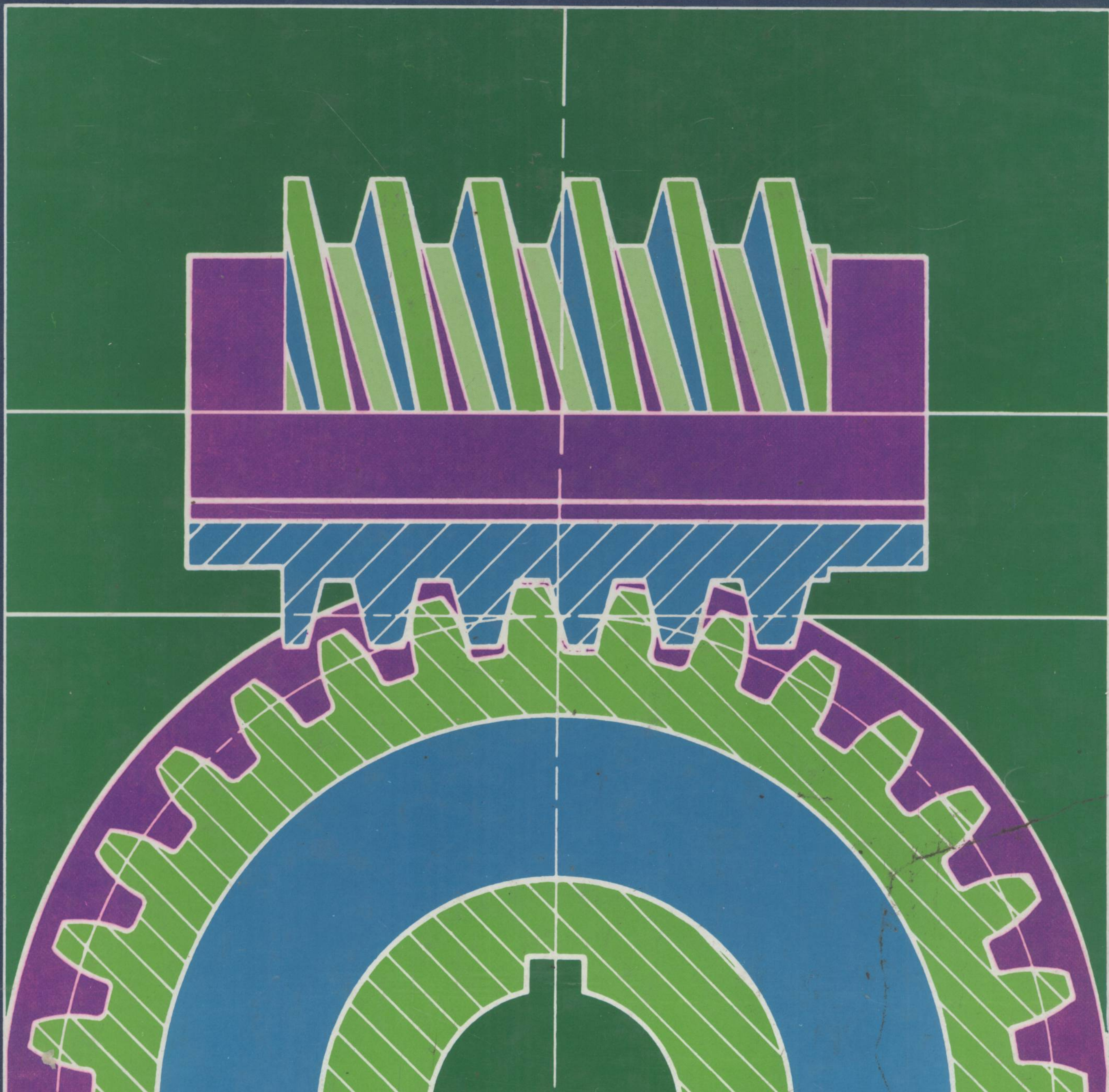
GIESECKE · MITCHELL · SPENCER · HILL · DYGDON

TECHNICAL DRAWING

SEVENTH EDITION



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Seventh Edition

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Books by the Authors

Basic Technical Drawing, rev. ed., by H. C. Spencer and J. T. Dygdon (Macmillan Publishing Co., Inc., 1980)

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Technical Drawing Problems, Series 3, 3rd ed., by H. C. Spencer, I. L. Hill, and J. T. Dygdon (Macmillan Publishing Co., Inc., 1980)

preface

This book is intended as a class text and reference book in technical drawing. It contains a great number of problems covering every phase of the subject, and it constitutes a complete teaching unit in itself. In addition to the problems in the text, three complete workbooks have been prepared especially for use with this text: *Technical Drawing Problems, Series 1,* by Giesecke, Mitchell, Spencer, Hill, and Dygdon; *Technical Drawing Problems, Series 2,* by Spencer, Hill, and Dygdon; and *Technical Drawing Problems, Series 3,* by Spencer, Hill, and Dygdon. Thus, there are available four alternate sources of problems, and problem assignments may be varied easily from year to year. In general, it is expected that the teacher who uses this text together with one of the three workbooks will supplement the workbook sheets by assignments from the text, to be drawn on blank paper. Many of the text problems are designed for Size A4 (210 mm x 297 mm) sheets; or for Size A (8.5″ x 11.0″) sheets, the same size as the easily filed workbook sheets.

