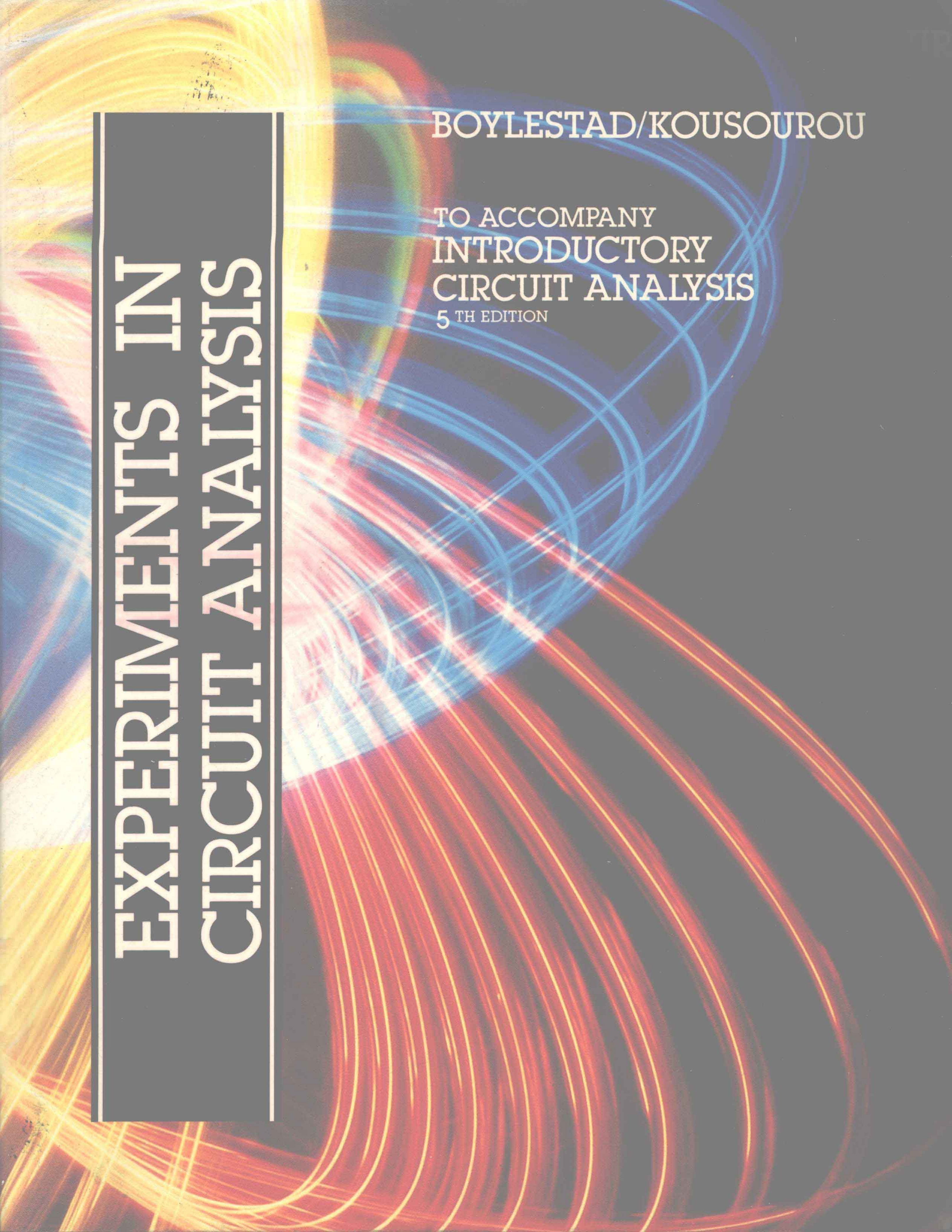
EXPERIMENTS IN CIRCUIT ANALYSIS

BOYLESTAD/KOUSOUROU

TO ACCOMPANY
INTRODUCTORY CIRCUIT ANALYSIS
5 TH EDITION



Experiments in Circuit Analysis to Accompany Introductory Circuit Analysis

5th Edition

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To our wives and children

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Preface

Although the laboratory manual for the previous edition was well received and widely adopted, it became apparent during recent laboratory sessions that significant modifications were needed to update and improve this edition.

