Van Nostrand's SCIENTIFIC ENCYCLOPEDIA

Fifth Edition

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Radiation
Thermodynamics
Thin Film Technology

Edited by **DOUGLAS M. CONSIDINE**

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Preface to Fifth Edition

In creating the fifth edition of the *Van Nostrand's Scientific Encyclopedia*, the authors and editors have maintained the time-proven, useful features and general format of earlier editions while simultaneously making improvements as the result of additional years of reader feedback from this publication.

Selected reference material is added to the end of most major entries for the first time in this edition, thus providing a bridge for the reader to further detailed and specialized knowledge. Large numbers of relatively short entries have been consolidated, thus yielding more concentrated information in fewer locations throughout the book. In so doing, the number of cross references has been increased so that the user can locate information easily whether approaching a topic from a generalized or from a detailed vantage point.

Increased emphasis has been given to illustrative and tabular presentations, both techniques assuring maximum utilization of available space. Space-saving procedures were extremely important to the fifth edition so that adequate coverage of numerous new areas of science and technology could be incorporated without sacrificing the detailed coverage of fundamentals from prior editions. Fortunately, it proved possible to update and to expand the fifth edition with the addition of approximately 300 pages, thus preserving the convenient one-volume format. However, in creating a new edition of this book, much more is involved than the simple updating of the prior edition. The fifth edition is essentially a completely new book, with less than approximately 20 percent of prior text and illustrations taken from the earlier edition.

As with past editions, much emphasis has been placed on scientific fundamentals and the logical ordering and classification of information. It is believed that many users of the book not only seek detailed data on numerous subjects, but also expect well-organized overviews so that any subsequent researching of periodicals and specialized shelf literature can be pursued in the most workmanlike and timesaving manner.

An encyclopedia of this type, of course, cannot be a news medium per se, that is, reporting the many ups and downs that occur almost daily in scientific areas. The editors had to sift the vast scientific data bank and sort out the trivia and unproven, even though such information may be momentarily exciting. Editorial concentration had to be in terms of solid, long-lasting scientific progress. Although often of interest to serious-minded science readers, there is no place in this volume for the pseudo sciences, the scientific fads, or material bordering on science fiction. Exposure to science coverage in much of the public news media demonstrates how often so-called discoveries or breakthroughs fail to materialize on a sound, firmly scientific footing. The editors of this volume have attempted to stress the proven, generally accepted descriptions of both new and old practices and concepts. In soundly controversial areas, however, where two well-grounded schools of thought may be arguing while awaiting the results of further investigations and experimentation, both sides of such questions are given.

Carrying on the practice of prior editions, an effort has been made to customize descriptions in terms of their innate simplicity or complexity, keeping in mind the probable background and experience profile of the reader who may be seeking information on a given topic. Thus, fundamental subjects may be introduced with a broad overview, whereas more complex, highly-specialized subjects will essentially commence with detailed descriptions.

A statistical summary of this volume would include: (1) an estimated 2 to 2.2 million words; (2) over 7200 editorial entries; (3) over 8000 cross references for convenient location of information, essentially an abridged alphabetical index incorporated within the regular pages of the book; (4) 2450 diagrams, graphs, and photographs; and (5) over 550 tables.

Nearly a decade has passed since the appearance of the fourth edition of this book. Each decade of scientific progress is characterized by particular attentions and achievements in selected areas of science and technology. The past decade has been characterized by a steady progress and consolidation of earlier observations in most of the major areas of scientific endeavor. Probably the most important overall areas for involvement of technology during the latter-half of the 1970s and continuing throughout the remainder of this century are energy and the environment. This observation, of course, does not relegate the great progress in molecular biology, the understanding of viruses, the significant advances in astronomy and astrophysics, and the like to second place. Scores of examples of scientific achievement over the past decade become evident even from a very quick scan of the contents of this volume.

Energy problems and probable solutions are explored in considerable detail, including extensive descriptions of the fossil fuels and nonconventional fuels, such as substitute natural gas, shale fuels, tar sands, and waste products. Both fission and fusion nuclear reactors are described in considerable detail, as well as geothermal energy sources and utilization, solar energy concepts, including ocean thermal energy systems and wind power systems, and new kinds of chemical fuels involving fuel cells, battery power, and the so-called hydrogen economy. Particular stress is given to the energy/environment interface as well as a lot of attention to the maturing environmental technologies and ecology.

Palos Verdes Peninsula, California
1 August 1976

DOUGLAS M. CONSIDINE
Editor-in-Chief

Preface to Fourth Edition

In 1935, members of the D. Van Nostrand Company and a group of its authors consolidated plans for a new type of scientific encyclopedia. It was designed to treat in integrated and interrelated entries the basic principles and more widely used terms of the physical sciences, the earth sciences, the biological sciences, the medical sciences, the various fields of engineering, and pure and applied mathematics and statistics. All topics were to be presented in depth sufficient for the needs—outside their fields of specialization—of scientists, engineers, medical doctors, mathematicians, students of those subjects, and anyone else who wanted comprehensive information.

The First Edition of the *Scientific Encyclopedia* was published in 1938 to be followed at ten-year intervals by the Second and Third Editions. The widespread acceptance and general use of these works throughout the world, and the publication in 1968 of the Fourth Edition, are of interest not only in their own right but because of the bright sidelight they throw upon the progress during the period in the development and application of new knowledge, and the rapidity with which it has become part of our professional training and educational programs.

The emphasis which the First Edition, of 1938, placed upon quantum mechanics (and wave mechanics) attracted considerable attention. When we consider how far many of the major contributions to those fields antedated that year (Planck, 1899; de Broglie, 1923; Schrödinger, 1925), we realize how much more slowly new knowledge achieved wide circulation then than now. The first edition also elicited favorable comment because of its policy (which has been maintained) of beginning the entries with a clear statement of the scientific or engineering principle, which was then followed by a mathematical treatment. For in those days the need of an engineer, or even a physical science undergraduate, to possess facility in handling differential equations had only been generally accepted for a short time.

The Second Edition, of 1948, reflected the explosion in knowledge arising from the intensive research that accompanied World War II. Nuclear science and technology had contributed virtually an entirely new discipline. The work on radar, and short-wave communications in general, had been attended by the development of much that was new in electronic principles and equipment. Among the more general and fundamental topics was the new approach to the solution of complex problems that is known as operations research. Another was the theory of games. Medicine had new antibiotics and sulfa drugs, while its organic pesticides, developed for insect-borne diseases, had laid the foundation for the great advance in agricultural chemicals.

Progress in that direction carried further, to become a prominent element in the Third Edition of 1958. Even more important were the great developments in rocketry, computers, and solid state science. In rocketry. Sputnik went into orbit while the Third Edition was in page proc requiring the remaking of several pages. The first generation of computers was well on its way, adding a new interest to Boolean algebra and logic circuitry. Solid state research was rapidly establishing this new science and its applications were having a profound effect upon metallurgy and semiconductors. Plastics, which had found some place in earlier editions, were rapidly proliferating in chemical composition, and in manufacturing and fabricating techniques.

The trend of expansion in plastics has continued into the Fourth Edition of 1968, which treats the impressive advances made in polymer science by methods of controlling chemical and physical structure, whereby these materials are "tailor-made" to fit their properties to their uses. Rocketry has now become space science and technology, occupying as many columns of type in the Fourth Edition as any other major subject. Computers have become so important throughout today's world that these entries, besides dealing fully with their electronics and operation, are now developed from the more fundamental approach of data processing, operations control, and systems engineering.

In fact, the most conspicuous advances in the Fourth Edition are in this area of fundamental knowledge. The notable shift in emphasis in teaching mathematics, apparent even in the elementary classroom, is reflected fully in these pages, as are many of the more advanced topics such as prediction analysis and group theory. The immense strides in biochemical science, for which so many awards have been bestowed, and which have so radically advanced our knowledge of living organisms, are featured in numerous new and extensive entries. They include not only the more recently discovered chemical structures and mechanisms, but also the techniques and instruments that have so materially expedited this progress. These instrumental entries portray vividly the extent of the use of specialized measurements in modern analysis and research and their critical importance to everyone interested in science or engineering. The other entries in chemistry have been essentially rewritten to stress the present emphasis at all levels of education and achievement upon fundamental concepts and relationships. Medicine has utilized more and more electronic equipment, artificial organs, and even organ transplants, as well as a wide array of new therapeutic agents. Recent advances in particle physics, nuclear reactor technology, meteorology, oceanography, and photoelectronics are featured prominently.

This edition retains all those features that characterize the unique and distinguished position held by predecessor editions. The *Encyclopedia* is still a basic reference work on science, engineering, mathematics, and medicine. It is a "cornerstone" volume for all professional and academic libraries and for every active scientist, engineer, mathematician, medical doctor, student, teacher, and general reader, and will find an important place on the shelves of many businessmen, lawyers, industrial executives, and professionals in the communications media. As increasingly large numbers of people have realized the extent to which their normal activities are influenced by the sophistication of today's science and the complexity of modern technology, they have sought to augment and update their technical knowledge and with it their ability to function integrally and to contribute significantly within their own society.

The *Encyclopedia's* entries have been carefully compiled to present the most topical knowledge in diverse areas of specialization; the reader can pursue any subject of interest to him, knowing that all articles begin with broad, fundamental concepts and progress to specific, more detailed information. The articles discuss topics in such areas as aeronautics, astronomy, botany, chemistry, chemical engineering, civil engineering, computer technology, electrical engineering, electronics and communications, geology, mathematics, mechanical engineering, medicine, metallurgy, meteorology, mineralogy, navigation, nuclear science and engineering, oceanography, photography, physics, space science and technology, including space travel and planetary exploration, statistics, zoology, and such related areas as astrophysics, biochemistry, biophysics, and nautical astronomy, among others.

In the process of preparing this comprehensive revision for availability in the fourth decade after publication of the First Edition, the contributors and editors of the *Encyclopedia* have not only expanded the volume in concept and coverage, but have reviewed and, where appropriate, rewritten each article, deleting the obsolete and eliminating the nonessential to make room for important new aspects of modern science. Their guiding principle throughout has been to offer adequate representation and coverage of all branches and disciplines of functional scientific knowledge. The skills they brought to this task were considerable and worthy of our grateful acknowledgment. In order to retain as an important feature a uniform consistency of language and level of presentation, the total content of the new edition—retained articles, rewritten articles, and new contributions by international experts—has been carefully reviewed and has undergone systematic editorial supervision by members of the *Encyclopedia's* board of editors. Where possible, the compilation of data in any particular field was the responsibility of a single authority in that field, another condition intended to promote unity and consistency within the articles. The contributions of many other authorities, including those whose work on the earlier editions formed the foundation from which the present volume arose, and those who contributed suggestions and material for this edition must also be acknowledged.

