Engineering Fundamentals

EXAMINATION REVIEW

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Contents

1 Introductory Comments

This book provides the engineer with a systematic review of the fundamental principles of engineering science. An orderly program of continuing education and professional registration are desirable and, in many cases, necessary elements in the professional development of the engineer. Ready access to a compact collection of basic engineering principles, to a large number of problems illustrating the use of these principles, and to a complete solution to every one of these many problems should materially assist the engineer in the review process.

Registration is uniformly recognized in the United States as a landmark along any engineer's path of professional development. In each of the 50 states, and the five other jurisdictions, laws regulate the practice of engineering and the right of an individual to designate himself as an engineer. These laws were enacted to protect the public from people who might call themselves engineers but who in reality are not qualified to perform competent engineering work. Thus registration as a professional engineer (PE) is a desirable and often mandatory goal.

There are normally four steps in becoming a registered professional engineer. Graduation from an engineering school, or practical engineering experience, is the first step. The individual then passes an eight-hour examination on the fundamentals of engineeering. The next step is the professional practice of engineering under responsible supervision. The minimum time varies from two to three years, depending on the state or jurisdiction. Finally, it is necessary to pass another eight-hour examination on the professional practice of a specific branch of engineering.

The fundamentals of engineering examination is prepared by the National Council of Engineering Examiners (NCEE) and is known by various names.

In many states it is called the EIT or Engineer-In-Training examination. Elsewhere it may be called the Engineering Fundamentals exam or the Intern Engineer exam. Engineers in 50 of the 55 states and other jurisdictions take the *same* nationally prepared examination at the same time. Engineers from all branches of engineering (CE, ME, EE, and so on) take the same engineering fundamentals examination. The completed examinations are sent to NCEE in South Carolina for scoring.

The engineering fundamentals examination is a test of basic engineering concepts. The eight-hour examination is split into two four-hour sessions. The first session presently consists of 150 multiple-choice questions with five choices. The topics and the approximate number of questions are as follows:

	No. of questions
Mathematics	22
Nucleonics and wave phenomena	5
Chemistry	14
Statics	14
Dynamics	14
Mechanics of materials	14
Fluid mechanics	14
Thermodynamics	18
Electrical theory	16
Materials science	9
Economic analysis	10
	150

A perfect score of 50 points is given for 100 correct answers.

The second four-hour session presently consists of three problem sets in each of the following subjects: statics, dynamics, mechanics of materials, fluid mechanics, thermodynamics, electrical theory, and economic analysis. Each of the problem sets consists of introductory information, followed by 10 multiple-choice problems that relate to the introductory material. The applicant must select and solve five of the 21 problem sets, making a total of 50 multiple-choice problems. The problems must be selected from at least four different subject areas, with the further restriction that no more than one problem set may be chosen from economic analysis.

This book is devoted exclusively to an orderly review of the content of the engineering fundamentals examination. (Other books have been written by one of the authors to cover the professional practice examinations.) Each chapter begins with a short review of the fundamental principles that are conceptually important and practically useful in the field. The goal is to present basic ideas compactly and directly; lengthy, detailed derivations are avoided. The result is a selective overview of the discipline rather than an encyclopedic coverage. The remainder of each chapter consists of multiple-choice problems. An important feature of the book is the presentation of a complete solution for each problem. The International System of Units (SI units) are used in some of the problems. (Conversion factors and other information on SI units are provided in Appendix A.) The goal has been to provide an orderly review of engineering fundamentals and typical examination problems for study and solution.

2 Mathematics

According to some, mathematics is *the* most fundamental branch of all science. Indeed, the goal of much scientific and technical work is to express in precise mathematical terms the behavior of our universe and its smaller component parts. In varying degrees mathematics is used in all the disciplines that together make up engineering fundamentals. For this reason it is highly desirable to have a working knowledge of some of the basic relations of algebra, trigonometry, geometry, and calculus. We present here a *brief* review of fundamental principles; a thorough review, including proofs, is outside the scope of this volume.

ALGEBRA

The basic rules of algebra apply equally well to real and complex numbers, that is, numbers expressible in the form $a_1 + ia_2$, where a_1 and a_2 are real numbers, zero or nonzero, and $i^2 = -1$. The basic rules, given in additive and multiplicative form, are three:

Commutative: $a + b = b + a \qquad ab = ba$

Distributive: $a(b + c) = ab + ac$

Associative: $a + (b + c) = (a + b) + c \qquad a(bc) = (ab)c$

The laws of exponents and logarithms are intimately related. For positive numbers a and b and any positive or negative exponents x and y, the rules for exponents are as follows:

$$b^{-x} = \frac{1}{b^x} \qquad b^x b^y = b^{x+y}$$

$$(ab)^x = a^x b^x \qquad b^{xy} = (b^x)^y$$

If $b^y = x$ for positive b and x, then $y = \log_b x$ is the definition of the logarithm of x to the base b. The logarithm is therefore a kind of exponent. The most commonly used base numbers are $b = 10$ for common logarithms and $b = e = 2.718\cdots$ for natural logarithms. (When $b = 10$ it is often not written down; when $b = e$ often $\log_e = \ln$ is written.) Regardless of the value of b these laws hold for logarithms:

$$b^{\log_b x} = x \qquad \log_b b^x = x$$

$$\log_b (xy^n) = \log_b x + n \log_b y \qquad \text{for any value of } n$$

To change, for example, the base of a logarithm from any base b to the base e,

$$\log_b x = \frac{\log_e x}{\log_e b} = \frac{\ln x}{\ln b} = \log_b e \times \ln x$$

since $(\log_b e)(\log_e b) = \log_e (b^{\log_b e}) = \log_e e = 1$.

An entire branch of mathematics, linear algebra, has grown out of an interest in solving sets of linear, simultaneous algebraic equations. The field is a generalization of solving the equation $ax = b$, which is linear in the one unknown x and has the obvious solution $x = b/a$. For two simultaneous equations in the unknowns x and y, the equations are often solved by eliminating y and solving for x:

$$a_{11}x + a_{12}y = b_1$$

$$a_{21}x + a_{22}y = b_2$$

From the first equation $y = (1/a_{12})(b_1 - a_{11}x)$. Insertion of this expression for y into the second equation yields an equation of the form of the single linear equation, which is easily solved.

The foregoing problem and also larger sets of simultaneous linear equations can be solved by using determinants. The determinant of the coefficients in the problem is

$$D = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21}$$

If D is nonzero, then Cramer's rule gives the solution for x and y as

$$x = \frac{D_1}{D} \qquad y = \frac{D_2}{D}$$

D_1 is formed from D by replacing a_{11} and a_{21} by b_1 and b_2, respectively. To find D_2, replace the second column of a's by the b's. The same procedure is followed for three or more unknown variables. A 3×3 determinant can be reduced to a 2×2 determinant by expanding it in terms of minors along one column or row:

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} = a_{11}\begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} - a_{12}\begin{vmatrix} a_{21} & a_{23} \\ a_{31} & a_{33} \end{vmatrix} + a_{13}\begin{vmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{vmatrix}$$

Systems of three linear equations in three unknowns can still be solved by successive elimination, but the use of Cramer's rule and determinants is often more efficient. For four or more unknowns the required bookkeeping becomes formidable by either method, but it is then preferable to use Cramer's rule because it is more systematic.

Quadratic equations are always solvable by algebra. If $ax^2 + bx + c = 0$, then the two solutions are

$$x = \frac{1}{2a}[-b \pm (b^2 - 4ac)^{1/2}]$$

If $b^2 < 4ac$, the roots of the equation are complex numbers. Formulas also exist that give the solutions to third- and fourth-order equations, but it is usually easier to try solving the equation by (a) attempting to factor the equation algebraically (often not successful), (b) graphing the equation and noting the points of intersection with the x-axis, or (c) substituting numerically by trial and error.

Another useful formula in algebra is the binomial theorem, which is a special form of the Taylor's series of calculus:

$$(a+b)^n = a^n + \frac{n}{1!}a^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \cdots$$

$$+ \frac{n(n-1)\cdots(n-r+1)}{r!}a^{n-r}b^r + \cdots + b^n$$

For a positive integer n this expansion has $(n+1)$ terms. In the formula the convenient "factorial" notation $n! = n(n-1)(n-2)\cdots(3)(2)(1)$ has been used.

TRIGONOMETRY

Trigonometry deals with the relations between the angles and the sides of triangles. The periodic functions defined by these relations, however, have vastly wider applications. In using these functions we often deal with angle measurement, of which there are two kinds. One system divides one revolution into 360° (degrees). Each degree is further divisible into 60′ (minutes), and each minute into 60″ (seconds), although often a fraction of a degree is written as a decimal (e.g., $30' = 0.5°$). The unit of measurement in the second system is the radian (rad); 2π rad equals one revolution, or $180° = \pi \text{ rad} = 3.14159 \cdots$ rad.