A mathematics review introduces the dc and ac sections. Its purpose is to establish a common plane of understanding that will carry students through the early stages of each course. The mathematics review can also be used as a delaying tactic in the laboratory session to ensure that students have sufficient background from the lecture portion of the course to perform a meaningful laboratory experiment.

Those laboratory experiments receiving the most attention and revision are the first few labs of each section of the manual. Instructor comments and our own teaching experience suggested this need to ensure that procedures were better defined in the early stages of each lab, a time when students are becoming aware of the terminology that surrounds the more practical orientation of the laboratory experience.

Sections of specific labs were removed, added, or modified to clarify the procedure to be verified by the experiment. Each of the labs in this revision has been carefully conceived and thoroughly class-tested, with a more direct avenue toward demonstrating that the lecture theory has experimental and practical application. Throughout the labs for both the dc and ac sections, the power requirements were reduced to permit the use of ½-watt resistors (or less in some cases). Experiments were also added to reflect a shift in emphasis and coverage in the associated text.

Both authors thank Professor Aidala at Queensborough Community College for his continuing comments, suggestions, and encouragement. In addition, the review of Professor Donald Szymanski at Owens Technical College and the efforts of Professor Alvin Schiff at Queensborough Community College to ensure the highest degree of accuracy are deeply appreciated. We thank the staff of Merrill Publishing, in particular Rex Davidson and Pete Robison, as well as Linda Johnstone, for their dedication and cooperation in producing this manual of experiments.

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Contents

dc EXPERIMENTS

ac EXPERIMENTS

APPENDICES

Math Review

dc

The analysis of dc circuits requires that a number of fundamental mathematical operations be performed on an ongoing basis. Most of the operations are typically covered in a secondary-level education; a few others will be introduced in the early sessions of the lecture portion of this course.

The material to follow is a brief review of the important mathematical procedures along with a few examples and exercises. Derivations and detailed explanations are not included but are left as topics for the course syllabus or as research exercises for the student.

It is strongly suggested that the exercises be performed with and without a calculator. Although the modern-day calculator is a marvelous development, the student should understand how to perform the operations in the long-hand fashion. Any student of a technical area should also develop a high level of expertise with the use of the calculator through frequent application with a variety of operations.

FRACTIONS

Addition and Subtraction

Addition and subtraction of fractions require that each term have a common denominator. A direct method of determining the common denominator is simply to multiply the numerator and denominator of each fraction by the denominator of the other fractions. The method of "selecting the least common denominator" will be left for a class lecture or research exercise.

EXAMPLES

$$\frac{1}{2} + \frac{2}{3} = \left(\frac{\mathbf{3}}{\mathbf{3}}\right)\left(\frac{1}{2}\right) + \left(\frac{\mathbf{2}}{\mathbf{2}}\right)\left(\frac{2}{3}\right) = \frac{3}{6} + \frac{4}{6} = \frac{7}{6}$$

$$\frac{3}{4} - \frac{2}{5} = \left(\frac{\mathbf{5}}{\mathbf{5}}\right)\left(\frac{3}{4}\right) - \left(\frac{\mathbf{4}}{\mathbf{4}}\right)\left(\frac{2}{5}\right) = \frac{15}{20} - \frac{8}{20} = \frac{7}{20}$$

$$\frac{5}{6} + \frac{1}{2} - \frac{3}{4} = \left(\frac{\mathbf{2}}{\mathbf{2}}\right)\left(\frac{\mathbf{4}}{\mathbf{4}}\right)\left(\frac{5}{6}\right) + \left(\frac{\mathbf{6}}{\mathbf{6}}\right)\left(\frac{\mathbf{4}}{\mathbf{4}}\right)\left(\frac{1}{2}\right) - \left(\frac{\mathbf{6}}{\mathbf{6}}\right)\left(\frac{\mathbf{2}}{\mathbf{2}}\right)\left(\frac{3}{4}\right)$$

$$= \frac{40}{48} + \frac{24}{48} - \frac{36}{48} = \frac{28}{48} = \frac{7}{12}$$

(12 being the least common denominator for the three fractions)

Multiplication

The multiplication of two fractions is straightforward, with the product of the numerator and denominator formed separately as shown below.