Any one-volume reference work inevitably has limits which necessarily restrict the length of the articles and the size and number of illustrations. In order to maintain the convenience and ready accessibility of a one-volume encyclopedia and yet meet the real need of including all the essential data such a book must have, an entirely new format was devised for the Fourth Edition. By accommodating more material on each page, this format enables the volume to contain its greatly increased contents without an equivalent increase in the overall bulk of the book. As before, the comprehensiveness of the book is noteworthy both in the scope of the terms covered and in the breadth of the treatment in the individual entries. The meticulous work of the contributors and the systematic cross-referencing have made possible the inclusion of a wealth of material within the covers of a single volume.

An important feature continued in this encyclopedia is the progressive development of the discussion of each topic, beginning with a simple definition expressed in the plainest of terms and progressing to a final reflection of the more detailed aspects of the topics treated. Articles dealing with simple concepts are, of course, treated generally in simple terms. Those articles of a more highly technical nature may be valuable both to the inquiring lay reader and to the trained technician if they will select their reading from the earlier or later portions of such an article.

All those concerned with the Fourth Edition have followed the highest standards in an effort not only to maintain that quality that has won international recognition for earlier editions, but to enhance it wherever possible. The successful development of the *Scientific Encyclopedia* must be attributed largely to the inspiring direction of William R. Minrath, now retired, who has acted as General Editor since the work's conception in 1935. His foresight and excellent judgment in assembling a single-volume compendium of scientific knowledge and his singular ability to bring together contributors of noteworthy scientific attainments to form a cohesive unit account in great part for the outstanding merits of this unique book.

The publishers, the contributors, and the editors will appreciate the reader's indulgence in the case of any significant omissions or in the case of errors. Selective judgment in treatment of material was unavoidable; necessity also required the recognition of a limit of difficulty beyond which it was impractical to go in attempting to cover so broad a field as modern science within the physical confines of one useful volume.

A

AA. An Hawaiian term introduced into geological nomenclature by C. E. Dutton, in 1883, and signifying the jagged, scoriaceous, blocky and exceedingly rough surface of some basic lava flows. Pronounced *ah-ah.*

AARD-VARK (*Mammalia, Tubulidentata*). African animals of peculiar form and ancient lineage, including an Ethiopian and a South African species. All are anteaters, feeding exclusively on ants and termites, nocturnal in habit, with acute hearing. The southern species has been called the ant bear. The aard-vark is the only living representative of its order. The animal's spine, curved from neck to tail in a near-half circle, gives it a truly prehistoric appearance.

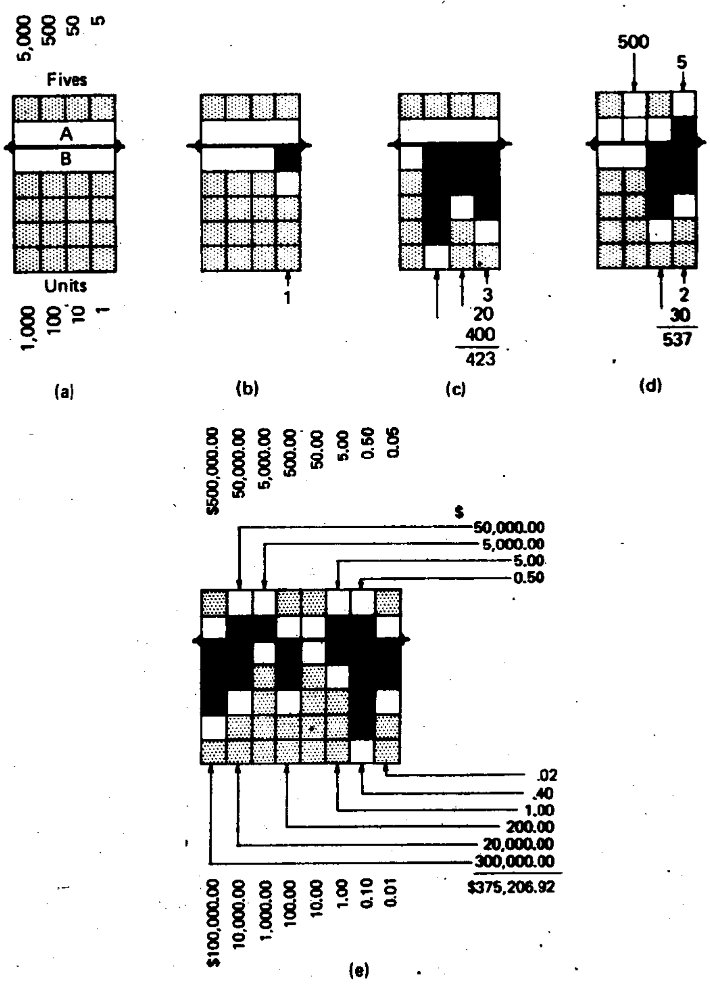
AARD-WOLF. **Hyena.**

ABACA. The sclerenchyma bundles from the sheathing leaf bases of *Musa textilis*, a plant closely resembling the edible banana plant. These bundles are stripped by hand, after which they are cleaned by drawing over a rough knife. The fiber bundles are now whitish and lustrous, and from six to twelve feet long. Being coarse, extremely strong and capable of resisting tension, they are much used in the manufacture of ropes and cables. Since the fibers swell only slightly when wet, they are particularly suited for rope which will be used in water. Waste manila fibers from rope manufacture and other sources are used in the making of a very tough grade of paper, known as manila paper. The fibers may be obtained from both wild and cultivated plants, the latter yielding a product of better grade. The cultivated plants, propagated by seeds, by cuttings of the thick *rhizomes* or by suckers, are ready for harvest at the end of three years, after which a crop may be expected approximately every three years.

ABACUS. This scheme represents one of man's first formalized approaches to counting and calculating beyond the use of his fingers and toes. Essentially, the abacus is a manually manipulated digital device. Records indicate that some form of the abacus was used as early as 3,000 B.C. by the Babylonians. Formats have ranged from ruled tables to moving coins around on checkered tablecloths (from which the term British Exchequer was derived) to the currently more familiar frame-and-bead construction. Experienced operators of commercial versions of the abacus, particularly in the Orient, can add, subtract, multiply, and divide with speeds comparable to those obtainable with modern, nonelectronic adding machines. Special versions of the abacus are used in some elementary schools for teaching the fundamentals of counting and arithmetic.

The principle of the abacus is shown by accompanying figures (a) through (e). Visualize a box or frame containing movable squares. In (a) the squares, all indicated by a gray tone, are in their "rest" or "zero" position. The squares along the top may be moved down into the "reckoning space" A, whereas the squares in the bottom portion of the box may be moved upward into "reckoning space" B. There is a "datum" line or bar that separates spaces A and B. The abacus is read by noting the number of squares that have been moved into the reckoning space, i.e., that make contact with the datum line. The squares in the upper portion, from right to left, represent, 5, 50, 500, 5,000... etc. Note that there is only one square in each column. The squares in the lower portion, from right to left, represent 1's, 10's, 100's, 1,000's... etc. The extreme right-hand column permits counting from 1 to 4, depending upon how many of the squares the operator moves upward to contact the datum line.

In figures (b) through (d), the squares that have been moved into contact with the datum line, i.e., the squares to be read, are shown in black. The indication of "1" is shown in (b); of "423" in (c). In (d), the squares in the upper portion of the box are brought into play. As indicated by (e), there is no limit to the number of columns that may be used in a frame, thus permitting calculations into 8 or 10 figures, or more. Because of the limitations of squares in the columns, however, the abacus operator frequently is called upon to make minor mental calculations, i.e., to introduce a subroutine. For example, in (c), the addition of "525" to the "423" indicated is quite simple, requiring no interim calculation. There is a "5" available to be moved down; there are two remaining "20's" which can be moved up; and there is a "500" available to be moved down. Thus, the abacus will read the correct sum, i.e., "948." However, in the case of



Fundamentals of the abacus.

adding "107" to the "423," the operator cannot handle the "7" because only one "5" and only one "1" is available, accounting for "6" whereas "7" is required. In this case, the operator will add "10" and take away "3." There is a further problem in adding the "100" because all four of the available "100's" are in use. This can be handled by adding "500" and taking away "400." With these manipulations completed, the abacus reads the proper sum, i.e., "530."

ABALONE (*Mollusca, Gasteropoda; Haliotis*). Marine species, mostly of the Pacific and Indian Oceans. The single broad shallow shell has a richly colored iridescent inner surface and is an important source of mother-of-pearl and blister pearls for costume jewelry. The flesh is palatable.

ABBE CONDENSER. A compound lens used for directing light through the object of a compound microscope. All the light enters the object at an angle with the axis of the microscope. See also **Microscope.**

ABBE NUMBER. The reciprocal of the dispersive power of a material. It is also called the ν-number.

ABBE REFRACTOMETER. **Refractometers.**

ABBE SINE CONDITION. The relationship

$$ny \sin \theta = n'y' \sin \theta',$$

where n,n' are refractive indices, y,y' are distances from optical axis, and θ,θ' are angles light rays make with the optical axis. A failure of an optical surface to satisfy the sine condition is a measure of the coma of the surface.

ABDOMEN. The abdomen is the posterior division of the body in many arthropods. It is the *posterior* portion of the trunk in vertebrates. In the vertebrates this region of the body contains most of the alimentary tract, the excretory system, and the reproductive organs. It contains part of the coelom and in mammals is separated from the thorax by the diaphragm.

The abdominal cavity of the human body is subdivided into the abdomen proper and the pelvic cavity.

The walls of the abdominal cavity are lined with a smooth membrane called the peritoneum, which also provides partial or complete covering for the organs within the cavity.

The abdomen proper is bounded above by the diaphragm; below it is continuous with the pelvic cavity; posteriorly it is bounded by the spinal column, and the back muscles; and on each side by muscles and the lower portion of the ribs. In front, the abdominal wall is made up of layers of fascia and muscles. The abdomen is divided into nine regions whose boundaries may be indicated by lines drawn on the surface. The mid-section above the navel between the angle of the ribs is known as the epigastric region; that portion around the navel, as the umbilical; below the navel and above the pubic bone, as the hypogastric region. It is further divided into right and left upper quadrants on each side above the navel, and right and left lower quadrants on each side below the navel. The lumbar region extends on either side of the navel posteriorly and laterally.

The principal organs of the abdominal cavity are the stomach, duodenum, jejunum, ileum, and colon or large intestine, the liver, gall bladder and biliary system, the spleen, pancreas and their blood and lymphatic vessels, lymph glands, and nerves, the kidneys and ureters.

The pelvic portion of the abdomen contains the sigmoid colon and rectrum, a portion of the small intestine, the bladder, in the male the prostate gland and seminal vesicles, in the female the uterus, Fallopian tubes and ovaries.

