Hardness and Hardening*

An Important Property Not Yet Satisfactorily Delimited

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HARDNESS is a property which is of great importance in connection with the practical uses of metals. This is evidenced by the numerous methods which have been introduced from time to time for testing hardness, and also by the abundant literature which has been published on the subject. The latest contribution to this study is a "Report of the Hardness Test Research Committee of the Institution of Mechanical Engineers" (November, 1916), in connection with which a bibliography has been prepared. I have been privileged to assist in the preparation of this bibliography, which contains references to some 131 papers and other publications dealing with hardness and hardness tests. Even this list does not touch the question of hardening, which has been discussed by Sir George Beilby, Professor Edwards, Mr. McCance, the present writer, and many others. To the report above mentioned three appendices are attached, which give the views on the nature of hardness of Professor Unwin, Sir R. Hadfield, and Dr. Tutton respectively. From these appendices, which are of great interest, it is evident that the members of the committee, and those who took part in the discussion, are not agreed upon the fundamental conceptions as to the nature and definitions of that which they were endeavoring to measure.

Definitions and Measurement of Hardness.—It has been frequently stated that hardness is a property which cannot be measured or readily defined. This is merely another way of saying that we have not made up our minds as to what we mean by the term "hardness," for there is little difficulty in framing a definition when once a clear mental conception is reached. That which can be accurately defined is capable of measurement.

Though so eminent an authority as the late M. F. Osmond has used the word "measurement" in connection with hardness tests—see report *Sur la Dureté: sa définition et sa mesure*, Paris, 1892—physicists appear to have pretty generally expressed the view that hardness cannot be measured. Professor H. Le Chatelier, in discussing the "Report of the Hardness Tests Research Committee" (page 777), admirably states this view as follows: "Two simple characteristics determined whether a quantity might be measured or not. If measurable, it should satisfy the laws of equivalence and accumulation. Temperature, though it followed the law of equivalence, did not follow that of accumulation. For instance, two bodies raised to the same temperature would not give a higher temperature if brought together. So that temperature could not be measured—all that could be done was to register it on certain scales. . . . Hardness was exactly the quantity which followed neither the law of equivalence nor that of accumulation."

It may be dangerous for one who can make no claim to be a physicist to differ from so recognized an authority as Professor Le Chatelier. On the other hand, it may be inconvenient to take words which have been familiar for centuries, and to endeavor to limit their application to the specialized uses of modern science. In the present instance it may be pointed out that a property is not necessarily a quantity; and it would scarcely be urged that hardness is a quantity in the sense of the physicist. Further, it may be remembered that the word "measure" has a much wider use in our language than is suggested by the laws of equivalence and accumulation.

What we require for practical purposes, is to be able to register hardness on a numerical scale, just as we do density, tenacity, viscosity, or other properties. For example, we determine relative density; it does not follow the law of accumulation, because if two bodies of the same density are brought together the density is not doubled—unless they are gases which can be compressed into half their original space. The determination is accurate, and similar results are obtained on repetition. Shall we say the density has been measured; or has it only been registered or determined? To the physicist the choice of a word here may be important. But the ordinary reader might be misled if he were told that the density, or the elastic limit, of a metal cannot be measured.

The definition which I myself prefer is that hardness is the property whereby a body is able to penetrate another body; and conversely, it is the property whereby a body resists being itself penetrated. This does not materially differ from the definition proposed by M. Osmond in 1892, that hardness is "resistance to permanent deformation." Sir Robert Hadfield's definition is simply "resistance to deformation." From the mechanical aspect, hardness, as so defined, will closely correspond with the "yield

point" or "breaking-down point" of the material. In ductile materials, such as relatively pure metals, of which mild steel is an example, the yield point is often roughly proportional to the ultimate tensile strength. In such cases the hardness, as measured by the stress per unit of area required to produce penetration, is less than, but varies with, the tenacity. In brittle materials the yield point and the ultimate strength are practically identical: in such cases tenacity and hardness will nearly coincide. The hardness may, however, exceed the tenacity, since in a tensile test the particles are drawn away or separated from each other, while in a penetration test there is a certain amount of "backing" in the material, which tends to support the penetrating body.