EXAMPLES

$$\left(\frac{1}{3}\right)\left(\frac{4}{5}\right) = \frac{(1)(4)}{(3)(5)} = \frac{4}{15}$$

$$\left(\frac{3}{7}\right)\left(\frac{1}{2}\right)\left(-\frac{4}{5}\right) = \frac{(3)(1)(-4)}{(7)(2)(5)} = -\frac{12}{70} = -\frac{6}{35}$$

Division

Division requires that the denominator be inverted and then multiplied by the numerator.

EXAMPLE

$$\frac{\frac{2}{3}}{\frac{4}{5}} = \frac{2}{3} \times \frac{\mathbf{5}}{\mathbf{4}} = \frac{10}{12} = \frac{5}{6}$$

Simplest Form

A fraction can be reduced to simplest form by finding the largest common divisor of both the numerator and denominator. As an illustration,

$$\frac{12}{60} = \frac{12/\mathbf{12}}{60/\mathbf{12}} = \frac{1}{5}$$

If the largest divisor is not obvious, start with a smaller common divisor, such as shown here:

$$\frac{12/\mathbf{6}}{60/\mathbf{6}} = \frac{2}{10} = \frac{2/2}{10/2} = \frac{1}{5}$$

Or, if you prefer, use repeated divisions of smaller common divisors, such as 2 or 3:

$$\frac{12/2}{60/2} = \frac{6}{30} = \frac{6/2}{30/2} = \frac{3}{15} = \frac{3/3}{15/3} = \frac{1}{5}$$

EXAMPLES

$$\frac{180}{300} = \frac{180/\mathbf{10}}{300/\mathbf{10}} = \frac{18}{30} = \frac{18/\mathbf{6}}{30/\mathbf{6}} = \frac{3}{5}$$

$$\frac{72}{256} = \frac{72/\mathbf{8}}{256/\mathbf{8}} = \frac{9}{32}$$

or

$$\frac{72}{256} = \frac{72/2}{256/2} = \frac{36}{128} = \frac{36/2}{128/2} = \frac{18}{64} = \frac{18/2}{64/2} = \frac{9}{32}$$

Mixed Numbers

Numbers in the mixed form (whole and fractional part) can be converted to the fractional form by multiplying the whole number by the denominator of the fractional part and adding the numerator.

EXAMPLES

$$3\frac{4}{5} = \frac{(3 \times 5) + 4}{5} = \frac{19}{5}$$

$$60\frac{1}{3} = \frac{(60 \times 3) + 1}{3} = \frac{181}{3}$$

The reverse process is simply a division operation with the remainder left in fractional form.

Conversion to Decimal Form

Fractions can be converted to decimal form by simply performing the indicated division.

EXAMPLES

$$\frac{1}{4} = 4\overline{)1.00}^{\;0.25} = 0.25$$

$$\frac{3}{7} = 7\overline{)3.0000}^{\;0.4285\ldots} = 0.4285\ldots$$

$$4\frac{1}{5} = 4 + 5\overline{)1.0}^{\;0.2} = 4.2$$

PROBLEMS

Perform each of the following operations by hand and compare to the calculator solution.

1. $\frac{3}{5} + \frac{1}{3} =$ ____________ (by hand) ____________ (calculator)

2. $\frac{5}{9} - \frac{1}{4} =$ ____________ (by hand) ____________ (calculator)

3. $\frac{9}{10} - \frac{1}{2} + \frac{1}{4} =$ ____________ (by hand) ____________ (calculator)

4. $\left(\frac{5}{6}\right)\left(\frac{9}{13}\right) =$ ____________ (by hand) ____________ (calculator)

5. $\left(-\frac{1}{7}\right)\left(+\frac{8}{15}\right)\left(-\frac{3}{5}\right) =$ ____________ (by hand) ____________ (calculator)