ABEL EQUATION. A mass point moves along a smooth curve in a vertical plane and under the influence of gravity alone. Given the time, t, required for the particle to fall from a point, x, to the lowest point on the curve as a function of x, what is the equation of the curve? The problem leads to a Volterra integral equation of the first kind

$$f(x) = \int_0^x \frac{\phi(t)\, dt}{\sqrt{2g(x-t)}}$$

where g is the acceleration of gravity. The solution is

$$\phi(x) = \frac{\sqrt{2g}}{\pi} \int_0^x \frac{f'(t)\, dt}{\sqrt{x-t}}$$

and the equation of the curve is

$$y = \int_0^x \sqrt{|\phi^2(t) - 1|}\, dt$$

A closely related problem is that of the brachistochrone, where the path is required for a minimum time of descent. Such matters were of considerable interest to many seventeenth and eighteenth century mathematicians; the one described here was solved by the Norwegian, N. H. Abel (1802–1829). See also **Brachistochrone.**

A more general case of the Abel equation is

$$f(x) = \int_0^x (x-y)^{-\alpha}\phi(y)\, dy$$

where $f(x)$ is continuously differentiable for $x \geq 0$ and $0 < \alpha < 1$. The solution is

$$\phi(y) = \frac{\sin \alpha\pi}{\pi}\left[\int_0^y (y-x)^{\alpha-1} f'(x)\, dx + f(0)y^{\alpha-1}\right]$$

A first-order differential equation

$$y' = f_0(x) + f_1(x)y + f_2(x)y^2 + f_3(x)y^3$$

is also known as an Abel equation. When the $f_i(x)$ are given explicitly, the equation can often be converted into one of simpler type and solved in terms of elementary functions. In the general case the solution involves elliptic functions.

ABELIAN GROUP. A commutative group, namely such that $AB = BA$ where A, B are any two elements contained in it.

ABERRATION OF LIGHT. The apparent change of position of an object, due to the speed of motion of the observer. Care must be taken not to confuse this effect with that of parallax.

If a telescope, assumed to be stationary, is pointed at a source of light, the light that enters the object glass centrally and in the direction of the optic axis will pass through the telescope along that axis and emerge through the center of the eyepiece. If the telescope is in motion relative to the source, in any direction other than parallel to the optic axis, the light that enters centrally will emerge off the center of the eyepiece. If this light is to emerge centrally, the telescope must be tilted forward in the plane containing the direction of motion of the instrument and the source. The amount of tilt will depend on the direction of the source and the ratio of the speed of the telescope to the speed of light.

This aberrational effect was first announced by Bradley in 1726. He noticed that stars had apparent periodic motions with a period of one sidereal year, and that the character of the apparent motion depended upon the celestial latitude of the star. He correctly interpreted the effect as due to the motion of th earth about the sun. Statistical discussions of the observations of a large number of stars have shown that the maximum value of this aberration due to the earth's orbital motion is 20".47. This is known as the "aberration angle" or the "constant of aberration," and is given by

$$\kappa = \frac{2\pi a \operatorname{cosec} 1''}{cT(1-e^2)^{1/2}}$$

where a is the mean radius of the earth's orbit, c is the velocity of light, T is the length of the year in seconds, and e is the eccentricity of the orbit. An aberrational effect of about 0".3, at maximum, is observed, due to the rotation of the earth on its axis, and is given by

$$k = \frac{2\pi\rho \cos\phi \operatorname{cosec} 1''}{ct}$$

where ρ is the radius of the earth, ϕ is the latitude of the place, and t is the length of the day in seconds.

In 1871, Airy made a series of observations for determination of the aberration constant, using a telescope filled with water. Because the value of the index of refraction of water is about $1\frac{1}{3}$, Airy expected that the value of the aberration would be 27".3 when using the water-filled tube. He found, however, that the value was 20".5 no matter what substance was placed in the telescope. The result of this so-called "Airy's Experiment" caused much discussion, but was eventually explained on the basis of the Michelson-Morley experiment and the theory of relativity.

All observations, in which the positions of the stars are involved, must be corrected for aberration of light if the results are to be accurate to within 20". Both the motion of the earth about the sun and the rotation of the earth must be considered. The magnitude of the correction depends upon the celestial coordinates of the star, the position of the observer on the earth, and the date and time of observation.

ABERRATION (Optical). The failure of an optical system to form an image of a point as a point, of a straight line as a straight line, and of an angle as an equal angle. See also **Astigmatism; Chromatic Aberration; Coma (Optics); Curvature of Field (Optics); Spherical Aberration.**

ABIES. Fir Trees.

ABIOGENESIS. A former, now rejected theory pertaining to the spontaneous generation of living organisms from lifeless matter.

ABLATION (Geomorphology). Essentially, the wasting away of rocks; the separation of rock material and formation of residual deposits, as caused by wind action or the washing away of loose and soluble materials.

ABLATION (Glaciology). The combined processes (sublimation, melting, evaporation) by which snow or ice is removed from the surface of a glacier or snowfield. In this sense, the opposite of alimentation. Ablation also refers to the amount of snow or ice removed by the aforementioned processes (the opposite of accumulation). The term may be applied to reduction of the entire snow-ice mass, and may also include losses by wind action and by calving (the breaking off of ice masses). Air temperature is the dominant factor in controlling ablation. During the ablation season, an ablation rate of about two millimeters/hour is typical of most glaciers. An ablatograph is an instrument that measures the distance through which the surface of snow, ice, or firn changes, as caused by ablation, during a specific period.

ABLATION (Meteorite). The direct vaporization of molten surface layers of meteorites and tektites during flight.

ABLATION (Spacecraft). In the interest of cooling space vehicles upon re-entry into the earth's atmosphere, ablation is used to control the temperature of strongly heated surfaces, such as parts of combustion chambers or nose cones. The process usually consists of the use of surface layers of materials which by their fusion, followed often by evaporation, absorb heat.

The heat of ablation is a measure of the effective heat capacity of an ablating material. Numerically, this is the heating rate input divided by the mass loss rate which results from ablation. In the most general case, heat of ablation is given by

$$(q_c + q_r - \sigma\varepsilon T_w^4)/\dot{m}$$

where q_c is the convective heat transfer in the absence of ablation; q_r is the radiative heat transfer from hot gases to ablation material; $\sigma\varepsilon T_w^4$ is the rate of heat rejection by radiation from external surface of ablation material; and $\dot{m}$ is rate at which gaseous ablation products are injected into the boundary layer.

Heat of ablation is sometimes evaluated neglecting the heat rejected by radiation and as a result unrealistically high heats of ablation are obtained.

If $q_r < \sigma\varepsilon T_w^4$, for moderate values of stream enthalpy h_s, the heat of ablation is given by

$$H_v + \eta(h_s - h_w)$$

where H_v is the heat required to cause a unit weight of mass to be injected into boundary layer; η is the blocking factor, with numerical value from about 0.2 to 0.6 depending on material and type of flow; and h_w is the enthalpy at wall temperature.

ABNEY EFFECT. A shift in hue which is the result of a variation in purity and, therefore, in saturation. The Abney effect may be represented by chromaticity loci, of specified luminance, with the hue and brightness constant, when purity and, therefore, saturation are varied. It is a relationship, of psychophysical nature, between psychophysical specifications and color sensation attributes.

ABNEY MOUNT. Reflection Grating.

ABORTION. In biology, an action to arrest the full development of an organ or living system, i.e., to bring to a halt the life process.

In the case of aborting human pregnancies, for the technical procedures involved, the reader is best referred to medical textbooks and various governmental health and sociological agencies.

In relatively rare instances, accidental pregnancies result from rape of a female. Also, in relatively rare cases, a pregnancy may be aborted because it may be found, after conception, that the female may be incapable of producing a healthy infant, or that pregnancy may be severely harmful to the health of the female. Except in highly backward areas, such serious consequencies of pregnancy will be known in advance by the female and hence such situations will also generally fall into the category of undesired pregnancies simply resulting from unplanned and careless sexual relations, again extremely rare among educated adults. See **Contraception.**

Human abortions have been and probably always will be much more of a social and moral issue rather than a scientific problem. As pointed out under **Embryo,** the creation of an embryo and development of a fetus and finally the birth of an infant is a *continuous* physiological process, commencing with conception and ending with the cutting of the umbilical cord. It is not in any way a digital, stepwise process with distinct periods. Even as early as the 3rd week after conception, traces of most of the important body structures can be observed in the embryo which, at that time, is about the size of a large English pea. Only for convenience in studying and teaching are certain rather fuzzily defined phases or stages of embryo and fetus development identified and given names. These phases are quantified in terms of several days, even weeks, rather than in terms of one or two days, or hours or minutes. The embryo and later the fetus is an individual entity, imbued with individualistic qualities which affect its rate of progress, much as later the progress of the infant to a mature adult will be determined by individualistic qualities. Hence, the developmental processes going on during pregnancy cannot be timed with precision.

As shown by Fig. 4(a) under **Embryo,** even at the end of only about 29 days after conception, the presence of a human living form would be quite obvious even to an untrained female if indeed she could see it. Were a female able to observe the life process of the embryo, as through a hypothetical window in her abdomen, or if, as in the case of the kangaroo, for example, the fetus were expelled at a stage much more premature than in the case of human beings, there is little doubt but that the psychological factors at play in abortion decisions would be grossly altered.

In contrast with human beings the baby kangaroo is expelled from its mother essentially as an "embryo-fetus" only two inches in length. Except for mouth and forelimbs, the being is in a very early stage of formation and is approximately comparable to the human embryo at about 40–42 days after conception. Spending very little time in the womb (5 to 6 weeks), the baby kangaroo after expulsion attaches itself to a nipple in its mother's pouch. Only at the end of 5 months does the baby kangaroo (now weighing about 10 pounds) leave the pouch for very short periods.

From a purely scientific standpoint, there is no question but that abortion represents the cessation of a human life. The moral aspects of when human life can be voluntarily halted vary, of course, from one culture to the next, and even from one sociological period to the next. The fact that the individual life (embryo) cannot be seen or its presence sensed by the female (except in secondary ways in connection with some of the usual discomforts of early pregnancy) tends to eliminate or at least minimize the so-called guilt complex in making a decision to halt the life process. In some cases, of course, post-abortion psychological problems may evolve. In the legal approaches to justification of abortion, concepts of viability have been presented, usually considered the 28th week of pregnancy.

Again, were it hypothetically possible to remove the fetus (as shown in Fig. 4(e) under **Embryo** or even at an earlier date, inspect it, and then make a decision as to whether or not to kill it, and if the decision were negative, it would be possible to "reinstall" it in the female for completion of its full developmental process, then needless to say both the moral and sociological aspects of abortion psychology would be altered. As medical science has made it possible to achieve safe abortions in most cases, in terms of the female, science has the counter responsibility of fully explaining to the female the fundamentals of embryology and pregnancy to make certain that her abortion decision is simply not one of personal convenience where the psychology of "out of sight-out of mind" can otherwise play an important role.

