

V_m	**50 mV**
r_m	**96 Ω**
I_m	**524 µA**

Step 8

r_m	**96 Ω**

TABLE 8-3.2

External R_x, Ω	Amount of Deflection	Scale Reading
0	**1.0 mA**	**0 Ω**
750	**0.68 mA**	**800 Ω**
1500	**0.50 mA**	**1.5 kΩ**
3000	**0.34 mA**	**2.8 kΩ**
150,000	≈**0 mA**	≈∞ **Ω**
500,000	≈**0 mA**	≈∞ **Ω**

TABLE 8-3.3

R	Known Meter	Design Meter	% Accuracy
100 Ω	**100 Ω**	**70 Ω**	**70**
1 kΩ	**1.0 kΩ**	**940 Ω**	**94**
4.7 kΩ	**4.7 kΩ**	**4.4 kΩ**	**93.6**
22 kΩ	**22 kΩ**	**28 kΩ**	**79**
100 kΩ	**100 kΩ**	≈∞	**—**
1 MΩ	**1 MΩ**	≈∞	**—**

EXPERIMENT 9-1: Kirchhoff's Laws

Answers to Questions

1. State Kirchhoff's current law, KCL.
   The algebraic sum of the current into and out of any point must equal zero.

2. State Kirchhoff's voltage, KVL.
   The algebraic sum of the applied voltages and IR voltage drops in any closed path must be equal to zero.

TABLES FOR EXPERIMENT 9-1

TABLE 9-1.1 Dry Cell Voltages

Battery	Measured Voltage
1	**1.42 V**
2	**1.45 V**

TABLE 9-1.2

Circuit	V_{R1}	V_{R2}	V_{R3}	I_1	I_2
Fig. 9-1.5	**0.47 V**	**1.03 V**		**4.8 mA**	
Fig. 9-1.6	**0.68 V**	**0.8 V**		**1.7 mA**	
Fig. 9-1.7	**20 mV**	**3.15 V**	**1.38 V**	**15 µA**	**6.8 mA**

TABLE 9-1.3

	Calculated	Measured
I_1	**6.3 mA**	**6.4 mA**
I_2	**2.93 mA**	**2.3 mA**
I_3	**6.3 mA**	**6.4 mA**
I_4	**1.89 mA**	**2.3 mA**
I_5	**9.23 mA**	**8.6 mA**
V_{R1}	**3.12 V**	**3 V**
V_{R2}	**0.97 V**	**0.8 V**
V_{R3}	**2.03 V**	**2 V**

NOTE: Values for Table 9-1.4 will vary depending on information and material provided.

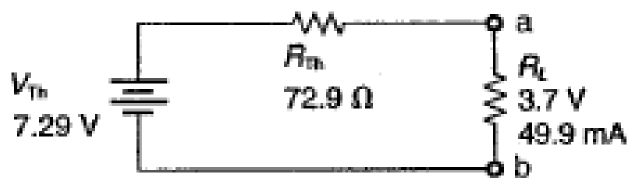
EXPERIMENT 10-1: Network Theorems

Answers to Questions

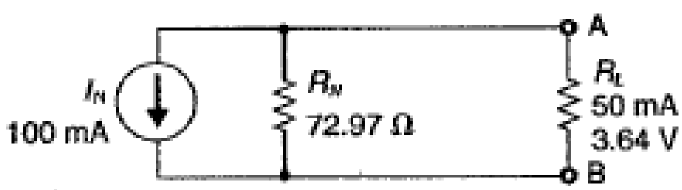
1. What are the primary use and importance of Thevenizing a circuit?
   To simplify a network circuit to a single voltage source in series with a single resistance connected to the same two terminals. This is useful in determining unknown voltages.

2. What are the primary use and importance of Nortonizing a circuit?
   Any two-terminal network can be replaced by a single current source in parallel with a single resistance to find unknown current values.

3. Draw a Thevenin equivalent of the circuit shown in Fig. 10-1.3.



4. Draw a Norton equivalent of Fig. 10-1.4.



5. Is the statement made at the end of procedure Step 6, which reads, "the advantage of Thevenizing the circuit is that the effect of R_L can be calculated easily for different values," valid? Explain and prove by example.
   Yes, it is valid because the values of V_{TH} and R_{TH} do not change. With a new value of $R_L = 100\ \Omega$, $I_L = V_{Th} / (R_{Th} + R_L)$ and $V_L = R_L I_L$.

TABLES FOR EXPERIMENT 10-1

TABLE 10-1.1

	Calculated	Measured	% Accuracy
V_{Th}	**7.29 V**	**7.55 V**	**96.5**
R_{Th}	**72.9 Ω**	**74.5 Ω**	**97.8**
V_L	**3.7 V**	**4.4 V**	**84.1**
I_L	**49.9 mA**	**44 mA**	**88.2**

TABLE 10-1.2

	Calculated	Measured	% Accuracy
I_N	**100 mA**	**97 mA**	**97.0**
R_N	**72.9 Ω**	**74.6 Ω**	**97.7**
I_L	**50 mA**	**45 mA**	**90.0**
V_L	**3.64 V**	**4.25 V**	**85.6**

EXPERIMENT 11-1: Conductors and Insulators

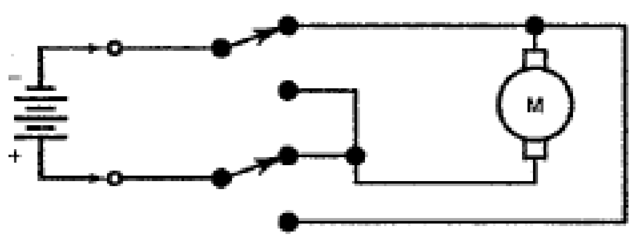
Answers to Questions

1. Considering that a current of 100 mA through your heart will almost certainly kill you, how much voltage across your hands would be lethal if you have a body resistance of 250 kΩ? **25,000 V**

2. How many connecting terminals does the SPST switch have? The SPDT? The DPST? The DPDT?
2, 3, 4, 6

3. What is the voltage drop across a closed switch? What is the voltage drop across an open switch?
Closed = zero ohms. Open = Infinite ohms

4. The double-pole, double-throw switch can be used to reverse the polarity of voltage across the terminals of a dc motor. From reading Chapter 11 in Basic Electronics, Grob/Schultz, draw the schematic diagram that would accomplish this task.



5. When an electrical open appears with a component found within a series circuit, such as a fuse or resistor, what can the assumed voltage be across the circuit's open? Is this always true? Explain what the implication is for electrical safety.
(A) The voltage can be assumed to be equal to the applied voltage. (B) Yes, it is always true. (C) When working on a circuit that has an open located somewhere within series components, care must be used because the applied voltage appears across the open and its voltage level could be dangerous and shock the technician.

6. Explain your results from Table 11-1.1 concerning the two fuses used in this experiment.
Different materials conduct current differently. The fuses were found to either conduct current (operable fuse), or not to conduct current (inoperable fuse).

7. Explain your results from Table 11-1.2. Using this information, how could you

improve your safety while working with electrical equipment?
The tighter the grip, the lower the body resistance. Wetness also decreases body resistance. Insulation from electrical currents improves the safety of the working technician. Avoiding wet environments while working with electrical current is also very important for improving the general electrical safety of the technician.

8. Explain your results from procedural steps 25 and 26 in Table 11-1.4. Using this information, how could you improve your safety while working with electrical equipment?
The voltage was found to be equal to the applied voltage. When working on a circuit that has an open, care must be used because the applied voltage appears across the open and its voltage level could be dangerous and shock the technician.

TABLES FOR EXPERIMENT 11-1

TABLE 11-1.1 Conductive Materials

Materials to be Measured	Resistance in Ω	Resistance in Ω
Water	**≈100,000 Ω***	**≈100,000 Ω***
Salt water	**≈50,000 Ω***	**≈50,000 Ω***
10-kΩ resistor	**≈10,000 Ω**	**≈10,000 Ω**
Disc capacitor	≈ ∞ **Ω**	≈∞ **Ω**
Inductor	**≈0 Ω**	**≈0 Ω**
1N4004 diode	**≈50 Ω***	**≈210,000 Ω***
Nichrome wire	**≈500 Ω***	**≈500 Ω***
Copper wire	**≈0 Ω**	**≈0 Ω**
Wood dowel	≈∞ **Ω**	≈∞ **Ω**
Plastic rod	≈∞ **Ω**	≈∞ **Ω**
Glass rod	≈∞ **Ω**	≈∞ **Ω**
Paper	≈∞ **Ω**	≈∞ **Ω**
Operational fuse	**≈0 Ω**	**≈0 Ω**
Non-operational fuse	≈∞ **Ω**	≈∞ **Ω**

***Values may vary**

NOTE: Resistance column 2 is with leads reversed.

TABLE 11-1.2 Body Resistance

Procedural Step and Measurement		Resistance Value
5	Loosely holding	**≈180,000 Ω**
6	Reverse ohmmeter measurement	**≈180,000 Ω**
7	Increased grip	**≈50,000 Ω**
8	Wet measurement	**≈25,000 Ω**

TABLE 11-1.3 Switches

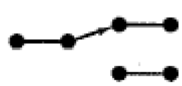
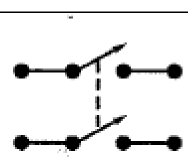
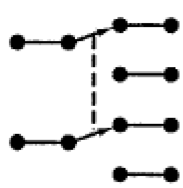
Schematic Diagram Including Pole And Throw Identifications	Switch Classification
	SPST
	SPDT
	DPST
	DPDT

TABLE 11-1.4 Fused Series Circuits

Analysis of Fused (Operational) and Un-Fused (Non-operational) Series Circuits

Procedural Step	Resistor	Measured Value
10	R_1	47 Ω
10	R_2	56 Ω

Establishing Maximum Circuit Parameters

Procedural Step	Maximum Parameters	Calculated/Measured Value With Appropriate Unit
12	R_T	103 Ω
13	V_{max}	25.75 V
14	I_T	97 mA

Analysis with the Operable Fuse Circuit

Procedural Step	Location	Calculated/Measured Value With Appropriate Unit
15	Calculated voltage A to ground	10 V
16	Measured voltage A to ground	10 V
17	Calculated voltage B to ground	10 V
18	Measured voltage B to ground	10 V
19	Calculated voltage R_1 to ground	10 V
20	Measured voltage R_1 to ground	10 V
21	Calculated voltage R_2 to ground	4.6 V
22	Measured voltage R_2 to ground	4.6 V
23	Calculated voltage A to B	0 V
24	Measured voltage A to B	0 V

Analysis with the Inoperable Fuse Circuit

15-Repeated	Calculated voltage A to ground	10 V
16-Repeated	Measured voltage A to ground	10 V
17-Repeated	Calculated voltage B to ground	0 V
18-Repeated	Measured voltage B to ground	0 V
19-Repeated	Calculated voltage R_1 to ground	0 V
20-Repeated	Measured voltage R_1 to ground	0 V
21-Repeated	Calculated voltage R_2 to ground	0 V
22-Repeated	Measured voltage R_2 to ground	0 V
23-Repeated	Calculated voltage A to B	10 V
24-Repeated	Measured voltage A to B	10 V

EXPERIMENT 12-1: Battery Internal Resistance

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following.

__**F**__ 1. Batteries have internal resistance, but dc power supplies do not.

__**F**__ 2. As load resistance increases, the terminal voltage decreases.

__**F**__ 3. As load current increases, terminal voltage increases.

__**T**__ 4. Connecting four batteries in parallel, each with r_i = 100 Ω, would increase the total r_i four times.

__**T**__ 5. Connecting four batteries in series, each with r_i = 100 Ω, would increase the total r_i four times.

__**T**__ 6. The internal resistance of a generator is always in parallel with a load.

__**T**__ 7. Subtracting the load voltage from the no-load voltage gives a remainder that is equal to the IR voltage drop in the internal resistance of the source.

__**T**__ 8. Internal resistance is in series with the load resistance.

__**F**__ 9. Short-circuiting a battery will not drain the battery.

__**F**__ 10. A 1.5-V dry cell battery with 1 Ω of internal resistance is probably a depleted battery.

TABLES FOR EXPERIMENT 12-1

TABLE 12.1.1 r_i = 1 kΩ (Steps 1-3)

R_L	Measured V_L, V	Measured I_L, A	Calculated R_i, Ω
10 kΩ	**10.95 V**	**1.16 mA**	**905**
5.6 kΩ	**10.1 V**	**1.7 mA**	**1.25 kΩ**
2.2 kΩ	**8.4 V**	**4.0 mA**	**900**
1 kΩ	**6.0 V**	**6.1 mA**	**984**
560 Ω	**4.3 V**	**7.8 mA**	**987**
220 Ω	**2.25 V**	**9.9 mA**	**985**

V_{NL} = **__12 V__**

TABLE 12-1.2 r_i = 560 Ω (Step 4)

R_L	Measured V_L, V	Measured I_L, A	Calculated R_i, Ω
10 kΩ	**11.4 V**	**1.2 mA**	**417 Ω**
5.6 kΩ	**11.0 V**	**2.0 mA**	**500 Ω**
2.2 kΩ	**10.0 V**	**4.55 mA**	**440 Ω**
1 kΩ	**8.05 V**	**8.2 mA**	**482 Ω**
560 Ω	**6.3 V**	**11.2 mA**	**509 Ω**
220 Ω	**3.42 V**	**16.0 mA**	**536 Ω**

TABLE 12-1.3 V_T = 6 V; r_i = 560 Ω (Step 5)

R_L	Measured V_L, V	Measured I_L, A	Calculated R_i, Ω
10 kΩ	**5.6 V**	**615 µA**	**650 Ω**
5.6 kΩ	**5.3 V**	**1.0 mA**	**700 Ω**
2.2 kΩ	**4.6 V**	**2.1 mA**	**667 Ω**
1 kΩ	**3.7 V**	**3.8 mA**	**605 Ω**
560 Ω	**2.95 V**	**5.2 mA**	**586 Ω**
220 Ω	**1.96 V**	**6.4 mA**	**631 Ω**

TABLE 12-1.4 Steps 6-8

	V_{NL}, V	Short-circuit I, A	Calculated R_i, Ω
1.5-V battery	≈1.5	≈1.5	≈1
Additional _____-V battery			

Note: Only the instructor will know the value of the three unknown values of r_i.