6. $\frac{5/6}{2/3} =$ ____________ (by hand) ____________ (calculator)

7. $\frac{9/10}{-6/7} =$ ____________ (by hand) ____________ (calculator)

8. Reduce to simplest form:

a. $\frac{72}{84} =$ ____________ (by hand) ____________ (calculator)

b. $\frac{144}{384} =$ ____________ (by hand) ____________ (calculator)

9. Convert to the mixed form:
   a. $\frac{16}{7} =$ ____________
   b. $\frac{320}{9} =$ ____________
10. Convert to decimal form:
   a. $\frac{3}{8} =$ ____________ (by hand) ____________ (calculator)
   b. $6\frac{5}{6} =$ ____________ (by hand) ____________ (calculator)

SCIENTIFIC NOTATION

The need to work with very small and large numbers requires that the use of powers of 10 be appreciated and clearly understood.

The direction of the shift of the decimal point and the number of places moved will determine the resulting power of 10. For instance:

$$1\underbrace{0{,}000.}_{4} = 1 \times 10^{+4} = 10^{+4}$$

$$5\underbrace{000.}_{3} = 5 \times 10^{+3}$$

$$0.\underbrace{000001}_{6} = 10^{-6}$$

$$0.\underbrace{004}_{3}56 = 4.56 \times 10^{-3}$$

Addition and Subtraction

Addition or subtraction of numbers using scientific notation requires that the power of 10 of each term be the same.

EXAMPLES

$$45{,}000 + 3000 + 500 = 45 \times 10^3 + 3 \times 10^3 + 0.5 \times 10^3 = 48.5 \times 10^3$$

$$0.02 - 0.003 + 0.0004 = 200 \times 10^{-4} - 30 \times 10^{-4} + 4 \times 10^{-4}$$
$$= (200 - 30 + 4) \times 10^{-4} = 174 \times 10^{-4}$$

Multiplication

Multiplication using powers of 10 employs the following equation, where *a* and *b* can be any positive or negative number:

$$\boxed{10^a \times 10^b = 10^{a+b}} \qquad \text{(M.1)}$$

EXAMPLES

$$(100)(5000) = (10^2)(5 \times 10^3) = 5 \times 10^2 \times 10^3 = 5 \times 10^{2+3} = 5 \times 10^5$$
$$(200)(0.0004) = (2 \times 10^2)(4 \times 10^{-4}) = (2)(4)(10^2)(10^{-4}) = 8 \times 10^{2-4} = 8 \times 10^{-2}$$

Note in the above examples that the operations with powers of 10 can be separated from the integer values.

Division

Division employs the following equation, where a and b can again be any positive or negative number:

$$\boxed{\frac{10^a}{10^b} = 10^{a-b}} \qquad \textbf{(M.2)}$$

EXAMPLES

$$\frac{320{,}000}{4000} = \frac{32 \times 10^4}{4 \times 10^3} = \frac{32}{4} \times 10^{4-3} = 8 \times 10^1 = 80$$
$$\frac{1600}{0.0008} = \frac{16 \times 10^2}{8 \times 10^{-4}} = 2 \times 10^{2-(-4)} = 2 \times 10^{2+4} = 2 \times 10^6$$

Note in the last example the importance of carrying the proper sign through Eq. M.2.

Powers

Powers of powers of 10 can be determined using the following equation, where a and b can be any positive or negative number:

$$\boxed{(10^a)^b = 10^{ab}} \qquad \textbf{(M.3)}$$

EXAMPLES

$$(1000)^4 = (10^3)^4 = 10^{12}$$
$$(0.002)^3 = (2 \times 10^{-3})^3 = (2)^3 \times (10^{-3})^3 = 8 \times 10^{-9}$$

PROBLEMS

Using powers of 10, perform the following operations by hand, and then compare to the calculator solution.