The cessation of abortion regulations in many areas of the world, including the United States, has made available an abundance of human tissue for research. Just as moral-legal-scientific issues remain to be resolved in the long term insofar as the practice of abortion per se is concerned, so do the issues facing the disposal of and research on fetuses that are now so numerous. As of the mid-1970s, these issues were a long way from resolution. Reference is suggested to *Science*, **186**, "Manslaughter," 4161, 327–330 (October 25, 1974); and "Grave-Robbing," 4162, 420–423 (November 1, 1974).

ABRAHAM'S TREE. Clouds and Cloud Formation.

ABRASION. All metallic and nonmetallic surfaces, no matter how smooth, consist of minute serrations and ridges which induce a cutting or tearing action when two surfaces in contact move with respect to each other. This wearing of the surfaces is termed abrasion. Undesirable abrasion may occur in bearings and other machine elements, but abrasion is also adapted to surface finishing and machining, where the material is too hard to be cut by other means, or where precision is a primary requisite.

ABRASION pH. A term originated by Stevens and Carron in 1948, "to designate the pH values obtained by grinding minerals in water." Abrasion pH measurements are useful in the field identification of minerals. The pH values range from 1 for ferric sulfate minerals, such as coquimbite, konelite, and rhomboclase, to 12 for calcium-sodium carbonates such as gaylussite, pirssonite, and shortite. The recommended technique for determination abrasion pH is to grind, in a

ABRASION pH VALUES OF REPRESENTATIVE MINERALS

Mineral	pH by Stevens-Carron Method	pH by Keller et al. Method*
Coquimbite	1	
Melanterite	2	
Alum	3	
Glauconite	5	5.5*
Kaolinite	5, 6, 7	5.5*
Anhydrite	6	
Barite	6	
Gypsum	6	
Quartz	6, 7	6.5
Muscovite	7, 8	8.0
Calcite	8	8.4
Biotite	8, 9	8.5
Microcline	8, 9	8.0 9.0*
Labradorite		8.0 9.2*
Albite	9, 10	
Dolomite	9, 10	8.5
Hornblende	10	8.9
Leucite	10	
Diopside	10, 11	9.9
Olivine	10, 11	9.6*
Magnesite	10, 11	

* indicates more recent values published in literature.

nonreactive mortar, a small amount of the mineral in a few drops of water for about one minute. Usually, a pH test paper is used. Values obtained in this manner are given in the left-hand column of the accompanying table. Another method, proposed by Keller et al. in 1963 involves the grinding of 10 grams of crushed mineral in 100 milliliters of water and noting the pH of the resulting slurry electronically. Values obtained in this manner are given in the right-hand column of the accompanying table. See also terms listed under **Mineralogy**.

References

Stevens, R. E. and M. K. Carron. Simple Field Test for Distinguishing Minerals by Abrasion pH, *American Mineralogist*, **33**, 31-49. 1948.

Keller, W. D., Balgord, W. D., and A. L. Reesman: Dissolved Products of Artifically Pulverized Silicate Minerals and Rocks, *Jrnl. Sediment. Petrol.* 33(1), 191-204, 1963.

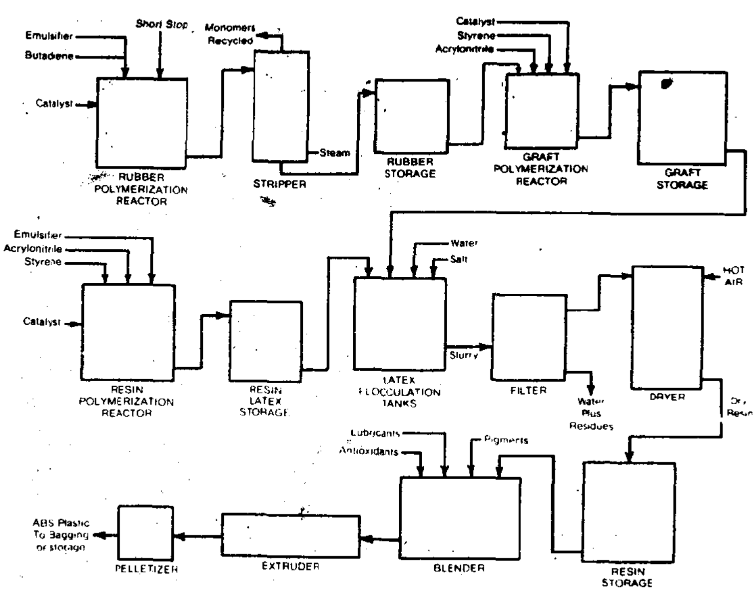
ABRASIVES. Grinding and Polishing Agents.

ABS (Acrylontrile-Butadiene-Styrene) RESINS. Thermoplastic resins which are produced by grafting styrene and acrylonitrile onto a diene-rubber backbone. The usually preferred substrate is polybutadiene because of its low glass-transition temperature (just above −80°C). Where ABS resin is prepared by suspension or mass polymerization methods, stereospecific diene rubber made by solution polymerization is the preferred diene. Otherwise, the diene used normally is a high-gel or cross-linked latex made by a "hot-emulsion" process.

As indicated by Tables 1 and 2, ABS resins possess an attractive balance of impact resistance, hardness, tensile strength, and elastic modulus properties. The temperature range is wide, from −40 to +107°C (−40 to +225°F). Other advantages include chemical resistance, high gloss, and nonstaining properties. The dimension stability of ABS is good and creep resistance is excellent. The resins show low water absorption or volume change at varying humidities. Commercially available ABS is in the form of custom color-matched compounded pellets, or granular resin for compounding or alloying with other plastics. A representative alloying ingredient is polyvinyl chloride (PVC). Almost all standard thermoplastic converting processes can be used with ABS plastics. Injection molded parts include telephone sets, refrigerator parts, plumbing fixtures and fittings, radio, television, and appliance housings, and auto parts. ABS can be extruded into sheet, pipe, and various cross sections. Thermoforming of large surface areas and deep draws from sheet stock is possible. Examples of parts which involve extrusion and subsequent thermoforming include lawn-mower housings, refrigerator liners, pipe and conduit, vehicle bodies, snowmobile shrouds, and camper bodies. The various thermoforming techniques applicable to ABS include plug and air assist, vacuum snapback, vacuum-plug forming, and drape forming.

The compatibility of ABS with other plastics makes them useful as impact modifiers and as processing additives with many other polymers to achieve a variety of final product specifications. Substitution of α-methyl styrene for styrene increases heat-distortion temperatures; or of methacrylonitrile for acrylonitrile improves barrier properties to gases such as carbon dioxide in connection with carbonated beverage containers. Over 75 grades of ABS are commercially available, including self-extinguishing, electroplating, antistatic-expandable, glass-reinforced, high-heat, cold-forming, and low-gloss sheet grades.

Three polymerization steps are involved in ABS manufacture. The process is shown in block diagram format in the accompanying illustration.



ABS manufacturing process. (*Marbon Division, Borg-Warner Corporation*)

TABLE 1. MECHANICAL PROPERTIES OF RIGID ABS PLASTICS

Property	Conditions	General purpose	High impact	Medium heat	High heat	Expansion casting	Self extinguishing*
Notched Izod Impact ft.-lbs./in.	73°F	5.5	7.5	3.4	2.6	1.2	2.1
	−40°F	1.7	3.0	1.0	0.7	0.6	0.5
Tensile Strength, psi at Yield	73°F	5900	4800	7800	7400	1700	5400
Tensile Modulus, psi at Yield	73°F	3.1×10^5	2.4×10^5	3.7×10^5	3.9×10^5	1.0×10^5	3.0×10^5
Hardness**	73°F	102R	87R	112R	111R	55D	96R
Heat Distortion Point, F	264 psi	191	188	203	226	158	182
(Unannealed)	66 psi	206	211	217	240	172	196
Specific Gravity	73°F	1.03	1.02	1.02	1.03	0.52	1.21
Mold Shrinkage	in./in./°F	0.005	0.007	0.005	0.004	0.005	0.0074
Coefficient of Expansion	in./in./°F	5.4×10^{-5}	5.8×10^{-5}	4.2×10^{-5}	3.3×10^{-5}	9.7×10^{-5}	9.9×10^{-5}

* NOTE: A self-extinguishing ABS compound that does not contain PVC, Non-burning by ASTM D635-63, self-ex by UL Subject 94 Group 1, with a GE oxygen index of 27.0.
** Hardness, Rockwell R or Shore D scales.

TABLE 2. MECHANICAL PROPERTIES OF ABS MOLDING ALLOYS
(With polyvinyl chloride (PVC); polyurethane (PU); and polycarbonate (PC))

Property	Condition	ABS/PVC (rigid)	ABS/PVC (flexible)	ABS/PU (rigid)	ABS/PC (rigid)
Notched Izod Impact, ft.lbs./in.	73°F	12.5	15.0	8.0	10.3
	−40°F	1.3	1.1	2.3	1.5
Tensile Strength, psi at Yield	73°F	5450	3000	4450	8200
Tensile Modulus, psi at Yield	73°F	3.2×10^5	1.0×10^5	2.2×10^5	3.7×10^5
Hardness, Rockwell R	73°F	102R	50R	82R	118R
Heat Distortion Point, °F	264 psi	147	165	182	246
(Unannealed)	66 psi	161	195	206	261
Specific Gravity	73°F	1.21	1.13	1.04	1.14

STEP 1—Polybutadiene rubber is formulated by feeding butadiene, water, an emulsifier, and catalyst into a glass-lined reactor. This is an exothermic reaction. About 80% conversion is achieved in a period of about 50 hours. The residual butadiene monomer is recovered by steam-stripping and recycled.

STEP 2—Polybutadiene rubber is further polymerized, but in the presence of styrene and acrylonitrile monomers. This is done in low-pressure reactors under a nitrogen atmosphere. In this operation, the monomers are grafted onto the rubber backbone through the residual unsaturation remaining from the first step.

STEP 3—In a separate step, styrene-acrylonitrile (SAN) resin is prepared by emulsion, suspension, or mass polymerization by free-radical techniques. The operation is carried out in stainless-steel reactors operated at about 75°C (167°F) and 5 psig for about 7 hours. The final chemical operation is the blending of the ABS graft phase with the SAN resin, plus adding various antioxidants, lubricants, stabilizers, and pigments. Final operations involve preparation of a slurry of fine resin particles (via chemical flocculation), filtering, and drying in a standard fluid-bed dryer at 121–132°C (250–270°F) inlet air temperature.

Assistance of the Marbon Division, Borg-Warner Corporation in preparation of this entry is appreciated.

ABSAROKITE. A geologic term proposed by Iddings in 1805 for a porphyritic basalt containing phenocrysts of olivine and augite in a ground mass of smaller labradorite crystals. Type locality, Absaroka Range, Wyoming.

ABSCESS. A localized collection of pus within a cavity; the collection of pus formed by disintegration of tissue.

In *mediastinitis*, which is an inflammation of the wall dividing the two pleural cavities, a common complication is mediastinal abscess. Sometimes the abscess opens and empties its contents into the trachea: either the patient will cough up large amounts of pus, or he may suffocate. Mediastinitis may occur as a result of perforation of the esophagus. This can happen when a sharp foreign body becomes lodged in the esophagus, during attempts to remove it, or during examination of the organ for other reasons. Mediastinitis also can result from a bullet or stab wound.

