THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

Some Non-Metallic Substances and their Characteristics.

BY

Captain N. F. CAVE-BROWNE-CAVE,
B.Sc., M.I.E.E.

A PAPER

Read before the Northern Centre of the Institution on the 20th April, 1932, and before the London Centre on 11th October, 1932.

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SUMMARY OF CONTENTS.

SOME NON-METALLIC SUBSTANCES AND THEIR CHARACTERISTICS.

INTRODUCTION.

This paper is a review, on quite broad lines, of certain non-metallic substances which are of particular interest or importance in communication engineering. These substances have been divided into two groups—covering materials, such as paints and enamels, fibres and fabrics, rubbers and resin products; and clay products, such as open line insulators, underground ducts and cements. Space could not be found for certain different types of non-metallic substances,—timber and creosote for example,—though they are equally important.

The every-day user of Post Office engineering stores must often feel curious as to what the articles supplied to him are made of; what their characteristics and special qualities are; and why certain materials are preferred to others. Some general technical knowledge of these subjects, even if not very profound, can hardly fail to interest and assist those who take a pride in supervising maintenance and construction work in a scientific manner. The object of this paper is to collect some practical information on these points for ready reference, though it is recognised that such a collection must inevitably include numerous items which are already well known to many readers. Elaborate chemical analyses and other abstruse details have been avoided; so also have quotations from Post Office and B.S.I. specifications, otherwise each section of the paper would have needed at least one complete paper. To facilitate references, an index has been included as Appendix 2. The Figures are on pages 46 and 47.

Grateful acknowledgment is hereby made to Messrs. R. Linch and H. F. Hourigan for much valuable advice and willing assistance; to their assistants in the Birmingham Testing Branch chemical laboratory, especially Mr. K. R. Honick, for photographs, slides and diagrams; to Messrs. Ericsson Telephones, Ltd., and Messrs. Bakelite, Ltd., for the loan of numerous samples and slides; and to Mr. C. Robinson and Lt.-Col. F. Reid for useful suggestions.

"The Inspection and Testing of Materials, Apparatus and Lines," by Mr. F. L. Henley, a former Post Office Test Section Staff Engineer, can be strongly recommended as a mine of information on materials in general. The publishers are Messrs. Longmans, Green & Co. There are innumerable other Text Books and Reference Books on one or more of these subjects.

PART 1. COVERINGS.

Science as applied to communication engineering utilises a vast net-work of electrical conductors which must be suitably insulated and supported. The whole construction, moreover, both indoors and out, should be protected against damage and corrosion, and made reasonably ornamental. This ideal necessitates the use of paints and enamels for covering constructional woodwork and metals, when such metallic coverings as galvanising and electro-plating are not provided; and it requires the protection and insulation, in varying degrees, of apparatus wiring, connecting cords, underground cables and open wires. Typical examples of the protecting and insulating materials employed are the fabrics used on cords; paper; indiarubber, gutta percha and balata; bakelite and ebonite; and such substances as mica and asbestos.

The conditions under which these materials are used provide great variations in the type and degree of exposure; in the amount of flexibility necessary; and in the insulating properties required. All the non-metallic coverings have considerable powers of insulation, but special attention will be called to those which can be regarded as first class insulators.

SECTION 1. OIL PAINTS AND VARNISHES AND THE LIKE.

1. *Pigments, Vehicles, Driers and Thinners.*

The four fundamental constituents of oil paints are:—

(*a*) Pigments,
(*b*) Vehicles,
(*c*) Driers,
and (*d*) Thinners.

The essential properties of good paints are briefly that they can readily be applied with a brush or by spraying; and that when dry they will leave a continuous, hard and durable film of the required colour. The pigments provide the colour; the vehicle—an oil—carries the pigments and forms the basis of the hard film; the driers assist and control the hardening process; and the thinners thin down the paint to the right consistency for working, without interfering with the hardening.

(*a*) *Pigments,* as used by the Post Office, are listed in Appendix I. Reference thereto will show the important parts played by lead compounds, by various oxides, and by lakes. A lake is a synthetic aniline dye, coupled with a base (or body) such as barytes or alumina. To facilitate thin and even coats of paint, all solid components must be ground very finely and uniformly.

(*b*) *The Vehicle* is a drying oil of vegetable origin. Linseed oil is the most favoured, but recently tung oil (a Chinese wood oil) has become popular, more particularly in varnishes. Drying oils have the property of changing slowly to a gum-like solid when they are exposed to the atmosphere in a thin layer—a conversion which can in the main be governed by a carefully controlled boiling process during manufacture. The eventual hardness of the paint film depends largely on the amount of this boiling. Too much boiling leads to excessive contraction, and consequently to surface cracking, so mixtures of boiled and unboiled oils are frequently used. The chemical changes in the film during drying and hardening are extremely complex, but the most important of these changes is oxidation.