The extensive use of this text during the past forty-seven years in college classes, technical schools, and industrial drafting rooms has encouraged the authors to continue with the original aim, which was and still is to prepare a book that *teaches the language of the engineer,* and to keep it in step with the latest developments in industry. The idea has been to illustrate and explain basic principles from the standpoint of the student—that is, to present each principle so clearly that the student is certain to understand it, and to make the text interesting enough to encourage the student to read and study on his own initiative. By this means we hope to free the instructor from the repetitive labor of teaching every student individually those things that the textbook can teach and thus provide for more attention to students having real difficulties.

Our purpose in preparing this new edition is not simply to enlarge the book, although this has been done to some extent, but primarily to bring the book completely up to date with the latest trends in engineering education and with the newest developments in industry, especially with the various sections of ANSI Y14 *American National Standard Drafting Manual.* The increased educational emphasis on the design function of the engineer is reflected throughout the text and especially in Chapter 14, "Design and Working Drawings." The intent of the material in this chapter is to help the student better understand the fundamentals of the design process.

Many of the problems and illustrations have been redrawn or revised to bring them completely up to date. With regard to dimensioning, a large number of drawings have been converted to the metric system, now that it has come into extensive use in industry. Many problems in Chapter 14 also present an opportunity for the student to convert the dimensions to the metric system.

An important objective has been to maintain and, where possible, to improve the quality of the drafting in the illustrations and problems. It is logical that in a drawing book the drawings are more important than anything else.

An outstanding feature is the emphasis on technical sketching throughout the text as well as in the complete chapter given early in the book. This chapter is unique in integrating the basic concepts of views with freehand rendering so that the subject of multiview drawing can be introduced through the medium of sketches.

The chapters on dimensioning and tolerancing have been revised to bring them into conformity with the American National Standard, *Dimensioning and Tolerancing for Engineering Drawings.*

The chapter on electronic diagrams has been prepared by Professor R. O. Loving and Mr. James E. Novak of the Illinois Institute of Technology. The chapters on structural drawing and topographic drawing and mapping have been revised by Professor Emeritus E. I. Fiesenheiser of the Illinois Institute of Technology. The chapters on graphs, alignment charts, empirical equations, and graphical mathematics have been revised by Mr. E. J. Mysiak, Manager, International Engineering, Molex Inc. The chapter on gearing and cams has been prepared by Professor Emeritus B. L. Wellman of Worcester Polytechnic Institute; and the chapter on shop processes has been prepared by Professors J. George H. Thompson and John Gilbert McGuire of Texas A&M University. We also are indebted to Professor H. E. Grant for certain problem material and valuable suggestions and to Mr. James E. Novak, Mr. Paul J. Chase, Mr. Stephen A. Smith, and Mr. James M. Komaniecki for their assistance with the revision of many of the illustrations.

Every effort has been made to bring the book completely abreast of the many technological developments that have occurred in the past few years. Through the cooperation of leading engineers and manufacturers, we have been able to include many commercial drawings of value in developing the subject. We wish to express our thanks to these persons and firms, and others too numerous to mention here, who have contributed to the production of this book.

Students, teachers, engineers, and draftsmen are invited to write concerning any questions that may arise. All comments or suggestions will be appreciated.

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contents

1 the graphic language and design

1.1 Evolution of Design. The old saying "necessity is the mother of invention" continues to be true, and a new machine, structure, system, or device is the result of that need. If the new device, machine, system, or gadget is really needed, people will buy it, providing it does not cost too much. Then, naturally, these questions may arise: Is there a wide potential market? Can this device or system be made available at a price that people are willing to pay? If these questions can be answered satisfactorily, then the inventor, designer, or officials of a company may elect to go ahead with the development of production and marketing plans for the new project or system.

A new machine, structure, or system, or an improvement thereof, must exist in the mind of the engineer or designer before it can become a reality. This original concept or idea is usually placed on paper and communicated to others by the way of the *graphic language* in the form of freehand *idea sketches*, Figs. 1.1 and 5.1. These idea or design sketches are then followed by other sketches, such as *computation sketches*, for developing the idea more fully.