TABLE 12-1.5 r_i Unknown; r_L = 1 kΩ (Step 9)

	Measured V_L, V	Measured I_L, A	Calculated r_i, Ω
Measured V_{NL} = _________			
r_i No. 1			
r_i No. 2			
r_i No. 3			

Chassis or box number (if applicable): ________

EXPERIMENT 12-2: Load Match and Maximum Power

Answers to Questions

1. Explain the difference between circuit efficiencies of 1, 50, and 100 percent. In other words, explain what is meant by *circuit efficiency* as it relates to transfer of maximum power.
   1% means minimal dissipation; 50% = maximum power transfer. 100% = no power dissipated. Whenever $R_L = r_i$, maximum power is transferred to the load.

2. Explain what would happen if the circuit of Fig. 12-2.3 had an internal resistance of 100 kΩ.
   R_L would have to match r_i for maximum power transfer to occur. If the procedure remained the same, maximum power transfer would not occur.

3. Explain what would happen if the circuit of Fig. 12-2.3 had an internal resistance of 0.001 Ω.
   Same answer as question 2.

4. Explain why semilog paper is used to graph the data.
   Going from 100 Ω to 10,000 Ω on regular (linear) graph paper would require the horizontal axis to be great or too long.

5. Explain how you could get maximum power transferred to a 15-kΩ load if the internal resistance of your source was 10 kΩ.
   Either change the R_L or r_i value.

TABLES FOR EXPERIMENT 12-2

TABLE 12-2.1 Data for Circuit Fig. 12-2.3

R_L	Measured V_L, V	Measured I, A	Calculated V_{Ri} , V P_{ri}	Calculated P_L, W	Calculated P_{ri} , W	Calculated P_T, W	% Efficiency
100 Ω	**1.05**	**11.0**	**8.95**	**11.55**	**98.5**	**110.1**	**10.5**
200 Ω	**2.0**	**10.0**	**8.00**	**20.0**	**80.0**	**100.0**	**20.0**
300 Ω	**2.6**	**9.4**	**7.4**	**24.4**	**69.6**	**94.0**	**26.0**
400 Ω	**3.35**	**8.7**	**6.7**	**29.1**	**58.3**	**87.4**	**33.3**
500 Ω	**3.9**	**8.0**	**6.1**	**31.2**	**48.8**	**80.0**	**39.0**
600 Ω	**4.25**	**7.6**	**5.75**	**32.3**	**43.7**	**76.0**	**42.5**
700 Ω	**4.7**	**7.0**	**5.3**	**32.9**	**37.1**	**70.0**	**47.0**
800 Ω	**5.0**	**6.8**	**5.0**	**34.0**	**34.0**	**68.0**	**50.0**
900 Ω	**5.4**	**6.4**	**4.6**	**34.6**	**29.4**	**64.0**	**54.0**
1 kΩ	**5.7**	**6.0**	**4.3**	**34.2**	**25.8**	**60.0**	**57.0**
2 kΩ	**7.4**	**3.8**	**2.6**	**28.1**	**9.88**	**38.0**	**74.0**
3 kΩ	**8.2**	**2.7**	**1.8**	**22.1**	**4.86**	**27.0**	**81.9**
4 kΩ	**8.65**	**2.2**	**1.35**	**19.0**	**2.97**	**22.0**	**86.4**
5 kΩ	**9.0**	**1.8**	**1.00**	**16.2**	**1.8**	**18.0**	**90.0**
6 kΩ	**9.2**	**1.6**	**0.80**	**14.7**	**1.28**	**16.0**	**91.9**
7 kΩ	**9.4**	**1.4**	**0.60**	**13.2**	**0.34**	**14.1**	**93.6**
8 kΩ	**9.55**	**1.25**	**0.45**	**11.9**	**0.56**	**12.5**	**95.2**
9 kΩ	**9.65**	**1.12**	**0.35**	**11.6**	**0.39**	**12.0**	**96.6**
10 kΩ	**9.78**	**1.03**	**0.22**	**10.1**	**0.23**	**10.3**	**98.1**

EXPERIMENT 13-1: Magnetism

Answers to Questions

1. Explain what is meant by shielding.
   It prevents one electronic component from affecting another.
   A metal conductor or a magnetic material is used.

2. Discuss the results of moving the magnet (in Step 7) faster or slower.
   Faster should give more current. Slower should give less current.

3. Explain which end of the nail attracted the iron filings, and why.
   North end---south end. Flux between poles.

4. Discuss any differences between the results of Steps 1 to 4 and Steps 6 to 8.

   NOTE: Answers will vary because procedures differ. They could discuss N poles vs. S poles or the amount of current shielding.

5. Explain the left-hand rule as it was applied in this experiment.
   Thumb points toward north pole if left hand is curled around a coil in the direction of current flow.

NOTE: There are no tables for this experiment.

EXPERIMENT 13-2: Electromagnetism and Coils

Answers to Questions

1. Which of the materials inserted into the solenoid coil had the greatest effect on the compass? Which of the materials had the least effect?
   Iron rod, plastic rod, wood rod, glass rod

2. Explain why some of the materials inserted into the solenoid had a greater effect than other materials.
   Materials with greater permeability exhibit the ability to concentrate magnetic lines of force, which enhances circuit action.

3. What were the observable changes, if any, when the power supply's polarity was reversed?
   No significant change other than the North/South polarity of the coil changed, which will affect the compass.

4. Explain any observable changes when a 300-turn coil replaced the 150-turn coil.
   A coil that has a larger number of turns exhibits a greater effect on circuit conditions.

5. What circuit characteristics influence the level of magnetomotive force?
   Size of coils, core material, and level of current flow

TABLES FOR EXPERIMENT 13-2

TABLE 13-2.1 Circuit Characteristics of the 150-Turn Coil

Procedural Step	Record the Observed Change in Compass Deflection	Record the Observed Change in Measured Circuit Current
3	**No change**	**No change**
4	**Significant change**	**Significant change**
5	**No change**	**No change**
6	**Some change**	**Some change**
7	**Little change**	**Little change**
8	**No change**	**No change**

TABLE 13-2.2 150-Turn Coil with a Reversed Supply Polarity

Procedural Step	Record the Observed Change in Compass Deflection	Record the Observed Change in Measured Circuit Current
3	**No change**	**No change**
4	**Significant change**	**Significant change**
5	**No change**	**No change**
6	**Some change**	**Some change**
7	**Little change**	**Little change**
8	**No change**	**No change**

TABLE 13-2.3 Circuit Characteristics of the 300-Turn Coil

Procedural Step	Record the Observed Change in Compass Deflection	Record the Observed Change in Measured Circuit Current
3	**No change**	**No change**
4	**Increased significant change**	**Increased significant change**
5	**No change**	**No change**
6	**Increased change**	**Increased change**
7	**Increased change**	**Increased change**
8	**No change**	**No change**

TABLE 13-2.4   300-Turn Coil with a Reversed Supply Polarity

Procedural Step	Record the Observed Change in Compass Deflection	Record the Observed Change in Measured Circuit Current
3	**No change**	**No change**
4	**Increased significant change**	**Increased significant change**
5	**No change**	**No change**
6	**Increased change**	**Increased change**
7	**Increased change**	**Increased change**
8	**No change**	**No change**

EXPERIMENT 14-1: Relays

Answers to Questions

1. Describe how an ohmmeter could be used to determine if the relay's coil had opened.
   If the coil was open, then the ohmmeter would measure infinite ohms.

2. Understanding that the relay is an electromechanical device, what electrical problems could you see developing when using the device over a long period of time?
   The contacts may become damaged with repeated use over a long period of time.

3. If a set of normally closed (NC) relay contacts are closed when the relay's coil is energized, is the relay operating correctly?
   No.

4. It has been stated that one of the main advantages of using a relay is its ability to control high-power loads with a low amount of input power. Could you describe why this is an advantage?
   The relay can protect the user from high power areas of the circuit.

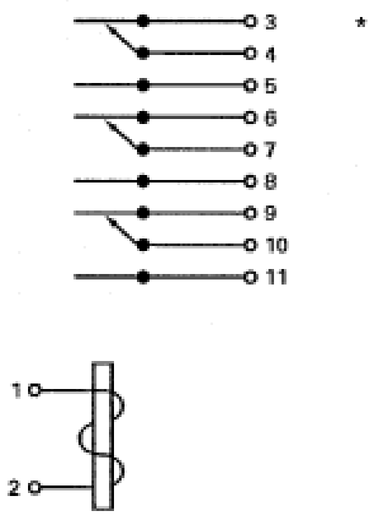
5. What is the advantage of using a relay over a mechanical switch in remote con-troll applications?
   Low power, control and safety.

6. What is the purpose (and/or probable use of) the schematic circuit shown in Figure 14-1.3?
   The relay latches on when the N.O. push button switch is activated. The N.C. push button switch turns off the latched relay. Such a circuit may be used to control motors.

TABLES FOR EXPERIMENT 14-1

TABLE 14-1.1 Identifying the Pins and Functions of a Relay

Using the pin numbers on the schematic diagram shown below, identify the function of each pin. If you are using a different type of relay, other than a 3PDT, create your own table.	Pin Numbers and Relay Function. Use the terms, coil, pole, NO (normally open), and NC (normally closed) in completing this section of the Table.



Pin Number	Relay Term*
1	**Coil**
2	**Coil**
3	**NC**
4	**Pole**
5	**NO**
6	**NC**
7	**Pole**
8	**NO**
9	**NC**
10	**Pole**
11	**NO**

*Answers can vary

TABLE 14-1.2 Instructors Option-Operational Characteristics

Electrical Specification	Electrical Rating	Short Written Description that Describes the Electrical Specification
Pickup voltage	__**22**__Volts	**The minimum amount of relay coil voltage necessary to energize the relay**
Pickup current	__**0.2**__ Amps	**The minimum amount of relay coil current necessary to energize the relay.**
Holding current	__**0.1**__ Amps	**The minimum amount of current required to keep the relay energized.**
Dropout voltage	__**16**__ Volts	**The maximum relay coil voltage at which the relay is no longer energized.**
Contact voltage rating	__**250**__ Volts	**The maximum voltage the relay contacts are capable of switching safely.**
Contact current rating	__**2**__ Amps	**The maximum current the relay contacts are capable of switching safely.**
Contact voltage drop	__**0.15**__ Volts	**The voltage drop across the closed contacts of a relay when operating.**
Insulation resistance	Infinite ≈**1000** M_ Ohms	**The resistance measured across the relay contacts in the open position.**

*Answers will vary with different manufacturer's relays.

TABLE 14-1.3 Measured Operational Characteristics

Procedural Step	Operational Characteristic	Measured Value
6	______ Pickup voltage	**22 Volts**
6	______ Pickup current	**0.2 Amps**
7	______ Dropout voltage	**16 Volts**
7	______ Holding current	**0.1 Amps**

TABLE 14-1.4 Measured Operational Characteristics

Procedural Step 12	For the circuit constructed from the latching relay schematic shown in Figure 14-1.3, describe below the observed circuit action.

I observed…**that the circuit latched (or set) when the normally open switch (N.O.) closed. I also observed that when the normally closed switch (N.C.) was pressed, the relay unlatched, or reset itself.**

EXPERIMENT 15-1: AC Voltage and Ohm's Law

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__F__ 1. Resistors do not function the same in ac circuits as in dc circuits.

__F__ 2. A 10-V battery and a 7-V (p-p) signal will produce the same amount of power across a 2-kΩ resistor.

__F__ 3. Ohm's law can be used only to find current in dc circuits.

__F__ 4. Current in an ac circuit can be measured with an ammeter just as a dc circuit can.

__F__ 5. A signal generator does not produce any current in an ac circuit.

TABLES FOR EXPERIMENT 15-1

TABLE 15-1.1

DC CIRCUIT – Fig. 15-1.5

Resistance	Nominal Value	Volts Measured	Current I = V/R	Power, Watts, V^2/R
R_1	**100 Ω**	**0.15 V**	**1.5 mA**	**0.2 mW**
R_2	**1 kΩ**	**1.85 V**	**1.9 mA**	**3.4 mW**
R_T	**1.1 kΩ**	**2.0 V**	**1.8 mA**	**3.6 mW**

AC CIRCUIT – Fig. 15-1.6* f = 1 kHz

R_1	**100 Ω**	**0.15 Vp-p**	**1.5 mAp-p**	**0.03 mW**
R_2	**1 kΩ**	**1.85 Vp-p**	**1.9 mAp-p**	**0.40 mW**
R_T	**1.1 kΩ**	**2.0 Vp-p**	**1.8 mAp-p**	**0.50 mW**

AC CIRCUIT – Fig. 15-1.6* f = 5 kHz

R_1	**100 Ω**	**0.15 Vp-p**	**1.5 mAp-p**	**0.03 mW**
R_2	**1 kΩ**	**1.85 Vp-p**	**1.9 mAp-p**	**0.40 mW**
R_T	**1.1 kΩ**	**2.0 Vp-p**	**1.8 mAp-p**	**0.50 mW**

*Note: Use p-p values. For example, 10Vp-p $\div$100Ω = 100 mA, Ip-p

Also, power = $(\frac{\text{Vp-p}}{2} \times 0.707)^2 \div$ R for ac circuits.

EXPERIMENT 15-2: Basic Oscilloscope Measurements for AC Circuits

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__T__ 1. An oscilloscope can measure both ac and dc voltages.

__T__ 2. The horizontal amplifier section controls the amplitude of the display on the CRT.

__F__ 3. The vertical amplifier section can be adjusted to increase or decrease the peak-to-peak voltage display.

__F__ 4. The oscilloscope probe does not have a grounded side.

__T__ 5. The oscilloscope input coupling switch is usually set to GND, AC, or DC, depending upon the desired usage.

TABLES FOR EXPERIMENT 15-2

TABLE 15-2.1 Measured DC Voltages for Fig. 15-2.6

	Voltmeter	Scope
V_{R1}	**0.651 V**	**0.65**
V_{R2}	**1.39 V**	**1.40 V**
V_{R3}	**2.96 V**	**2.95 V**
V_T	**5.00 V**	**5.00 V**

TABLE 15-2.2 AC Voltages for Fig. 15-2.7

	Measured Vp-p	Calculated V_{peak}	Calculated V_{av}	Calculated V_{rms}
R_1 = 2.2 kΩ	**0.65**	**0.325**	**0.207**	**0.230**
R_2 = 4.7 kΩ	**1.40**	**0.70**	**0.445**	**0.495**
R_3 = 10 kΩ	**2.95**	**1.48**	**0.941**	**1.046**
V_T	**5.00**	**2.50**	**1.59**	**1.77**

EXPERIMENT 15-3: Additional AC Oscilloscope Measurements

Answers to Questions

Provide a short answer for each of these questions, referring to the measurements.