(*c*) *The Driers* usually contain salts of manganese, cobalt or lead. They are oxygen-carrying substances which appear to catalyze the oxidation and other changes of the drying film, and thus control the speed of hardening. In exposed positions dust or rain will partly spoil the drying film, so that a reasonably quick speed of drying is desirable; but it is certain that the too rapid drying of an oil paint or varnish film tends to lead to its early breakdown. When the film finally reaches the solid oxidised condition it is no longer very elastic and is liable to crack; so an excess of driers must not be allowed in the film or else at this stage rapid cracking will almost certainly follow.

When two coats are applied, much time is saved if the first coat be reasonably quick-drying. This is permissible in flat-drying under-coats, as they will later be shielded from the atmosphere by a finish coat of paint or varnish.

(*d*) *Thinners* belong to a group of liquids which include turpentine, rosin spirit, mineral spirit, and coal tar naphtha. Turpentine seems in many ways to be the best.

2. *Practical Properties.*

Drying time and covering powers are the two properties most readily tested, durability tests taking a very long time unless elaborate apparatus be used. By the use of ultra-violet rays and of quick cycles of heat and cold, and of dryness and dampness, durability tests can be much accelerated.

As stated above, the longer the drying time the better—within the limits dictated by the conditions of application. The covering power, including the ability to hide, can be tested by first using a standard pink priming on well-surfaced yellow deal, and then ascertaining the weight of paint required to blot out completely, say, one sq. ft. of this priming. Under such conditions the minimum covering powers, expressed in square feet covered per one pound of paint, should be:—

White paint, 50-60; Stone, 70-80; Lead, 90-100;
Chocolate, 110-120; Green, 120; Red Oxide, 140-150.

A sieve test detects any coarse particles or skin.

In painting almost all kinds of *woodwork*, it is best to use as a priming a thin-bodied paint, which should preferably contain a lead pigment. Paints with a genuine white lead base work better from the brush than any others and lead compounds kill most of the many varieties of fungi which attack woodwork; they also have a dangerous poisoning effect on the user if he fails to take reasonable precautions with his hands. Any suitable priming coat soaks into the wood and, when dry, provides a key on which to fix the next coat, thus avoiding any likelihood of peeling. As an alternative, aluminium paint has recently been used as a primer, and is stated to form an impermeable coating between the wood and the weather. It is claimed that such a moisture-proof metallic covering preserves the wood from swelling and warping, prevents stains from exuding, and gives a perfect base for finish coats. By this method the outer coats are said to retain their appearance without breakdown far longer than they will on other primings, though this is not yet fully proved.

Aluminium paint may be found to be an exceptionally good priming when it is necessary to paint poles which have been creosoted. Experiments to prove this are now in progress.

Non-cellulose *enamels* are really very carefully selected pigments which have been ground in a varnish medium. They can best be used on a good body of flat, quick-drying paint. The glossy coat is then hardly more than a veneer, and need contain but little pigment.

In painting *metal surfaces* it is essential to ensure that the undercoat shall not cause corrosion of the metal, and that the film shall be truly continuous, *i.e.*, entirely free from even invisible breaks or imperfections. Thus, pigments containing graphite, carbon black, or lamp black, though they make a very durable water-resisting outer coat, must not be used as an undercoat because of corrosion; also the oil and pigment in the undercoat must have an exceptionally strong affinity for each other, and the primer must be ground extremely finely. Absolute continuity of film can then be assured. Red lead (Pb_3O_4) is very suitable in this respect; and red lead, lead oxide (PbO) and basic lead chromate all inhibit the corrosion of iron. There is a further group of neutral or inert pigments which excite no corrosion and produce a durable film, this group including black, brown and red oxides of iron; china clay; silica; talc and barium sulphate.

Post Office letter boxes furnish an excellent example of the special selection of an oil paint and varnish for exceptional conditions. For cheapness in repainting the enormously large number of boxes involved, it has been considered essential to make it possible for a box to be re-painted and varnished in one day. A matt, quick-drying paint is used, which hardens in about 20 minutes. The pigment is a special red lake. This coat is then covered by a single coat of a first class elastic varnish, which sets in about eight hours. The result will last for at least a year, probably for two years, under the extremely severe conditions of exposure which prevail. Similarly for repainting the frames, etc., of concrete kiosks, the old paint should be sand-papered and a coat of oil paint applied, followed by a coat of first class varnish. A good brushing cellulose covering of " P.O. red " colour has not yet been found; it is at present almost essential to spray cellulose coverings, a process which might be found impracticable in the streets.

Coal Tar Paints are of no value for covering iron work, as they can only stand a few months' exposure, but high class *bituminous paints* have been shown to stand exposure for more than two years. Yet even they are best used over a priming coat of real inhibitive paint.

Oil Blacking is used on pole climbers and other tools. The tools are heated to a temperature just below red heat and are plunged into oil. The oil carbonises on the hot surface and there is appreciable penetration of a protective mixture of the oil and carbon. This process entails some danger of spoiling the temper of the tools and seems likely to be superseded by painting with a bituminous paint.