With penetration tests, such as those of Brinell, in which an appreciable quantity of metal is displaced, the true hardness is not obtained, since the displaced material becomes more or less work-hardened, and another similar test on the same spot will not give the same result. The difference may, however, not be large. In wearing tests the polishing, and consequent hardening, of the rubbing surfaces on the one hand, or their disintegration on the other, may lead to quite erroneous conclusions. Theoretically, the production of a scratch of standard width, and of indefinite thinness, with the employment of an ascertained weight, would appear to most nearly meet the ideal conception. For practical purposes the requirement of a smooth surface, and the difficulty of accurately deciding the character of the scratch, has prevented the extensive use of scratching tests by engineers, though such tests are still preferred by mineralogists and other workers. The conception underlying the Brinell test is a simple one—namely, that a unit of surface will just maintain a stated pressure before being deformed. So long as the amount of deformation of the sample is not excessive, and provided the body to be tested is not brittle, the Brinell hardness number closely corresponds with true physical hardness.

Resistance to Wear.—For many purposes, however, the engineer does not really require hardness, though he asks for it. What he does desire is resistance to wear, or to deformation, or some other property or combination of properties which are of importance for the particular purpose he has in view. Thus, if we consider a wearing or grinding test, it is necessary, if the metal is not to wear away quickly, (1) that the particles on the surface shall not be readily displaced, and (2) that the particles so displaced shall not be readily removed. Both conditions are necessary; either alone is not sufficient. Substances which are really hard do not permit of their particles being readily displaced—hence they wear well. Plastic metals do not permit of their displaced particles being readily removed—hence they, too, may give good wearing surfaces, though they are really very soft. The wearing properties of manganese steel, for instance, would appear to be due to two causes: (1) The relatively high natural hardness of the material itself; (2) the fact that the particles which are displaced from the surface do not come away and form a powder, but are plastically spread over other parts of the surface; they are thus capable of being repeatedly displaced, and are work-hardened before being ultimately lost.

A number of unfortunate terms have been introduced during the last few years, such as "tensile hardness," "wearing hardness," "elastic hardness," and so forth. These terms are misnomers. Thus tensile hardness is merely tenacity; but tenacity indirectly measured by some apparatus which is found to give results which, when multiplied by a suitable factor, are approximately the same as those obtained by the tensile testing machine. This term has been almost exclusively used in connection with tests of mild steel, such as is used for constructional purposes and for somewhat harder material as employed for rails. In such cases, as has been already pointed out, the true hardness is less than, though approximately proportional to, the ultimate tensile strength.

Hardness of Pure Metals.—If attention were confined to the pure metals in their cast, annealed, or unwrought condition, the question would be much simplified, for the hardness varies inversely as the atomic volume. In other words, the hardness increases as the number of atoms in a unit space increases. Mr. S. W. Smith has also shown that with liquid metals surface tension varies inversely as some function of the atomic volume,¹ while Dr. F. C. Thompson suggests that the elastic limit is dependent upon surface tension. Dr. Tutton has shown that with

a number of substances other than metals, the hardness varies as the molecular volume, provided always that similar materials are compared. Dr. Tutton has also pointed out that it may be anticipated in crystallized substances, owing to the arrangement of atoms in the crystals, there may be some differences of hardness in different directions in the same crystal.

It is frequently stated that pure metals are not to be obtained commercially; but it is worthy of remark how exceedingly pure some commercial samples of metal really are. Thus lead, tin, and zinc are sold by the ton with an analysis which shows 99.95 per cent of the respective metal, and only one part in two thousand of total impurity. But for the majority of purposes pure metals are too soft, and must be hardened in some way.

Methods of Hardening.—There are three methods whereby the hardness of a pure metal may be increased: (1) by alloying; (2) by cold working; (3) by chilling.

Chilling may be regarded as a combination or variation of the first two methods. It may lead to the setting up of internal strains, which really produce the effect of cold work; or it may change the chemical composition of an alloy by causing some constituent to remain in solution, or even prevent a constituent from going into solution. The hardening of steel, and the softening of certain bronzes, by chilling, are examples of this effect on internal composition. Ultimately, therefore, metals or alloys can only be hardened by a change of composition or by strain.

When we add to one metal another metal, or other element, and allow the product to solidify, the result is a mixture, a compound, an eutectic, or a solid solution. The useful ductile alloys are, almost without exception, solid solutions. Since this fact has been recognized, special attention has been given to the nature and properties of metallic solid solutions, and some important generalizations are now fairly well known.²

Hardness of Solid Solution.—As we pass from either end of a series of solid solutions towards the center of the series it will be found that the hardness, the limit of elasticity, and the tensile strength increase, but the ductility—as measured by the extension and the reduction of area—and the electrical conductivity decrease. The melting point usually changes fairly regularly throughout the series. These facts for a series of solid solutions of a metal A, and any other metal, metallic compound, or non-metal B, which forms a series of solid solutions with the metal A, may be diagrammatically represented in the simplest possible manner, as in Fig. 1.