11. $5{,}800{,}000 + 450{,}000 + 2000 =$ __________ (by hand) __________ (calculator)

12. $0.04 + 0.008 - 0.3 =$ __________ (by hand) __________ (calculator)

13. $2400 + 0.05 \times 10^3 - 40{,}000 \times 10^{-3} =$ __________ (by hand) __________ (calculator)

14. $(68{,}000)(40{,}000) =$ ______________ (by hand) ______________ (calculator)
15. $(0.0009)(0.006) =$ ______________ (by hand) ______________ (calculator)
16. $(-5 \times 10^{-8})(8 \times 10^{5})(-0.02 \times 10^{4}) =$ ______________ (by hand) ______________ (calculator)
17. $\dfrac{0.00081}{0.009} =$ ______________ (by hand) ______________ (calculator)
18. $\dfrac{5000}{6 \times 10^{6}} =$ ______________ (by hand) ______________ (calculator)
19. $\dfrac{-8 \times 10^{-4}}{0.002} =$ ______________ (by hand) ______________ (calculator)
20. $(4 \times 10^{5})^{3} =$ ______________ (by hand) ______________ (calculator)
21. $(0.0003)^{4} =$ ______________ (by hand) ______________ (calculator)
22. $[(4000)(0.0003)]^{3} =$ ______________ (by hand) ______________ (calculator)

PREFIXES

The frequent use of some powers of 10 has resulted in their being assigned abbreviations that can be applied as prefixes to a numerical value in order to quickly identify its relative magnitude.

The following is a list of the most frequently used prefixes in electrical and electronic technology:

$$10^{6} = \text{mega (M)}$$
$$10^{3} = \text{kilo (k)}$$
$$10^{-3} = \text{milli (m)}$$
$$10^{-6} = \text{micro } (\mu)$$
$$10^{-9} = \text{nano (n)}$$
$$10^{-12} = \text{pico (p)}$$

EXAMPLES

$$6{,}000{,}000\,\Omega = 6 \text{ megohms} = 6\,\text{M}\Omega$$
$$0.04\,\text{A} = 40 \times 10^{-3}\,\text{A} = 40\,\text{mA}$$
$$0.00005\,\text{V} = 50 \times 10^{-6}\,\text{V} = 50\,\mu\text{V}$$

When converting from one form to another, be aware of the relative magnitude of the quantity before you start to provide a check once the conversion is complete. Starting out with a relatively small quantity and ending up with a result of large relative magnitude clearly indicates an error in the conversion process. In many cases the best method may be to return to the decimal form before establishing the new form for the quantity.

EXAMPLES

$$0.008\,\text{M}\Omega = 0.008 \times 10^{6}\,\Omega = 8 \times 10^{3}\,\Omega = 8\,\text{k}\Omega$$
$$5600\,\text{mA} = 5600 \times 10^{-3}\,\text{A} = 5.6\,\text{A}$$
$$20{,}000\,\text{mV} = 20{,}000 \times 10^{-3}\,\text{V} = 20\,\text{V} = 0.02\,\text{kV}$$

PROBLEMS

Apply the most appropriate prefix to each of the following quantities.

23. 0.00006 A = ______________

24. 504,000 Ω = ______________

25. 32,000 V = ______________

26. 0.000000009 A = ______________

Perform the following conversions.

27. 35 mA = ______________ A

28. 0.005 kV = ______________ V = ______________ mV

29. 8,000,000 Ω = ______________ MΩ = ______________ kΩ

30. 4000 pF = ______________ nF = ______________ μF

OTHER FUNCTIONS

The student will encounter a variety of other mathematical functions in the study of electrical and electronic systems. A few will now be examined to insure their correct evaluation when the need arises.

Square and Cubic Root of a Number

The calculator will always be used to determine the square and cubic roots of a number. In each case, the power of 10 must be divisible by 2 or 3, respectively, or the resulting power of 10 will not be a whole number.