Enamel on Copper Wire, such as is used in " Wire, enamelled and flame proof," must have first class elastic and insulating properties. The specified tests include insulation tests at 1,000 volts after 24 hours' immersion in 1.20 S.G. caustic soda and in 1.25 S.G. sulphuric acid; and require the enamelled conductor to withstand 10 volts whilst a length of ten inches is steadily elongated under water to the extent of 7.5%. These tests are likely to be modified and the caustic soda test omitted. Such a Post Office enamel is usually based on fossil bitumen or on a petroleum pitch. Other wire enamels are really " long oil " varnishes, (as defined below), and may contain 90% linseed or tung oil and 10% copal gum or fossil bitumen.

Enamelled Iron is used for Call Office and other signs, and for caution plates, etc. The " enamel " in this case is not a paint, but consists of a pigment suspended in a *glass*. This glass, in a molten state, is sprayed on to the iron. Several coats are applied and the lettering is obtained by means of stencils.

Acid-resisting Enamels are shellac or resin varnishes containing colouring agents. These enamels must give a film which is reasonably elastic and absolutely continuous, so as to preclude acid penetration.

Lanoline, a product of lambs' wool, is an excellent temporary preservative for bright metal surfaces. It is smeared on, and does not, of course, set like a paint.

3. *Oil Varnishes and similar Finishes.*

Varnishes usually consist of resins dissolved in drying oils, with the addition of a thinner which may be turpentine, or white spirit, or a mixture of the two. Most resins have to be thoroughly fused before they will dissolve in the oil. With incomplete solution a bloom from the suspended particles will appear when the film oxidises and sets. The oils most commonly used are boiled linseed oil and tung oil.

For *very pale varnishes*, pale resins and pale oils are essential—the resins being fused at the lowest possible temperature. Within the last few years suitable resin-like materials called " Ester Gums " have been evolved, which are derived largely from common pine resin. They must have a low acid value. They do not need the high temperatures of fusion which are required by *fossil* resins, and they are specially suitable for these very light-coloured varnishes. They are combined with China wood oil to make them durable.

Varnishes are called " *long* " when the oil to gum ratio is high—at least 20 galls. of oil to 100 lbs. of gum; and they are called " *short* " for a low oil to gum ratio, say, 8 to 16 galls. of oil to 100 lbs. of gum. This oil to gum ratio largely controls the drying time, durability, hardness and elasticity of the film. For places exposed to the weather two coats of long oil varnish should be used wherever possible. These coats should be chosen so that the outer coat is the tougher and more elastic, and so that they dry in from 6 to 8 hours each. A good long oil varnish may last 18 to 24 months. For interiors and furniture, short oil varnishes are used which produce an exceptionally hard film. They set quickly, but this is incidental; they are not suitable for exposed conditions.

" *Japanning* " is an important varnish finish for metal parts. In one process these parts are first " coslettized," by boiling in ferric oxide and phosphoric acid, which gives a black and slightly porous matt coating; they are then dipped in a black oil varnish and stoved. An excellent finish is obtained which is glossy, hard and durable, and reaches all edges and corners.

" *Parkerising* " is a more recent process of special value for iron goods. Their surface is first thoroughly cleaned by a trichlorethylene degreaser, and they are then immersed for a minimum period of 20 minutes in a boiling " Parkerising " solution. The iron surface reacts with the solution and an insoluble non-metallic coat is formed which is claimed to prevent the spreading of rust. Two coats of stoved enamel are then added. The protection thus afforded promises to be exceptionally complete and long lasting.

Lacquered Brass telegraph instruments are given a pleasing yellow finish which, though not very hard, resists atmospheric corrosion for many years. The metal is first warmed—it must not be really hot—and is then painted with a mixture of 10% shellac and 90% methylated spirits.

Remarkable " pattern " effects are produced with tung oil varnishes in which the oil has not been properly boiled. These varnishes are extremely difficult to control in manufacture, and do not yet appear to be as reliable as linseed oil varnishes. Tung oil is produced from trees which are indigenous to Japan as as well as to China. These trees are now cultivated on a large scale, especially in America.

A recent development is a varnish containing *vulcanised* linseed oil. This varnish appears to be superior to others, but sufficient time has not yet elapsed for complete exposure tests.

Practical tests of a varnish include its " pulling power " or " feel " when being brushed; its drying time; its colour; and its appearance of depth when dry.

4. *French Polish.*

French Polish is used when it is desired to give an extremely glossy finish to high-class cabinet work, and to exhibit the grain of the wood to the best advantage. Varnish can be used for the same purpose, but not nearly so effectively. The polish consists of shellac dissolved in methylated spirits and is used in conjunction with a dye or stain which is selected to produce the desired tint. The surface of the wood is first made perfectly smooth with glass paper; next it is filled with stained Plaster of Paris and water, which is rubbed off; it is then stained and rubbed down lightly with fine glass paper; and finally the polish is laboriously rubbed on with a cloth. There are many permissible variations in these stages, but in all of them the process needs much skill and is slow and expensive. Success depends on the ability of the operator himself much more than is desirable.