Abscess and gangrene of the lung are secondary complications of the more severe cases of pneumonia. Usually, there are several small abscesses scattered over the affected area. The signs of lung abscess include fever, sweating, and the production of puslike sputum.

Infection of the anus is the cause of anal fissure, hemorrhoids, abscess, and fistula, and is usually the result of invasion of the numerous tiny glands or crypts, which abound in the tissues adjacent to the anus. If the infection spreads through the wall of the anus, an abscess may occur in the tissues around the anus, and this may burst through the skin around the anus or back into the rectum. In either case, the abscess cavity has two openings, the original site of entry of the infection and the point where it bursts through. Fistula is the term by which such a condition is designated.

Prostatic abscesses sometimes follow acute prostatitis. The abscess can be drained by manipulation by the physician; also, drainage may occur spontaneously.

Inflammation of the breast is termed *mastitis*. The name given mastitis following childbirth is acute puerperal mastitis. It is often preceded by painful or cracked nipples. An abscess of the breast occurs most frequently within one month after childbirth. It is caused by infection entering through a "cracked nipple." The unfortunate consequences of a breast abscess are that the infant is deprived of breast milk, plus the fact that the mother has a long period of discomfort and pain. Treatment is instituted as quickly as possible in order to avoid a prolonged convalescent period, as well as the possibility of the destruction of a large amount of breast tissue.

In abscess of the external ear, there is pain and tenderness over the affected area. The auricle may enlarge to two or three times the normal size. If proper care is not given, the ear may be permanently distorted in shape. Antibiotics and sulfonamide drugs may be used effectively. Surgical treatment may be required, but only after careful examination by a specialist.

Periapical abscesses occur at the apical (apex) region of a tooth as the result of death of the pulp tissue. Periodontal abscesses occur in the tissues closely surrounding a tooth, such as gingiva, bone, or the periodontal membrane. When an abscess breaks through a limiting membrane, working through surrounding bone to external soft tissue, a gum boil may result.

ABSCESS (Peritonsillar). **Quinsy Sore Throat.**

ABSCISSA. **Coordinate System.**

ABSCISSION. This term is applied to the process whereby leaves, leaflets, fruits, or other plant parts become detached from the plant. Leaf abscission is a characteristic phenomenon of many species of woody dicots and is especially conspicuous during the autumn period of leaf fall. The onset of abscission seems to be regulated by plant hormones. Three main stages can be distinguished in the usual process of leaf abscission. The first is the formation of an abscission layer which is typically a transverse zone of parenchymatous cells located at the base of the petiole. The cells of this layer may become differentiated weeks or even months before abscission actually occurs. The second step is the abscission process proper which occurs as a result of a dissolution of the middle lamellae of the cells of the abscission layer. This results in the leaf remaining attached to the stem only by the vascular elements which are soon broken by the pressure of wind or the pull of gravity and the leaf falls from the plant. In the final stage of the process the exposed cells of the leaf scar are rendered impervious to water by lignification and suberization of the walls.

Subsequently other layers of corky cells develop beneath the outer layer. These layers eventually become a part of the periderm of the stem. The broken xylem elements of the leaf scar become plugged with gums or tyloses and the phloem elements become compressed and sealed off.

In some kinds of plants an abscission layer is only imperfectly formed and in many others, especially herbaceous species, no abscission layer develops at the base of the petiole. In a few herbaceous species, of which coleus, begonia, and fuchsia are examples, an abscission layer develops. In the majority of herbaceous species, however, and in some woody species, there is no true abscission process. In such herbaceous plants most or all of the leaves are retained until the death of the plant. In the woody plants falling in this category (example: shingle oak, *Quercus imbricaria*) the leaves are shed only by mechanical disruption from the plant. Abscission of the fruits of apple and doubtless of many other species occurs in much the same manner as abscission of leaves. The abscission of apple fruits can be artificially retarded by spraying with certain growth regulators.

For related topical coverage in this volume, see list of subjects given under **Tree.**

ABSINTHE. Artemisia.

ABSOLUTE HUMIDITY. Humidity.

ABSOLUTE MAGNITUDE. Stellar Magnitude.

ABSOLUTE SPACETIME. A fundamental concept underlying Newtonian mechanics is that there exists a preferred reference system to which all measurements should be referred. This is known as absolute space-time. The assumption of such a system is replaced in relativistic mechanics by the principle of equivalence. See **Equivalence Principle; Relativity and Relativity Theory.**

ABSOLUTE TENSOR (Tensor Field). Tensor (tensor field) of weight zero. Often called tensor (tensor field) when context admits no confusion. See also **Tensor Field**

ABSOLUTE ZERO. Conceptually that temperature where there is no molecular motion, no heat. On the Celsius scale, absolute zero is −273.15°C; on the Fahrenheit scale, −459.67°F; and zero degrees Kelvin (0K). The concept of absolute zero stems from thermodynamic postulations.

Heat and temperature were poorly understood prior to Carnot's analysis of heat engines in 1824. The Carnot cycle became the conceptual foundation for the definition of temperature. This led to the somewhat later work of Lord Kelvin, who proposed the Kelvin scale based upon a consideration of the second law of thermodynamics. This leads to a temperature at which all the thermal motion of the atoms stops. By using this as the zero point or absolute zero and another reference point to determine the size of the degrees, a scale can be defined. The Comité Consultative of the International Committee of Weights and Measures selected 273.16K as the value for the triple point for water. This set the ice-point at 273.15K.

From the standpoint of thermodynamics, the thermal efficiency E of an engine is equal to the work W derived from the engine divided by the heat supplied to the engine, $Q2$. If $Q1$ is the heat exhausted from the engine,

$$E = (W/Q2) = (Q2 - Q1)/Q2 = 1 - (Q1/Q2)$$

where W, $Q1$, and $Q2$ are all in the same units. A Carnot engine is a theoretical one in which all the heat is supplied at a single high temperature and the heat output is rejected at a single temperature. The cycle consists of two adiabatics and two isothermals. Here the ratio $Q1/Q2$ must depend only on the two temperatures and on nothing else. The Kelvin temperatures are then defined by the relation

$$\frac{Q1}{Q2} = \frac{T1}{T2}$$

where $Q1/Q2$ is the ratio of the heats rejected and absorbed, and $T1/T2$ is the ratio of the Kelvin temperatures of the reservoir and the source. If one starts with a given size for the degree, then the equation completely defines a thermodynamic temperature scale.

A series of Carnot engines can be postulated so that the first engine absorbs heat Q from a source, does work W, and rejects a smaller amount of heat at a lower temperature. The second engine absorbs all the heat rejected by the first one, does work and rejects a still smaller amount of heat which is absorbed by a third engine, and so on. The temperature at which each successive engine rejects its heat becomes smaller and smaller, and in the limit this becomes zero so that an engine is reached which rejects no heat at a temperature which is absolute zero. A reservoir at absolute zero cannot have heat rejected to it by a Carnot engine operating between a higher temperature reservoir and the one at absolute zero. This can be used as the definition of absolute zero. Absolute zero is then such a temperature that a reservoir at that temperature cannot have heat rejected to it by a Carnot engine which uses a heat source at some higher temperature.

ABSORBANCE. By combining the laws of Bouguer and Beer, the absorbance

$$A = -\log T = \log \frac{I_0}{I} = abc$$

where T is the transmittance, I_0 and I are the intensities of light incident and transmitted by a sample of thickness b, concentration c (if the sample is in solution) and absorptivity a. It is assumed that all necessary corrections have been made in a reported value of A, hence terms such as absorbancy, absorptance, and absorptancy should now not be used.

Absorbancy is the common logarithm of the reciprocal of the transmittancy. The quantity is sometimes referred to as the *absorbancy index*.

Absorptancy. If T_s is the transmittancy of a dissolved solute, then the absorptancy may be defined as $1 - T_s$. The term is no longer used in precise absorptimetry.

ABSORBER. In general, a medium, substance or functional part that takes up matter or energy. In radiation and particle physics, an absorber is a body of material introduced between a source of radiation and a detector to (1) determine the energy or nature of the radiation; (2) to shield the detector from the radiation; or (3) to transmit selectively one or more components of the radiation, so that the radiation undergoes a change in its energy spectrum. Such an absorber may function through a combination of processes of true absorption, scattering and slowing-down.

ABSORBER (Solar). Solar Energy.

ABSORPTIMETRY. A method of instrumental analysis, frequently chemical, in which the absorption (or absence thereof) of selected electromagnetic radiation is a qualitative (and often quantitative) indication of the chemical composition or other characteristics of the material under observation. The type of radiation utilized in various absorption-type intruments ranges from radio and microwaves through infrared, visible, and ultraviolet radiation to x-rays and gamma rays. See also **Analysis (Chemical);** and **Spectro Instruments.**

ABSORPTION COEFFICIENT. 1. For the absorption of one substance or phase in another, as in the absorption of a gas in a liquid, the absorption coefficient is the volume of gas dissolved by a specified volume of solvent; thus a widely used coefficient is the quantity α in the expression $\alpha = V_0/Vp$, where V_0 is the volume of gas reduced to standard conditions, V is the volume of liquid and p is the partial pressure of the gas.

2. In the case of sound, the absorption coefficient (which is also called the acoustical absorptivity) is defined as the fraction of the incident sound energy absorbed by a surface or medium, the surface being considered part of an infinite area.

3. In the most general use of the term absorption coefficient, applied to electromagnetic radiation and atomic and sub-atomic particles, it is a measure of the rate of decrease in intensity of a beam of photons or particles in its passage through a particular substance. One complication in the statement of the absorption coefficient arises from the cause of the decrease in intensity. When light, x-rays, or other electromagnetic radiation enters a body of matter, it experiences in general two types of attenuation. Part of it is subjected to scattering, being reflected in all directions, while another portion is absorbed by being converted into other forms of energy. The scattered radiation may still be effective in the same ways as the original, but the absorbed portion ceases to exist as radiation or is re-emitted as secondary radiation. Strictly, therefore, we have to distinguish the true absorption coefficient from the scattering coefficient; but for practical purposes it is sometimes convenient to add them together as the total attenuation or extinction coefficient.

If appropriate corrections are made for scattering and related effects, the ratio I/I_0 is given by the laws of Bouguer and Beer. Here, I_0 is the intensity or radiant power of the light incident on the sample and I is the intensity of the transmitted light. This ratio $I/I_0 = T$ is known as the transmittance. See also **Spectrochemical Analysis (Visible).**

ABSORPTION CURVE. The graphical relationship between thickness of absorbing material or concentration of dissolved substance and intensity of transmitted radiation.

