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Chemistry in the Telephone Industry¹

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An account is given of the activities of the Chemical Department of the Bell Telephone Laboratories. In the Laboratories chemists act chiefly as advisers and critics. They concern themselves with such problems as the theory of chemical structure as related to dielectric properties and simultaneously attack the task of making an improved substitute for gutta-percha which renders possible a transatlantic telephone. They are interested in the colloidal structure of cotton and silk and the influence of moisture and electrolytes on their insulating properties. The dispersion hardening and fatigue resistance of lead and its alloys, the fabrication of platinum-alloy vacuum-tube filaments, and of new magnetic materials such as permalloy and permivar have required their attention. The corrosion of cable systems is due largely to stray currents but is strongly influenced by chemical factors. Other underground corrosion, and particularly the slower and more insidious corrosion and tarnishing of indoor telephone apparatus, have justified a broad program of investigation of the corrosive factors involved in ocean, earth, and atmosphere. Related to these studies are those of protective finishes, whether metallic coatings or organic paints and lacquers. The permanence of a great variety of materials must often be predicted as best it may without the test of service life. This interest in permanence is reflected in a program of experiments in preservation of telephone poles.

THE public mind associates the chemist with glass retorts and evil smells, with war gases or the glare of furnaces against the sky. To the technical leader in industry, however, the wide distribution of chemists outside predominantly chemical enterprises has become a familiar fact. A casual reference to the thirty subject classification headings in *Chemical Abstracts* will serve to illustrate how widely industrial chemists have become disseminated and how large a volume of work they are producing.

When one reflects that all engineering is essentially applied physics, and that it has become subdivided into a score of specialized fields, it seems very natural that chemistry also should have found varied applications as the sum total of chemical knowledge has increased. Perhaps the day is not far distant when the term "physical chemist" will represent to the lay mind as well-defined and distinct a calling as that of civil engineer.

It is therefore only a part of a general movement in industry that has placed the chemist in a position of some importance in the telephone business. His relative importance in the communication field is small, as the industry must permanently remain essentially electrical rather

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than chemical. His usefulness depends primarily, not upon the number or size of the operations which are entrusted to his exclusive care, but upon the distinctive mode of thought which he contributes to a critical consideration of the methods and processes in use. As in medicine, so in telephony the chemist is an aid to progress, not a prime mover.

If one endeavors to define the distinctive mode of thought of chemists, he is at once led to point out the fact that the chemist by his training intuitively tries to account for most phenomena by a consideration of the composition of the materials involved. From his first days in the laboratory he is taught what "chemically pure" means and learns that even minor impurities may often have most important consequences, good or bad. While it is obviously true that many things happen without a chemical cause, it is equally, though less obviously, true that variations of composition or chemical changes in composition are frequently associated with the happenings. No one is so well qualified as the chemist to ferret out such obscure correlated and often important facts.

The distinctive nature of the training of chemists tends to adapt them to the role of critics. The fundamentals of the old-school physics reached a point some thirty or forty years ago when it was felt that the whole field had been fairly thoroughly combed over and all essential principles were known. These principles became embodied in formulas and conventionalized modes of attack upon the problems of engineering which have often been accepted at more than their true value by the average product of the engineering school. Chemistry, on the other hand, has never reached so high a development. Even in first-year chemistry one encounters facts not explained satisfactorily by any known theory, and the reading of even a score of pages of an elementary chemistry which has passed its first printing will bring one upon statements which require modification in the light of more recently acquired knowledge. By comparison with applied classical physics, chemistry is a youthful science and its devotees are inclined to a juvenile disrespect for tradition.

The enormous consumption in a telephone plant of such materials as lead and copper, paper and textiles, rubber and asphaltic compounds immediately implies the necessity of the chemist for the performance of his most conventional function, that of analysis. While the Bell Telephone Laboratories does not undertake the systematic inspection analyses of the large variety of products purchased, it does undertake a great volume of analysis of such products as a referee. Such work often reveals defects of analytical methods or defective statement of specification requirements that necessitate large numbers of comparative analyses to form a basis for proper amendment.

Another large portion of the work of our analytical laboratory has to do with materials used in the prosecution of research problems by physicists, engineers, and chemists in other groups. For example, in the course of development of such magnetic materials as permalloy and perminvar, methods for the analysis of unusual alloys have had to be devised. The utilization of microchemical and electrometric methods has often offered a way out of difficulties. For instance, it became necessary in connection with a corrosion problem to measure accurately the amounts of volatile acids in certain woods, and for this purpose a differential electrometric titration method was developed. Spectroscopic analysis finds its use, not only in the examination of minute specimens of material such as the deposits on vacuum tube filaments, but also in the estimation of minute impurities in grosser products, as, for example, the presence of zinc in solder. A not inconsiderable volume of research in analytical chemistry has grown out of these problems.