1. What is the purpose of starting with a free-running setup?
   It verifies no signal is applied and is a consistent starting point for measurements.

2. What do the SLOPE and LEVEL adjustment do?
   SLOPE changes the triggering to the positive or negative edge and the LEVEL changes the triggering value (level) but is not often used for peak-to-peak signals.

3. What observations did you make in steps 7 and 8?
   A 60-Hz signal appears when connected.

4. What is rise time?
   The time it takes for a signal to rise from 10 to 90 percent of its peak value.

5. Does a square wave have an rms value? Why?
   No, because rms value = 0.

TABLES FOR EXPERIMENT 15-3

TABLE 15-3.1 Sine-Wave Measurements

$V_A = 5\ V_{p-p}$ f = 10 kHz	V_{p-p}	SLOPE / V_{p-p}
R_1	**3.4**	**3.4**
R_2	**1.6**	**1.6**
R_3	**5.0**	**5.0**

TABLE 15-3.2 Wave Type = ___Square___ (Square or Rectangular)

$V_A = 2\ V_{p-p}$ f = 50 kHz	V_{p-p}	Period (s)	Pulse Width (s)	Rise Time 10% to 90% (s)
R_1	**3.4**	**0.2 ms**	**0.1 ms**	**Answers will vary**
R_2	**1.6**	**0.2 ms**	**0.1 ms**	**but by $\approx$0.01 ms**
R_3	**5.0**	**0.2 ms**	**0.1 ms**	**or less**

Wave Type = ___Sawtooth___ (Sawtooth or Triangular)

R_1	**3.4**
R_2	**1.6**
R_3	**5.0**

PROBE ADJ Signal

________	________	________	________
V_{p-p}	**Period**	**Pulse Width**	**Rise Time**

Answers will vary according to the oscilloscope accuracy and type.

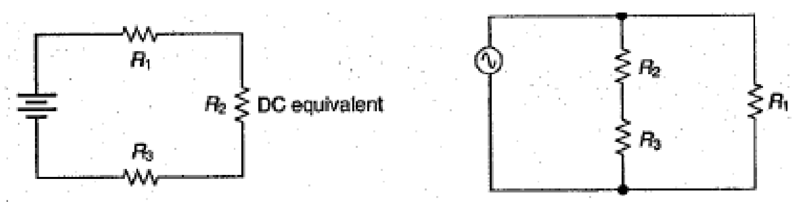
EXPERIMENT 15-4: Oscilloscope Measurements – Superposing AC on DC

1. What function does the coupling capacitor perform?
   The coupling capacitor functions to isolate the signal generator from any circuit dc voltage.

2. What function does the bypassing capacitor perform?
   The bypassing capacitor acts as a short circuit for the ac signal.

3. Was the effective ac resistance of the power supply equal to 0 Ω?
   The effective ac resistance was equal to zero because the measured ac voltage drops across the circuit equaled the applied ac voltage.

4. Draw the ac and dc equivalent circuit diagrams for the circuit shown in Fig. 15-5.2.



5. Is AC resistance the same as DC resistance? Explain. **DC and AC resistance are the same in circuits with resistance only (no phase angle to consider).**

TABLES FOR EXPERIMENT 15-5

TABLE 15-5.1 Measured and Calculated Voltages for Fig. 15-5.1a and b

Procedure Step		V_{R1}	V_{R2}	V_{R3}	V_T
1	AC measured	**0.130 Vp-p**	**0.280 Vp-p**	**0.60 Vp-p**	**1.00 Vp-p**
2	DC measured	**0.640 V**	**1.40 V**	**2.98 V**	**5.00 V**
4	AC calculated	**0.127 Vp-p**	**0.279 Vp-p**	**0.597 Vp-p**	**1.00 Vp-p**
	DC calculated	**0.633 V**	**1.393 V**	**2.975 V**	**5.00 V**

TABLE 15-5.2 Measured and Calculated Voltages for Fig. 15-5.2

Procedure Step		V_{R1}	V_{R2}	V_{R3}	V_T
3	AC measured	**1 Vp-p**	**1 Vp-p**	**≈0 Vp-p≈**	**1 Vp-p**
	DC measured	**0.640 V**	**1.40 V**	**2.98 V**	**5.00 V**
4	AC calculated	**1 Vp-p**	**1 Vp-p**	**≈0 Vp-p**	**1 Vp-p**
	DC calculated	**0.633 V**	**1.393 V**	**2.975 V**	**5.00 V**

EXPERIMENT 16-1: Capacitors

Answers to Questions

1. Why is a capacitor able to block direct current?
   Because it insulates one side from the other so that no dc current can flow.

2. When is a capacitor like a 100-MΩ resistor?
   When it blocks dc or when f is very low (close to dc).

3. When is a capacitor like a 0.001-Ω resistor?
   When it is in series with high frequency.

4. Why is a capacitor able to pass high frequencies?
   Because it charges and discharges.

5. How can you verify the operation of a capacitor?
   Check it with an ohmmeter. High resistance is good.

6. Is it possible for a capacitor to be leaky?
   Yes. It can allow current to leak through.

7. What type of capacitor needs to be connected with respect to polarity?
   Electrolytic.

8. What precautions should you take to be sure a capacitor cannot be a hazard?
   Discharge it with an insulated tool.

9. What differences, if any, did you notice between the capacitor voltage at 1 kHz and at 100 kHz in the circuit?
   Very little difference, but a little voltage may appear across at the lower frequency with higher values of C.

10. Describe the effects of removing the blocking capacitor C_1 from the last circuit, including any measurements that were significant.
    DC current was no longer blocked from the circuit. No effect upon ac voltages.

TABLES FOR EXPERIMENT 16-1

TABLE 16-1.1

			f = 1 kHz		f = 100 kHz	
C (μF) (←)	V_T = 1 V V_C	V_T = 5 V V_C	V_{ac} = 1 Vp-p	V_{ac} = 5 Vp-p	V_{ac} = 1 Vp-p	V_{ac} = 5 Vp-p
0.01 ←	**1 V**	**5 V**	≈**0 V**	≈**0 V**	≈**0 V**	≈**0 V**
0.068 ←	**1 V**	**5 V**	≈**0 V**	≈**0 V**	≈**0 V**	≈**0 V**
0.1 ←	**1 V**	**5 V**	≈**0 V**	≈**0 V**	≈**0 V**	≈**0 V**
10 ←	**1 V**	**5 V**	≈**0 V***	≈**0 V***	≈**0 V**	≈**0 V**
100 ←	**1 V**	**5 V**	≈**0 V***	≈**0 V***	≈**0 V**	≈**0 V**

*Some small voltage may be recorded

TABLE 16-1.2 V_{C1} **=** ___0 V_{ac}___

	With C_1		Without C_1		
R	V_{dc}	V_{ac}	V_{dc}	V_{ac}	
R_1 = 1 kΩ	**0 V**	**4.5 Vp-p**	**4.5 V**	**4.5 Vp-p**	
R_2 = 100 Ω	**0 V**	**0.5 Vp-p**	**0.5 V**	**0.5 Vp-p**	**Answers**
R_3 = 330 Ω	**0 V**	**3.5 Vp-p**	**3.5 V**	**3.5 Vp-p**	**Will vary**
R_4 = 1 kΩ	**0 V**	**3.5 Vp-p**	**3.5 V**	**3.5 Vp-p**	
R_5 = 100 Ω	**0 V**	**1.5 Vp-p**	**1.5 V**	**1.5 Vp-p**	

EXPERIMENT 17-1: Capacitive Reactance

Answers to Questions

Answer the following. Use a separate sheet of paper if necessary and show all work.

1. Using your graphed data, calculate the circuit phase angle at 8k Hz.

   X_C = 2.93 MΩ; theta = $\tan^{-1} \dfrac{2.93 \text{ M}\Omega}{4.7 \text{ K}\Omega} = 89.9°$

2. Using your graphed data, calculate the circuit phase angle at 600 Hz.

   X_C = 39 kΩ; theta = $\tan^{-1} \dfrac{39 \text{ k}\Omega}{4.7 \text{ K}\Omega} = 83.13°$

3. For a series RC circuit, at what frequency would a 10-µF capacitor have X_C = 100 Ω?

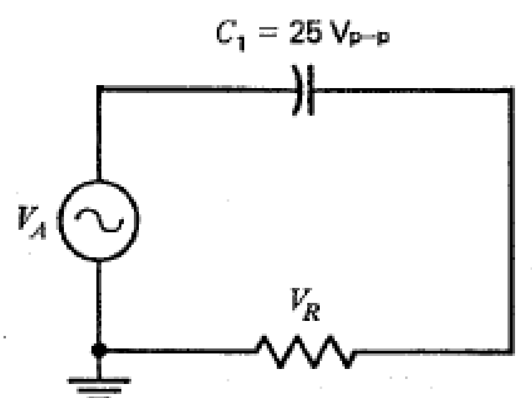
   $$f = \frac{1}{2\pi(100\ \Omega)(10\mu F)} = 159.2 \text{ Hz}$$

4. For a series RC circuit, what value of capacitor would have 31.8 Ω of X_C at 5 Hz?

   $$C = \frac{1}{2\pi(31.8\ \Omega)(5 \text{ Hz})} = 1000\ \mu F$$

5. For the circuit in Fig. 17-1.4, the voltage across C = 25 Vp-p. The circuit phase angle is 45°. What is the voltage across R and V_A?

   V_R = 25 Vp-p; V_A = 35.4 Vp-p



TABLES FOR EXPERIMENT 17-1

TABLE 17-1.1

Procedure Step	Measurement	Value	Calculations
2	X_C		**23.4 kΩ**
3	V_C	**4.8 Vp-p**	
4	V_R	**1.0 Vp-p**	
5a	I_T		**0.213 mA**
5b	I_T		**0.235 mA**
6	Z_T		**4.96 kΩ**
7	X_C		**1.59 kΩ**
	V_C	**1.6 Vp-p**	
	V_R	**4.4 Vp-p**	
	I_T (a)		**0.094 mA**
	I_T (b)		**0.095 mA**
	Z_T		**53.4 kΩ**

The students should prepare their own tables for
R = 47 kΩ (Step 8) and Steps 9 to 13.

EXPERIMENT 18-1: Capacitive Reactance

Answers to Questions

1. After reading the capacitor coupling section in your book, describe what a coupling capacitor is used for?
   A coupling capacitor is used to couple or pass an ac signal from one circuit to another while providing dc isolation between circuits.

2. What importance does the one-tenth rule have, and where is it used?
   The one-tenth rule is important because it provides a reference for adverse effects. An increase or decrease in signal voltage is tolerable up to 10 percent, or one-tenth. This rule is used in frequency-related components where the reactance of a capacitor is one-tenth or less of Z_{in}.

3. What effect does a coupling capacitor have on the DC current?
   The capacitor is a effective OPEN circuit for the DC current – so it blocks DC.

TABLES FOR EXPERIMENT 18-1

TABLE 18-1.1

Frequency	V_s (p-p)	V_c (p-p)	V_R (p-p)
100 Hz	**5**	**4.00**	**2.30**
200 Hz	**5**	**3.10**	**3.55**
300 Hz	**5**	**2.50**	**4.10**
400 Hz	**5**	**1.94**	**4.40**
500 Hz	**5**	**1.62**	**4.55**
600 Hz	**5**	**1.40**	**4.60**
700 Hz	**5**	**1.23**	**4.70**
800 Hz	**5**	**1.10**	**4.75**
900 Hz	**5**	**0.98**	**4.80**
1.0 k Hz	**5**	**0.88**	**4.83**
1.1 k Hz	**5**	**0.83**	**4.85**
1.2 k Hz	**5**	**0.74**	**4.86**
1.3 k Hz	**5**	**0.70**	**4.88**
1.4 k Hz	**5**	**0.64**	**4.90**
1.5 k Hz	**5**	**0.60**	**4.91**
1.6 k Hz	**5**	**0.56**	**4.92**
1.7 k Hz	**5**	**0.53**	**4.93**
1.8 k Hz	**5**	**0.50**	**4.94**
1.9 k Hz	**5**	**0.47**	**4.95**
2.0 k Hz	**5**	**0.45**	**4.96**
3.0 k Hz	**5**	**0.30**	**4.97**
4.0 k Hz	**5**	**0.23**	**4.98**
5.0 k Hz	**5**	**0.18**	**4.99**
6.0 k Hz	**5**	**0.15**	**4.99**
7.0 k Hz	**5**	**0.13**	**4.99**
8.0 k Hz	**5**	**0.11**	**4.99**
9.0 k Hz	**5**	**0.10**	**4.99**
10 k Hz	**5**	**0.09**	**4.99**
15 k Hz	**5**	**0.06**	**4.99**
20 k Hz	**5**	**0.04**	**4.99**

TABLE 18-1.2

Frequency Where C_c Becomes a Coupling Capacitor	V_s (p-p)	V_c (p-p)	V_R (p-p)
1.59 kHz	**5 Vp-p**	**o.57 Vp-p**	**4.9 Vp-p**

EXPERIMENT 18-2: Capacitive Phase Measurements – using an Oscilloscope

Answers to Questions

1. Why did changing the frequency of V_G cause a different phase angle?

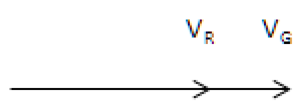
   Changing the frequency of V_G caused a different phase angle because the phase of V_G was also shifted.

2. If you didn't have any test equipment, could you calculate the phase angle between V_G and V_R? How?

   Without test equipment, the phase angle could be calculated if V_G and V_R were known and their frequencies were the same: Arc cos or cos V_G/V_R.