There are two serious drawbacks to varnished surfaces, both on wood and metal, and to French polished cabinet work:—they are easily scratched, even by wiping off dust, and they are irreparably marked by contact with any hot substance, even with a hot plate. These two facts have led to the production of cellulose lacquers and enamels such as are next described. These cellulose coverings have almost banished oil coverings from many fields because the film they produce has a very hard and durable surface. Moreover cellulose coverings can be sprayed on and are quick drying. They set, or harden, chiefly by the rapid evaporation of solvents,—not mainly by slow oxidation as do oil coverings. In certain circumstances there may be difficulty with cellulose because hand painting may be desired, but may be found impracticable because of too rapid drying.

Section 2. Cellulose Lacquers and Enamels.

Great progress has been made in recent years in the production of first class cellulose lacquers and enamels. They are usually sprayed on; they are quick drying, durable, readily polished and reasonably elastic; yet they are so hard that it is difficult to scratch them and they are proof against easy damage by contact with hot plates, etc. They will not carry pigments so densely packed as will oil paints, but this drawback is off-set by the much thicker film which can quickly be obtained by successive coats. An outstanding example of their utility is in the motor car body industry. They are now coming into almost universal use in the telephone industry, too, and are becoming popular also for office and other kinds of furniture,—or, in other words, whenever spraying is practicable.

No special mention is necessary of the colouring matter used, except to say that in this section of the paper "lacquers" are taken to have no colouring matter except perhaps a dye, whereas "enamels" contain pigments, much as in the case of oil paints.

Colour apart, the constitution of lacquers and enamels is practically identical, and may be summarised broadly as follows:—

A "vehicle" is employed consisting of cellulose nitrate (nitro-cotton), or alternatively cellulose acetate, which has been dissolved in a suitable solvent; and there are added "plasticisers" to reduce contraction of the film and to keep it sufficiently elastic after evaporation of the solvent; thinners or diluents, to permit of easy application; and gums and resins to improve adhesion and ensure a suitable gloss.

In the past it was often urged that an under-coat of oil paint greatly improved adhesion and filling, and facilitated the transition from the expansion figure of metal, in particular, to that of cellulose. But the latest plasticisers and solvents seem to ensure a perfectly satisfactory all-cellulose process. Amazing progress has recently been made; even cellulose dipping is now entirely successful.

5. *Cellulose, Nitro-cotton and Cellulose Acetate.*

Cellulose is a very widely distributed carbo-hydrate of the form $(C_6 H_{10} O_5)n$. Cotton, flax, hemp, jute and many other plants are cultivated as sources of cellulose, cotton being the one most used for cellulose lacquers and enamels. The first step is to transform the cotton into either nitro-cotton (cellulose nitrate) or into cellulose acetate.

For the production of *nitro-cotton*, fibres of cotton which are too short for spinning and weaving are found to be quite suitable and are relatively cheap. These fibres are first cleaned by being boiled in caustic soda, and are then washed and dried. Next they are immersed in a bath of mixed nitric and sulphuric acids. Skilled and careful control of the strength of the acids and of the time of immersion governs the viscosity and general suitability of the resulting nitro-cotton. The final step is the complete removal of all traces of free acid. This is essential for a long-lived film, and also to avoid corrosion when applied as an under-coat over metal.

Cellulose Acetate is a more stable and, for certain purposes, a superior alternative of recent development. It is produced from cotton (cellulose) and acetic anhydride. Its greatest advantage is that it is practically non-inflammable. It gives great promise of further development. The same general principles of treatment apply to both the nitrate and the acetate forms.

Messrs. Ericsson Telephones, Ltd., the well known Telephone Manufacturers, have been particularly successful in producing cellulose lacquers and enamels. To give just three examples, they produce:—(1) a nitro-cotton "water-white" lacquer, which is scratch-proof and very durable and is much used for covering plating; (2) cellulose acetate enamels, which are proof against water, oil, petrol and acid and yet are so exceptionally elastic that they can be used to cover flexible braided cable without fear of splitting; and (3) a cellulose acetate insulating lacquer or varnish, (tinted with a dye to show its presence), which can be used, for example, on the carbons of protectors in place of sheets of mica.

Protected and armoured lead-covered cables are now being laid in, or drawn into, the bare ground in many places. It would seem at least possible that an insulating, resistant and elastic cellulose enamel or lacquer may prove to be the best first coating next to the lead.

6. *Plasticisers, Solvents, Thinners and Gums.*

The choice of plasticisers, solvents, etc., is governed by the purpose of the finished product, since this purpose controls the properties required in the film.