The most important function of the chemist in the telephone laboratory is not a conventional one. It consists in a scrutiny of the apparatus, equipment, materials, and processes of the industry to determine where and how chemical reactions or variations in composition are affecting functional operation. Sometimes the problems so encountered lead to extended researches pursued over a period of years to answer specific questions or to accumulate a reservoir of general information to be drawn upon as needs arise. Sometimes questions are brought to us by workers in other fields, apparatus designers perhaps, questions such as can be answered offhand, or at most require a few days or weeks of work. A considerable part of the more interesting work is published.

In order to make clear how chemistry applies to telephone problems, a number of examples have been chosen from various parts of the general field. Many of the tasks enumerated below are shared by the chemists with technical staffs of other departments. They will be discussed from the chemical viewpoint with only sufficient reference to the general engineering considerations to make the problems intelligible.

CHEMICAL CONSTITUTION AND ELECTRICAL CHARACTERISTICS OF PURE SUBSTANCES

The most fundamental piece of work in dielectrics which we are undertaking is a study of chemical constitution of pure substances in relation to their electrical characteristics. This work is going forward under the direction of H. H. Lowry, and is expected to serve as a valuable supplement to similar work being conducted elsewhere, principally in university laboratories. While it is well known to all chemists that aqueous

solutions are in general relatively good conductors, and that solutions of substances in fat solvents are relatively good insulators, a much closer analysis of the latter class is necessary for telephone purposes. Among the electrical characteristics of importance are dielectric constant, insulation resistance, a.c. conductivity, and dielectric strength. Each of these characteristics varies over quite wide ranges, depending upon certain conditions, of which temperature and frequency of alternation of the electric current may be mentioned as most important.

In this work an endeavor is being made to determine, for example, how the symmetry of the molecule affects the dielectric constant, and to distinguish in dielectrics the contribution of energy loss made severally by the electron, the atom, and the molecule. For such a purpose it is obviously necessary to deal with highly purified substances and to begin with those of simple chemical structure. Many of these, such as hexane, benzene, ethyl ether, and alcohol, are not expected to have the slightest importance as practical insulators, but serve to show how particular atomic groupings affect dielectric behavior. For this purpose we have included the methyl halides in our study, making measurements both in the pure state and in dilute solution, of dielectric constant and a.c. conductivity at temperatures ranging from 100° C. to the boiling point of the liquid. The frequency of the current has also been varied from 1 to 100 kilocycles.

RUBBER AND GUTTA-PERCHA

Parallel with this study of the theory of dielectric behavior, a number of more immediately practical problems are being prosecuted, the majority of them under the direction of A. R. Kemp. One of these relates to the use of rubber and gutta-percha in submarine insulation. The latter is the classical material for this purpose, while rubber has been regarded as an inferior substitute. The supremacy of gutta-percha is due in part to its mechanical characteristic of thermoplasticity, which permits it to be extruded as a continuous insulating layer about a conductor, requiring nothing but the simple process of cooling to convert it into a tough, firm sheath. An even more peculiar virtue of gutta-percha is the stability of its electrical characteristics during prolonged immersion in water. By patient experiments extending over several years it has been demonstrated that the inferiority of rubber in this one respect is due wholly to its non-hydrocarbon constituents. Methods for the elimination of these foreign substances, notably water-soluble salts, proteins, and quebrachitol, which could be applied without damage to the hydrocarbon, have required extended study.

In connection with the water-soluble impurities, an interesting problem in osmosis arose. The absorption of water by rubber is found to be a direct function of its content of water-soluble substances and an in-

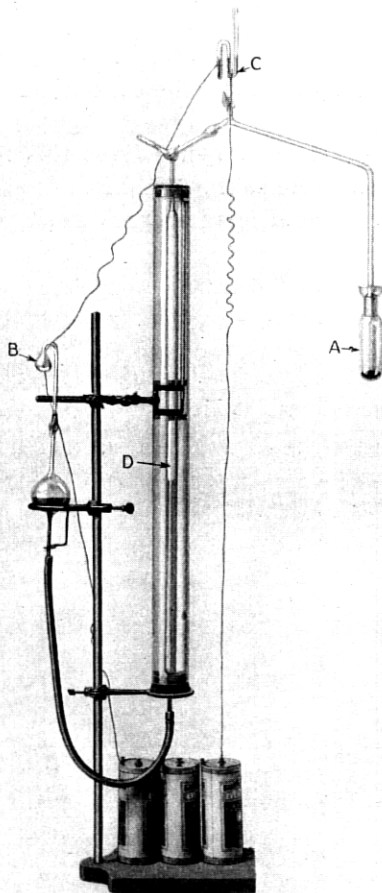


Fig. 1—Apparatus for observing rate of oxygen absorption. Rubber, asphalt, or paint film to be studied is placed in bulb *A* (enclosed in thermostat not shown) and apparatus is filled with pure oxygen. By operation of the manometer *C*, water is electrolyzed in bulb *B*, generating gas automatically in quantity just sufficient to maintain oxygen in buret *D* constantly at atmospheric pressure.

verse function of the salt content of the external water. Thus a sheet of raw rubber which is produced by the evaporation of latex, and therefore contains all the natural water-soluble impurities, will, upon immer-

sion in distilled water, gradually absorb more water than was contained in the original latex, though the sheet still retains its original form, somewhat swollen of course by water absorption. On the other hand, rubber which has been carefully freed of all water-soluble impurities absorbs but a small percentage of water under the same conditions. Fresh-water cables are more liable to degradation from water absorption than cables in salt water, and if the ocean were a saturated solution of sodium chloride the problem of the use of ordinary rubber would be materially simplified.