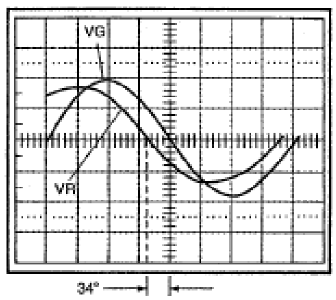
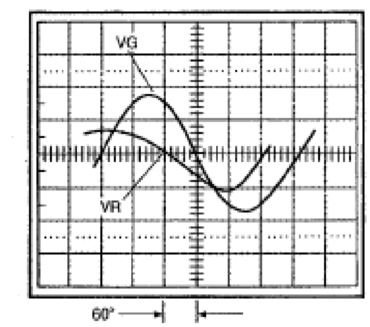
3. Draw the phasor showing the results for a phase angle where V_G =12 V and V_R=8.4V.

ANSWER NOTE: This a like a "trick question" because the voltages of VG and VR are actually in phase. This re-enforces the idea of no reactance for resistors. Students may draw this as:



TABLES FOR EXPERIMENT 18-2

TABLE 18-2.1 / **TABLE 18-2.2**

Procedure Step	V_G = 23kHz		Procedure Step	V_G = 8kHz
2	V_R = __**1.5**__ Vp-p V_G = __**2.0**__ Vp-p		2	V_R = __**2**__ Vp-p V_G = __**2.0**__ Vp-p
3	 Degrees per DIV = __**45°**__		3	 Degrees per DIV = __**60°**__
5 Calculated using: X_c and R	Using inverse tangent button = 30°		6	Using inverse tangent button = 60°
5 Measured using: V_R and V_G	Using inverse cosine button = 34° * *Values will vary.		6	Using inverse cosine button = 58° * *Values will vary.

* NOTE: Measured values of V_R and V_G will affect the answers.

EXPERIMENT 19-1: Inductors

Answers to Questions

1. How is an inductor constructed?
   Copper wire is wound around a core, usually iron or some other material.

2. How can you check if an inductor is working?
   Use an ohmmeter to verify continuity, which is little or no resistance to direct current.

3. How does a transformer tap work to produce various voltages?
   The number of turns determines the voltages at which the ratio of windings is proportional to the voltage taps.

4. Is an inductor sensitive to changes in frequency?
   Yes, it becomes more reactive (resistive) as frequency increases.

5. If an inductor measured 75Ω, would it still be good?
   Only if it is a very large inductor.

6. What difference was there between the inductor voltage at 100 Hz and at 15 kHz?
   The voltage was greater at the higher frequency.

7. Why is an inductor called a choke?
   Because it chokes or cuts off high frequencies.

8. How is voltage induced in a coil?
   A magnetic field is built up, which opposes current flow.

9. How could you keep the neon bulb lit longer?
   Use a bigger choke.

10. Is an inductor capable of causing a shock if you touch it?
    No, because it does not build up a charge.

TABLES FOR EXPERIMENT 19-1

TABLE 19-1.1 Transformer

Inductor	Wire Colors	Resistance	
Primary			
Secondary			**Student answers**
			depend on the
			value of L

TABLE 19-1.2 Inductors

Value (H) and Resistance	V_T = 1 V V_L	V_T = 5 V V_L	**f = 100 Hz** Vac = 1 Vp-p	Vac = 5 Vp-p		**f = 15 kHz** Vac = 1 Vp-p	Vac = 5 Vp-p

All measurements depend upon the value of L.

TABLE 19-1.3 Induced Voltage Circuit (Neon Bulb)

Applied DC Voltage												
Volts	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5
Volts	8	8.5	9	9.5	10							

Circle the voltage that lights the bulb.

NOTE: student answers should be within the range of 7 V to 9 V.

EXPERIMENT 20-1: Inductive Reactance

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__**T**__ 1. As frequency increases, X_L increases.

__**F**__ 2. The dc resistance of a coil is always 0 Ω.

__**T**__ 3. As frequency decreases, X_L increases.

__**F**__ 4. Two parallel coils of equal value will have twice as much inductance as one coil.

__**F**__ 5. Two series coils of equal value will have half as much inductance.

__**F**__ 6. If, in a series RL circuit, V_R = 2 Vp-p and V_L = 2 Vp-p, the applied voltage would equal 4 Vp-p.

__**T**__ 7. In a series RL circuit, the voltage across the resistor always lags the voltage across the inductor by 90°.

__**T**__ 8. The current in an RL series circuit is the same in all parts of the circuit.

__**F**__ 9. There is a phase relationship in an RL circuit because the resistor opposes a change in current.

__**T**__ 10. The phase angle of an RL series circuit, where R and X_L are equal, will always be 45°.

TABLES FOR EXPERIMENT 20-1

TABLE 20-1.1

Procedure Step	Circuit Component	Value
1	R_L Measured	**58 Ω**
3	X_L Calculated	**415 Ω**
4	V_L Measured	**2.5 Vp-p**
5	V_R Measured	**3.6 Vp-p**
6a	I_T Calculated	**6.43 mA**
6b	I_T Calculated	**6.43 mA**
7a	Z_T Calculated	**778 Ω**
7b	Z_T Calculated	**778 Ω**
8	F Calculated	**2 kHz**
9	L Calculated	**30.9 H**

TABLE 20-1.2

f	V_L	X_L
100 Hz	**0.47 Vp-p**	**66 Ω**
200 Hz	**0.55 Vp-p**	**77 Ω**
300 Hz	**0.67 Vp-p**	**94 Ω**
400 Hz	**0.80 Vp-p**	**112 Ω**
500 Hz	**0.92 Vp-p**	**129 Ω**
600 Hz	**1.04 Vp-p**	**146 Ω**
700 Hz	**1.20 Vp-p**	**168 Ω**
800 Hz	**1.30 Vp-p**	**182 Ω**
900 Hz	**1.45 Vp-p**	**202 Ω**
1 kHz	**1.48 Vp-p**	**207 Ω**
2 kHz	**2.50 Vp-p**	**378 Ω**
3 kHz	**3.20 Vp-p**	**578 Ω**
4 kHz	**3.50 Vp-p**	**745 Ω**
5 kHz	**3.80 Vp-p**	**925 Ω**
6 kHz	**3.93 Vp-p**	**1.1 kΩ**
7 kHz	**3.97 Vp-p**	**1.2 kΩ**
8 kHz	**4.00 Vp-p**	**1.4 kΩ**
9 kHz	**4.00 Vp-p**	**1.6 kΩ**
10 kHz	**4.00 Vp-p**	**1.7 kΩ**

EXPERIMENT 21-1: Inductive Circuits

Answers to Questions

1. Why is the dc voltage across the load resistor the same as the generator?
   Because the load resistor is in parallel with the AC signal generator which is a short circuit to DC. Therefore, no DC voltage can develop across R load.

2. Why is the AC voltage across the load resistor the same as the generator?
   Because the load resistor is in parallel with the AC signal generator and therefore the signal will be constant across both.

3. What would happen if the inductor value (100mH) increased greatly, for example to 1H, in the first two circuits measured?
   There would be little or no change for the DC condition measurements, but as the AC frequency increases, the voltage across the inductor will increase.

4. In the last circuit, what was the effect on the phase (time axis) of the two traces as the applied voltage was decreased?
   As frequency was decreased, the phase difference between the signals also decreased. This occurred because the closer the signal got to DC, the less reactance and therefore the less phase shift.

5. In the last circuit, was the applied voltage (4 V p-p) decreased or increased as you increased the frequency for the last steps? Explain why you think this was necessary.
   It was necessary to decrease the applied voltage as frequency was increased because the circuit impedance became greater. With greater circuit impedance, a greater signal is developed and therefore the signal generator amplitude was decreased.

6. In the last step, was the signal across the resistor (point B) greater or lesser for the branch with 33mH, instead of 100mH and why?
   In the branch with 33 mH (point B), the ac signal voltage is greater because the inductor is not as large and therefore has less reactance.

TABLES FOR EXPERIMENT 21-1

TABLE 21-1.1 **X_L = 400 Ω Approx: with R coil ≈40-50 Ω at dc.** Q = X_L/R.

Resistance and Q of 33 mH inductor		Resistance and Q of 100 mH inductor
R = **40 Ω**		R = **50 Ω**
Q = **10**		Q = **8**

TABLE 21-1.2

Applied dc voltage	DC voltage point B	DC voltage point C
5.0	**0 V**	**0 V**

TABLE 21-1.3

		Approx:	
Frequency	A: Peak Volts	B: Peak Volts	C: Peak Volts
100 Hz	**0**	**10.0**	**10**
300 Hz	**0**	**9.9**	**10**
500 Hz	**0**	**9.5**	**10**
700 Hz	**0**	**9.2**	**10**
1 k Hz	**0**	**8.7**	**10**
3 k Hz	**0**	**8.5**	**10**
5 k Hz	**0**	**4.7**	**10**
7 k Hz	**0**	**3.0**	**10**
9 k Hz	**0**	**2.2**	**10**
10 k Hz	**0**	**1.5**	**10**

TABLE 21-1.4

Applied dc voltage	DC voltage point B	DC voltage point C
5.0	**5.0 V**	**1.0 V**

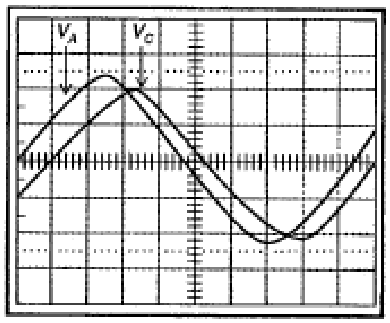
TABLE 21-1.5

Frequency	A: Peak Volts	B: Peak Volts	C: Peak Volts
100 Hz	**0**	**0.6**	**10**
300 Hz	**0**	**1.9**	**10**
500 Hz	**0**	**3.0**	**10**
700 Hz	**0**	**4.0**	**10**
1 k Hz	**0**	**5.0**	**10**
3 k Hz	**0**	**5.3**	**10**
5 k Hz	**0**	**8.8**	**10**
7 k Hz	**0**	**9.5**	**10**
9 k Hz	**0**	**9.8**	**10**
10 k Hz	**0**	**9.9**	**10**

GRAPHS FOR EXPERIMENT 21-1

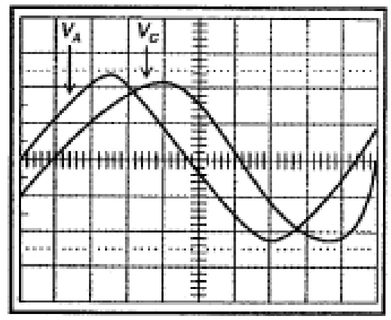
TABLE 21-1.6

STEP 9: 200 Hz



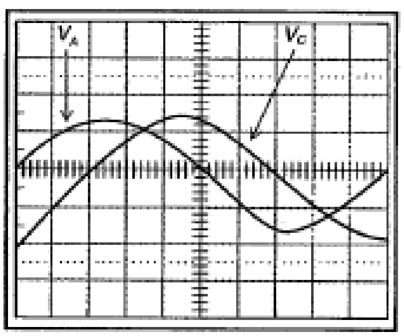
V_A = 4 Vp-p applied
V_C = __1.7 V__ p-p
*Time difference = __0.5 ms__
Phase shift = __2°__

STEP 11: 1 kHz



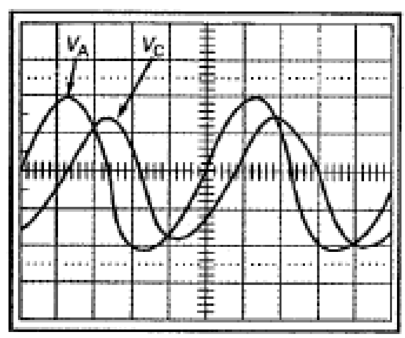
V_A = 4 Vp-p applied
V_C = __0.5 V__ p-p
*Time difference = __0.2 ms__
Phase shift = __70°__

STEP 12: 10 kHz



V_A = 4 Vp-p applied
V_C = __60 mV__ p-p
*Time difference = __30 ms__
Phase shift = __108°__

EXAMPLE: 1 kHz



V_A = 4 Vp-p applied
V_C = __400 mV__ p-p
*Time difference = 0.1 ms
at 1 ms per division

$$\text{Phase shift} = \frac{0.1\text{ ms}}{1\text{ ms}} \times 360 = 36°$$

Use this formula:

$$\frac{\text{time difference}}{\text{time for 1 cycle}} \times 360$$

NOTE: **Graphs show 1 or 2 time periods and phase shift increases with frequency.**

EXPERIMENT 22-1: RC Time Constant

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__**F**__ 1. The RC time constant is expressed in units of farads.

__**F**__ 2. The formula for the RC time constant is T = 1/RC.

__**F**__ 3. The time constant T is the time for the voltage across R to change by 36.8 percent.

__**F**__ 4. The change of 63.2 percent is constant for all values of R and C as long as a sine wave is the applied voltage.

__**F**__ 5. For a 1000-Ω R in series with an 18-μF C, the time constant would be 180 ms.

__**T**__ 6. The time constant formula is the same for a discharging capacitor.

__**T**__ 7. After approximately five time constants, a capacitor is considered charged to the applied dc voltage.

__**T**__ 8. After two time constants in an RC circuit where R = 2 kΩ and C = 15 μF, the capacitor would be charged to about 86 V with an applied voltage of 100 V.

__**F**__ 9. For question 8, if C were increased to 30 μF and R were increased to 4 kΩ, the capacitor would charge twice as fast.

__**T**__ 10. An RC charge or discharge curve usually has the same shape, regardless of the values of R and C.

NOTE: Values are approximate because readings will vary.

TABLES FOR EXPERIMENT 22-1 (Resistor value is 1.2 M ohms)

Table 22-1.1: Single Capacitor with I_T = 17 μA and C = 4 μF.

Time (s)	Current (μA)	Voltage (V)
0	17	0
2	15	3
4	12	7
6	10	9
8	8	11
10	7	12
12	5	13
14	3	14
16	2	15
18	1	16
20	1	17
22	1	17
24	0	17
26	0	18
28	0	18
30	0	18

Table 22-1.2: Two series Capacitors with I_T = 17 μA and C = 2 μF.