(*a*) *Plasticisers,* ofter with high-sounding names, are claimed to give to the film such properties as increased hardness, weather-proofness, elasticity, flexibility, tensile strength, durability, and gloss; and reduced inflammability. Where cheapness is an important feature, and where quick drying and hardness of film are not essential, castor oil is much used —particularly in aeroplane and leather dopes. Camphor is little used now, as it is costly and evaporates quickly, leaving the film too brittle.

(*b*) *Solvents and Thinners* have to be selected and blended by experts, bearing in mind the climatic conditions obtaining in the spraying rooms, and the ultimate purpose in view. The thinners, or diluents, which usually consist of coal tar and petroleum products, are much cheaper than solvents. As both are evaporated during drying, the cheaper thinners are naturally preferred to solvents for reducing the liquid to the required consistency; but there must be enough true solvent to retain the nitro-cotton in solution when the diluents have evaporated, otherwise it will be impossible to keep the film clear as it sets.

(*c*) *Gums and Resins* are incorporated because a pure cellulose film has little or no gloss and does not adhere particularly well. They are used in greater proportion on woodwork, because of the absorbent character of the wood, and to give body and thickness to the film. Besides natural gums, synthetic resins such as " Albertols " are being more and more used; they are purer and more consistent in action.

It is essential not to overload enamels with pigments, as such overloading causes rapid surface deterioration. The pigments protrude through the surface, where they are exposed and unprotected, the gloss vanishes, and a chalky appearance quickly develops.

It is always necessary to ensure that hardness of film is not secured at the expense of adequate elasticity.

7. *Polishing, particularly for Cabinet Work.*

When it is desired to give a bright glossy finish to an exposed coating of enamel, it is not good practice to obtain this gloss by giving a final coat of clear lacquer, because this finish will not stand exposure. With enamels over metals, for example, it is preferable thoroughly to sand an under-coat of enamel with paper or pumice stone, and water or mineral oil, and then to spray on a light film of clear *solvent*. Alternatively, polishing pastes, which are a combination of wax and abrasives, can be applied directly to the enamel, either dry or with water or paraffin; or, again, there are excellent liquid polishes which usually consist of an abrasive, ammonia, white spirit and a quantity of solvent. The solvent is insufficient to soften the enamel film, while the ammonia prevents that hazy appearance which is often experienced with wax polishes.

With cabinet work, when the natural grain is to be displayed, cellulose lacquers will give a cheaper, quicker and much more durable polish than is possible with French polish or varnish. French polishing is a costly and tedious business, and—like varnish—is all too easily ruined. With the cellulose lacquer process, cheap wood fittings are first filled with a stain and then sprayed with 2 or 3 coats of clear cellulose lacquer. For high class finishes, the wood must be well seasoned and thoroughly sand-papered, and then filled by a suitably coloured paste. In this instance, thorough brushing across the grain is preferable to spraying. When the filler has had just sufficient time to set, the surplus is brushed off across the grain; and when the filler has become hard, the wood is sanded to a smooth surface and stained, and about three coats of clear lacquer are sprayed on. The spray finish is glossy enough for some purposes; for a really high gloss, however, it is necessary to polish, possibly by rottenstone and oil, or preferably by one of the modern non-abrasive special solvent compounds which remove practically no cellulose. In this latter process polishing is done by a cotton pad wrapped in linen or chamois leather. This pad is moistened by a mixture of solvents and diluents such as will have only a slight solvent action on the outer surface of the film, and in this simple manner an extremely brilliant polish is ensured.

8. *Special Finishes.*

Cellulose enamels and lacquers can readily be used to give some striking ornamental finishes which are suitable for various special purposes. To give a few examples very briefly :—

(*a*) A " *Crackle finish* " for radio horns, picture frames, etc., is obtained by using an outer-coat in a contrasting shade, and giving it an excess of pigment content. This film is certain to crack in every direction on drying, thus exposing the pigments. A finishing coat of clear lacquer should then be applied.

(*b*) In " *Marbling* " a feather moistened with a spirit-soluble dye is used to put splashes of colour on a white or buff under-coat. When the surface has dried, a coat of matt white is applied and the dyes " bleed " through and give a marble-like effect.

(*c*) For a " *Speckle finish,*" pigments of contrasting shades are sprinkled by hand, or from a sifter, on to a wet coat of enamel; or alternatively metallic powders may be used, which are found to float into very pleasing star-shaped designs.

(*d*) An excellent " *Old Ivory finish* " for ornaments, door plates, etc., is given by rubbing a mixture of burnt umber and oil on to a dried coat of sprayed semi-matt light ivory enamel, and covering with a semi-matt transparent lacquer.

(*e*) " *Frosting* " is obtained by sprinkling mica flakes on to wet enamel.

(*f*) A " *Crystalline finish,*" common to radio horns and fancy goods, can be produced by utilising the natural shrinkage of unboiled tung oil in a copal varnish. This is applied over a ground coat of enamel and is stoved for one hour at 120°F.