The two most basic trigonometric functions are the sine and cosine (Fig. 2-1), which are defined as follows:

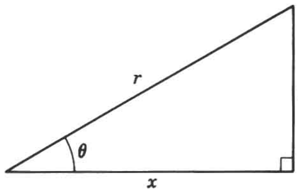


Figure 2-1

$$\sin\theta = \frac{y}{r} \qquad \cos\theta = \frac{x}{r}$$

Here x and y may assume any value, but r is always positive. The other four basic functions are

$$\tan\theta = \frac{\sin\theta}{\cos\theta} = \frac{y}{x} \qquad \cot\theta = \frac{1}{\tan\theta} = \frac{x}{y}$$

$$\sec\theta = \frac{1}{\cos\theta} = \frac{r}{x} \qquad \csc\theta = \frac{1}{\sin\theta} = \frac{r}{y}$$

The sine and cosine are odd and even periodic functions, respectively, with periods of 2π (Fig. 2-2). By learning the variations of these two functions, one can easily deduce the variation of the other functions.

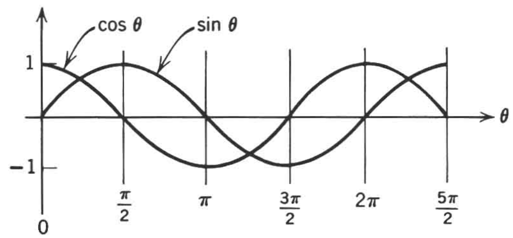


Figure 2-2

Much can be done in trigonometry by remembering a few fundamental identities. Among them are these:

$$\sin^2\theta + \cos^2\theta = 1 \qquad 1 + \tan^2\theta = \sec^2\theta \qquad 1 + \cot^2\theta = \csc^2\theta$$

$$\sin(\theta \pm \phi) = \sin\theta\cos\phi \pm \cos\theta\sin\phi$$

$$\cos(\theta \pm \phi) = \cos\theta\cos\phi \mp \sin\theta\sin\phi$$

From these last two identities the double-angle ($\sin 2\theta$, $\cos 2\theta$) formulas can be derived by letting $\theta = \phi$. The half-angle ($\sin \theta/2$, $\cos \theta/2$) formulas can also be derived by replacing θ and ϕ by $\theta/2$ and rearranging the resulting expressions.

In solving for the unknown parts of a plane triangle (Fig. 2-3), two or three basic formulas are often useful. These are

Sum of angles: $\alpha + \beta + \gamma = 180°$

Law of sines: $$\frac{a}{\sin \alpha} = \frac{b}{\sin \beta} = \frac{c}{\sin \gamma}$$

Law of cosines: $a^2 = b^2 + c^2 - 2bc \cos \alpha$

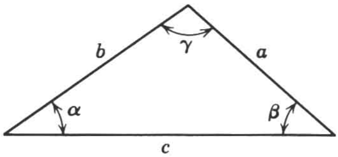


Figure 2-3

Note that if $\alpha = 90°$ the triangle is a right triangle, and the law of cosines then becomes a statement of the Pythagorean formula.

GEOMETRY

Here we group together some elements of elementary plane geometry, which describes some spatial properties of objects of various shapes, and analytic geometry, which employs algebraic notation in its more detailed description of some of these same objects.

The triangle and rectangle are basic geometric figures; they may also be considered as special cases of the trapezoid. From Fig. 2-4 we can consider

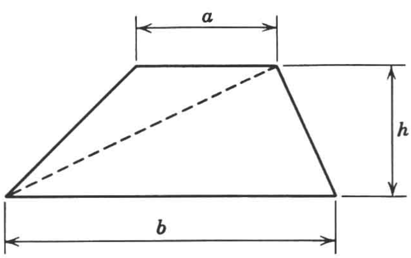


Figure 2-4

the trapezoid as the sum of two triangles. The area A of each shape is as follows:

$$\text{Trapezoid:} \qquad A = \frac{h}{2}(a+b)$$

$$\text{Rectangle:} \qquad A = hb \qquad (a=b)$$

$$\text{Triangle:} \qquad A = \frac{hb}{2} \qquad (a=0)$$

Another important shape is the regular polygon having n sides. The central angle subtended by one side is the vertex angle; its value is $2\pi/n$. The included angle between two successive sides of the polygon is $(n-2)\pi/n$.

The most important nonpolygonal geometric shape is the circle. For a circle of radius r and diameter $d = 2r$, the circumference is $c = \pi d$ and the enclosed area $A = \pi r^2$. In three dimensions its counterpart is the sphere which has a surface area $S = 4\pi r^2$ and an enclosed volume $V = \frac{4}{3}\pi r^3$.

Plane analytic geometry describes algebraically the properties of one- and two-dimensional geometric forms in an (x, y) plane.