1.2 The Young Engineer.* The engineer or designer must be able to create idea sketches, calculate stresses, analyze motions, size the parts, specify materials and production methods, make design layouts, and supervise the preparation of drawings and specifications

*Henceforth in this text, all conventional titles such as student, draftsman, designer, engineer, etc., are intended to refer to all persons, male and female.

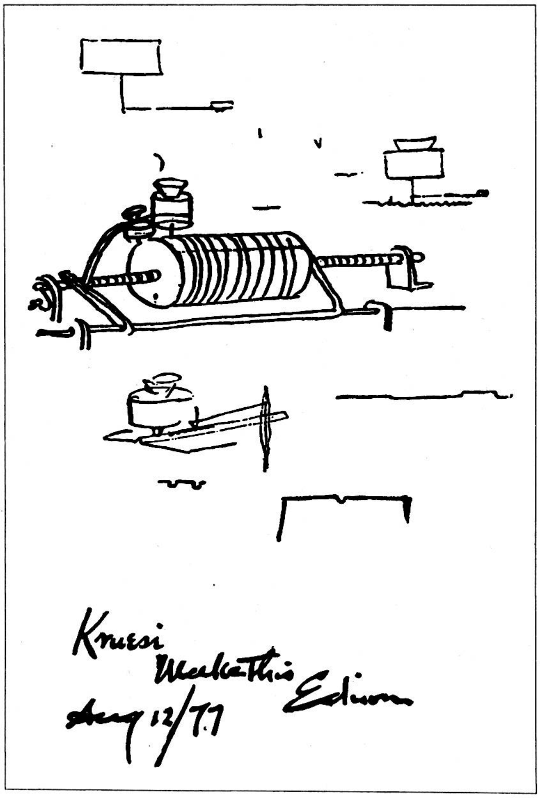


Fig. 1.1 **Edison's Phonograph.***

that will control the numerous details of production, assembly, and maintenance of the product. In order to perform or supervise these many tasks, the engineer makes liberal use of freehand drawings. He or she must be able to record and communicate ideas quickly to associates and support personnel. Facility in freehand sketching, Chapter 5, or the ability to work with computer-controlled drawing techniques, §14.12, requires extensive training in drawing with instruments and a thorough knowledge of the graphic language.

A typical engineering and design department is shown in Fig. 1.2. Many of the staff have considerable training and experience; others are recent graduates who are gaining experience. There is so much to be learned on the job and it is necessary for the inexperienced person to start at a low level and advance to more responsibility as experience is gained. Very much to the point is the following statement by the chief engineer of a large corporation:*

"Many of the male and female engineering students whom we interview have the impression that if they go to work at the drafting board, they will be only draftspersons doing routine work. This impression is completely erroneous. All of our engineers work at the board at least occasionally. Actually, drawing is only one phase of responsibility which includes site evaluations, engineering calculations, cost estimates, preliminary layouts, engineering specifications, equipment selection, complete drawings (with the help of detailers), and follow-up on construction and installation.

"Our policy is to promote from within, and it is our normal practice to hire engineers at the time they finish school, and to give them the opportunity for growth and development by diversified experience. These newly hired engineers without experience are assigned to productive work at a level which their education and experience qualify them to handle successfully. The immediate requirement is for the young engineer to obtain practical engineering experience, and to learn our equipment and processes. In design work, these initial assignments are on engineering details in any one of several fields of engineering study (structural, mechanical, electrical, etc.). Our experience has shown that it is not wise to give a newly graduated engineer without experience a problem in advanced engineering, such as creative design, on the assumption that quick sketches or layouts can be made and then have them detailed by someone else. Rather than start a young engineer at an advanced responsibility level where he or she may fail or make costly mistakes, we assign the engineer initially to work which requires complete and accurate detail drawings to be made, and the assignments become increasingly complex as the ability to do work of an advanced engineering caliber is demonstrated. If the capacity to assume design responsibility is shown, then the direction of other engineers with less experience is given who in turn do the detailed engineering."

1.3 The Graphic Language.

Many of the troubles of the world are caused by the fact that the various peoples do not understand

*Original sketch of Thomas A. Edison's first conception of the phonograph; reproduced by special permission of Mrs. Edison.

*C. G. R. Johnson, Kimberly-Clark Corp.

Fig. 1.2 Section of an Engineering Department. *Courtesy Bell Telephone Laboratories, Indianapolis*

one another. The infinite number of languages and dialects that contributed to this condition resulted from a lack of intercommunication of peoples widely separated in various parts of the world. Even today when communication is so greatly improved, the progress toward a world language is painfully slow—so slow, indeed, that we cannot foresee the time when it will be a fact.