A development of primary importance in this connection has been the elimination of the proteins from rubber. It appears that the protein constituents form an intricate network which permeates the entire

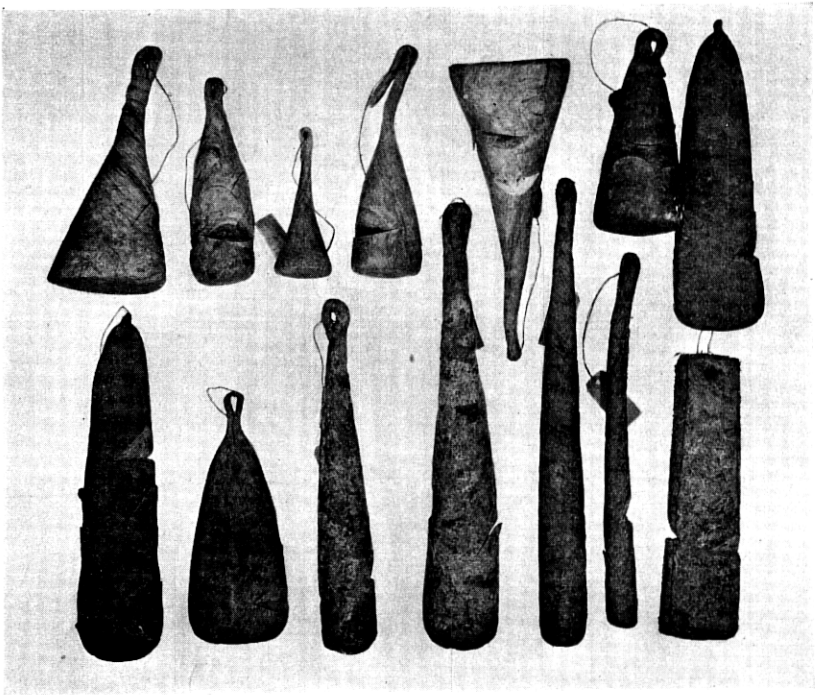


Fig. 2—High-grade gutta-percha in shapes popular with the forest gatherers.

mass. While the amount of proteins present is too small to cause a large absorption of water, they do insure that such water as is absorbed causes a maximum electrical damage by extending the water-bearing filaments through and through the material. The partial hydrolysis of the proteins and the thorough coagulation of any remaining residues by

autoclaving the rubber by steam pressure has afforded a simple but effective means of stabilizing the material electrically against the action of water.

Rubber also finds many uses in aerial insulation, a field which is rather backward in its development as compared with the tire industry. The latter has received an incalculable benefit from the large amount of technical research carried on in the last ten years. To a considerable extent it has been our task to adapt technical information derived from the tire industry to the needs of the telephone. The adoption of such expedients as accelerators and anti-aging compounds has contributed a great improvement in the field of insulation. In fact, the aging of rubber in the case of insulation is obviously even more important than in the case of tires. One scarcely expects automobile tires to last for more than a season or two, but rubber insulation must often be exposed to sun and rain for ten years or more.

Rubber for wire insulation must offer resistance to cutting of the wire through the insulation under severe load, such as is produced by a deposit of sleet. Our chemists have therefore been called upon to contribute to the development of a compression-testing machine for rubber which automatically plots the reduction of thickness of wall under an increasing compressive load. By the use of this testing machine surprisingly great variations were discovered and corrected in the material supplied by different manufacturers.

Other useful tools in the study of rubber have been developed. A method has been devised for the direct determination of rubber hydrocarbon in compounds by means of iodine titration. Direct gasometric measurement of oxygen consumption by rubber and other organic materials is performed with a special apparatus for automatically maintaining oxygen pressure constant at one atmosphere. Included in the program are cooperative studies of various accelerated aging tests for rubber, notably the Geer test and that of Bierer and Davis. In these ways we hope we are repaying in part our debt to technologists of the rubber industry, as well as serving our own needs.

TEXTILES

Another general class of insulating materials in which study has been well rewarded is that of textiles. It has now been quite clearly shown that textile fibers serve as filaments upon which the moisture of the atmosphere is deposited, and that the electrical characteristics of the textiles are determined largely by the thickness and continuity of these water films and the conductivity of the solutions formed by contact

with the textiles. The presence of water-soluble impurities in textile insulations is therefore very important and their thorough removal by controlled processes of washing has resulted in vast improvements in both cotton and silk.