Time (s)	Current (μA)	Voltage (V)
0	17	0
2	13	5
4	10	8
6	7	14
8	5	16
10	3	17
12	2	17
14	1	18
16	1	18
18	0	18
20	0	18
22	0	18
24	0	18
26	0	18
28	0	18
30	0	18

Table 22-1.3: Two Parallel Capacitors with I_T = 17 μA and C = 8 μF.

Time (s)	Current (μA)	Voltage (V)
0	17	0
2	16	2
4	14	3
6	13	5
8	11	6
10	10	8
12	9	10
14	8	11
16	7	13
18	6	14
20	5	14
22	4	15
24	3	16
26	3	17
28	2	17
30	2	18

EXPERIMENT 23-1: AC Circuits - RLC Series

Answers to Questions

1. In an RLC series circuit, why can an inductor have more measured voltage than the applied voltage?
   Because the capacitor discharges into the inductor, which itself has an induced voltage.

2. If X_L and X_C were zero, what would the phase angle of Fig. 23-1.5 be?
   Zero degrees.

3. Explain the difference between real power and apparent power.
   One is calculated (apparent) as VI, without regard to dissipated heat or light. The other (real) is calculated as I^2R, where the resistive component actually dissipates power.

4. If an RLC series circuit had four inductors, five resistors, and seven capacitors all in series, would the value of current be the same in all parts of the circuit?
   Yes.

5. At what frequency would the circuit of Fig. 23-1.5 (as shown) have the opposite net reactance?
   At higher frequencies – for example, greater than 1 MHZ.

TABLES FOR EXPERIMENT 23-1

TABLE 23-1.1

Procedure Step	Circuit Component	Steps 2-6: Value at f = 1 kHz	Step 7: Value at f = 10K Hz
2	V_C measured	**10 V**	**10 V**
	V_L measured	**0.14 V**	**1.5 mV**
	V_R measured	**0.7 V**	**0.007 V**
3	X_L calculated	**207 Ω**	**20.9 Ω**
	X_C calculated	**15.9 kΩ**	**159 kΩ**
4	$I_T = V_R/R$	**700 µA**	**70 µA**
	$I_T = V_C/X_C$	**629 µA**	**63 µA**
	$I_T = V_L/X_L$	**669 µA**	**72 µA**
5	X_O calculated (net reactance)	**≈15.7 kΩ X_C ≈**	**≈159 kΩ X_C**
	Z calculated	**15.7 kΩ**	**159 kΩ**
6	Apparent power	**0.007 VA**	**0.0007 V**
	Real power	**490 µW**	**4.9 µW**
	Power factor	**0.0722**	**0.0063**

EXPERIMENT 24-1: Complex Numbers for AC Circuits

Answers to Questions

1. In the circuit R-C of Figure 24-1.4, which signal was leading and which was lagging in time? Explain your answer and remember that the oscilloscope x axis is in the time domain. Therefore, a signal peak that appears first (starting from the left or earlier time point) is really the leading signal—the one that follows later in time is lagging.
   V_A leads V_C or V_C is lagging V_A.

2. In the circuit of Fig. 24-1.5, which signal was leading and which was lagging in time?
   V_A lags V_C or V_C is leading V_A.

3. Explain any phase difference between the measured signals at V_A and either V_C or V_L in the RC and RL circuits.
   Student answers will vary. However, they should explain that the phase difference between the applied voltage V_A and the measurement points Vc and V_L is due to one or more of the following: reactance, charging of C, opposition of L (windings). Students may also indicate that the ideal 90 degree phase shift is not measured because of the scope grounding.

4. In the last circuit (Fig. 23-1.6), why do you think the p-p values of V_X were equal to V_A? Use your data to explain this. HINT: compare the reactance to the 50 Ω of resistance.
   The reactance was large (10x) compared to the 50-Ω resistor. Therefore, most of the voltage was dropped across point V_X.

5. Would it be possible to use parallel L-C, instead of series L-C, to achieve the same result? Explain your answer.
   Students should answer no, indicating that parallel L-C, at resonance, would mean maximum impedance and minimum current. However, some credit should be given to students who understand that both parallel and series L-C can resonate, but the effects are different.

TABLES FOR EXPERIMENT 24-1

TABLE 24-1.1 R-C Complex Impedance Circuit (Fig. 24-1.4)

Frequency	V_A p-p	V_C p-p	Approx: X_C	Delta Time	Complex Z
3 kHz	2 V p-p	1.5 V	53 Ω	40 µS	50 – j53
300 Hz	2 V p-p	2.0 V	530 Ω	0	50 – j530

TABLE 24-1.2 R-L Complex Impedance Circuit (Fig. 24-1.5)

Frequency	V_A p-p	V_L p-p	Approx: X_L	Delta Time	Complex Z
3 kHz	2 V p-p	2.0 V	620 Ω	0	50 + j620
300 Hz	2 V p-p	1.5 V	62 Ω	200 µS	50 + j62

TABLE 24-1.3 RLC Complex Impedance Circuit (Fig. 24.1.6)

Frequency	V_A p-p	V_X p-p	Net Reactance X_O	Delta Time	Complex Z
3 kHz	2 V p-p	1.99 V	568 Ω	≈0 Sec	50 + j568
300 Hz	2 V p-p	1.99 V	468 Ω	≈0 Sec	50 – j468

NOTE: X_O is the net reactance.

TABLE 24-1.4 Minimal Z Values (Fig. 24-1.6)

Frequency (within 10 Hz) for 50 + j0		Approx p-p value of V_X
876 Hz		**0 V**

EXPERIMENT 25-1: Series Resonance

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__F__ 1. The resonant effect occurs when X_L is greater than X_C.

__F__ 2. The resonant frequency of a series L_C circuit must always be above 60 Hz.

__F__ 3. The circuit impedance Z of a series circuit is maximum at f_r.

__F__ 4. X_L and X_C are 90° out of phase at resonance.

__T__ 5. The highest value of series circuit current is at resonance.

__F__ 6. The greater the circuit Q, the higher the resonant frequency.

__T__ 7. $f_r = 1/[2\pi(LC)^{1/2}]$ and $Q = X_L/X_C$.

__T__ 8. The resonant frequency of a series RLC circuit with R = 100 Ω, L = 8 H, and C = 4 μF is 28 Hz.

__T__ 9. The Q of the circuit values in question 8 is 14.

__T__ 10. The resonant frequency of the circuit values of question 8 would not change if L = 4 H and C = 8 μF.

TABLES FOR EXPERIMENT 25-1

TABLE 25-1.1

Procedure Step	Measurement	Measured Value	Calculation
2	f_r	**2.65 k**Hz	**2.77 k**Hz
3	V_R	**0.45** V at 1 kHz	
	V_L	**1.8** V at 1 kHz	
	V_C	**11.8** V at 1 kHz	

GRAPH – for step 9 will vary but will show frequency vs: VR, VL, ad VC.

EXPERIMENT 25-2: Parallel Resonance

Answers to Questions

Answer TRUE (T) or FALSE (F) to the following:

__**F**__ 1. The formula for resonance is $1/(2\pi fC)$.

__**T**__ 2. The higher the Q, the sharper the bandwidth response.

__**F**__ 3. One difference between a series resonant circuit and a parallel resonant circuit is that the parallel resonant circuit has minimum impedance at f_r, while the series has maximum impedance at f_r.

__**F**__ 4. Greater values of L and C will result in increased bandwidth.

__**F**__ 5. If a tank circuit had a resonant frequency of 8 kHz with a 2-kHz bandwidth, the bandwidth could not be decreased without changing the resonant frequency.

__**T**__ 6. At the resonant frequency, a tank circuit requires minimum input power from the source.

__**F**__ 7. In a tank circuit, line current is maximum and tank current is minimum at resonance.

__**T**__ 8. If a voltage were applied to a tank circuit, like the circuit in Fig. 25-2.1, no current would flow.

__**T**__ 9. For a tank circuit with L = 2 H and C = 10 μF, the resonant frequency is approximately 36 Hz.

__**F**__ 10. For question 9, a resonant frequency of 3600 Hz could be obtained by increasing L to equal 200 H.

TABLES FOR EXPERIEMNT 25-2

TABLE 25-2.1

Procedure Step	Measurement	Measured Value	Calculation
1	f_r		**5.033 k**Hz
2	Q		**31.6** (X_L = **3.16 kΩ**)
3	BW		**159** Hz
5	V_{rs1} V_{rs2}	**5.56** Vp-p at 3.5 kHz	
	V_{rs2}	**0.018** Vp-p at 3.5 kHz	
	V_L	**0.422** Vp-p at 3.5 kHz	
	V_C	**0.44** Vp-p at 3.5 kHz	
	I_{tank}		**180** μA
	I_{line}		**118** μA
7	Z_T	**145 kΩ**	

GRAPH from step 8 will show frequency vs tank current and main line current – also, bandwidth.

EXPERIMENT 26-1: Filters

Answers to Questions

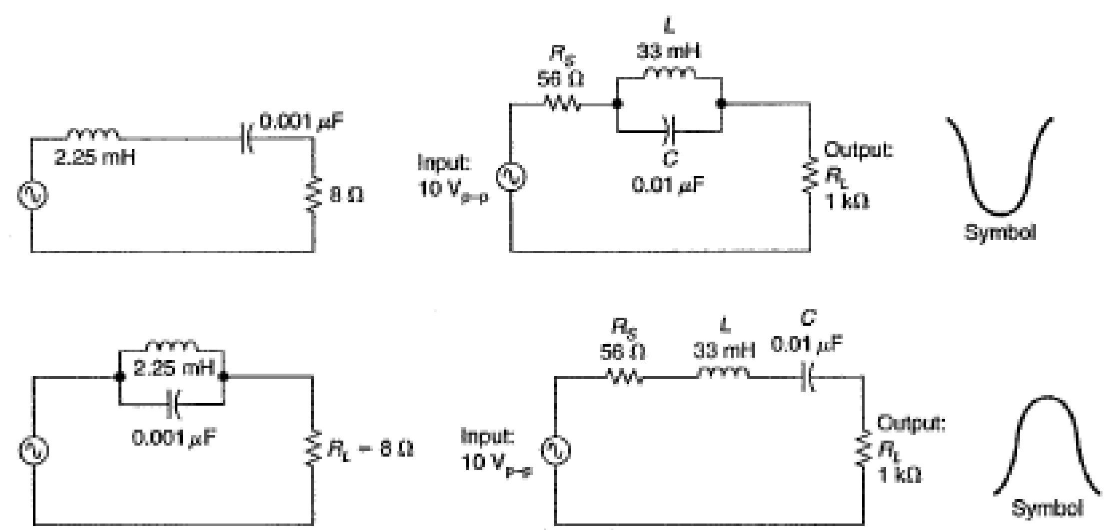
1. Explain what happens to low frequencies in the circuit of Fig.26-1.1. Why don't they reach the load R_L?
   Low frequencies are shunted to ground through the coil. The reactance of the coil is small relative to that of the capacitor and circuit current flows through the coil back to the source.

2. Explain what happens to high frequencies in the circuit of Fig. 26-1.2. Why don't they reach the load R_L?
   Low frequencies are passed by the coil in this configuration, whereas high frequencies are shunted to ground.

3. Explain how the resonant effect works as a filter in the circuit of Fig. 26-1.3.
   The parallel combination of L and C creates a very high impedance and prevents current flow at the desired resonant frequency.

4. Explain how the resonant effect works as a filter in the circuit of Fig. 26-1.4.
   The resonant effect produces the desired output. The desired output has a narrow bandwidth where the resonant frequency is at the center of the band.

5. Design a filter circuit that (a) passes frequencies from approximately 8 kHz to 12 kHz and (b) stops or rejects frequencies from 8 kHz to 12 kHz. Show all values and calculations, where V_A= 1 Vp-p and R_L = 8Ω (similar to a radio speaker).



TABLES FOR EXPERIMENT 26-1

TABLE 26-1.1

Procedure Step	Measurement Frequency	Load Voltage, Vp-p
2	1 kHz	**0.12**
	2 kHz	**0.24**
	3 kHz	**0.36**
	4 kHz	**0.49**
	5 kHz	**0.58**
	6 kHz	**0.68**
	7 kHz	**0.78**
	8 kHz	**0.86**
	9 kHz	**0.95**
	10 kHz	**1.02**
3	10 kHz	**1.20**
4	10 kHz	**1.90**
6	10 kHz	**1.00**
	9 kHz	**1.10**
	8 kHz	**1.18**
	7 kHz	**1.20**
	6 kHz	**1.22**
	5 kHz	**1.25**
	4 kHz	**1.27**
	3 kHz	**1.29**
	2 kHz	**1.38**
	1 kHz	**1.40**
	500 Hz	**1.40**
	200 Hz	**1.40**
	100 Hz	**1.40**
	50 Hz	**1.40**
7	10 kHz	**1.00**
	5 kHz	**1.25**
	2 kHz	**1.30**
	1 kHz	**1.4**
	500 Hz	**1.40**
	100 Hz	**1.40**
	50 Hz	**1.40**

TABLE 26-1.1 (continued)

Procedure Step	Measurement Frequency	Load Voltage, Vp-p
9	2.0 kHz	**8.2**
(C = 0.001 μF)	3.0 kHz	**8.1**
$f_c \approx 9$ kHz	4.0 kHz	**7.6**
	5.0 kHz	**6.2**
	6.0 kHz	**5.8**
	6.5 kHz	**5.0**
	7.0 kHz	**4.0**
	7.5 kHz	**3.8**
	8.0 kHz	**3.8**
	8.5 kHz	**1.5**
	9.0 kHz	**0.8**
	9.5 kHz	**1.0**
	10.0 kHz	**1.5**
	12.0	**3.8**
	14.0	**5.0**
	16.0	**6.4**
	18.0	**7.0**
11	2.0 kHz	**1.2**
(C = 0.01 μF	3.0 kHz	**1.7**
$f_o \approx 9$ kHz)	4.0 kHz	**2.5**
	5.0 kHz	**3.2**
	6.0 kHz	**4.0**
	7.0 kHz	**4.8**
	8.0 kHz	**5.2**
	8.5 kHz	**5.4**
	9.0 kHz	**5.7**
	9.5 kHz	**5.5**
	10.0 kHz	**5.3**
	11.0 kHz	**5.1**
	12.0 kHz	**4.9**
	13.0 kHz	**4.6**
	14.0 kHz	**4.1**
	15.0 kHz	**3.6**
	18.0 kHz	**3.0**

EXPERIMENT 26-2 Filter Applications

Answers to Questions

1. What elements control the BW of a resonant filter?
   Circuit Q = X_L/r (coil): coil resistance and the reactance.

2. What is meant by the Q of a resonant circuit?
   Q of a circuit is its response or BW. Q is also a measure of quality. High Q is preferred.