ABSORPTION DISCONTINUITY. A discontinuity appearing in the absorption coefficient of a substance for a particular type of radiation when expressed as a function of the energy (or frequency or wavelength) of this radiation. An absorption discontinuity is often associated with anomalies in other variables such as the refractive index. See **Anomalous Dispersion.**

ABSORPTION DYNAMOMETER. Dynamometer.

ABSORPTION EDGE. The wavelength corresponding to an abrupt discontinuity in the intensity of an absorption spectrum, notably an x-ray absorption spectrum, which gives the appearance of a sharp edge in the photograph of such a spectrum.

ABSORPTION (Energy). The process whereby the total number of particles emerging from a body of matter is reduced relative to the number entering as a result of interaction of the particles with the body. Also, the process whereby the kinetic energy of a particle is reduced while traversing a body of matter. This loss of kinetic energy or radiation is also referred to as moderation, slowing, or stopping. See also **Blackbody.** The absorption of mechanical energy by dynamometers, which convert the mechanical energy to heat or electricity, has led to the use of the term "absorption dynamometer" to distinguish these machines. See also **Dynamometer.** In acoustics, absorption is the process whereby some or all of the energy of sound waves is transferred to a substance on which they are incident or which they traverse.

ABSORPTION (Infrared). Infrared Radiation.

ABSORPTION LAWS. Spectrochemical Analysis (Visible).

ABSORPTION (Physiology). The process by which materials enter the living substance of which the organism is composed. Materials including food and oxygen are taken into special organs by ingestion and respiration, but they must pass through the cell wall to become an integral part of the organism by absorption. The basic physical forces involved are those of osmosis and diffusion.

ABSORPTION (Process). Absorption is commonly used in the process industries for separating materials, notably a specific gas from a mixture of gases; and in the production of solutions such as hydrochloric and sulfuric acids. Absorption operations are very important to many air pollution abatement systems where it is desired to remove a noxious gas, such as sulfur dioxide or hydrogen sulfide, from an effluent gas prior to releasing the material to the atmosphere. The absorption medium is a liquid in which (1) the gas to be removed, i.e., absorbed is soluble in the liquid, or (2) a chemical reaction takes place between the gas and the absorbing liquid. In some instances a chemical reagent is added to the absorbing liquid to increase the ability of the solvent to absorb.

Wherever possible, it is desired to select an absorbing liquid that can be regenerated and thus recycled and used over and over. An example of absorption with chemical reaction is the absorption of carbon dioxide from a flue gas with aqueous sodium hydroxide. In this reaction, sodium carbonate is formed. This reaction is irreversible. However, continued absorption of the carbon dioxide with the sodium carbonate solution results in the formation of sodium acid carbonate. The latter can be decomposed upon heating to carbon dioxide, water, and sodium carbonate and thus the sodium carbonate can be recycled.

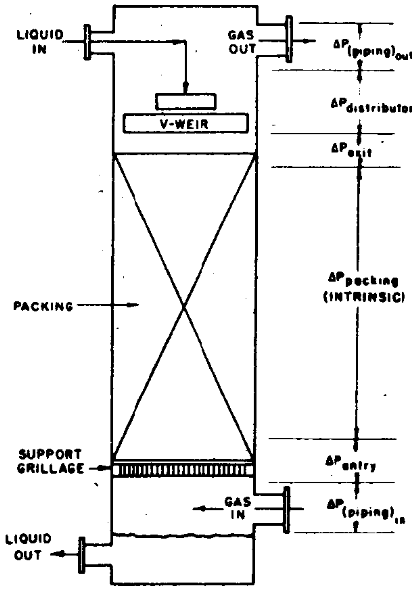


Fig. 1. Section of representative packed absorption tower.

Types of equipment used for absorption include (1) a packed tower filled with packing material, absorbent liquid flowing down through the packing (designed to provide a maximum of contact surface), and gas flowing upward in a countercurrent fashion; (2) a spray tower in which the absorbing liquid is sprayed into essentially an empty tower with the gas flowing upward; (3) a tray tower containing bubble caps, sieve trays, or valve trays; (4) a falling-film absorber or wetted-wall column; and (5) stirred vessels. Packed towers are the most commonly used.

A representative packed-type absorption tower is shown in Fig. 1. In addition to absorption efficiency, a primary concern of the tower designer is that of minimizing the pressure drop through the tower. The principal elements of pressure drop are shown at the right of the diagram. Important to efficiency of absorption and pressure drop is the type of packing used. As shown by Fig. 2, over the years numerous types of packings (mostly ceramic) have been developed to meet a wide variety of operating parameters. A major objective is that of providing as much contact surface as is possible with a minimum of pressure drop. Where corrosion conditions permit, metal packing sometimes can be used. Of the packing designs illustrated, the berl saddles range in size from 1/4 inch up to 2 inches; raschig rings range from 1/4 inch up to 4 inches; lessing rings range from

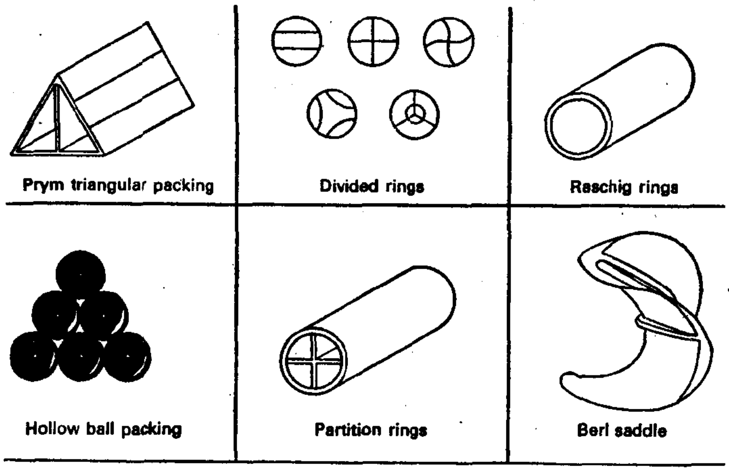


Fig. 2. Types of packing used in absorption towers.

1 inch up to 2 inches; partition and spiral rings range from 3 inches up to 6 inches, when grouped as shown.

In operation, the absorbing liquid is pumped into the top of the column where it is distributed by means of a weir to provide uniform distribution of the liquid over the underlying packing. Gas enters at the base of the tower and flows upward (countercurrent with the liquid) and out the top of the tower. The liquid may or may not be recycled without regeneration, depending upon the strength of the absorbent versus the quantity of material (concentration) in the gas to be removed. In a continuous operation, of course, a point is reached where fresh absorbing liquid must be added.

It is interesting to note that over 100,000 of the 1/4-inch size packing shapes will be contained in each cubic foot of tower space if dense packing is desired.

In the purification of natural gas, the gas is fed into the bottom of an absorption tower where the gas is contacted countercurrently by a lean absorption oil. Hydrochloric acid is produced by absorbing gaseous hydrogen chloride in water, usually in a spray-type tower. Unreacted ammonia in the manufacture of hydrogen cyanide is absorbed in dilute sulfuric acid. In the production of nitric acid, ammonia is catalytically oxidized and the gaseous products are absorbed in water. The ethanolamines are widely used in scrubbing gases for removal of acid compounds. Hydrocarbon gases containing hydrogen sulfide can be scrubbed with monoethanolamine, which combines with it by salt formation and effectively removes it from the gas stream. In plants synthesizing ammonia, hydrogen and carbon dioxide are formed. The hydrogen can be obtained by countercurrently scrubbing the gas mixture in a packed or tray column with monoethanolamine which absorbs the carbon dioxide. The latter can be recovered by heating the monoethanolamine. In a non-liquid system, sulfur dioxide can be absorbed by dry cupric oxide on activated alumina, thus avoiding the disadvantages of a wet process. Sulfuric acid is produced by absorbing sulfur trioxide in weak acid or water.

ABSORPTION SPECTROMETRY. **Spectro Instruments.**

ABSORPTION SPECTRUM. The spectrum of radiation which has been filtered through a material medium. When white light traverses a transparent medium, a certain portion of it is absorbed, the amount varying, in general, progressively with the frequency, of which the absorption coefficient is a function. Analysis of the transmitted light may, however, reveal that certain frequency ranges are absorbed to a degree out of all proportion to the adjacent regions; that is, with a distinct selectivity. These abnormally absorbed frequencies constitute, collectively, the "absorption spectrum" of the medium, and appear as dark lines or bands in the otherwise continuous spectrum of the transmitted light. The phenomenon is not confined to the visible range, but may be found to extend throughout the spectrum from the far infrared to the extreme ultraviolet and into the x-ray region.

A study of such spectra shows that the lines or bands therein accurately coincide in frequency with certain lines or bands of the emission spectra of the same substances. This was formerly attributed to resonance of electronic vibrations, but is now more satisfactorily explained by quantum theory on the assumption that those quanta of the incident radiation which are absorbed are able to excite atoms or molecules of the medium to some (but not all) of the energy levels involved in the production of the complete emission spectrum.

A very familiar example is the spectrum of sunlight, which is crossed by innumerable dark lines—the Fraunhofer lines—from which so much has been learned about the constitution of the sun, stars, and other astronomical objects.

A noteworthy characteristic of selective absorption is found in the existence of certain anomalies in the refractive index in the neighborhood of absorption frequencies; discussed under **Dispersion (Radiation).**

References

Bauman, Robert P.: "Absorption Spectroscopy," Wiley, New York, 1962.
Harrison, George R., Lord, Richard C., and John R. Loofbourow: "Practical Spectroscopy," Prentice-Hall, Englewood Cliffs, N.J., 1948.
Evans, Ralph M.: "An Introduction to Color," Wiley, New York, 1948.
Jenkins, Francis A. and Harvey E. White: "Fundamentals of Physical Optics," 3rd edition, McGraw-Hill, New York, 1957.
Stearns, E. I.: "Practice of Absorption Spectrophotometry," Wiley, New York, 1969.
Harrick, N. J.: "Internal Reflection Spectroscopy," Wiley, New York, 1967.

ABSORPTIVITY (Optical). If A is the absorbance of a solution b cm. in thickness and at a concentration c, the absorptivity is $a = A/bc$. See also **Beer's Law.**

ABUNDANCE OF CHEMICAL ELEMENTS. **Chemical Elements.**

ABUNDANCE RATIO. The proportions of the various isotopes making up a particular specimen of an element. See **Chemical Elements.**

ABYSSAL HILLS. Small hills up to several hundred feet in height that occupy the ocean floor. These may be nearly isolated or may occupy virtually the whole floor. See **Abyssal Plain.**

ABYSSAL PELAGIC ZONE. The lowest layer of water in the oceans. It is not penetrated by sunlight.

ABYSSAL PLAIN. An area on the ocean floor having a flat bottom and a very slight slope of less than 1 part in 1000. It is believed that these very flat surfaces arise from the continued deposition of mud and silt from turbidity currents. See **Ocean. Seismographic** studies support that these surfaces consist of such deposits. Mid-ocean canyons may be found on these abyssal plains; these are flat-bottomed depressions in the plains, varying from one to several miles in width and varying in depth up to several hundred feet. These, too, are believed to be the product of certain turbidity currents.