For some reason not yet fully understood, silk is much superior to cotton as an insulating material over the usual range of atmospheric humidities. This is true in spite of the fact that cotton absorbs less water than silk at a given humidity, and that, over the usual range of use, silk is more sensitive electrically to a given increment of water than cotton. This is responsible for the extensive use of silk in the electrical industry at several dollars per pound in place of cotton, which may be had for about a tenth as much. The purification of cotton, however, has made it good enough to replace silk for a large number of purposes, especially in telephone cords, and the saving thus effected amounts to several hundred thousand dollars per year for the Bell System. In addition to this practical result, such studies as these have suggested interesting scientific possibilities in the use of electrical measurements for determining the structures of colloids.

PAPER

An allied product is paper, which is used in enormous quantities in the construction of the common type of telephone cable. This cable consists of a bundle of wires individually insulated from one another by strips of paper helically served about each. Before being enclosed in a lead sheath the bundles of insulated wires are thoroughly dried and thereafter throughout their use have to be protected from entrance of atmospheric moisture by hermetically sealing the lead covering. The functioning of the cables depends absolutely upon the maintenance of an extremely dry atmosphere within the cable. Our chemists have been called upon for elaborate studies of the effects of minute increments of moisture upon the insulating qualities of paper and the effect of temperature upon the electrical characteristics of paper containing various small proportions of moisture. Incident to this task it has been necessary to develop a humidity recorder sensitive to as little as 10 parts per million of water vapor in the air. Such a commercial recorder, produced by Leeds and Northrup at our instance, is in successful use as a guide in controlling the atmosphere of cable-drying ovens. Improved devices for determining the brittleness of cable paper and for judging its predisposition to lose flexibility upon baking have also received attention.

Still another dielectric problem is that of condensers, which are unique

in that an insulator of maximum dielectric constant is required, whereas in most electrical apparatus a minimum dielectric constant is sought. For the sake of economy the usual telephone condenser is made of alternate strips of paper and tinfoil which are wound up into a compact roll, and after drying is impregnated with some form of waxy material to bring the capacity to a maximum and prevent subsequent variations with changes of atmospheric humidity. The complexity of the effects of the choice of the impregnating material upon the electrical characteristics of the condenser is most surprising. It might be supposed that condensers of high insulation resistance would also have a high breakdown strength, but this is by no means always the case. It has become evident that the nature of the interface between the individual fibers of the paper and the surrounding waxy material is of vital importance.

PHENOL PLASTICS

A class of materials very widely used in the electrical industry for insulating purposes is well known under the general term of "phenol plastics." Cellulose acetate is another insulating material of excellent electrical characteristics and is superior to the usual fibrous materials owing to its lower water absorption. Although the uses of such materials, both in massive form and as impregnants for fibrous insulation, are very extensive in the telephone field, little chemical work has been done in the Laboratories on them, partly because they are the products of a rather highly developed industry which has conducted a great deal of investigation for us. For certain types of uses, however, the phenol plastics have required some special chemical study from the standpoint of their stability. Being in the nature of condensation products formed by the elimination of water, the phenol plastics are more or less subject to the reversion of the reaction by which they were formed with the production of free phenol and ammonia. For certain uses the presence of these uncondensed constituents or hydrolytic products, as the case may be, is objectionable and has required a special investigation of means of controlling their presence. An important improvement and economy has been effected in certain textile-insulated wires by applying a cellulose acetate lacquer to the exterior so as to partially impregnate the textile. The film of cellulose acetate contributes a continuous smooth surface and a measure of resistance to atmospheric humidity variations.

CONDUCTIVITY OF COPPER

Passing from insulators, one naturally thinks of conducting materials, of which of course copper is first in importance. It is a well-known and thoroughly tried principle that the metallic elements in the pure state

have a higher electrical conductivity than their alloys. The problem of conductivity of copper is therefore essentially one of purity, and has been fairly satisfactorily solved by the copper-refining industry. We are, however, attacking some special problems in conductivity of copper.

CARBON

A unique conducting material in the field of telephony is carbon. A small mass of granules of this material in every transmitter serves the all-important purpose of converting the variations of the mechanical energy of the voice into equivalent variations of the transmissible electric current. This the carbon does by variation of its electrical resistance with variation of mechanical pressure.