9. *"Brushing" Lacquers and Enamels.*

For some years cellulose lacquers and enamels could not satisfactorily be "brushed" on, because excessively rapid drying gave no time for irregularities to be smoothed down nor for brush marks to flow out. This resulted in an uneven and wrinkled finish. Another trouble was that a second or further coat so far dissolved the previous coat as to work it up. The addition of gums and plasticisers improved brushing, but softened the film.

A new blending of solvents has overcome these difficulties. This new solvent has three great advantages:—

(*a*) Being an exceptionally powerful solvent, it gives greater hiding and binding powers by reason of the abnormal amount of cellulose and pigments which can be incorporated. (*b*) Being a somewhat slow-acting solvent, a second or further coat can be thoroughly brushed out without unduly dissolving and pulling up the previous coat. And (*c*) the film dries sufficiently slowly to permit of all the brushing out required, yet it is extremely hard and durable. Except for quite small surfaces, however, "brushing" still calls for considerable skill and experience.

It can well be imagined how serious a rival these cellulose coverings have become to oil paints and varnishes, and to French polish. A French polish costs about four times as much as a varnish finish, and considerably more than cellulose lacquer. As regards the cost of bright cellulose enamel as compared with that of oil paint and varnish, taking both labour and materials into account, cellulose is much cheaper in straight-forward cases suitable for spraying without masking—it may cost less than half. The saving may be reduced to perhaps 25% if a moderate amount of masking be necessary. Yet in the decorative and in-door field, where spraying predominates, cellulose gives more varied effects and a far harder and more durable film. In the preservative and outdoor field, where brushing is often essential, cellulose has the extremely important advantage of drying much more rapidly, though skilled application is necessary. Cellulose has not the fungicidal properties which lead compounds enjoy against most, though not against all, fungi.

SECTION 3. PROTECTIVE AND INSULATING SUBSTANCES.

This paper has so far dealt with coverings which undergo modification and hardening when they are brought into use. Next comes a group of *stable* covering substances which are much used in telephone engineering either for their protective or for their insulating properties, or for both. Liquid, flexible and more or less rigid materials will be dealt with in turn.

OILS AND LATEX MATERIALS.

10. *Insulating Oils.*

Transformer oils are highly refined mineral oils which are absolutely free from moisture. The Post Office specifies that such oils shall withstand 30,000 volts across a submerged gap of 0.15 inch. The slightest trace of moisture will reduce this voltage to about one tenth; but oils can be purchased which will give twice this value. Any extraneous matter leads to sparking and breakdown by forming a "rope" between the electrodes; and in actual use in transformers any unsaturated bodies in the oil form a sludge on the windings and reduce the effective spacing. It is interesting to note by way of comparison that about 13,000 volts will just spark across an open *air* gap between ball tips which also are 0.15 inch apart; and that about half a million volts are necessary if the tips be separated by best quality mica sheeting.

For mushroom insulators on battery racks a "dead" oil is used, which is a creosote oil from which the naphthalene and phenols have been extracted. Any reasonably well refined mineral oil would be equally suitable.

11. *Indiarubber.*

The latex of certain tropical trees is found to be a colloidal substance containing some 30% to 40% of rubber, besides over 50% of water. The Hevea tree of Brazil was the original and most common rubber-bearing tree to be cultivated. Either heating the latex over a smoky fire, or adding to it a chemical electrolyte, usually acetic acid, separates the rubber from the latex and allows it to coagulate. It should not be allowed to ferment. When this product has been washed, passed through rollers, and dried, we have raw rubber, often called "caoutchouc." It is of the form $(C_{10} H_{16})n$.

Rubber, whilst in the raw condition, *i.e.*, prior to vulcanisation, is rather unstable and in this form its uses are limited. At 0°C it is hard; at 15° to 20°C it can be stretched tremendously, and newly cut surfaces will readily stick together; and at about 50°C it is very plastic and can be pressed into any desired shape. Rubber is now known to be a crystalline substance.

For general use the raw rubber must first be vulcanised. The hot sulphur process is the most common, and is employed for rubber wire-sheathings and most other Post Office rubbers. The raw rubber is heated with sulphur under pressure under conditions which are varied according to the rubber compound required. These variable conditions include the duration and temperature of heating and the possible admixture of selected mineral ingredients. For example, the addition of zinc oxide and carbon black will give much greater strength than if sulphur alone be used; and the greater the proportion of these ingredients, the more rigid is the product. The exceptional fineness of carbon black particles permits of extremely close association with the rubber, and provides the maximum of toughness and resistance to abrasion. Carbon black and zinc oxide together comprise quite a large proportion of a "rubber" cycle or motor car tyre—few people realise how large. It is often about two-fifths.

There are alternative "cold cure" vulcanising processes. In one of them—used in the case of indiarubber gloves and suitable only for thin sheets, proofed cloths and the like—the rubber sheet is treated by a roller process, using a weak solution of sulphur chloride in carbon bisulphide. The mechanical and ageing properties of the rubber are much improved thereby, but it is essential to remove all traces of acid so as to ensure a long life.