Although we have not been able to get together on a world language of words and sentences, there has actually been a universal language in use since the earliest times: the *graphic language*. The idea of communicating thoughts from one person to another by means of *pictures* occurred to even the earliest cave dwellers, and we have examples still in existence to prove it. These earliest men communicated orally, undoubtedly by grunts and other elementary sounds. However, when they wished to *record* an idea, they made *pictures* upon skins, stones, walls of caves or whatever materials they could find. The earliest forms of writing were through picture forms, such as the Egyptian hieroglyphics, Fig. 1.3. Later

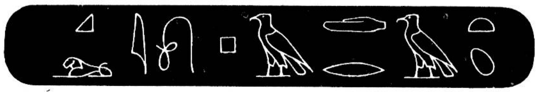


Fig. 1.3 Egyptian Hieroglyphics.

these forms were simplified and became the abstract symbols used in our writing today. Thus, even the letter characters in present word languages have their basis in drawings. See §3.1.

A drawing is a *graphic representation* of a real thing, an idea, or a proposed design for construction later. Drawings may take many forms, but the graphic method of representation is a basic natural form of communication of ideas that is universal and timeless in character.

1.4 Two Types of Drawings.

Man has developed graphic representation along two distinct lines, according to his purpose: (1) Artistic and (2) Technical.

From the beginning of time, artists have used drawings to express aesthetic, philo-

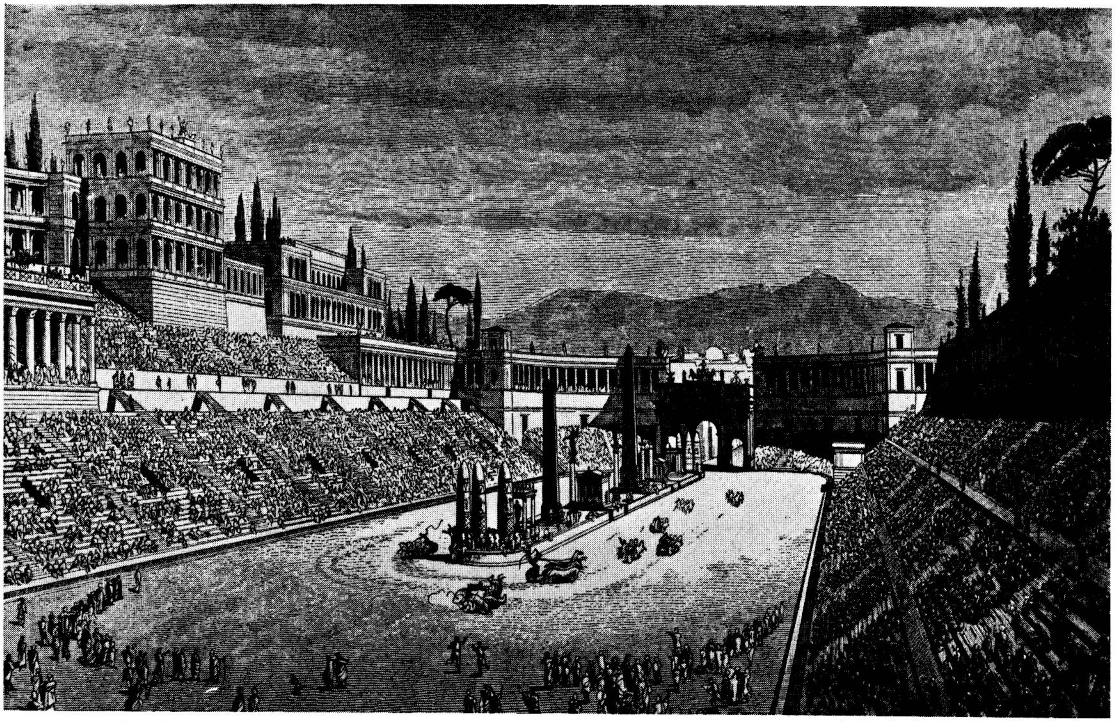


Fig. 1.4 The Circus Maximus in Rome. *The Bettmann Archive, Inc.*

sophic, or other abstract ideas. In ancient times nearly everybody was illiterate. There was no printing, and hence no newspapers or books as we know them today. Books were hand lettered on papyrus or parchment and were not available to the general public. People learned by listening to their superiors and by looking at sculptures, pictures, or drawings in public places. Everybody could understand pictures and they were a principal source of information. In our museums and in ruins of antiquity are thousands of examples of story-telling or teaching by means of drawings. If anyone wished to preserve his own image or a friend's, the job had to be done in stone, in bronze, in oil on canvas, or in some other art medium—there were no photographs. The artist was not just an artist in the aesthetic sense, but also a teacher or philosopher, a means of expression and communication.