If a series of solid solutions be interrupted by the presence of compounds, or of eutectics, these will be indicated by irregularities in the hardness and other physical properties, at such points as correspond with the end of the series in the respective cases.

It will thus be seen that it is possible to harden either constituent by addition of moderate proportions of the other. At the same time the material becomes less ductile—in other words, more brittle. A point is frequently reached at which the tenacity can no longer be increased with safety, owing to the continued increase in brittleness. But the metals we add do not necessarily diminish the ductility in their alloys at the same rate as they increase the tensile strength. For example, nickel, copper, manganese, or chromium may be added to steel in such proportions that the improvement in tenacity is much greater than the deterioration in ductility. Hence the application of such metals, in suitable proportions, in steels for special purposes.

In the copper alloys the same general principles are adopted. The proportion of zinc which can be added to copper, in order to strengthen it, is limited by the loss of ductility, having regard to the purpose in view. For ductile bronzes, as is well known, the limit of zinc is usually about 30 per cent. Small quantities of iron or of manganese may increase the tenacity more rapidly than they deteriorate the ductility. Of this we have examples in the manganese and iron bronzes.

It is stated in the "Ninth Report of the Alloys Research Committee"—page 133—that the effect of adding manganese to an alloy of copper and aluminium was to raise its yield and tensile strength without reducing its ductility to a corresponding extent. With increased knowledge of the effects produced by relatively small additions of the less common metals to our alloys, it is

²See Kurnakow and Shemtschushny, *Journal of the Russian Physical Chemical Society*, 1908, Vol. XI, page 1067, also Dr. Desch, "The Hardness of Solid Solutions," *Faraday Society Discussion*, 1914, page 46.

*Institute of Metals, September, 1917. Reported in *The Engineer*.

¹*Journal of the Institute of Metals*, No. 2, 1914, Vol. XII, page 206.

probable that a useful field will be opened for increasing their hardness without producing brittleness.³

Hardening by Cold Work.—Turning now to the hardening of metals by cold working, it is well known, to those interested in the wrought metal industries, that the effect of such processes upon the mechanical properties of many metals and alloys is remarkable. The yield point and tensile strength are raised, while the elongation and reduction in area—or ductility—are markedly lowered. The electrical conductivity is only slightly affected. Further work put upon the metal causes it to fracture. By suitable annealing the material may be rendered soft and ductile as before. The material in its wrought state not only has greater strength, but is also harder than the original metal or alloy. But when that hardness is measured by different instruments, such as the sclerometer, the scleroscope, or the Brinell tester, it is not found that the values obtained are in agreement. Hence the hardness produced by cold working is different in kind from that resulting from the alloying we have previously discussed.

It might, perhaps, be assumed that rolling, hammering, or pressing a metal would render it more dense, and that the observed increase of hardness is due to such added density. But any change of density due to mechanical processes is far too small to permit of being explained on the principle of atomic volume. Further, as a matter of fact, the change is ultimately in the opposite direction. The first result of pressure is to close up any pores, cracks, or blow-holes, and thus to increase the apparent density; hence bars are usually more dense than the ingots from which they have been rolled. The subsequent effect of cold working is to slightly but appreciably diminish the relative density of the worked material. It is important to consider how this change is brought about.

If a piece of metal be stressed to any extent below its elastic limit, and the stress is removed, the metal returns to its original form and volume, and no hardening results. But if the stress be increased, so that the elastic limit is passed, permanent stretching or strain results, and the metal becomes worked hard. This stretching or deformation occurs, as has been shown by Rosenhain and other workers, chiefly, if not entirely, by shearing slip along planes of internal crystal symmetry. It matters not whether the force be applied in the form of a pull of a tensile machine, a blow as from a hammer, or pressure as in a compression test; there is no hardening unless there has been shearing flow, and this flow generally, if not universally, results in a small but appreciable diminution of density.⁴ We may profitably inquire how this change of density originates.

Cause of Work Hardness.—If we imagine a solid crystal which is under strain, as a result of which shear occurs along a plane of crystal symmetry, it will be evident that at the moment the particles are pushed asunder and caused to slide upon each other, they were clinging to each other, and were separated only with difficulty, and by what we usually call a "pull" of sufficient strength. The materials thus clinging to each other, and forcibly separated, were in a state of tension. It would, therefore, appear that the intervening layer of "amorphous" material cannot be in a normal or unstrained condition, neither can it be in compression; it must, therefore, be in a state of tension. When a bar of metal is in tension it becomes longer, and the extension is proportional to the stress applied. But in such a case the bar becomes thinner as it elongates; so the extension must not be regarded as indicating any volume change. Yet doubtless there is a small, but nevertheless real, volume change when a bar is stretched or compressed. It is just as real as the expansion of a gas on reducing the pressure, though almost indefinitely smaller in amount. It is this volume change, due to tension, which leads to the observed diminution of density in wrought metals.