3. Why is a high-Q circuit desirable?
   Because the BW response is sharper.

4. When would you expect one inductor to have a greater resistance than another?
   If the windings were longer (more turns).

5. What would happen if the series resistor R_S were not in the circuit of Fig. 26-2.5?
   A dc short would occur through the inductor; excess current might occur.

TABLES FOR EXPERIMENT 26-2

TABLE 26-2.1 (Steps 1 through 10).

	Freq. Calc.	Freq. Meas.	V_{RL} Meas.	BW Meas.	R_{coil} Meas.	X_L Calc.	Q Calc.	BW Calc.
With 10-Ω R_{coil} added								

All answers depend upon the value of L used.

TABLE 26-2.2 (Steps 11 through 20)

	Freq. Calc.	Freq. Meas.	V_{RL} Meas.	BW Meas.	R_{coil} Meas.	X_L Calc.	Q Calc.	BW Calc.
With 10-Ω R_{coil} added								

Answers will vary.

GRAPH will accompany data.

EXPERIMENT 27-1: P-N Junction

Answers to Questions

1. What general statement could be made for the forward and reverse resistances of a good diode?
   The internal forward resistance of a diode is low and the reverse resistance is almost infinite.

2. Under what conditions can the diode be forward-biased?
   When the applied forward voltage exceeds 0.7 V, to overcome the barrier potential, the silicon diode is forward-biased.

3. Under what conditions can the diode be reversed-biased?
   Applying a positive voltage to the cathode and a negative potential to the anode will reverse-bias the diode.

4. Describe the significance of the curve found in quadrant 1 of Fig. 27-1.4.
   It demonstrates the forward voltage characteristics in which the dynamic resistance decreases rapidly as applied voltage increases.

5. Describe the significance of the curve found in quadrant 3 of Fig. 27-1.4.
   It demonstrates the reverse voltage characteristics in which resistance remains constant until breakdown.

TABLES FOR EXPERIMENT 27-1

TABLE 27-1.1

Procedure Step		R_L	V_T	V_D	$V_{R\ LOAD}$
1	Fwd. bias R = **3.5k** Ω Rev. bias R = ∞ Ω				
2	Fwd. bias	12 kΩ	**4.0 V**	**0.51 V**	**3.4 V**
3	Fwd. bias	680 Ω	**4.0 V**	**0.64 V**	**3.25 V**
4	Rev. bias	12 kΩ	**4.0 V**	**4.0 V**	**0 V**
		680 Ω	**4.0 V**	**4.0 V**	**0 V**
6	330 Ω R (nominal) = **325** Ω (measured)				

TABLE 27-1.2

Procedure Step	V_T	V_{FWD}	Calculated I_F
7	0.20 V	**0 V**	**0 mA**
8	0.25 V	**0 V**	**0 mA**
	0.30 V	**0 V**	**0 mA**
	0.35 V	**0 V**	**0 mA**
	0.40 V	**0.01**	**0.0308 mA**
	0.45 V	**0.015**	**0.0462 mA**
	0.50 V	**0.034**	**0.105 mA**
	0.55 V	**0.065**	**0.200 mA**
	0.50 V	**0.098**	**0.302 mA**
	0.55 V	**0.130**	**0.400 mA**
	0.60 V	**0.165**	**0.508 mA**
	0.70 V	**0.210**	**0.646 mA**
	0.75 V	**0.245**	**0.754 mA**
	0.80 V	**0.290**	**0.892 mA**
	0.85 V	**0.335**	**1.03 mA**
	0.90 V	**0.380**	**1.17 mA**
	1.00 V	**0.420**	**1.29 mA**

TABLE 27-1.3

Procedure Step	V_T	V_{REV}	Calculated I_R
11 and	50 V	**46 V**	**142 mA**
12	100 V	**92 V**	**283 mA**
	150 V	**137 V**	**422 mA**

EXPERIMENT 27-2: Transistor as a Switch

Answers to Questions

1. In the prior circuits, what voltage level would a binary 1 represent? A binary 0? Are the answers the same for both the circuits shown in Figs.27-2.3 and 27-2.4?
   Binary 1: +5V in Fig. 27-.3 and 0 V in Fig. 27-2.4. Binary 0: 0 V in Fig. 27-2.3 and -5V in Fig. 27-2.4.

2. What is saturation? How is it demonstrated in this experiment?
   Saturation is maximum flow of current. It is demonstrated by binary 1 in Fig. 27-2.3 and binary 0 in Fig. 27-2.4.

3. What is cutoff? How is it demonstrated in this experiment?
   Minimum current flow. Binary 0 in Fig. 27-2.3 and binary 1 in Fig. 27-2.4

4. Are the saturation and cutoff points the same for both the circuits shown in Figs. 27-2.3 and 27-2.4?
   No. See above.

5. What are the fundamental differences between the two circuits shown in Figs. 27-2.3 and 27-2.4? Do the differences significantly affect overall outcomes? Explain.
   The differences are the polarities of the applied voltages. Obviously they significantly affect overall outcomes. See above.

TABLE FOR EXPERIMENT 27-2

TABLE 27-2.1

Procedure Step	Function and Measurement	Value
2	Point B to ground	**5** V
3	Point B to ground	**0** V
5	Point B to ground	**−5** V
6	Point B to ground	**0** V

EXPERIMENT 27-3: Diode Rectifiers

Answers to Questions

1. How does a full-wave bridge rectifier circuit compare with a center-tap circuit?
   The same amplitude of output requires twice the input for the center-tap circuit.

2. Concerning each of the circuits studied, how do the graticule displays compare?
   The inputs are sine waves of specified amplitudes; the outputs are displayed as either half-wave or full-wave rectified wave shapes.

3. How does the oscilloscope input coupling affect the displayed waveform?
   Ac coupling causes the rectified wave shape to be irregular at the bottom because of internal capacitor action in the oscilloscope.

4. Make a general statement concerning the resistance of a PN junction diode.
   It is dynamic.

5. Which of the studied circuits would be best as a dc power supply?
   The full-wave bridge.

GRAPHS FOR EXPERIMENT 27-3

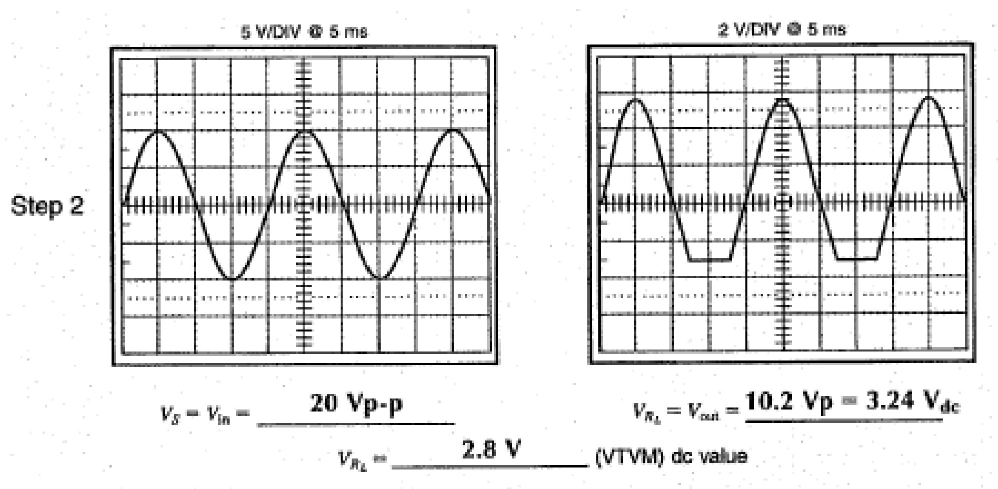


Fig. 27-3.5 Graticule for step 2.

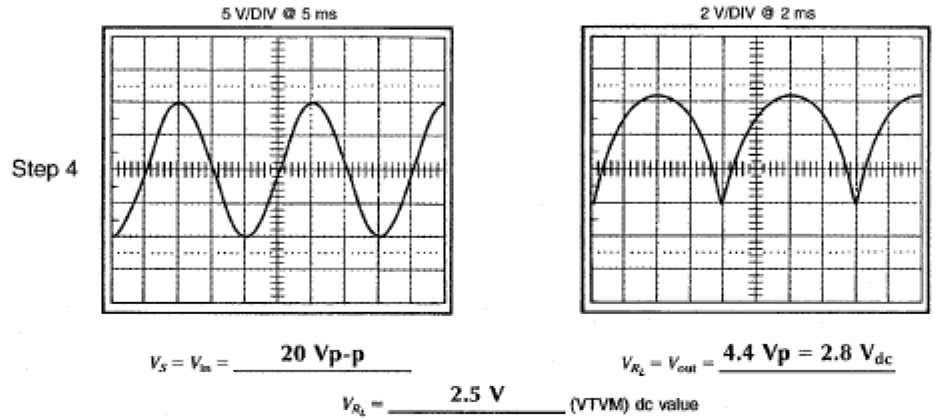


Fig. 27-3.6 Graticule for Step 4

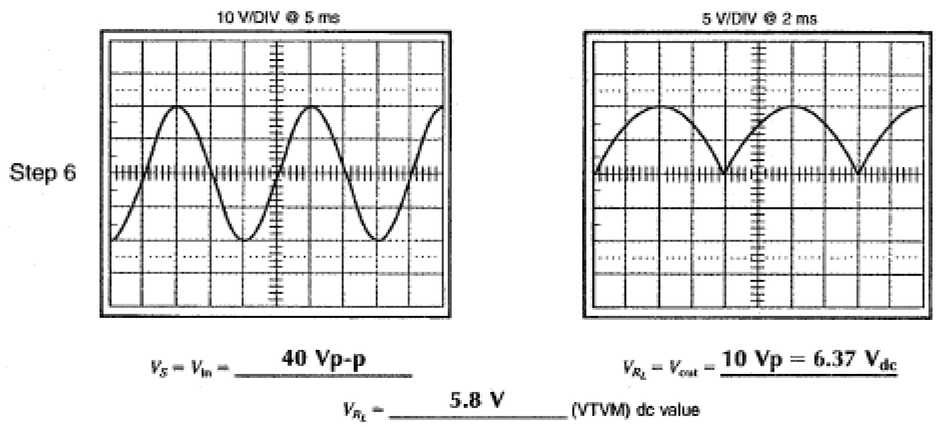


Fig. 27-3.7 Graticule for Step 6

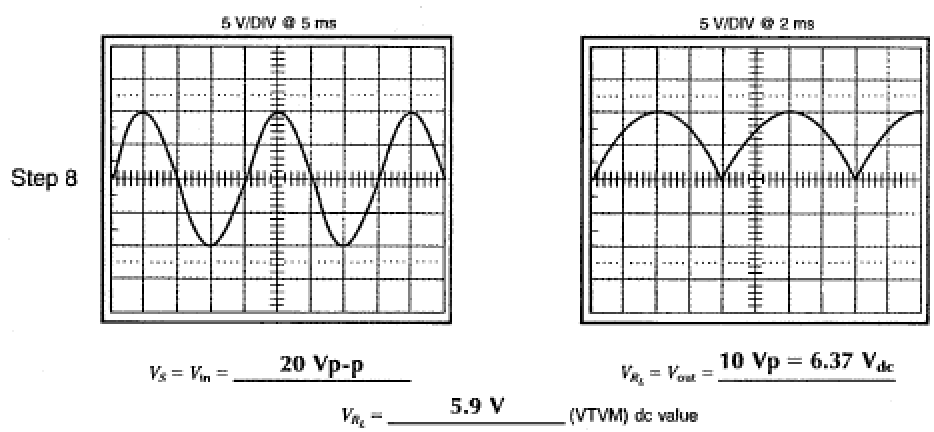


Fig. 27-3.8 Graticule for Step 8

EXPERIMENT 27-4: Rectification and Filters

Answers to Questions

1. How does a full-wave bridge rectifier compare with a center-tap circuit in this experiment?
   See Experiment 23-1, question 1.

2. Concerning each of the circuits studied in this experiment, how do each of the displayed oscilloscope waveforms compare?
   See experiment 23-1, question 2.

3. How does the oscilloscope input coupling affect the displayed waveform?
   See Experiment 23-1, question 3.

4. Does the resistance of the PN junction diodes affect the operation of the rectified circuits studied?
   Yes. There is a voltage drop across each diode when it is conducting; this affects output.

5. With respect to this experiment, what would be a definition of filtration?
   The removal of ac ripple voltage.

TABLES FOR EXPERIMENT 27-4

TABLE 27-4.1

Procedure Step	Measurement	Value	Ripple Calculation
2	V_{RL} (oscill.)	**9.6** Vp-p	
3	V_{RL} (DMM)	**2.85** V	
4	V_{RL} (oscill.)	**3.2** Vp-p	
	V_{RL} (DMM)	**7.82** V	
5	% ripple		**14.5** %
7	V_{RL} (oscill.)	**8.8** Vp-p	
	V_{RL} (DMM)	**5.20** V	
	V_{RL} (oscill.)	**1.8** Vp-p	
	V_{RL} (DMM)	V	
	% ripple		**8.35** %
9	V_{RL} (ac)	**9.6** Vp-p	
10	V_{RL} (dc)	**5.9** V	
11	V_{RL} (ac)	**1.96** Vp-p	
	V_{RL} (dc)	**8.49** V	**8.1** %
12	V_{RL} (ac)	**64.0 m**Vp-p	
	V_{RL} (dc)	**6.58** V	**0.34** %
13	V_{RL} (ac)	**14.0 m**Vp-p	
	V_{RL} (dc)	**6.55** V	**0.08** %
14	V_{RL} (ac)	**24.5 m**Vp-p	
	V_{RL} (dc)	**2.2** V	**0.4** %

EXPERIMENT 27-5: Troubleshooting Power Supplies

Answers to Questions

1. What are the circuit characteristics of a power supply with an open output capacitor?
   A power supply with an open output capacitor will exhibit noise, ripple, and a slight decrease in dc output level.