The other line along which drawing has developed has been the technical. From the beginning of recorded history, man has used drawings to *represent* his design of objects to be built or constructed. Of these earliest drawings no trace remains today, but we definitely know that drawings were used, for man could not have designed and built as he did without using fairly accurate drawings. In the Bible the statement is made that Solomon's Temple was "built of stone made ready before it was brought thither."* Each stone and timber was carved or hewn into shape, brought to the site, and fitted into place. It is evident that accurate drawings were used, showing the exact shapes and sizes of the component parts for the design of the temple.

Moreover, we can see today the ruins of fine old buildings, aqueducts, bridges, and other structures of antiquity that could not possibly have been erected without carefully made drawings to guide the builders. Many of these structures are still regarded as "Wonders of the World," such as the Temple of Amon at Karnak in ancient Egypt, completed in about 980 B.C., which took seven centuries to construct. In sheer mass of stone, this building exceeded any roofed structure ever built, so

*1 Kings 6:6.

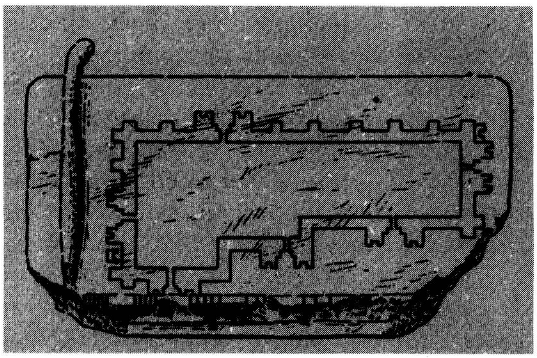
far as we know, being 1200 feet long and 350 feet wide at its greatest width. Likewise, the Circus Maximus in Rome was a large structure, Fig. 1.4; according to the historian Pliny, it seated a total of 250,000 spectators.

1.5 Earliest Technical Drawings.

Perhaps the earliest known technical drawing in existence is the plan view for a design of a fortress drawn by the Chaldean engineer Gudea and engraved upon a stone tablet, Fig. 1.5. It is remarkable how similar this plan is to those made by architects today, although "drawn" thousands of years before paper was invented.

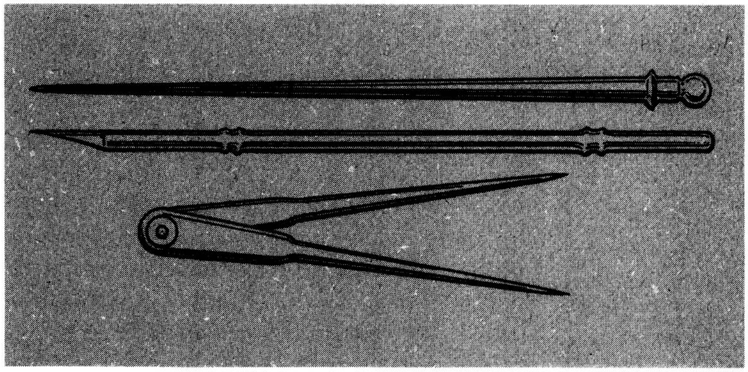
The first written evidence of the use of technical drawings was in 30 B.C. when the Roman architect Vitruvius wrote a treatise on architecture in which he said, "The architect must be skillful with the pencil and have a knowledge of drawing so that he readily can make the drawings required to show the appearance of the work he proposes to construct." He went on to discuss the use of the rule and compass in geometric constructions, in drawing the plan and elevation views of a building, and in drawing perspectives.

In the museums we can see actual specimens of early drawing instruments. Compasses were made of bronze and were about the same size as those used today. As shown in Fig. 1.6, the old compass resembled the dividers of today. Pens were cut from reeds.