ABYSSAL ROCKS. Proposed by Brögger as a general term for deep-seated igneous rocks, or those which have crystallized from magmas far below the surface of the earth, very slowly and under great pressure. Granite is a typical abyssal rock. The term plutonic is synonymous.

ABYSSAL ZONE. The region of the ocean beyond the point of penetration of light, including the ocean floor in the deep areas. According to various investigators who have descended into the ocean depths, no light penetrates beyond about 1,500 feet, and penetration may be much less if the water is murky with suspended particles. The water is always extremely cold in the abyssal zone and the pressure is very great. Still many forms of animal life are to be found at these great depths, feeding upon the organic matter which drifts down from the upper waters.

Abyssal animals fall into two groups: *scavengers*, living on the shower of organic matter, and *predators*, which prey upon the scavengers or upon each other. The most abundant deep-sea animals are the sea cucumbers, snails, crustaceans, tunicates, cephalopods, and fish. The predaceous fish have large mouths filled with long, sharp teeth, and stomachs capable of great stretching; they are actually known to swallow fish larger than themselves. Many of the fish have a lure with a light on the end which attracts prey. Others have rows of light-producing organs on the sides of their bodies. Other animals with light-producing organs are coelenterates, echinoderms, annelids, crustaceans, and cephalopods. It is believed that the lights not only help these animals in finding food, but also in finding each other during the reproductive season. See also **Ecology; Ocean**.

ACACIA SENEGAL. **Gums.**

ACACIA TREES. Of the family *Leguminosae* (pea family), the genus *Acacia* represents a large number of mostly evergreen trees and shrubs, particularly abundant in Africa and Australia. The trees like warmth and full sun. The small flowers are aggregated into ball-like or elongate clusters, which are quite conspicuous. The leaves are rather diverse in shape; quite commonly they are dissected into compound pinnate forms; in other instances, especially in the Australian species, they are reduced even to a point where only the flattened petiole, called a phyllode, remains. This petiole grows with the edges vertical, a fact which some observers consider a protective adaptation against too intense sunlight on the surface. Some species, particularly those growing in Africa and tropical Asia, yield products of commercial value. Gum arabic is obtained from the *Acacia senegal*. A brown or black dye called clutch is obtained from *A. catechu*. Some acacias are used for timber. Shittinwood referred to in the scriptures, "And thous shalt make staves of shittinwood and overlay them with gold," (Exodus 26: 26–37), is considered by authorities as wood from *Acacia seyal* (then referred to as the shittah tree).

Certain tropical American species are of particular interest because of the curious pairs of thorns, which are united at their base. These thorns are often hollowed out and used as nests by species of stinging ants. The leaves of some species, notably *Mimosa pudica*, are sensitive to the touch. The mimosa tree or silver wattle, native to Australia, is the *Acacia dealbata*. The leaves are fern-like and of a silver-green coloration. They attain a height of about 50 feet within 20 years, prefer full sun, and can be severely damaged by prolonged frosts. The tree has been introduced into warm regions of other parts of the world and has done well. The so-called catclaw acacia (*A. greggii*) has done well in southwestern United States. One specimen, selected by The American Forestry Association for its "Social Register of Big Trees," is located at Red Rock, New Mexico. The circumference at 4-1/2 feet above the base is 6 feet, 5 inches; the height is 49 feet; and the spread is 46 feet.

A. baileyana, also a native of Australia, is known as the Cootamundra wattle or Bailey's mimosa. It attains a height of 20 feet or more, has long, narrow, waxy evergreen leaves of a silver-green color. The contour of the tree is often weeping.

The *Robinia pseudoacacia*, also referred to as black locust, common acacia, or false acacia, is found in the eastern United States. The tree is highly tolerant of dryness and industrial environments. This tree may attain a height of from 60 to 80 feet, with a trunk diameter up to 4 feet. It is a highly favored tree for gardens, often described as graceful and decorative.

ACANTHOCEPHALA (Thorny-Headed Worms). Worms, slender and hollow (pseudocoelom) with recurved hooks on invaginate proboscis, no digestive tracts, and adults parasitic in intestine of vertebrates with larva in intermediate arthropod host. They are usually regarded as a class of roundworm (*Nemathelminthes*), but ranking as a separate phylum is now favored.

ACANTHUS. Genus of the family *Acanthaceae* (acanthus family). This is a relatively small genus of Mediterranean plants grown mainly for ornamental purposes. The flowers are white or various shades of red. The term *ancanthus* also is used in architecture with reference to an ornamental design patterned after the leaves of the acanthus.

ACARINA. The order of *Arachnida* which includes the mites and ticks.

ACCELERATED FLIGHT (Airplane). When the velocity of an airplane along its flight path contains elements of acceleration, the structure receives increments of inertial or dynamic loading that may prove to be far more severe upon the structure than the loading imposed by the static weight of the airplane and its contents. Consequently, accelerated flight has been the subject of extensive analytical and experimental investigation. Acceleration of rectilinear velocity below the speed of sound, as by increasing the thrust of the power plant in straight level flight, is of small import, since radial accelerations resulting from curvilinear flight at constant speed are so large as to be the critical influence. Cases of curved flight paths capable of accelerations of several g (acceleration due to gravity, i.e., 32.2 feet/second^2) are quick pull-ups (or "zooms") from high-speed rectilinear flight, spins, steeply banked turns, and loops. The magnitude of the effect of accelerated flight is well illustrated by considering the centrifugal force on an airplane following a curved flight path in the vertical plane. With a constant tangential speed as low as 120 mph, the airplane experiences a radial acceleration of 4 g (4 times the acceleration of gravity) even though the radius of curvature be about 240 feet. See **Load Factor**.

An acceleration also is caused when the airplane encounters a gust.

ACCELERATION. The rate of change of the velocity with respect to the time is called acceleration. It is expressed mathematically by $d\mathbf{v}/dt$, the vector derivative of the velocity, $\mathbf{v}$ with respect to the time, t. If the motion is in a straight line whose position is clearly understood, it is convenient to treat the velocity v and the acceleration dv/dt as scalars with appropriate algebraic signs; otherwise they must be treated by vector methods.

Acceleration may be rectilinear or curvilinear, depending upon whether the path of motion is a straight line or a curved line. A body which moves along a curved path has acceleration components at every point. One component is in the direction of the tangent to the curve and is equal to the rate of change of the speed at the point. For uniform circular motion this component is zero. The second component is normal to the tangent and is equal to the square of the tangential speed divided by the radius of curvature at the point. This normal component, which is directed toward the center of curvature, also equals the square of the angular velocity multiplied by the radius of curvature. The acceleration due to gravity is equal to an increase in the velocity of about 32.2 feet/second/second at the earth's surface and is of prime importance since it is the ratio of the weight to the mass of a body. For examples of acceleration in both curved and linear motion, see **Kinematics**. See also **Angular Velocity and Angular Acceleration**.

ACCELERATION (Due to Gravity). The universal character of the gravitational force for point masses or spherical bodies can be expressed by the equation:

$$F = \frac{GM_1M_2}{R^2}, \qquad (1)$$

where

M_1, M_2 = masses of two bodies

R = distance between two bodies

G = a constant = 6.670×10^{-8} dyne cm^2 gm^{-2}

The constant G is independent of all properties of the particular bodies involved.

VARIATION OF ACCELERATION DUE TO GRAVITY ON EARTH WITH LATITUDE (At Sea Level)

Latitude	g centimeters/(second)^2	g feet/(second)^2
0°	977.989	32.0862
10°	978.147	32.0916
20°	978.600	32.1062
30°	979.295	32.1290
40°	980.147	32.1570
50°	981.053	32.1867
60°	981.905	32.2147
70°	982.600	32.2375
80°	983.053	32.2523
90°	983.210	32.2575

The weight of a body of mass M on the earth is the force with which it is attracted to the center of the earth. On the surface of the earth, the weight is given by:

$$W = Mg, \qquad (2)$$

where the acceleration due to gravity is obtained from Equation (1):

$$g = \frac{GM_E}{R_E^2}$$
$$= 980.665 \text{ cm/(second)}^2$$
$$= 32.174 \text{ feet/(second)}^2 \qquad (3)$$

Variation of the acceleration due to gravity at sea level for different latitudes on earth is given in the accompanying table.

Using the gravity of earth as unity, the gravity at the surface of the sun, moon, and planets is approximately:

Moon	0.16
Mercury	0.38
Mars	0.39
Venus	0.88
Earth	1.00
Uranus	1.05
Saturn	1.17
Neptune	1.23
Jupiter	2.65
Sun	27.9

See also **Gravitation.**

ACCELERATION (Gravitational). Gravitation.

ACCELERATION MEASUREMENT. Acceleration cannot be measured directly, but must be computed by measuring the force exerted by restraints that are placed on a mass to hold its position fixed in an accelerating body. The relationship between restraint and acceleration is defined by Newton's second law, namely, force = mass X acceleration.

A very simple form of accelerometer is the spring-restrained mass as shown in Fig. 1. The principal components are a constant seismic mass, a calibrated restraint, a support bearing, and a pickoff. Displacement of the mass must occur before the pickoff will work. Thus, a transient error is introduced during the time the mass is acquiring displacement. The mathematical relationships that pertain to the classical spring-mass device are shown in Fig. 2.

In order to reduce the transient error, developments have been undertaken to increase the stiffness of the system. Because of increased stiffness, low displacements result, requiring much more sensitive pickoffs and also pickoffs that operate over a smaller range. The useful output then becomes the restraint upon the mass. A basic servoed accelerometer is shown in Fig. 3; and the relevant block diagram and mathematical relationships are given in Fig. 4. The pickoff simply detects small changes in mass position and commands a proportional change in a current which is sent through the force generator. This current is used as a direct measure of restraining force. The accuracy of this current measurement depends upon maintaining the magnetic field around the forcer coil constant. Any forces of an extraneous nature acting on the mass will cause an erroneous reading of acceleration. Hence, elimination of such forces often demands sophisticated designs.

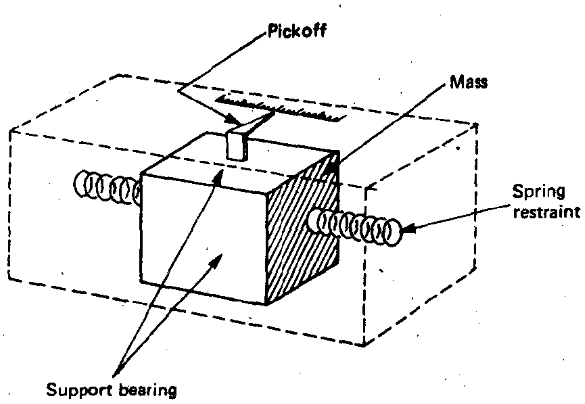
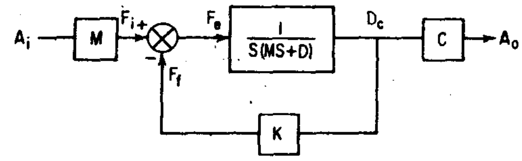


Fig. 1. Accelerometer based on a spring-restrained mass.