2. What are the circuit characteristics of a power supply with an open input capacitor?
   A power supply with an open input capacitor will exhibit more ripple, noise and a somewhat lower dc level.

3. What are the circuit characteristics of a power supply with an open rectifier diode?
   A power supply with an open rectifier diode will operate like a half-wave rectifier with decreased dc output levels and increased ripple frequency and voltage.

4. What does the percentage of full-load ripple indicate?
   The percentage of full-load ripple indicates the smoothness of the dc output or the ac component.

5. Why is a bleeder resistor important in a power supply?
   The bleeder resistor is important because it allows the filter capacitor to discharge quickly. It also provides a path to ground that could protect the load in the event of excess current flow (depending upon its resistance).

6. What safety factors must be observed when you are working with a power supply?
   Observe the following safety measures when you are working with a power supply: do not work near water, use an isolation transformer, remove jewelry, do not leave voltages exposed, observe ratings, and use service manuals to replace components. Finally, always be sure you are qualified to work on the equipment.

TABLES FOR EXPERIMENT 27-5

TABLE 27-5.1

Procedure Step	Value	Measured	Calculated
3	V_{dc}	**17.2 V**	
3	V_{ripple}	**30 mVp-p**	
6	V_{dc}	**9.0 V**	
6	V_{ripple}	**110 mVp-p**	
8	% Regulation		**91 %**
9	T for C_2	**<1 s**	**0.24 s**
10	T for C_2	**≈45 s≈**	**23.5 s**
12	V_{ripple}	**15 mVp-p**	
12	V_{rms}		**5.3 mV**
14	V_{ripple}	**110 mVp-p**	
14	V_{rms}		**39 mV**
15	% Ripple		**0.4 %**
16	V_{dc}	**6.4 V**	
	V_{ripple}	**600 mVp-p**	
18	V_{dc}	**3.4 V**	
20	V_{dc}	**7.1 V**	
	V_{ripple}	**200 mVp-p**	
	V_{ripple}	**120 Hz**	
23	V_{dc}	**9 V_{dc}**	
	V_{ripple}	**350 mVp-p**	

EXPERIMENT 28-1 Common Emitter Amplifier

Answers to Questions

1. What is the purpose of biasing the transistor?
   To establish the desired operational point (Q point) on a load line.

2. What were the values of biasing resistors used?
   The 100-kΩ potentiometer was adjusted to obtain the proper biasing resistance values. See data.

3. What is the difference between using NPN versus PNP transistors with respect to bias supply voltage?
   An NPN requires a positive voltage and a PNP requires a negative voltage.

4. What is the phase relationship of the input voltage versus the output voltage?
   The output is 180 degrees out of phase with the input.

5. Explain the differences between dc and ac characteristics.
   The dc characteristics of a transistor, specifically V_{BEQ}, do not change perceptibly under different conditions. Ac characteristics are dynamic.

TABLES FOR EXPERIMENT 28-1

TABLE 28-1.1 V_{in} = 30 mVp-p

Procedure Step	Measurement	Value
5	V_{out}	**5.1** Vp-p
6	V_{BE}	**590 m**V
7	A_V	**170**
8	R_A	**101.4 kΩ**
	R_B	**8.1 kΩ**

TABLE 28-1.2 R_C = 470 Ω

Procedure Step	Measurement	Value
9	V_{out}	**4.2**
	V_{BE}	**650 m**V
	A_V	**140**
	R_A	**98.2 kΩ**
	R_B	**10.7 kΩ**

TABLE 28-1.3 R_C = 4.7 kΩ

Procedure Step	Measurement	Value
10	V_{out}	**5.3** Vp-p
	V_{BE}	**560 m**V
	A_V	**177**
	R_A	**102 kΩ**
	R_B	**7.1 kΩ**

TABLE 28-1.4 V_{CEQ} = −5V

Procedure Step	Measurement	Value
17	V_{BEQ}	**−650 m**V
18	R_A	**99.6 kΩ**
	R_B	**10.4 kΩ**

TABLE 28-1.5 V_{CEQ} = −8.5 V

Procedure Step	Measurement	Value
19	V_{BEQ}	**−620 m**V
	R_A	**101.5 kΩ**
	R_B	**8.1 kΩ**

TABLE 28-1.6 V_{CEQ} = −1.5 V

Procedure Step	Measurement	Value
19	V_{BEQ}	**−670 m**V
	R_A	**94.7 kΩ**
	R_B	**15.1 kΩ**

TABLE 28-1.7

Procedure Step	Measurement	Value
21	V_{in}	**40.0 m**Vp-p
23	V_{CEQ} = 8.5 V	V_{out} = **2.2** Vp-p
	V_{CEQ} = 1.5 V	V_{out} = **4.6** Vp-p

EXPERIMENT 30-1: FET Amplifier

Answers to Questions

1. What was the polarity of the JFET used in this experiment?
   N-channel.

2. What is the function of the bypass capacitor? What happens when it is removed from the amplifier circuit?
   It prevents an ac voltage drop across R_S. When C_B is removed, there is a considerable reduction in gain.

3. What factors influence the input resistance of the amplifier?
   In theory, the input resistance should be approximately equal to the ohmic value of R_G.

4. What is the overall effect that is created by increasing the value of the load resistance?
   With the lower supply voltage (15V), the gain increases as the value of R_D increases, with the exception of an R_D of 8.2 kΩ.

5. What effects to the amplifier are created by increasing the value of the power supply voltage?
   Increased applied voltage results in increased gain. For optimum operating conditions a JFET needs a larger power supply voltage than a transistor.

TABLES FOR EXPERIMENT 30-1

TABLE 30-1.1

Procedure Step	Measurement	R, Ω
1	S to G	∞ **Ω**
	G to D	**8 kΩ**
	S to D	**146 Ω**
Leads reversed	S to G	**8 kΩ**
Leads reversed	G to D	∞ **Ω**
Leads reversed	S to D	**146 Ω**

TABLE 30-1.2

Procedure Step	R_D, kΩ	V_G(dc)	V_D(dc)	V_S(dc)	V_G(ac)	V_D(ac)	V_S(ac)	A_V
2	2.2	**0 V**	**12.8 V**	**0.95 V**	**0.1 Vp**	**0.56 Vp-p**	**0 Vp**	**5.6**
3	4.7	**0 V**	**10.05 V**	**0.95 V**	**0.1 Vp**	**1.16 Vp-p**	**0 Vp**	**11.6**
	5.6	**0 V**	**9.8 V**	**0.95 V**	**0.1 Vp**	**1.35 Vp-p**	**0 Vp**	**13.5**
	8.2	**0 V**	**7.1 V**	**0.95 V**	**0.1 Vp**	**0.2 Vp-p**	**0 Vp**	**2**

TABLE 30-1.3

Procedure Step	V_{DD}	Noted Effects
4	30 Vdc	**R_D = 8.2 kΩ. A_V = 20.5 a noticeable increase in gain.**
5	15 Vdc	**Capacitor removed: R_D = 5.6 kΩ. A_V = 4 Gain is obviously reduced.**

EXPERIMENT 31-1: Two Stage Transistor Amplifier

Answers to Questions

1. With reference to amplifiers, define the term gain.
   Gain is when there is a greater output than input level.

2. What is the general purpose or reason for the creation of the cascading amplifier circuit?
   To increase gain.

3. When determining the calculated voltage gain of an amplifier, which two resistance values can be used to determine its value? How is this different from a single stage amplifier? Explain your answer.
   R_C and R_e can be used to determine the voltage gain of an amplifier. Depending upon the type of amplifier, there may not be an emitter resistor (R_e). Then the formula: $A_V = V_{out}/V_{in}$ must be used.

4. Describe the importance of the Q point. Explain your answer.
   The location of the Q point will determine the level of distortion (if any) in the output waveform.

5. Describe the process used to determine the value of the capacitors used for the cascaded amplifier.
   The coupling capacitors are selected such that their reactance will not create any appreciable voltage drop at the amplifier's lowest operating frequency.

TABLE FOR EXPERIMENT 31-1

TABLE 31-1.1

	Resistor	Nominal Value	Measured Voltage	Calculated Current	Voltages with Stages Disconnected
Step 2	R_{a1} R_{e2}	82 KΩ	**10.9 V**	**133 µA**	**10.9 V**
	R_{b1}	10 kΩ	**1.1 V**	**110 µA**	**1.1 V**
	R_{c1}	1.5 kΩ	**5.0 V**	**3.33 mA**	**5.0 V**
	R_{e1}	150 Ω	**0.5 V**	**3.33 mA**	**0.5 V**
	R_{a2}	82 kΩ	**10.9 V**	**133 µA**	**10.9 V**
	R_{b2}	10 kΩ	**1.1 V**	**110 µA**	**1.1 V**
	R_{c2}	1.5 kΩ	**5.0 V**	**3.33 mA**	**5.0 V**
	R_{e2}	150 Ω	**0.5 V**	**3.33 ma**	**0.5 V**
Two Stages					
Step 3	V_{in} = 100 mV, V_{out} = __**6.7_Vp-p**__, A_V = ___**67**____ *Note:* V_{out} = stage 2 output				
Single Stages					
Step 5	Stage 1:	V_{in} = 100 mV,	Vout = **890 m**V,	A_V = **8.9**	
	Stage 2:	V_{in} = 100 mV,	Vout = **880 m**V,	A_V = **8.8**	
Bandwidth					
Step 6	At V_{in} = 100 mV,	f_1 = <**100** Hz	at **4.74** V_{out}		
	BW = **1.4 MHz**	f_2 = **1.4 M**Hz	at **4.74** V_{out}		
Step 7	R_L = 1 kΩ,	V_{out} = **3.3** V,	A_V = **33**		
Step 8	R_L = 100 Ω,	V_{out} = **560 m**V,	A_V = **5.6**		
Step 9	R_L = 10 kΩ,	V_{out} = **6.0** V,	A_V = **60**		

EXPERIMENT 32-1: Light Sensitive Diodes

Answers to Questions

1. Describe how these types of photocells could be used in three different applications.
   Three applications for solar cells are to be used as: Transducers – These cells can be used to convert light energy into electrical current for powering some small devices. Sensors – These cells can be used to sense when too much light is undesirable and then signal an alarm. Switches – These cells can be used to switch lights on and off, depending upon their accompanying circuitry. The cells would then be acting as triggering devices.

2. Describe the difference between a Zener diode and a regular diode.
   A Zener diode differs from a regular diode in that a Zener diode is "doped" such that it can be used in the reverse direction.

TABLE FOR EXPERIMENT 32-1

TABLE 32-1.1

Step(s)		Light Bulb or Wattage		Current I		Volts Across 330Ω
2 and 3						
4						
5						
6						
Two Devices in Series						
7						
Two Devices in Parallel						
8						

Instructors should run the experiment to obtain the data. The results will depend upon the type of light-sensitive device used and the proximity of the light source.

EXPERIMENT 32-2: Zener Diodes for Regulation and Protection

Answers to Questions

1. How does a Zener diode act when it is connected in the forward-bias manner?
   A Zener diode acts like a PN junction diode when it is connected in the forward-bias manner.

2. How does a Zener diode operate when it is connected as a voltage regulator?
   A Zener diode keeps a constant voltage across it and this regulates the voltage across the load by keeping it constant also.

3. How does a Zener diode operate when it is connected as a protection device?
   When connected as a protection device, a Zener diode will become a closed switch when the Zener voltage is across it. This will keep excess voltage and current from the load.

4. Explain the difference between a Zener diode and a PN junction diode.
   A Zener diode differs from a PN junction because it is used in reverse bias.

5. What was the purpose of R_S in the circuit in Fig. 32-2.5?
   R_S is a current-limiting resistor.

TABLES FOR EXPERIMENT 32-2

TABLE 32-2.1

Step(s)	V_Z Measured, V	V Applied (V_a) Measured, V	I_T Measured, mA	I_T Calculated, mA	V_{RS} Measured, V
2-4	5	**24 V**	**52 mA**	**56 mA**	**18.6 V**
5 V_a + 2 V	**5 V**	**26 V**	**55 mA**	**62 mA**	**20.6 V**
6 V_a + 4 V	**5 V**	**28 V**	**58 mA**	**65 mA**	**22.6 V**
8 R_L = 4.7kΩ	5	**28 V**	**58 mA**	**65 mA**	**22.6 V**
9 R_L = 100Ω	5	**28 V**	**59 mA**	**69 mA**	**22.8 V**

TABLE 32-2.2 Step 10

V Applied (V_a), V	V_Z, V	I_T, mA
0	**0 V**	**0 V**
1	**0.66 V**	**0.9 mA**
2	**0.72 V**	**3.9 mA**
3	**0.74 V**	**6.7 mA**
4	**0.75 V**	**9.5 mA**
5	**0.76 V**	**12.2 mA**
6	**0.77 V**	**15.9 mA**
7	**0.78 V**	**18.9 mA**
8	**0.79 V**	**21.7 mA**

EXPERIMENT 32-3: Silicon Controlled Rectifier

Answers to Questions

1. What is the difference between an SCR and a transistor?
   A transistor has two P-N junctions or three layers and an SCR has three P-N junctions or 4 layers. .