From Transactions ASCE, May 1891

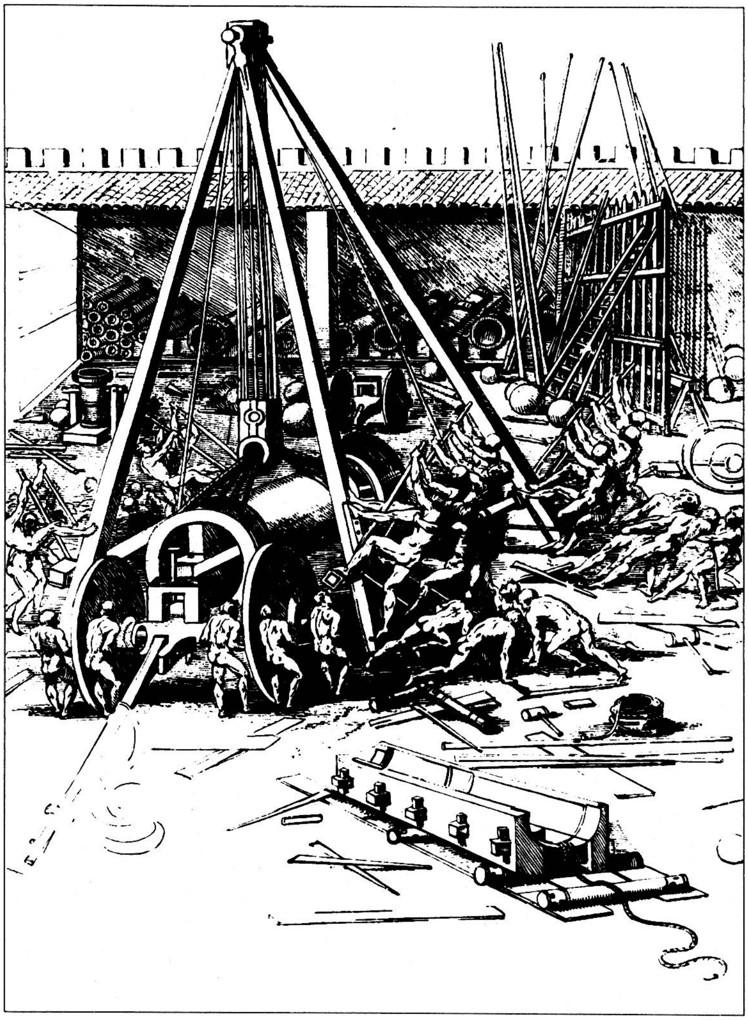
Fig. 1.5 Plan of a Fortress. This stone tablet is part of a statue now in the Louvre, in Paris, and is classified in the earliest period of Chaldean art, about 4000 B.C.



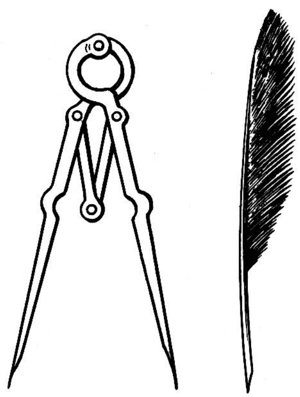
From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

Fig. 1.6 Roman Stylus, Pen, and Compass.

Fig. 1.7 An Arsenal, by Leonardo da Vinci. *The Bettmann Archive, Inc.*



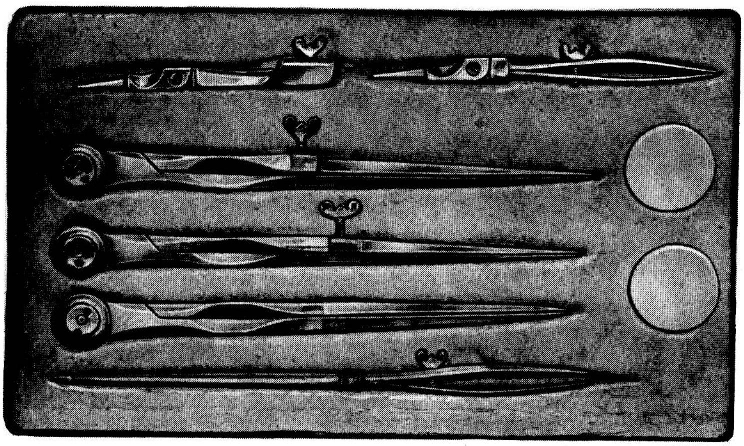
The theory of projections of objects upon imaginary planes of projection (to obtain *views,* §6.1) apparently was not developed until the early part of the fifteenth century—by the Italian architects Alberti, Brunelleschi, and others. It is well known that Leonardo da Vinci used drawings to record and transmit to others his ideas and designs for mechanical constructions, and many of these drawings are in existence today, Fig. 1.7. It is not clear whether Leonardo ever made mechanical drawings showing orthographic views as we know them today, but it is probable that he did. Leonardo's treatise on painting, published in 1651, is regarded as the first book ever printed on the theory of projection drawing; however, its subject was perspective and not orthographic projection.



From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

Fig. 1.8 Compass and Pen, Renaissance Period. Compass after a drawing by Leonardo da Vinci.

Fig. 1.9 George Washington's Drawing Instruments.



From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

The compass of the Romans remained very much the same during Leonardo's time, Fig. 1.8. Circles were still scratched with metal points, since graphite pencils were not invented until the eighteenth century, when the firm of Faber was established in Nuremburg, Germany. By the seventh century reed pens had been replaced by quills made from bird feathers, usually those of geese (hence: goose-quill pens).

The scriber-type compass gave way to the compass with a graphite lead shortly after graphite pencils were developed. At Mount Vernon we can see the drawing instruments used by the great civil engineer, George Washington, and bearing the date 1749. This set, Fig. 1.9, is very similar to the conventional drawing instruments used today, consisting of a divider and a compass with pencil and pen attachments plus a ruling pen with parallel blades similar to the modern pens.