That diminution of density does result from cold working has been shown experimentally by many observers. Thus Brunton found that in drawing steel wire its specific gravity could be increased from 7.768 to 7.998 by cold work, but that when this point was reached further drawing caused the density to decrease. Kahlbaum has shown that the density of platinum wire is reduced from 21.43 to 21.41 by wire drawing. Lowry and Parker found that metallic filings are in a worked hard condition, and that by annealing their density increased. Professor Lea, of Birmingham, has found that the density of mild steel is diminished if it be subjected to compressive stress which leads to distortion. Lastly, it may be recalled that Professor Heyn, in his May Lecture,⁵ has proved that in

cold-rolled bars the outside is in tension and the inside in compression.

Hardness and Tension.—When steel, which contains carbon, is hardened by means of rapid cooling, it is well known that the density of the hard steel is less than that of the soft or annealed material. Hence Professor J. W. Langley suggested the hypothesis that hardness corresponds with a condition of internal tension, and softness with the absence of tension. H. E. Field,⁶ a little later, suggested that the hardening of iron is due to the particles being forced and held farther and farther apart, whether by heat or mechanical means. W. Metcalf, in discussing Field's paper, stated that cold working reduces specific gravity, while it increases the hardness, tensile, transverse and torsional strength. He has also proved by actual measurement and weighing, on a commercial scale, that the density of cold-rolled wrought iron bar was less than that of the original metal.

These tests were conducted at Messrs. Jones and Laughlin's works when Mr. Metcalf was acting as assistant to Major W. Wade. Specific gravity tests showed that the cold-rolled iron was less dense than the hot-rolled bars. Major Wade was so surprised with the results that he arranged for a number of samples to be weighed, without vouchsafing any reason. Mr. Metcalf's results agreed with those of Major Wade, but they were so contrary to what was then the general theory that further tests were made. Hot-rolled bars were pickled, cleaned, carefully measured, and the cubic contents calculated. They were then cold rolled and carefully measured, when it was found that the increase of length more than compensated for the reduction in diameter. Many similar examples could readily be found.

Films in Tension.—The conception of stretched layers existing between the particles of a cold worked metal, or at the surface of a polished metal, has led various thinkers and especially our President, Sir George Beilby, to recognize the similarity which must exist between such layers, and the surface tension with which we are familiar in liquids. This surface tension leads to the formation of so strong a skin upon water that a fly can walk upon it, or a greased needle float. But it would be unwise to assume, because there are some obvious similarities, that, therefore, all the laws which are applicable in the one case are equally true in the other.

It is evident that if a membrane is to be stretched there must be some body to which it can be attached, or to which it can adhere. The head of a drum is an illustration of this fact. In the case of a liquid drop the skin extends all around; but in other instances the film support is supplied by the sides of the containing vessel. It is interesting to inquire how the planes can remain stretched in a solid body, such as a cold worked metal.

If we could imagine the extreme case of the whole of the crystalline material being converted into the amorphous state, and all the planes being parallel to the length of the body, we should have an impossible condition, since all the layers would be in extension, with nothing to keep them extended. This could only exist with a body acting under external tensile stress. Such a body would be incapable of shearing strain; its yield point and its ultimate stress would coincide; it would be brittle like glass. Glass is brittle because there are no planes of shear. But in the case of a metal or alloy consisting of mixed crystals, differently oriented, strain leads to the production of a series of slip planes in each crystal aggregate. Adjoining areas, as viewed in a microscopic section, have their planes at various angles to each other, owing to the different arrangement of the component microcrystals in each crystal aggregate. These planes, or thin films of amorphous material, may be regarded as being held in tension either by the rigidity of the crystal envelope—or cement—or by the mass of the unchanged material, or by both of these. But in ordinary mechanical processes, such as rolling, hammering, or drawing, we have not to deal with a single deformation, and one set of shearing planes in each crystal grain. Deformation follows deformation, and planes are set up in many directions. These slip planes cross and recross each other, their direction being limited only by the necessities

⁵Bulletin of the American Institute of Mining Engineers, 1903, page 571.

of crystal symmetry. A section thus shows a network of crossing lines, each of which we assume to correspond with an extremely thin layer in tension. We have in such a section an intricate network, which is held together by tightly stretched strings or tapes, and supported by intervening, unaltered crystalline material. When we remember the great strength of a lattice girder, or of woven wire, we can more readily understand how these extremely thin layers of amorphous material, all of which are in tension, are able to confer great tenacity and hardness upon a worked ductile metal. The fact, referred to by Rosenhain, that metal which has been hardened against tension is softened against compression, is entirely in harmony with the foregoing explanation. But since the whole of the crystalline material never is, and never can be, completely converted into the amorphous condition, it follows that there must be unequal hardness and unequal tenacity throughout the various portions of the worked hard material.