2. Why are SCRs used to control motors?
   Because they are designed for high current volumes required by motors.

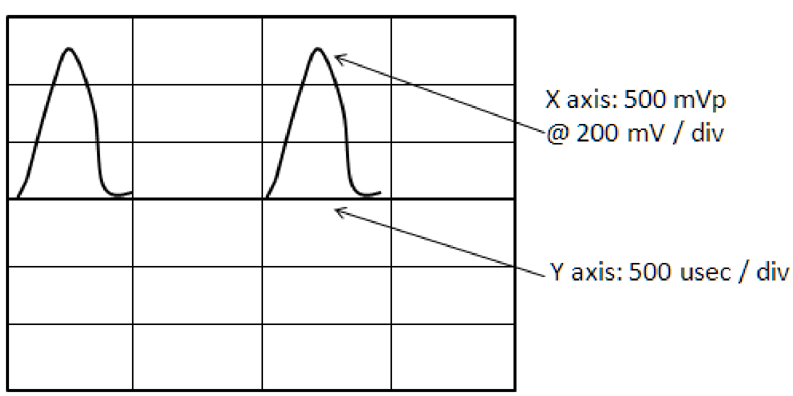
3. How can an SCR be turned on?
   The SCR is turned on at the gate but it also requires that enough current flow to overcome the *breakover* voltage level.

TABLE FOR EXPERIMENT 32-3 (Multisim results)

Continuity test Gate to cathode resistance Ω: **34M Ω**
Continuity test Gate to anode resistance Ω: **73M Ω**
Continuity test Anode to cathode resistance Ω: **39M Ω**

DC test: voltages across load R1	AC test: voltages across load R1
V_1 = 0 V: V_{R1} = **125uV**	V_1= 0 V:, **0 Vp**
V_1 = 0.5V: V_{R1} = **125uV**	V_1= 0.5 V: **0 Vp**
V_1 = 0.7 V: V_{R1} **= 4.43 V**	V_1 =0.7 V: **500 mV p**
V_1 = 1.0 V: V_{R1} = **4.43V**	V_1 = 1.0 V: **500mVp**
V_1 = 2.0 V: V_{R1} = **4.43V**	V_1 = 2.0 V: **500mVp**

Waveforms: drawings should show 2 cycles latched or one off and one latched. Note that the off waveform would be zero (below 0.7 volts DC at the gate).



EXPERIMENT 33-1: Operational Amplifiers

Answers to Questions

1. For a voltage follower circuit, what is the difference between the input and the output signals for phase and gain?
   Phase = 0 degrees, gain less than or equal to 1.

2. For the non-inverting amplifier, how does the measured voltage gain compare with the formula for determining gain? What is the percentage of error between these two values?
   Percent of error ranged between 0.5 percent and 3 percent. Very close.

3. For the inverting amplifier, do the experimental results agree with the gain equation?
   Results agreed within a range from 1 percent to 6.5 percent.

4. What would be the purpose for a buffer amplifier?
   To isolate the input from the output, a buffer amplifier would also be used for impedance matching.

5. What voltage gain can be expected from a non-inverting amplifier?
   A gain of less than or equal to one (unity).

TABLES FOR EXPERIMENT 33-1

TABLE 33-1.1 V_{in} = 1 Vp-p **TABLE 33-1.2 V_{in} = Vp-p**

R_1, kΩ	V_{out}	A_V		R_1, kΩ	V_{out}	A_V
27	**1.41 Vp-p**	**1.41**		27	**375 mVp-p**	**0.375**
39	**1.26 Vp-p**	**1.26**		39	**260 mVp-p**	**0.260**
47	**1.21 Vp-p**	**1.21**		47	**215 mVp-p**	**0.215**
82	**1.13 Vp-p**	**1.13**		82	**130 mVp-p**	**0.130**

EXPERIMENT A-1: Digital OR and AND Gates

Answers to Questions

1. In the prior circuits, what voltage level would a binary 1 represent? A binary 0? Are the answers the same for both circuits of Figs. A-1.5 and A-1.6?
   Binary 1 = +5 V; binary 0 = 0 V (gnd).

2. What is an OR gate? For what percentage of time is the three-input circuit on?
   It is a mostly on device. It is on 75 percent of the time.

3. What is an AND gate? For what percentage of time is the three-input circuit off?
   It is a mostly off device. It is off 75 percent of the time.

4. What functions do the diodes perform in the OR and AND gates?
   They allow the diodes to be pulled low or high, as desired, for a preset state.

5. What are the fundamental differences between the two circuits shown in Figs. A-1.5 and A-1.6? Do the differences significantly affect overall outcomes? Explain.
   Figure A-1.5 requires forward bias input signal. Figure A-1.6 requires reverse-bias input signal.

TABLE FOR EXPERIMENT A-1

A	B	C	Y		A	B	C	Y
0	0	0	**0**		0	0	0	**0**
0	0	1	**1**		0	0	1	**0**
0	1	0	**1**		0	1	0	**0**
0	1	1	**1**		0	1	1	**0**
1	0	0	**1**		1	0	0	**0**
1	0	1	**1**		1	0	1	**0**
1	1	0	**1**		1	1	0	**0**
1	1	1	**1**		1	1	1	**1**

EXPERIMENT A-2: Digital NOR and NAND Gates

Answers to Questions

1. In the circuits in Figs. A-2.5 and A-2.6, what voltage level would a binary 1 represent? Binary 0? Are the answers the same for both circuits in both of these figures?
   Binary 1 is represented by approximately 5 V and binary 0 is approximately 0 V. However, Fig. A-2.6 is just the opposite if the NAND condition represents binary 1 or 0 V at the output.

2. What is a NOR gate? What percentage of the time is the three-input circuit off?
   A NOR gate is a circuit with two or more inputs and one output where any high input causes a low output. The three-input circuit has a low or off output seven-eighths or 87.5 percent of the time.

3. What is a NAND gate? What percentage of the time is the three-input circuit on?
   The **NAND gate has two or more inputs, but has only one condition where the output is low when all inputs are high. Otherwise, the output is ON or high more than 87.5 percent of the time.**

4. What function do the diodes perform in the NOR and NAND gates?
   In NOR and NAND gates, the diodes provide a conducti**ve path to current when forward-biased with the proper voltage levels. The diodes also act as switches and dc blocking components.**

5. What are the fundamental differences between the two circuits shown in Figs. A-2.3 and A-2.4? Do the differences significantly affect overall outcomes? Explain.
   There is no difference between these figures.

TABLE FOR A-2

TABLE A-2.1

A	B	C	Y		A	B	C	Y
0	0	0	**1**		0	0	0	**1**
0	0	1	**0**		0	0	1	**1**
0	1	0	**0**		0	1	0	**1**
0	1	1	**0**		0	1	1	**1**
1	0	0	**0**		1	0	0	**1**
1	0	1	**0**		1	0	1	**1**
1	1	0	**0**		1	1	0	**1**
1	1	1	**0**		1	1	1	**0**

EXPERIMENT A-3: Multivibrator Flip-Flop

Answers to Questions

1. What components determine the frequency of operation?
   The capacitors determine the frequency of operation.

2. What does a multivibrator do?
   A multivibrator generates a pulse, depending on its circuit components.

ANSWERS TO PROCEDURES

2. **With C = 25 μF and frequency $\approx$0.5 Hz, approximately 1 blink of both LEDs in 2 s, or each LED blinks once per second.**

3. **With C = 50 μF and frequency $\approx$0.25 Hz, approximately 1 blink of both LEDs in 4 s, or each LED blinks once in 2 s.**

   Conclusion: Increasing the value of capacitance decreases the frequency.

EXPERIMENT A-4: Integrated Logic Circuits

Answers to Questions

1. In the circuits shown in Figs. A-4.3 and A-4.4, what voltage level would binary 1 represent? Binary 0? Are the answers the same for both circuits?
   Binary 1 represents +5 V, and 0 V, or ground, represents a binary 0.

2. What is an OR gate?
   An OR gate is a circuit with two or more inputs. If any input is high, there is a resulting high output.

3. In a three-input OR gate circuit, what percentage of the time is the circuit on?
   87.5 percent.

4. What is an AND gate?
   An AND gate is a circuit with two or more inputs. If both inputs are high, there is a resulting high output.

5. In a three-input AND gate circuit, what percentage of the time is the circuit off?
   87.5 percent.

6. What are the fundamental differences between the two circuits constructed in this experiment?
   The fundamental difference between the OR gate and AND gate ICs is their output states as shown by their respective truth tables. Otherwise, they are packaged and biased in similar manners.

TABLES FOR EXPERIMENT A-4

TABLE A-4.1 **TABLE A-4.2**

A	B	Y		A	B	Y
0	0	**0**		0	0	**0**
0	1	**1**		0	1	**0**
1	0	**1**		1	0	**0**
1	1	**1**		1	1	**1**

EXPERIMENT B-1: Vacuum Tube Amplifier

Answers to Questions

1. Define the purpose and function of each of the elements found in a triode?
   Cathode: Electron emitter (negative potential). Grid: Controls electron flow between cathode and plate. Plate: Electron attractor or acceptor (positive potential).

2. In this experiment, what step had the largest effect on gain?
   Step 3, with the least negative grid voltage.

3. For this tube experiment, define the condition causing saturation.
   When the grid voltage is the most positive is causes saturation.

4. For this tube experiment, define the condition causing cutoff.
   When grid voltage is the most negative it causes cutoff.

5. How do the calculated values of voltage gain compare to the actual measured values? How are the differences accounted for?
   With the R_P of 22 kΩ, gain was generally lower than calculated. With 8.2 kΩ R_P, gain was higher than calculated. Dynamic plate resistance is a constant for calculation purposes, whereas in actuality it is dynamic.

TABLE FOR EXPERIMENT B-1

TABLE B-1.1

Procedure Step	Measurement	Value V	Calculated A_V	Measured A_V
3	V_{GK}	**2.0 Vp-p**		
4	V_{in} at $V_G = -2$ V	**2.0 Vp-p**	**15.2**	**17.0**
	V_{out} at $V_G = -2$ V	**34.0 Vp-p**		
	V_{in} at $V_G = -4$ V	**2.0 Vp-p**	**15.2**	**15.0**
	V_{out} at $V_G = -4$ V	**30.0 Vp-p**		
	V_{in} at $V_G = -6$ V	**2.0 Vp-p**	**15.2**	**13.8**
	V_{out} at $V_G = -6$ V	**21.5 Vp-p**		
5	V_{out} at 20 Hz	**28.0 Vp-p**		
	V_{out} at 15 kHz	**28.5 Vp-p**		
	V_{out} at 50 kHz	**27.5 Vp-p**		
6			**15.2**	
7	Percent of error =			
	9.21 %			
8	V_P with $V_G = -2$ V	**144 V**		
	V_P with $V_G = -4$ V	**172 V**		
	V_P with $V_G = -6$ V	**205 V**		
	V_P with $V_G = -8$ V	**232 V**		

Appendix I Component List

Resistors

All resistors are 0.25 W, 5% unless indicated otherwise.

Qty	Value		Qty	Value
1	10 Ω		4	10 kΩ
1	15 Ω		1	12 kΩ, 1 W
1	47 Ω, 2 W		4	22 kΩ
1	56 Ω		1	22 kΩ, 2 W
1	56 Ω, 2 W		1	27 kΩ
1	68 Ω		1	33 kΩ
3	100 Ω		1	39 kΩ
1	100 Ω, 1 W		2	47 kΩ
1	120 Ω		1	68 kΩ
2	150 Ω		2	82 kΩ
2	150 Ω, 1 W		1	86 kΩ
5	220 Ω		2	100 kΩ
1	270 Ω		1	100 kΩ, 1 W
2	330 Ω		1	150 kΩ
1	330 Ω, 1 W		1	220 kΩ
7	390 Ω		1	470 kΩ
3	470 Ω		1	1 MΩ
5	560 Ω		1	1.2 MΩ
3	680 Ω		1	3 MΩ
3	820 Ω		1	3.3 MΩ
4	1 kΩ			
3	1.2 kΩ			
2	1.5 kΩ			
3	2.2 kΩ			
1	2.7 kΩ			
1	3.3 kΩ			
1	3.9 kΩ			
3	4.7 kΩ			
1	5.6 kΩ			
1	8.2 kΩ			

Capacitors All capacitors are rated 25 V or greater.

Qty	Value		Qty	Value
1	0.0068 μF		2	47 μF electrolytic
1	0.068 μF		2	47 μF
4	0.01 μF		2	4 μF or 1 μF
2	0.1 μF		1	100 μF
4	10 μF			
2	25 μF			

Inductors

Qty	Value
2	33 mH
1	100 mH
1	1 H (or optional value)
4	Values from 10 mH to 0.5 H
1	0.5 H
1	0.01 H

Potentiometers

Qty	Value
1	1 kΩ, 1 W, linear taper
1	5 kΩ, 1 W, linear taper
1	100 kΩ, 1 W, linear taper
1	1 MΩ, 1 W, linear taper

Batteries

Qty	Value
4	D cells
4	D-cell holders

Diodes

Qty	Value
4	1N4004 or equivalent
4	LEDs
1	Zener, 5V (1 W)
2	IR#S1M solar cells or Equivalent photo diode

Transistors

Qty	Value
1	2N3638
2	2N3904

FETs

Qty	Value
1	2N3823 or equivalent

Op Amps and ICs

Qty	Value
1	741
1	7408
1	7432

Vacuum Tube (Optional)

Qty	Value
1	6J5 or equivalent

Transformers

Qty	Value
1	60-Hz with two or three taps

Bench Equipment

DMM with 30-mA capacity
NOTE: Individual meters (voltmeter and ammeter) and also be used
DC power supply, 0-30 V (± 15 V for op amps experiment)
High-voltage power supply with 120:12.6 V center-tap @ 6.3 V filament transformer
Galvanometer or microammeter movement
Signal generator (sine wave, to 1 MHz preferred)
Oscilloscope (digital is preferred) and operation manual if available
Frequency counter
Proto-board (breadboard) or springboard
AC signal generator

Multisim software for students from National Instruments

Miscellaneous Parts

Qty	Description
2	SPST switch
1	SPST switch
1	0-1 mA meter movement
1	50 μA meter movement
6	Test leads (3 red, 3 black)
1	Decade box
1	Magnetic compass
1	Heavy-duty horseshoe magnet, 20 lb plus pull
1	Sheet-metal shield, 6 × 6 in
1	Grease pencil
2 – 3 ft	Thin insulated wire
Some	Iron filings
1	No. 18 steel nail
4	Light bulbs (25, 60, 100, 150 W)
1	Clear glass functioning fuse (any current rating)
1	Clear glass nonfunctioning fuse (any current rating)
1	Neon bulb, approximately 60 V
1	SCR (not required) because high voltage/current may be a safety factor. Recommended: use Multisim.