1.6 Early Descriptive Geometry.

The beginnings of descriptive geometry are associated with the problems encountered in designs for building construction and military fortifications of France in the eighteenth century. Gaspard Monge (1746–1818) is considered the "inventor" of descriptive geometry, although his efforts were preceded by publications on stereotomy, architecture, and perspective in which many of the principles were used. It was while he was a professor at the Polytechnic School in France near the close of the eighteenth century that Monge developed the principles of projection that are today the basis of our technical drawing. These principles of descriptive geometry were soon recognized to be of such military importance that Monge was compelled to keep his principles secret until 1795, following which they became an important part of technical education in France and Germany and later in the United States. His book, *La Géometrie Descriptive,* is still regarded as the first text to expound the basic principles of projection drawing.

Monge's principles were brought to the United States in 1816 from France by Claude Crozet, an alumnus of the Polytechnical School and a professor at the United States Military Academy at West Point. He published the first text on the subject of descriptive geometry in the English language in 1821. In the years immediately following, these principles became a regular part of early engineering curricula at Rensselaer Polytechnic Institute, Harvard University, Yale University, and others. During the same period, the idea of manufacturing interchangeable parts in the early arms industries was being developed, and the principles of projection drawing were applied to these problems.

1.7 Modern Technical Drawing. Perhaps the first text on technical drawing in this country was *Geometrical Drawing,* published in 1849 by William Minifie, a high school teacher in Baltimore. In 1850 the Alteneder family organized the first drawing instrument manufacturing company in this country (Theo. Alteneder & Sons, Philadelphia). In 1876 the blueprint process was introduced in this country at the Philadelphia Centennial Exposition. Up to this time the graphic language was more or less an art, characterized by fine-line drawings made to resemble copper-plate engraving, by the use of shade lines, and by the use of water color "washes." These techniques became unnecessary after the introduction of blueprinting, and drawings gradually were made less ornate to obtain the best results from this method of reproduction. This was the beginning of modern technical drawing. The graphic language now became a relatively exact method of representation, and the building of a working model as a regular preliminary to construction became unnecessary.

Up to about the turn of the nineteenth century throughout the world, drawings were generally made in what is called *first-angle projection,* §6.38, in which the top view was placed *under* the front view, the left-side view was placed at the *right* of the front view, etc. At this time in the United States, after a considerable period of argument pro and con, practice gradually settled on the present *third-angle projection* in which the views are situated in what we regard as their more logical or natural positions. Today, third-angle projection is standard in the United States, but first-angle projection is still used throughout much of the world.

During the early part of the twentieth century, many books on the subject were published in which the graphic language was analyzed and explained in connection with its rapidly changing engineering design and industrial applications. Many of these writers were not satisfied with the term "mechanical drawing" because they were aware of the fact that technical drawing was really a *graphic language.* Anthony's *An Introduction to the Graphic Language,* French's *Engineering Drawing,* and this text, *Technical Drawing,* were all written with this point of view.

1.8 Drafting Standards. In all of the above books there has been a definite tendency to standardize the characters of the graphic language, to eliminate its provincialisms and dialects, and to give industry, engineering, and science a uniform, effective graphic language. Of prime importance in this movement in the United States has been the work of the American National Standards Institute (ANSI), with the American Society for Engineering Education, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. As sponsors they have prepared the *American National Standard Drafting Manual—Y14,* which will contain twenty-seven or more separate sections when completed. These sections are published as approved standards as they are completed. See Appendix 1.

These sections outline the most important idioms and usages in a form that is acceptable to the majority, and are considered the most authoritative guide to uniform drafting practices in this country today. The Y14 Standard gives the *characters* of the graphic language, and it remains for the textbooks to explain the *grammar* and the *penmanship.*

1.9 Definitions. After surveying briefly the historical development of the graphic language and before starting a serious study of theory and applications, the definitions of a few terms should be considered.

Descriptive Geometry is the grammar of the graphic language; it is the three-dimensional geometry forming the background for the practical applications of the language and through which many of its problems may be solved graphically.

Instrumental or *Mechanical Drawing* should be applied only to a drawing made with drawing instruments. Mechanical Drawing has been used to denote all industrial drawings, which is unfortunate not only because such drawings are not always mechanically drawn, but also because it tends to belittle the broad scope of the graphic language by naming it superficially for its principal mode of execution.

Engineering Drawing and *Engineering Drafting* are broad terms widely used to denote the graphic language. However, since the language is not used by engineers only, but also by a much larger group of people in diverse fields who are concerned with technical work or with industrial production, the term is still not broad enough.

Technical Drawing is a broad term that adequately suggests the scope of the graphic language. It is rightly applied to any drawing used to express technical ideas. This term has been used by various writers since Monge's time at least and is still widely used, mostly in Europe.