The general equation of a straight line is $Ax + By + C = 0$. This equation is often more usefully written in one of the three following forms:

$$\text{Point-slope:} \qquad y - y_1 = m(x - x_1)$$

$$\text{Slope-intercept:} \qquad y = mx + b$$

$$\text{Two-intercept:} \qquad \frac{x}{a} + \frac{y}{b} = 1$$

For a straight line passing through the points $P_1 = (x_1, y_1)$ and $P_2 = (x_2, y_2)$, the slope $m = (y_2 - y_1)/(x_2 - x_1)$; the intercepts a and b are the coordinate values occurring where the line intersects the x- and y-axes, respectively. The distance between points P_1 and P_2 is $D = [(x_2 - x_1)^2 + (y_2 - y_1)^2]^{1/2}$. Also, parallel lines have equal slopes, whereas perpendicular lines have negative reciprocal slopes.

Included in the general equation of second degree $Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0$ are a set of geometric shapes called the conic sections. The different conic sections can be recognized by investigating $B^2 - 4AC$:

If $B^2 - 4AC > 0$, the section is a hyperbola

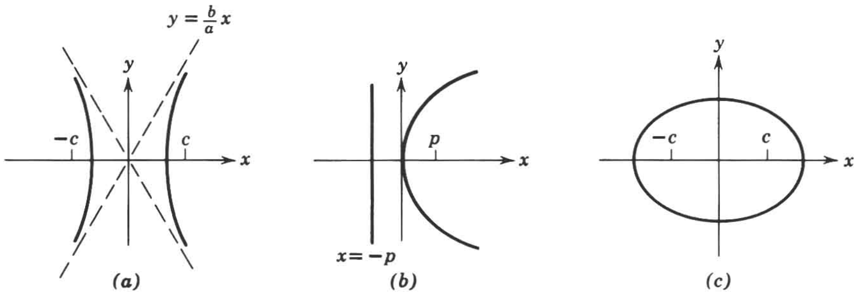
If $B^2 - 4AC = 0$, the section is a parabola

If $B^2 - 4AC < 0$, the section is an ellipse

In the last case if $A = C$ and they are not zero, the section is a circle. If A, B, and C are all zero, the straight line again results.

The basic equation for the hyperbola can be found from the general second-degree equation. For a hyperbola centered at the coordinate origin with limbs opening left and right (Fig. 2-5a), the equation is

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$



Hyperbola $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$ Parabola $y^2 = 4px$ Ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

Figure 2-5

The difference of distances from the two focuses ($\pm c$, 0) to a point on the hyperbola is always constant, where $c^2 = a^2 + b^2$. The limbs are asymptotic to the straight lines $y = \pm(b/a)x$. For a hyperbola centered at the point (h, k), replace x by $(x - h)$ and y by $(y - k)$. (This procedure for shifting the location of figures applies generally for all conic sections.)

The parabola, which geometrically is the locus of points equidistant from a point and a line (Fig. 2-5b), may be written in type form as

$$y^2 = 4px$$

when the vertex of the parabola is at the coordinate origin and the parabola opens to the right. Here the parabola is equidistant from the focus point (p, 0) and the directrix line $x = -p$. Change the sign of p to obtain a parabola opening to the right; interchange the roles of y and x to obtain parabolas opening upward or downward.

The type equation for an ellipse, centered on the coordinate origin (Fig. 2-5c), is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

The semimajor and semiminor axes are a and b. The focuses of the ellipse are at $(\pm c, 0)$, where $c^2 = a^2 - b^2$. Any point on the ellipse is such that the sum of the distances to that point from the two focuses is a constant. If $a = b = r$, the ellipse then becomes a circle of radius r.

Sometimes it is more convenient to use the polar (r, θ), cylindrical (r, θ, z), or spherical (ρ, θ, ϕ) coordinate system in place of the two- or three-dimensional Cartesian (x, y, z) coordinate system. By reference to Fig. 2-6,

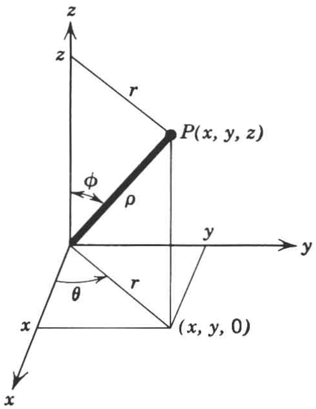


Figure 2-6

these coordinate systems can be related to one another. The relations between the polar, cylindrical, and Cartesian coordinate systems are

$$x = r \cos \theta \qquad y = r \sin \theta \qquad z = z$$

Since we also have

$$z = \rho \cos \phi \qquad r = \rho \sin \phi$$

the relations between the spherical and Cartesian coordinate systems are

$$x = \rho \sin \phi \cos \theta \qquad y = \rho \sin \phi \sin \theta \qquad z = \rho \cos \phi$$

CALCULUS

At a point on the curve $y = f(x)$ the slope of the curve is the ratio of the change in $f(x)$ to the change in x when the change in x approaches zero in the limit; mathematically,

$$\text{Slope} = \frac{dy}{dx} = \frac{df(x)}{dx} = f'(x)$$