Herein lies the essential difference in the character of the added hardness which is conferred by alloying and by cold working respectively. In the case of alloying we deal as a rule with a solid solution, which as a result of osmotic pressure is in a state of molecular tension, and every unit of which is of similar composition. It is true that with castings "coreing" occurs, but that does not really affect the argument. With a solid solution various methods of testing hardness should give results which are in general agreement. Worked hard metals, on the other hand, are less uniform in hardness, and if tested in various ways may give different results, depending upon the character of test selected.

Limits of Work Hardening.—It may be of interest to consider to what extent a metal may be hardened, or have its tenacity increased, as a result of cold working. It is difficult to suppose that any means could be found whereby the tenacity of a film of metal could be made to exceed the tenacity of a thin polished film at the surface—that is to say, to exceed the surface tension. Now Quincke calculated the capillarity constant of certain solid metals and alloys, or, in other words, the pull exerted upon one millimeter of surface. With iron, silver and gold the ratios of the hard to the annealed state were about 3 or 4 to 1. With certain alloys it was less than 2. With steel it was about 7 to 1. These values must be regarded as rough approximations, and merely indicate the kind of numbers with which we have to deal. What they do show is that even if the whole of a sample of metal could be converted into material having the properties of a surface film, there is a definite limit to the hardness which could be imparted by the processes of cold working. In other words, after a certain point had been reached further work would not confer greater hardness, but would cause fracture.

But if it be true, as before suggested, that it is impossible to convert the whole of any metal into thin films, in a parallel direction, then it would follow that the attainable limit for increased hardness is below the figures which have been previously mentioned. In practice, for example, cast copper has a tenacity of from about 10 to 14 tons per square inch. When it has been drawn as far as is mechanically possible, in view of the purposes to which it is to be applied, its tenacity is from about 24 to 28 tons. Roughly, therefore, its tenacity has been doubled. In some cases less than this is possible; in exceptional cases more can be obtained. But always the maximum is only a small multiple of the original.

Even if we had information as to the proportion of the mass which had been converted in stretched films, it would not appear possible to calculate what the increased hardness or tenacity should be, and so check it by experiment. For if we accept the view that these planes are like so many strong bands passing through the material; that they are of varying length, and crossing and interlocking with each other at an indefinite variety of angles, it will be seen that we are dealing with a system of astonishing complexity which none of the usual methods of examining stresses would be able to unravel.

In a recent paper by P. Ludwik,⁷ of which I have only as yet seen an abstract, the view is expressed that the phenomena of cold working are not explicable by Sir George Beilby's amorphous hypothesis, or by Tamman's translation hypothesis. Ludwik draws attention to the fact, which had already been stated by Professor H. M. Howe, and carefully studied by Matthewson, that the greater the amount of mechanical work the lower is the temperature at which softening takes place on annealing. In the foregoing remarks I have endeavored to show that if it be assumed that the amorphous material exists in the condition of thin films, in tension, akin to surface films of liquids, then the results of cold working can be readily understood. And it would appear to follow that the more numerous these films are, and the more they are strained, the more readily will they tend to adjust themselves as the temperature is raised.

⁷International Journal of Metallography, 1916, Vol. VIII, p. 53.

³P. Ludwik has recently published a research dealing with the hardness of a large number of alloys—Abstract, *The Ironmonger*, April 7th, 1917.

⁴I understand that when coinage blanks are pressed there is an increase of density. If this is so it must be regarded as a special case, as the specimen is practically in a closed box and is not free to expand.

⁵Journal of the Institute of Metals, No. 2, 1914, Vol. XII, page 18.

NEW BOOKS, ETC.

THE MASTERY OF NERVOUSNESS, by Robert S. Carroll, M. D., New York, 1917. The Macmillan Company, 12 mo. 346 pp. Price \$2.00.