K = spring constant
C = readout device characteristic, e.g., volts/inch for a potentiometric pickoff excited by a fixed voltage

Transfer function is

$$\frac{A_O(s)}{A_i(s)} = \frac{MC/K}{(M/K)S^2 + (D/K)S + 1}$$

or

$$\frac{A_O(s)}{A_i(s)} = \frac{C/\omega_n^2}{(S^2/\omega_n^2) + 2\zeta(S/\omega_n) + 1}$$

where ω_n = the undamped natural frequency
ζ = the damping ratio D/DC

Fig. 2. Technical description of classical spring-mass accelerometer.

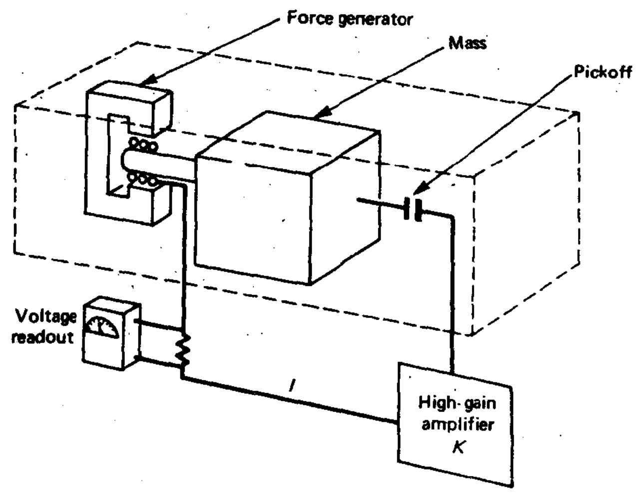
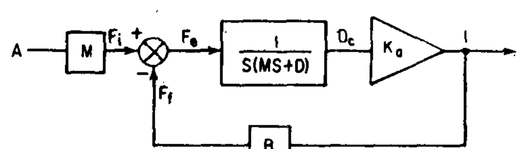


Fig. 3. Simple servoed accelerometer.



Transfer function is

$$\frac{I(s)}{A(s)} = \frac{M/B}{(M/K_aB)S^2 + (D/K_aB)S + 1}$$

or

$$\frac{I(s)}{A(s)} = \frac{M/B}{(S^2/\omega_n^2) + 2\zeta(S/\omega_n) + 1}$$

Fig. 4. Technical description of servoed accelerometer.

Types of Accelerometers. A convenient classification of accelerometers, based upon basic operating principles used, is:

(1) *Dynamic-Acceleration (Vibration) Instruments.* Included in this class are crystal types of accelerometers that do not respond to static acceleration. Devices of this type are used mainly in the control of vibration-test systems and in the monitoring of localized vibration response on an item under test.

(2) *Nonservoed Static and Dynamic Instruments.* Included are strain-gage devices and spring-mass units with either potentiometric or inductive pickoffs. The devices are used in instrumentation and control systems. They have an accuracy of from 1 to 5%, depending mainly on the ambient temperature.

(3) *Servoed Static and Dynamic Instruments.* Included are the

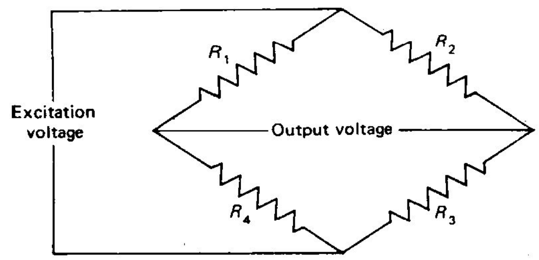


Fig. 5. Bridge of strain-gage accelerometer.

active devices that essentially measure the force required to accelerate the proof mass with the case rather than measure the deflection of the mass at the end of a spring. Servoed devices of this type are usually accurate within $\pm 0.1\%$, although in some designs and under adverse ambient conditions the accuracy may be much poorer.

(4) *Gyroscopic Instruments.* These devices are used for navigation and guidance applications where the acceleration signal is integrated twice to obtain distance traveled. Accuracies obtainable are ± 0.001 to 0.01%. This higher accuracy is attainable because inertia can be increased by spinning the proof mass and making use of gyroscopic-precession principles.

Velocity meters and vibrating-string accelerometers would fall into a special class of accelerometers.

Strain-Gage Accelerometer. In this device, the strain in a material whose stress is used to provide the rebalance force of an accelerometer mass is measured. Accuracy depends on linearity of stress and

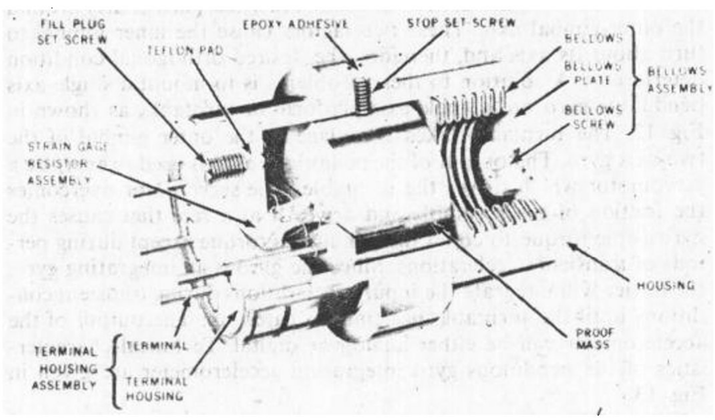


Fig. 6. Single-crystal silicon beam is used in this strain-gage accelerometer to obtain linear stress versus strain. (*Honeywell*)

strain in the material. In a strain-gage accelerometer, the moving mass causes the resistance to increase in two resistive elements and to decrease in two resistive elements. The elements are placed in a bridge arrangement to provide an output that is proportional to acceleration. See Fig. 5. In the accelerometer shown in Fig. 6, a single-crystal silicon beam is used to obtain linear stress versus strain. Two piezoresistive strain elements are diffused into both sides of the beam to provide the basic sensing elements. Interconnection of the four elements into an electric bridge permits measurement of beam stress as a function of acceleration input. Locating two elements on one side of the beam and two elements on the opposite side provides

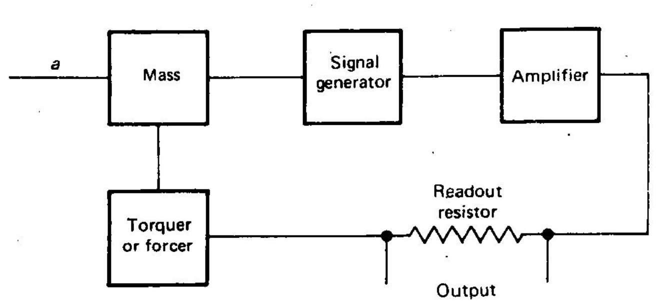


Fig. 7. Force-balance hinged-pendulum accelerometer. a = response to an acceleration.

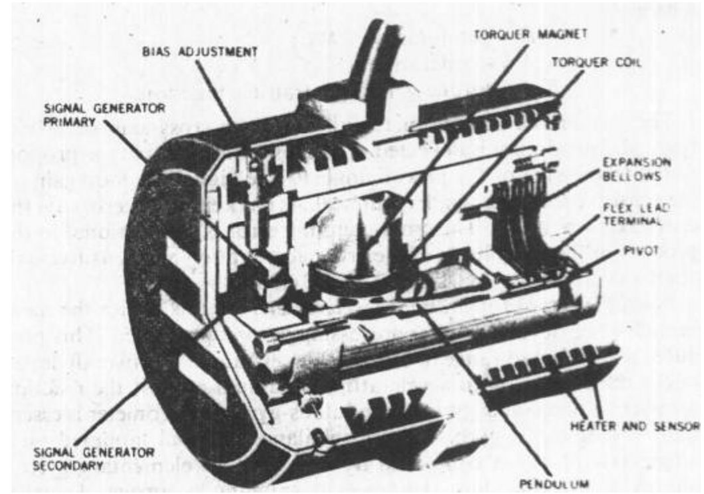


Fig. 8. Force balance accelerometer. No external amplifier. (*Honeywell*)

a bridge wherein the resistance of two elements increases while the resistance of the other two elements decreases when acceleration is applied. Accelerometers of this type are used for control and stabilization.

Force-Balance Hinged-Pendulum Accelerometer. The force-balance unit includes a torquer or forcer which performs the function of restraining the mass near its null position. The device is used with external electronics to provide the appropriate gain or amplification. A block diagram of the unit is given in Fig. 7. A force-balance accelerometer without external amplifier is shown in Fig. 8. The small pendulous mass is supported on a pair of flexural pivots. The pivots deflect freely in one axis, but are highly resistant to displacement in the other axis, thus reducing cross-coupling errors. Torque rebalance of the pendulum is accomplished by two permanent-magnet torquing elements operating in a push-pull manner. A moving-coil pickoff element is used. The device is filled with fluid to provide viscous damping of the pendulous element and to provide

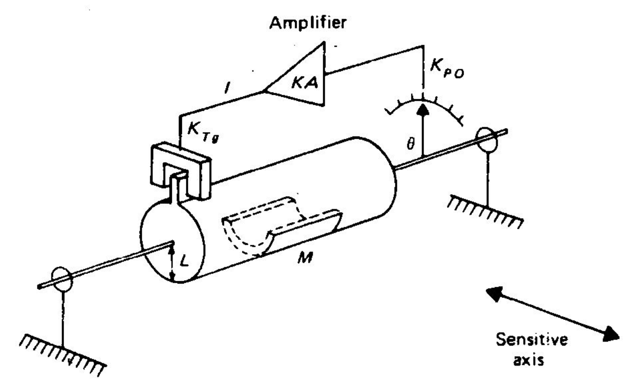


Fig. 9. Operating principle of pendulous accelerometer.

resistance to high vibration and shock. Accelerometers of this type are used for inertial navigation and are capable of sensing acceleration of less than micro-g's.

Pendulous Accelerometer. The effort to reduce friction has led to pendulous accelerometers which use rotational bearings. By floating the pendulum, the bearing loads also have been reduced. One advantage of the pendulous accelerometer is its cross-axis suspension. This is usually achieved by floating a pendulous cylinder in a viscous heavy liquid. The cylinder is pivoted on its axis and is pendulous about it. Because the cylinder is floated, cross-axis accelerations do not displace it. Some damping is also provided by the flotation liquid. Operating principles of the device are shown in Fig. 9. Acceleration along the sensitive axis causes deflection of the pendulum. The pickoff senses this, after which the signal is amplified and applied to a torquer in a direction to reduce the deflection. Response is given by:

$$A = \frac{IK_{T}}{P}$$