There is another cold process which is of special value when it is desired to introduce a variety of organic filling and colouring agents which would be affected by other processes. The rubber is wetted with benzene and then for about 30 minutes is subjected to the action of sulphur dioxide and hydrogen sulphide gases. Excellent floor coverings are produced by mixing cork dust or wood meal with raw rubber, and then sheeting and vulcanising them in this way; or leather waste can be used similarly to give a "reformed" leather for the manufacture of boots, shoes, upholstery, etc.

To ensure good insulating properties and maximum life a pure high grade rubber is essential. This is impossible if, for example, indiarubber substitute be used, *i.e.*, a rubber containing oxidised or vulcanised oils. For V.I.R. cable only the best quality indiarubber is permissible, and it must be vulcanised to the correct degree. With vulcanised rubber coverings copper conductors are always tinned, and not infrequently with unvulcanised rubber. Various useful purposes may be served by the tinning, such as improved soldering facilities; but the most important result is to protect the rubber from the deleterious effects produced on it by bare copper.

12. *Gutta Percha, Balata, and Paragutta.*

Certain trees in the Malay States and Borneo produce a latex containing *gutta percha*; others in Venezuela and Guiana yield *balata,* which is collected by people known as "balata bleeders"! Neither material needs vulcanising and both are good insulators and offer great resistance to water under high pressure. Balata is not nearly so stable in contact with the air as is gutta percha, but on the other hand it gives considerably lower attenuation in cables. It was thus an advantage to use balata in the submarine portion of a cable and gutta percha at the shore ends. Both are hard, though not brittle, and are less elastic than rubber. They resemble rubber chemically, though gutta percha does not necessitate the conductor being tinned to preclude corrosion. Vulcanised rubber, as already stated, does; some authorities think that balata does, too.

For the Anglo-Belgian submarine cable laid in 1911, Messrs. Siemens produced a *specially treated balata mixture* which resulted in the leakance to capacity (G to C) ratio being reduced from about 100 to 12 at a frequency of 800 p.p.s. Moreover the insulating material was reduced by half, compared with previous practice.

Paragutta is a much more recent improvement. It is specially valuable for submarine cables containing carrier circuits or other circuits needing relatively high frequencies. By its use a cable has been made with the G to C ratio as low as 7.1 at 800 p.p.s.; and only about one-sixth of that of pure balata at 8,000 p.p.s. Paragutta is produced by deproteinizing rubber by treating it in water at 150°C, and then washing and mixing the rubber with balata and montan wax.

Fibres.

Next comes a group of fibres, most of them of vegetable origin. Only those used largely in telephone engineering will be dealt with. Cotton is the most used, particularly for coverings, braidings and certain bindings of cords. It has excellent powers of resisting abrasion, particularly when glazed. Even when waxed, however, ordinary cotton is not regarded as a first class insulating material, though recent developments in treating cotton give extraordinary improvements in its insulation resistance. For water-proof and out-door instrument cords, a cotton lapping next to the conductor is allowed because it is covered by a lapping of pure rubber ribbon; but for ordinary instrument and connecting cords, and for all switchboard cords, nothing but silk or cellulose acetate rayon or cotopa is at present permitted to be in contact with the conductor. This restriction is extended even to the bindings. Officers who supervise cord repairers should see that waxed linen thread or the like is not used by repairers in contact with conductors; natural silk, cellulose acetate rayon or cotopa, all waxed, alone should be used. Wool is particularly suitable as a covering for flame-proof wire because it resists the spreading of a flame.

In America fabric-covered wires are being surface-treated with several coats of cellulose acetate lacquer applied in an acetone solution. The physical effect is to give a firmer surface which remains transparent to colours, but which ensures separation of the fibres from those of adjoining wires. The electrical effect is to reduce and stabilise the conductance and capacitance losses and to render them almost independent of humidity changes. In many cases an enamel undercoat is then no longer found necessary.

13. *Cotton, Mercerised Cotton, Glazed Cotton & "Cotopa."*

A cotton fibre, (particularly from American cotton), takes the form of a twisted band or ribbon of the type shown much magnified in Fig. 1. This and the other figures are shown on pages 46 and 47. Fig. 9 shows the cross section. Immature fibres, known as "dead" fibres, must be avoided because they are not durable; so also must any impurities in the cotton. The best quality fibres approach 2 inches in length and are ½ mil thick; those of poor quality may be as short as half an inch, and perhaps three times as thick as good quality fibres. A single cotton thread of 60 count, (*i.e.*, 50,400 yards per 1 lb.), should break at about 3.8 ozs. and give 6.5% to 8.5% elongation with an 18 inch test length.

Plain cotton, as used for first lappings on a conductor, is called " soft " cotton. A " standard hank " of cotton yarn is 840 yards long. The " count " is the number of such 840 yd. hanks in 1 lb. of yarn.