The man or woman, suffering from nervous debility, will find this book an ever-ready, practical help in the way back to health. Dr. Carroll gives in simple, fluent language, apt in expression, the causes of nervousness, its relation to contemporary conditions of living and efficient methods to overcome it. The physician who recommends this work to his patient will find it a valuable assistant to supplement his treatment. This is a particularly valuable book, for the problem that the modern man is facing today for himself and his children and which is becoming more complicated each decade.

SCIENCE AND LEARNING IN FRANCE. With a Survey of Opportunities for American Students in French Universities. An Appreciation by American Scholars. Published by The Society for American Fellowships in French Universities, 1917. 8vo.; 492 pp.; illustrated.

It is well indeed at this time, when the United States and France are fighting side by side for common principles, that we should know the full extent of our indebtedness to each other. Most of us have vague ideas of what France has given to the world in scientific knowledge and research; our representative American scholars have in this series of papers definitely set forth, for each particular field, the great leaders and the achievements of the past century, the courses of instruction offered by French universities, and the general facilities available for study and research. From anthropology to zoology each subject is handled by two or more men qualified to speak with authority; John Dewey of Columbia University is one of the four notables responsible for the section on education; Charles W. Eliot of Harvard and George E. Hale, foreign secretary of the National Academy of Sciences, give us introductions dealing with the mind of France and the intellectual inspiration of Paris. Our visiting students will be greatly aided by the information of the appendix, which explains the organization, the standards of preparation and system of degrees of the French universities. The section on medicine is particularly thorough, including physiology, neurology, surgery and pathology.

LOCOMOTIVE VALVES AND VALVE GEARS. With a Special Treatise on Valve Setting. By Jacob H. Yoder, B.S., M.E., and George B. Wharen, B.S., M.E. New York: D. Van Nostrand Company, 1917. 8vo.; 286 pp.; illustrated. Price, \$3 net.

Valve setting presupposes a knowledge of the principles of valve motion, and this is a subject on which the initiated are apt to be a little cryptic; the railroad shop man on a voyage of mental discovery is likely here to run into mist and mystery. This commendable work, based upon notes used in the apprentice schools of the Pennsylvania Railroad, is an exposition that dispels the fog and gives the facts in simple English. The plain slide valve, piston valve, and operating gears are taken up from the points of view of construction and action, and their application to the locomotive is made plain to the everyday worker. The engineman and fireman, the draftsman and the designing engineer may also use the work to advantage as a reference book of practical information.

THE AMERICAN FERTILIZER HAND BOOK. 1917. Philadelphia: Ware Bros. Company. Price, \$1.

It was no easy task which faced the compilers of this year's issue of the Hand Book; the war had created a condition which made it difficult to include anything like complete statistics, yet the intimate relationship of the commercial fertilizer to the food supply, and of the food supply to the successful prosecution of the war, gives added importance to a work dealing with commercial fertilizers and offering directories of fertilizer manufacturers and allied trades; the result is a triumph for the compilers worthy of the highest praise. Their work is also a guide to materials, machinery, and all kinds of equipment and supplies; to brokers and shippers; to chemists, assayers, engineers and contractors; to cotton seed oil mills and to packers and renderers. These directories have been subjected to the most careful revision, and the trade can readily obtain from them exact information as to sources of supply for plant equipment, raw materials and expert service.

THE MAGIC OF SCIENCE. By A. Frederick Collins. New York and Chicago: Fleming H. Revell Company, 1917. 12mo.; 215 pp.; illustrated. Price, \$1.25 net.

The author has mastered the art of writing for boys in such manner as to convey instruction by means of recreation; his latest work is full of fascinating experiments capable of being performed with the aid of simple, home-made apparatus and toys, yet highly educational in that they initiate the young experimenter into the mysteries of matter, force, and mechanical principles. Natural magic is thus made interesting to the normal boy, a new world dawns upon his intelligence, and he learns to take the keenest pleasure in tracing effect to cause. There are a few mistakes such as reference in the text to non-

existent letters in the illustrations, but these are in no case serious; the line drawings are very attractive and make it easy to follow the directions and explanations.

WHITE'S VEST POCKET SUNDAE FORMULARY. By E. F. White. Boston: The Spatulary Publishing Co., 1917. 200 pp.; illustrated. Price, \$1.

The soda-fountain dispenser will welcome this handy little formulary, which provides him with a new frozen confection for every day for four years, or a new "special" every week for twenty-five years; in other words there are 1,200 different sundaes and 300 dressings here mentioned, enabling the dispenser to prepare, with a glance at the concise instructions, any sundae a customer is at all likely to ask for.