No other material approaches carbon in its usefulness for this purpose, but there are still many obscurities about the functioning of a carbon transmitter. Decades of physical and chemical research have, however, established certain points. Transmitter carbons in general are not highly active carbons in the sense in which we have become familiar with that term in connection with absorptive charcoals. Gas films on the carbon, however, do play some role in their microphonic functioning. Of more practical importance for the present is the evidence that the microphonic effectiveness of carbon is very much dependent on the method of its preparation, and particularly the time, temperature, and atmosphere in which it is roasted. Carbon for transmitters is made from anthracite coal of maximum hardness and low ash content. The roasting processes are designed to produce a material of as high uniformity as possible, especially with reference to the hardness, compactness, and abrasion resistance of the surfaces of the finished product. It has come to be recognized that such physical characteristics of transmitter carbon as these to a great extent determine, not only its original effectiveness, but also its resistance to atmospheric disturbances and its durability under the mechanical and electrical forces exerted upon it during use.

The hydrogen content of carbon has been found a useful index of the time-temperature cycle to which it has been subjected during roasting. As anthracite coal is roasted there is a progressive loss of hydrogen, which, however, does not reach zero value until a temperature above 1500° C. is obtained, at which point the material is converted rapidly to graphite. It is only at upper intermediate temperatures that satisfactory transmitter carbons can be produced.

The study of the hydrogen contents of coal and carbons and of related microphonic behavior has led to a definite theory that there are, contrary to belief of some authorities, only two allotropic forms of car-

bon—namely, graphite and diamond. The so-called amorphous carbons, according to this view, are complex hydrocarbons in which the carbon greatly predominates over the hydrogen and in which, especially if the carbon has been roasted at a high temperature, the carbon atoms are in part arranged in a graphite lattice.

VACUUM-TUBE FILAMENTS

The filaments of vacuum tubes represent a very special form of conductor, the primary function of which is, of course, the emission of electrons. Vacuum tubes are used in repeater sets in all long-distance telephone lines. The filaments in these vacuum tubes consist of platinum alloys coated with the oxides of barium and strontium. It is important that these filaments should be constant in their electrical characteristics and have as long a life as possible. The manufacture of platinum alloys and the methods of coating them have been subjects of study by our metallurgists and chemists for several years, and as a

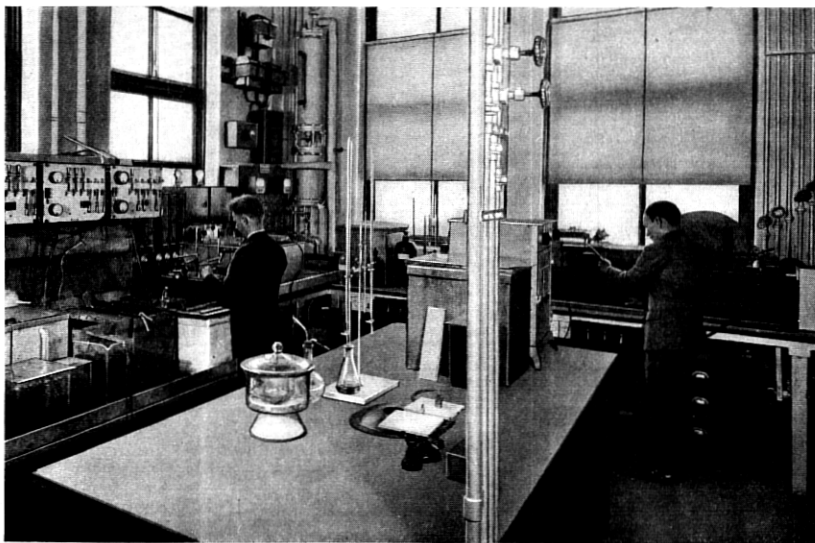


Fig. 3—A corner of the electroplating laboratory.

result many improvements in the manufacture of the filaments have been made. Probably the most outstanding improvement has consisted in the substitution of platinum-nickel and platinum-cobalt alloys for the platinum-iridium-rhodium alloy formerly used as a filament core. This substitution resulted in increasing the life of repeater tubes from a few months to several years.

METALS

The metallurgical group, as far as chemical investigation is concerned, is in charge of J. E. Harris. One of his principal interests is the production in varied forms of special magnetic materials, illustrated by permalloy and perminvar. The field of magnetic materials has been so intimately connected with the fundamental physical theory of ferromagnetism that the primary responsibility for these investigations has been lodged in a physical research group, the members of which have been responsible for fundamental inventions in this connection. The