EXAMPLES

$$\sqrt{200} = (200)^{1/2} = (2 \times 10^{2})^{1/2} = (2)^{1/2} \times (10^{2})^{1/2} \cong 1.414 \times 10^{1} = 14.14$$
$$\sqrt{0.004} = (0.004)^{1/2} = (40 \times 10^{-4})^{1/2} = (40)^{1/2} \times (10^{-4})^{1/2}$$
$$= 6.325 \times 10^{-2} = 0.06325$$
$$\sqrt[3]{5000} = (5000)^{1/3} = (5 \times 10^{3})^{1/3} = (5)^{1/3} \times 10^{1} \cong 1.71 \times 10^{1} = 17.1$$

Some calculators provide the $\sqrt[3]{\ }$ function while others require that you use the $\sqrt[x]{y}$ function. For some calculators, the y^x function is all that is available, requiring that the y value be entered first, followed by the y^x function and then the power ($x = 1/3 = 0.3333$).

PROBLEMS

31. $\sqrt{6.4}$ = ____________

32. $\sqrt[3]{3000}$ = ____________

33. $\sqrt{0.00005}$ = ____________

EXPONENTIAL FUNCTIONS

The exponential functions e^x and e^{-x} will appear frequently in the analysis of R-C and R-L networks with switched dc inputs (or square-wave inputs). On most calculators, only e^x is provided, requiring that the user insert the negative sign when necessary.

Keep in mind that e^x is equivalent to $(2.71828\ldots)^x$ or a number to a power x. For any positive values of x greater than 1, the result is a magnitude greater than 2.71828. . . . In other words, for increasing values of x, the magnitude of e^x will increase rapidly. For $x = 0$, $e^0 = 1$, and for increasing negative values of x, e^{-x} will become increasingly smaller.

When inserting the negative sign for e^{-x} functions, be sure to use the proper key to enter the negative sign. It is not always the key used for addition.

EXAMPLES

$$e^{+2} \cong 7.3890$$
$$e^{+10} \cong 22026.47$$
$$e^{-2} \cong 0.13534$$
$$e^{-10} \cong 0.0000454$$

PROBLEMS

34. $e^{+4.2}$ = ____________

35. $e^{+0.5}$ = ____________

36. $e^{-0.02}$ = ____________

ALGEBRAIC MANIPULATIONS

The following is a brief review of some basic algebraic manipulations that must be performed in the analysis of dc circuits. It is assumed that a supporting math course will expand on the coverage provided here.

EXAMPLES

(a) Given $v = \dfrac{d}{t}$, solve for d and t.

Both sides of the equation must first be multiplied by t:

$$(t)(v) = \left(\frac{d}{\not t}\right)(\not t)$$

resulting in $d = vt$.

Dividing both sides of $d = vt$ by v yields

$$\frac{d}{v} = \frac{\not v t}{\not v}$$

and

$$t = \frac{d}{v}$$

In other words, the proper choice of multiplying factors for both sides of the equation will result in an equation for the desired quantity.

(b) Given $R_1 + 4 = 3R_1$, solve for R_1.

In this case, $-R_1$ is added to both sides, resulting in

$$(R_1 + 4) - R_1 = 3R_1 - R_1$$

and

$$4 = 2R_1$$

with

$$R_1 = \frac{4}{2} = 2\,\Omega$$

(c) Given $\dfrac{1}{R_1} = \dfrac{1}{3R_1} + \dfrac{1}{6}$, solve for R_1.

Multiplying both sides of the equation by R_1 results in

$$\frac{\not R_1}{\not R_1} = \frac{\not R_1}{3\not R_1} + \frac{R_1}{6}$$

or

$$1 = \frac{1}{3} + \frac{R_1}{6}$$

Subtracting 1/3 from both sides gives

$$1 - \frac{1}{3} = \frac{1}{3} - \frac{1}{3} + \frac{R_1}{6}$$

and

$$\frac{2}{3} = \frac{R_1}{6}$$

with

$$R_1 = \frac{(6)(2)}{3} = \frac{12}{3} = 4\,\Omega$$

PROBLEMS

37. Given $I = \dfrac{E}{R}$, solve for R and E.

$R =$ ______________, $E =$ ______________

38. Given $30I = 5I + 5$, solve for I.

$I =$ ______________

39. Given $\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{4R_1}$, solve for R_T in terms of R_1.

$R_T =$ ______________

40. Given $F = \dfrac{kQ_1Q_2}{r^2}$, solve for Q_1 and r.

$Q_1 =$ ______________, $r =$ ______________