THE LIFE OF ROBERT HARE. An American Chemist (1781-1858). By Edgar Fahs Smith, Provost of the University of Pennsylvania. Philadelphia: J. B. Lippincott Company, 1917. 8vo.; 508 pp.; illustrated. Price, \$5 net.

When a man is called before a learned society at the age of 21 to demonstrate his discovery of the oxyhydrogen blowpipe, and when that man's passion for research carries him through all difficulties until the publications of the day herald him as "the greatest American light of chemical science" and the peer of Sir Humphrey Davy and Volta—then we have a character that must present splendid material for an inspiring biography. This fascinating volume tells the story of Robert Hare's struggles and triumphs, with the view of making the public better acquainted with the strong personality and the epoch-making achievements of one of America's most eminent pioneers in science. The author comes to his subject with a steady enthusiasm that gives us an intimate and sympathetic delineation of the great thinker and experimenter. The frontispiece is a fine portrait of the chemist and physicist, reproduced from an oil painting in possession of the University of Pennsylvania.

THE YACHTSMAN'S ANNUAL GUIDE AND NAUTICAL CALENDAR. 1917. Boston: Clarence B. Hogg. 8vo.; 392 pp.; illustrated. Price, paper, \$1; cotton duck, \$2.

An encyclopedia of nautical information and instruction is offered the yachtsman each year in this old, reliable Guide. There are a dozen large charts of the principal harbors, one of Long Island Sound, and one of the Cape Cod Canal. Besides the usual miscellany of racing rules, signaling codes, tide tables and water routes, there are four new pages on New York State and Canadian canals; sailing directions, distances and harbors on the Great Lakes; and many other additions and revisions. Other valuable sections are those on the operation of motors, weather signs, life-saving and power boat regulations; and the directory and flag index of American and Canadian clubs, showing the flags in colors, is a valuable feature of the Guide.

LAWS OF PHYSICAL SCIENCE. By Edwin F. Northrup, Ph.D. Philadelphia: J. B. Lippincott Company, 1917. 12mo.; 210 pp. Price, \$2 net.

The author has here given us an epitome of the fundamentals of science, a full list of its general propositions or laws. The value of such a list as a work of reference is obvious, and will appeal to students in all branches of natural science. The subject-matter includes mechanics; hydrostatics, hydrodynamics and capillarity; sound; heat and physical chemistry; electricity and magnetism; and light. There are frequent references to standard text-books of the various subjects and a good bibliography is appended.

LIFE AT THE U. S. NAVAL ACADEMY. The Making of the American Naval Officer. By Ralph Earle, Commander, U. S. Navy, Head of the Department of Ordnance and Gunnery, United States Naval Academy. With an Introduction by Franklin D. Roosevelt, Assistant Secretary of the Navy. New York: G. P. Putnam's Sons, 1917. 8vo.; 380 pp.; 73 illustrations and map. Price, \$2 net.

How few of us realize what must be packed into the four-year course of the Naval Academy! In 48 months, as the Assistant Secretary of the Navy points out in his admirable introduction, high school graduates are fashioned into "not only educated gentlemen, but also international lawyers, keen observers, navigators, artillerymen, engineers and also all around men and specialists." Commander Ralph Earle tells exactly how this miracle is accomplished and throws open to the reader the whole educational, moral and recreational life of the Academy; the mental and physical requirements of the candidate are helpfully set forth; the settling down of the raw midshipman into routine is described; we are carried through the interesting life of the officer in embryo until the study and drill culminate in the final examinations, and the midshipman becomes that proud product of wisdom and discipline—the ensign. An appendix gives the courses of study in the post-graduate department, and there is a folding plan of the Academy Reservations. Not only the prospective candidate, but every American boy and man might profit by learning from this well-written volume what America expects of her naval officers, and what she owes to their indefatigable labors as humble midshipmen.

MR. BRITLING SEES IT THROUGH. By H. G. Wells. New York: The Macmillan Company, 1917. 8vo.; 443 pp.; illustrated. Price, \$1.60.

Inasmuch as the individual can typify the nation, Mr. Britling embodies the soul of England. We live the happy life of Matching's Easy, make the acquaintance of Mr. Britling and his unconventional family, and play Homeric hockey oblivious to the gathering clouds; seldom has Mr. Wells been so felicitous in his humor as here; it is delicious. Then the storm breaks; the young and lovable German tutor leaves to fight for his country. "Verdamme Dummheit!" is his comment on the situation. England is involved in the monstrous war; there is bewilderment, incredulity; the Zeppelins appear, and realization and rage arrive with them. From the point where the son of the house enlists, the narrative takes mainly the form of Mr. Britling's musings; the readjustments of his mind correspond to the readjustments of national life, and reflect the "web of the ineffective" in which England struggles. Mr. Britling loses his son, and finds his mental conceptions plunged into chaos; the book leaves him as he begins to regain a sense of beneficent purpose behind it all. Aside from the high literary value of the work it is one that all Americans should read, for it will give us sympathy and understanding for our allies and may educate us into avoiding some of the errors into which they fell.