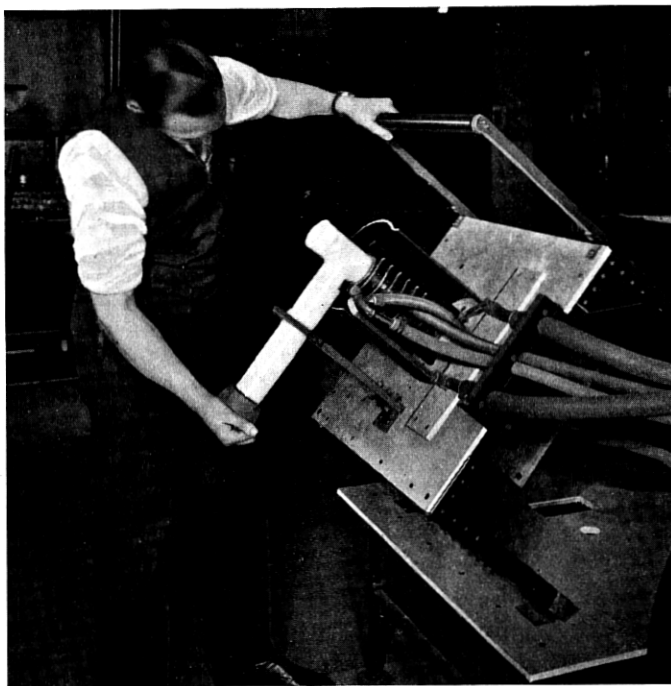


Fig. 4—Pouring a metallic melt in vacuum by tilting a high-frequency induction furnace.

problems of fabrication and composition control in the experimental work in this connection have, however, afforded much opportunity for the ingenuity of chemists.

A particular case in point is that of the production of brittle forms of such special magnetic materials, the object being to permit the grinding of the metal into a coarse dust. The dust particles are then insulated by deposition of a film on their surfaces and are pressed into rings which form the cores of modified Pupin-type loading coils. This unusual objec-

tive of rendering metal brittle has been achieved in general by the principle of introducing an impurity into the melt, which has a tendency to segregate at the grain boundaries, thus facilitating subsequent fracture. Each alloy requires some special consideration, both as to choice of embrittling agent and heat treatment and working schedules for development of proper grain size.

Scarcely any metallic material has given the telephone industry more concern than the lead alloy used for cable sheath. Pure lead is too soft for the purpose and can be too easily damaged mechanically. Years ago about 3 per cent of tin was alloyed with the lead as a hardening agent. Tin was later superseded by 1 per cent of antimony, primarily for reasons of economy, and it has been reported that twenty million dollars have been saved to the telephone system by this substitution alone.

The use of these hardening agents affords an example of the dispersion hardening of metals, which has become familiar to the public most conspicuously in the case of duralumin. It is the belief of metallurgists that the introduction into a molten metal of a constituent, which is precipitated out in very finely divided form upon cooling the metal, diminishes the deformability of the finished material by interposing itself in the slip planes among the atoms of the metal.

Dispersion hardening in a metal as soft as lead represents a rather extreme case, for lead at atmospheric temperatures is approximately as deformable as steel at dull red heat. It has been found that the antimony used as a hardening agent in lead cable sheath tends, especially under the influence of repeated flexings such as those due to thermal expansion, to redissolve in the metal and redeposit elsewhere. In this fashion large particles of the antimony grow at the expense of small particles, and the hard-worked portion of the metal is eventually deprived of antimony content and fracture occurs.

This has been the source of considerable trouble in aerial cables, especially at the bends in the cable which occur at the poles due to expansion. The working out of this problem in fatigue of metals has been a long process, but promises to bear further fruit in the development of better hardening agents. One of these, a joint development with the Western Electric Company and one which still remains to be tested on a commercial scale, is calcium, which in the minute proportion of 0.04 per cent has been found in laboratory experiments to produce a hardening well surpassing that of 1 per cent of antimony.

Another interesting metallurgical problem is that of solders for use in wiping joints in telephone cables. Somewhat to our surprise we found that some of the supposed prejudices of workmen responsible for

cable splicing were well founded and that it is scarcely practicable to make a satisfactory wiped joint with a lead-tin solder containing less than 38 per cent or more than 42 per cent of tin. New solders may well grow out of our study of why and how the old-fashioned solder works.

The interests of the telephone system extend of course to many other metallic materials, notably iron and steel, brasses and bronzes, die-casting alloys, etc. For the most part, however, progress in these fields has been along the lines of that of other industries. Part of our metallurgic shops are largely devoted to the melting, casting, and fabrication of a great variety of alloys into wire rods or sheets of specified dimensions for experimental trials in electrical apparatus design.

WOOD AND ITS PRESERVATION

It is a far cry from metals to wood, and particularly to wood preservation, which is one of our important chemical interests. The telephone pole is our most urgent concern. Large numbers of poles of cedar, chestnut, and southern pine are in use and the greater part have been subjected to a preservative treatment. Pine poles possess a layer of 2 or 3 inches of sapwood which is subject to impregnation under pressure, and such a treatment with creosote has long been the standard practice in the system.

The problems in this field are innumerable. We will mention only a few. Given a train load of telephone poles, how does one determine the average quantity of creosote they contain and the uniformity of distribution from pole to pole and in various parts of a given pole? No two trees grow alike. Soil, climate, sun exposure, accidents in past histories such as fires in forests—all make for peculiarities of growth in each individual tree. These peculiarities reflect themselves in the absorption of creosote, so that it is entirely possible for two poles treated simultaneously in the same cylinder to differ by a factor of 5 or even 10 in the over-all creosote content per unit volume. How can one obtain a sample which will be representative of a large group of such poles?