Engineering Graphics or *Engineering Design Graphics* is generally applied to drawings for technical use and has come to mean that part of technical drawing which is concerned with the graphical representation of designs and specifications for physical objects and data relationships as used in engineering and science.

Technical sketching is the freehand expression of the graphic language, while *mechanical drawing* is the instrumental expression of it. Technical sketching is a most valuable tool for the engineer and others engaged in technical work, because through it most technical ideas can be expressed quickly and effectively without the use of special equipment.

Blueprint reading is the term applied to the "reading" of the language from drawings made by others. Actually, the blueprint process is only one of many forms by which drawings are reproduced today (see Chapter 15), but the term "blueprint reading" has been accepted through usage to mean the interpretation of all ideas expressed on technical drawings, whether the drawings are blueprints or not.

Computer Graphics is the application of conventional computer techniques with the aid of one of many graphic data processing systems available to the analysis, modification, and the finalizing of a graphical solution.

1.10 What Engineering and Science Students Should Know. The development of technical knowledge from the dawn of history has been accompanied, and to a large extent made possible, by a corresponding graphic language. Today the intimate connection between engineering and science and the universal graphic language is more vital than ever before, and the engineer or scientist who is ignorant of or deficient in the principal mode of expression in his technical field is *professionally illiterate*. That this is true is shown by the fact that training in the application of technical drawing is required in virtually every engineering school in the world.

The old days of fine-line drawings and of shading and "washes" are gone forever; no artistic talent is necessary for the modern technical student to learn the fundamentals of the graphic language. For its mastery he needs precisely the aptitudes and abilities he will need to learn the science and engineering courses that he studies concurrently and later. The student who does poorly in the graphic language courses is like to do poorly in his other technical courses.

The well-trained engineer, scientist, or technician must be able to make correct graphical representations of engineering structures, designs, and data relationships.

This means that he must understand the fundamental principles, or the *grammar* of the language, and must be able to execute the work with reasonable skill, which is *penmanship*.

Graphics students often try to excuse themselves for inferior results (usually caused by lack of application) by arguing that after graduation they do not expect to do any drafting at all; they expect to have others make any needed drawings under their direction. Such a student presumptuously pictures himself, immediately after graduation, as the accomplished engineer concerned with bigger things and forgets that in his first assignment he may well be working with drawings and possibly may be called upon to make or revise drawings either on the board or with computerized aids under the direction of a really experienced engineer. Entering the engineering profession via graphics provides an excellent opportunity to learn about the product, the company operations, and the supervision of others.

Even if the young engineer has not been too successful in developing a skillful penmanship in the graphic language, he still will have great use for its grammar, since the ability to *read* a drawing is of utmost importance, and he will need this ability throughout his professional life. See §14.1.

Furthermore, the engineering student is apt to overlook the fact that, in practically all the subsequent courses taken in college, technical drawings will be encountered in most textbooks. The student is often called upon by instructors to supplement calculations with mechanical drawings or sketches. Thus, a mastery of a course in technical drawing will aid materially not only in professional practice after graduation but more immediately in other technical courses, and it will have a definite bearing on scholastic progress.

Besides the direct values to be obtained from a serious study of the graphic language, there are a number of very important training values which, though they may be considered by-products, are fully as essential as the language itself. Many a student learns for the first time in a drawing course the meaning of *neatness, speed,* and *accuracy*—basic habits that every successful engineer and scientist must have or acquire.

All authorities agree that the ability to *think in three dimensions* is one of the most important requisites of the successful scientist and engineer. This training to visualize objects in space, to use the constructive imagination, is one of the principal values to be obtained from a study of the graphic language. The ability to *visualize* is possessed in an outstanding degree by persons of extraordinary creative ability. It is difficult to think of Edison, De Forest, or Einstein as being deficient in constructive imagination.

With the increase in technological development and the consequent crowding of drawing courses by the other engineering and science courses in our colleges, it is doubly necessary for the engineering or science student to make the most of the limited time devoted to the language of the profession, to the end that he will not be professionally illiterate, but will possess an ability to express ideas quickly and accurately through the correct use of the graphic language.

1.11 Projections.

Behind every drawing of an object is a space relationship involving four imaginary things: the *observer's eye* or *station point*, the *object*, the *plane* or *planes of projection*, and the *projectors*.* For example, in Fig. 1.10 (a) the drawing EFGH is the projection on the plane of projection A of the square ABCD as viewed by an observer whose eye is at the point O. The projection or drawing upon the plane is produced by the piercing points of the projectors in the plane of projection. In this case, where the observer is relatively close to the object and the projectors form a "cone" of projectors, the resulting projection is known as a *perspective*.

If the observer's eye is imagined as infinitely distant from the object and the plane of projection, the projectors will be parallel, as shown in Fig. 1.10 (b); hence, this type of

*Also called *visual rays* and *lines of sight*.