HENDRICKS' COMMERCIAL REGISTER OF THE UNITED STATES. New York: S. E. Hendricks' Co., 1917. 4to.; 2,227 pp. Price, \$10.

It would be hard indeed to lay too great a stress on the value of this massive collection of industrial and mercantile information, or on the sterling service it renders to the business world. The amplitude of its offering leaves little to be desired, and anyone interested, either as buyer or seller, in any kind of building construction and equipment, or in railroad, mining, or engineering materials, will find that this widely-used directory gives ready access to the sources of supply and demand. It furnishes three very complete, correlative lists, one of trades classified, another of trade names, brands, etc., and a third containing the names of all firms and individuals appearing in the classified-trades section, arranged alphabetically, with particulars of their chief activities and other specific and helpful items of information not generally found in less comprehensive publications, yet necessary to the expeditious and economical procuring of supplies. The method used in obtaining these details is the only one that ensures fullness and accuracy in compilations of this kind: that is, direct appeal to the firms listed, and the brief embodiment of the data thus acquired under the proper classification, thus making the whole work authoritative. Two indexes, one to classifications, the other to advertisers, greatly facilitate reference. The third section of the volume constitutes a new feature that offers such appreciable advantages that it will doubtless be retained in future editions. The trades and professions to which the register especially caters must accord it a grateful reception; indeed, there are few branches of industrial activity that would not be materially advantaged by its constant use in their purchasing and selling departments.

FRENCH MEASURE AND ENGLISH EQUIVALENTS. By John Brook. New York: Spon & Chamberlain, 1917. Price, 40 cents.

THE BAROMETRICAL DETERMINATION OF HEIGHTS. By F. J. B. Cordeiro. New York: Spon & Chamberlain, 1917. Price, 50 cents.

Merchants, manufacturers, engineers and others will welcome Mr. Brook's compilation, which will fit the vest pocket and contains the English equivalents of French measures both in decimals and fractions; the decimals are carried to six places. It includes also the French Old System, still occasionally used in connection with tool steel and files, and some Prussian, Austrian and Russian equivalents. Mr. Cordeiro's little work presents a practical method of barometrical leveling and hypsometry for the benefit of surveyors and mountaineers, with methods and formulas that, unlike the older ones, give accurate and consistent results. The work is in its second edition; when it becomes generally known to mountain climbers the annoying discrepancies now noted in their findings, and due either to false assumptions or to failure in including all the conditions of the problem, will disappear.

PRACTICAL BANKING. By O. Howard Wolfe, Assistant Cashier, The Philadelphia National Bank. Chicago: La Salle Extension University, 1917. 8vo.; 302 pp.; illustrated. Price, \$2.00 net.

Banking is of course only to be mastered by entering a bank, and by tracing the channels of its varied activities from beginning to end; but there can be no doubt of the benefit a student may derive from a work such as Mr. Wolfe here gives us. The business man, less excusably, is often woefully ignorant of inside banking methods, and to such a one the work should come as a welcome revelation. It is the commercial institution, in its functions of deposit, discount and issue, to which the exposition is mainly devoted, and it thoroughly canvasses the duties and systems of the executives, the tellers, and the bookkeepers. Under the subject of sight drafts

(Chapter II), there is a rather bewildering statement that the deposit of a hundred drafts causes the bank 600 times more work than the deposit of one draft; and the review question concerning issue does not seem to be elucidated by anything in the chapter. On the whole, however, the book well fills a distinct need, and is characterized by illuminating simplicity of statement.

PELOUBET'S SELECT NOTES ON THE INTERNATIONAL SUNDAY SCHOOL LESSONS. 1918. By Rev. F. N. Peloubet, D.D. and Amos R. Wells, Litt.D., LL.D. Boston: W. A. Wilde Company. 8vo., 372 pp.; illustrated. Price, \$1.25 net.

In the 44th annual volume of these widely-used Notes we find the usual lesson discussions, chronologies, and aids to teaching, with maps, large colored plates, and numerous illustrations in the text. The aim of the guide is to make the lessons distinct, vivid and emphatic, and any teacher using the International Lessons must admit that this object has been completely attained.

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