The sampling problem was approximately solved by taking a sufficient number of cylindrical solid cores with an increment borer and splitting these borings diagonally along a length which represents the approximate radius of the pole. Mathematically such a tapered cylinder approaches a wedge such as would represent a true sample of the pole's cross section. The borer holes are plugged with a creosoted peg and the poles are still fit for use, so one can sample as many poles as he likes.

This method is gradually being applied to a study of the content and

distribution of creosote, not only in new poles, but also in those that have been in service for varying periods of years. In order to determine how much creosote is present and also its present wood-preservative value, we have adopted a biological method of testing the toxicity to pure fungus cultures of creosote extracts from such old wood. An interesting story could be written about the specific resistance of various species of wood-destroying fungi to the numerous toxic agents that have been used and proposed.

In passing upon the merits of a new preservative it is difficult to predict its permanence in the wood when exposed to the weather. A promising method, though one which does not offer the ultimate in economy of time, is the use of small twigs or saplings which are impregnated with the preservative in question and exposed in groups to the action of the weather in a fast rotting climate.

In this test we are depending for acceleration entirely upon the reduction of the dimensions of the wood, while preserving at least the more salient features of wood structure by using natural twigs or stems rather than artificially shaped pieces. In applying this principle of reduction of dimensions for purposes of acceleration, we took a leaf from our book of experiments on submarine insulation in which we had found a strong case of parallelism between the absorption of water by rubber and the saturation of a material by heat as epitomized in Fick's law. The time required to reach a given degree of saturation is approximately inversely proportional to the square of the thickness of the specimen. The depletion of creosote from wood appears to be an inverse process, with of course some complications. Reasoning by analogy we hope by the use of small stems to shorten the time required for depletion of creosote and other preservatives and the beginning of rot in wood by ten to thirty years—a great economy in patience.

ELECTROCHEMICAL INVESTIGATIONS

Another large field of chemical investigation comes under the general head of electrochemistry, which for convenience includes corrosion, corrosion prevention, and finishes of both metallic and organic (paints, etc.) types. This work as well as the analytical laboratories, is under the supervision of R. M. Burns.

Among the electroplating developments has been the successful deposition of permalloy from a bath containing iron and nickel salts. The composition of the alloy containing 79 per cent nickel and 21 per cent iron can be maintained constant to less than 0.5 per cent. It is of interest to find that the alloy is deposited from the bath as a solid solution and that it has desirable magnetic properties.

The corrosion work consists of both corrosion testing and fundamental studies on the mechanism of corrosion processes. The corrosion tests are carried on under normal service conditions and by laboratory-accelerated processes. The results furnish guidance in engineering decisions as to the use of materials. More fundamental investigations in the field of corrosion have to do mainly with the study of the electrochemistry of corrosion reactions, film formation, etc. It is of importance, for instance, in the development of corrosion theory to determine

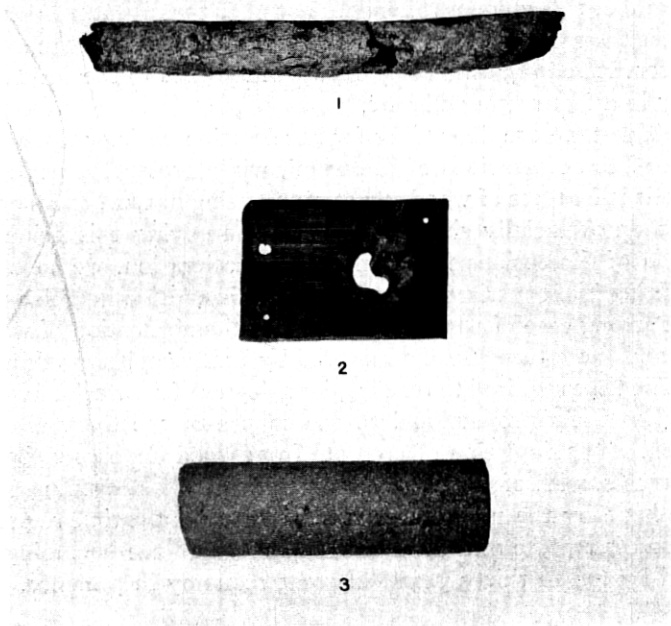


Fig. 5—Corrosion of lead cable sheath. (1) By direct contact with a pernicious soil. (2) Stray current anodic corrosion. (3) Acetic acid corrosion in fir duct.

the effect of the environment, and of the passage of small electrical currents, upon the anodic and cathodic behavior of pure metals, and work of this nature is being carried on.

Underground corrosion is an important part of the field. The most striking examples of this phenomenon are found in steel and iron structures and particularly in the lead sheaths of subterranean cables. Stray currents from trolley systems often cause such corrosion and an elaborate and expensive electrical bonding system is maintained in order to minimize these troubles. The physical and chemical nature of

the soils and the underground waters and atmosphere often play an important role in determining the kind and extent of corrosion by stray current.

Other occasional cases of electrochemical corrosion have been encountered in which stray current, though present, does not arise from trolley-line power houses. In one large city it was found that a battery covering a square mile or more of area had been inadvertently created, such that it affected a large part of the cable system in the center of the city. The cinder fills underlying the duct runs in this area contained enough carbon to serve as one electrode, while the iron-pipe systems supplying gas and water to the city furnished the other electrode. The



Fig. 6—Experimental metallurgical shop.

moist soil afforded a conducting path for a galvanic current that wrought a widespread damage to telephone cables in the area.

In another and much larger area widespread injury to cables came about through the presence of traces of acetic acid in the air in wooden duct systems. The source of this acid was the wood itself, which happened to be of a rather highly acid variety. The natural acidity of the wood was further increased by the somewhat drastic process of heating

which was necessary to secure a fair penetration of the wood with creosote. In so far as the creosote penetrated, the acid produced in heating was neutralized to a great extent by the nitrogenous bases in the creosote. Often, however, the total acid produced far exceeded the neutralizing power of the creosote bases contained in the external shell of creosoted wood. The sheath of many miles of cables underwent a partial conversion into white lead via the classical Dutch process which, though highly regarded by paint manufacturers, became anathema to telephone engineers. The difficulty was met by fumigating the ducts in service with a dilute ammonia-air mixture and by choosing a less acid and more easily treatable wood for future construction.

Underground corrosion of other metals, notably of iron and steel, is also often serious. In the alkali soils of the southwest anchor rods for telephone poles have sometimes corroded through in a few months. Marshes represent another severe exposure for iron and steel, as, for example, in the form of loading coil cases. A newly introduced form of telephone cable for direct burial in the soil demands careful consideration from this standpoint. A variety of protective finishes, chiefly of asphaltic or pitchy nature, have been studied in this connection. Some remarkable cases have been noted, in which a finish that proved to have a superior protective effect in one highly corrosive soil was worse than useless in another soil which had been regarded as less corrosive in the general sense.

The chemistry and physics of soils from many areas have required attention with the control of corrosion as an object. Particle size, saline content, and composition of subsoil atmospheres each has an influence.

In a like way the telephone chemist must concern himself with atmospheric causes of corrosion in equipment above ground, especially in central offices. Moisture and dust contribute to electrical leakage from point to point through the complicated assemblies of electrical equipment. Corrosion products of such leakage may build up at critical points and interfere with contacts, or essential though usually minute portions of equipment may be etched away. Even faint tarnishes on metallic contacts can so increase contact resistance as to imperil signaling. In industrial areas soot and traces of sulfurous gases add materially to these hazards.

FINISHES

It is partly to avoid such difficulties and partly for the equally utilitarian purpose of a good appearance that metal telephone apparatus receives some special form of finish coating, whether paint, varnish, lacquer, or electroplated surfacing. In the selection of such finishes

we have drawn heavily upon the scientific work of our confrères in allied fields, but have still found ourselves faced with peculiar difficulties.

A great deal of the truly excellent scientific work on finishes has been done by manufacturers with the idea of disclosing uses which will justify the sale of a particular material. But comparative data on the durability of very dissimilar finishes as, for example, galvanized coatings in contrast to cellulose lacquers, are usually lacking. The fact that finishes are often used primarily for decorative purposes on relatively short lived articles has limited the study of the durability of such coatings. This is reflected in the fact that nearly all the scientific work in this field refers to outdoor exposures where corrosion tends to occur rapidly. Indoor exposures are commonly regarded as so mild as to be negligible. Changing fashions, as in the case of furniture, often bring an obsolescence so early as to be prohibitive were similar consideration to be applied to telephone plant. The prevalent custom of trading in one's motor car for a new model each year is a factor in another large industry involving extensive use of finishes, which tends to put great emphasis upon initial beauty rather than permanence over periods of ten to twenty years, such as must be considered in telephone plant.

With the manufacturing and operating telephone companies tied into a single system, in which the Bell Laboratories' responsibility is to insure quality of product, there can be no unloading of defective apparatus upon the consumer, for the manufacturer is liable in the last analysis for defects which may appear only after years of use.

These considerations have received special emphasis in the discussion of finishes because they afford an excellent illustration of the point. The same sort of considerations, however, apply to nearly all the problems with which we are concerned, to such an extent that our chemical staff is widely thought of in our own organization as a group of specialists in the "permanence" of materials. Such an emphasis by the general management upon ultimate economy rather than first cost alone would doubtless be welcomed everywhere by thoughtful technical men throughout the country. It is a source of peculiar pride to the staff of the Bell Laboratories that the nature and organization of their business is such as not only to permit such an attitude but also aggressively to promote it.