Mercerised Cotton is used for the centre of tinsel threads, for the second braiding (over silk) of ordinary instrument cord conductors, and also for the outside of certain cords which have a braided covering over a group of conductors. Mercerising is brought about by immersing the fibres in caustic soda solution. The fibres are thereby changed from flat twisted ribbons into almost solid thick-walled cylinders, (see Figs 2 and 9). The process increases the strength by from 35% if stretched, to as much as 68% if unstretched; and it produces a lustre which is increased by calendering, (ironing with rollers). This lustre may then approach that of silk.

Glazed Cotton has a finish similar to horsehair. It is produced by dipping the cotton first into a solution of aluminium and alkaline earth salts, and then into an ammonia bath, and finally by calendering. Glazed cotton is used for the outer braiding of the conductors of certain connecting, waterproof and outdoor instrument cords; for the outside braidings over stranded conductors in certain instrument cords; and also for the overall braiding of switchboard cords. It is not used in contact with conductors for fear of corrosion; it is valued mostly for its powers of resisting abrasion.

" Cotopa " cotton yarn is produced by a new and patented process and is claimed to be superior in insulating qualities to the best natural silk. The cotton yarn is esterified and the process involved converts either the outer skin or possibly the whole fibre into lower cellulose acetates whilst maintaining the original form of the cotton. This has the sensational result of increasing the insulation to some ten thousand times that of the original cotton. It seems likely to prove one of the finest flexible insulating materials known—possibly superior, particularly at high humidities, to the best rayons and natural silks. It is already allowed as an alternative to them for many purposes.

14. *Flax, Hemp and Jute.*

There now follows a group of multi-cellular vegetable fibres.

Flax yields long fibres which are known as " linen." They are illustrated in Figs. 3 and 9. These fibres are spun into threads, and produce for example " thread linen," which is much used in a beeswaxed form in the bindings of cords. The shorter fibres are known as " tow."

Hemp is a name applied commercially to textile fibres produced by several unrelated plants which are grown in many different countries. Its main use by the Post Office is for rope, for which *Manila hemp* and *Italian hemp* are most suitable. Manila (sometimes spelt Manilla) hemp fibres are obtainable several feet in length, though they are made up from cells only about one inch long. Such cells are illustrated in Figs. 4 and 9. They come from leaves of a plant of the banana family which is grown mainly in the Phillipine Islands, and in Borneo and Java. Italian hemp comes from the true hemp plant, and (like real Manila hemp) makes a splendid rope.

Sisal hemp is indigenous to Yucatan, and is much grown also in the Bahamas and in Florida. When burnt it gives a white ash, whereas real Manila hemp gives a greyish black ash. It is doubtful whether rope satisfactory for Post Office purposes can be made from Sisal hemp, but further experiments are likely to be made as Sisal is obtainable from British sources.

Jute fibres, (see Figs. 5 and 9), are much used nowadays in place of hemp in the manufacture of cheap strings. Jute comes mainly from the East Indies. These fibres have a fine lustre when new, but their tensile strength is low, they tend to ravel, and they are liable to rot. When suitably tanned they have proved completely successful in submarine cable coverings.

Tests can be made (using chloride of lime solution, hydrochloric acid and ammonium), which will distinguish between flax, manila hemp, sisal hemp and jute fibres by the final colour reached; but these tests should be supplementary to a microscopic examination.

15. *Paper, Vulcanised Fibre, and the like.*

The term " paper " includes materials, mainly composed of cellulose, which are of greatly varying origins and properties. Paper for insulating cable conductors used to be made from pure manila hemp; but now any paper is accepted which is strong and flexible, and which also permits of each conductor in a cable attaining an insulation standard of up to 25,000 megohms per mile. Such insulating paper is not less than $2\frac{1}{2}$ mils thick and must be free from metallic particles and other deleterious matter; and it must be able to withstand a pull of 4 lbs. per inch of width for each mil in thickness. Wood pulp paper, probably covered by the title "manila" (not "pure") and possibly containing no manila hemp whatever, seems frequently to be selected by cable manufacturers. It is unfortunate that a suitable paper is not available with a specific inductive capacity less than about 2.5, or in some cases 2.0.

When subjected to a fluorescence test with ultra-violet rays, papers made from cotton rag, linen rag, or wood pulp, show up clear white, blueish, and from brownish gray to black, respectively.

In America a new process has been developed by which cable conductors, (so far only $6\frac{1}{2}$ lbs. and less), are covered by a loose continuous *paper sleeving which is made directly out of wood pulp* simultaneously with the covering process. This saves the manufacture of separate paper ribbon and its subsequent wrapping on to the wire.

"*Wire, Insulated, P.B.J.*" is a special case of a paper-insulated weather-resisting overhead wire which is proof against contact with 500 volt power wires. The inner insulation consists of two layers of paper impregnated with insulating oil. This is protected by a braiding, (jute, pre-war, but now cotton), which is impregnated with a solidified mixture of 72% red lead, 16% linseed oil, and 12% paraffin wax. This mixture also acts as a weather-proof external covering. P.B.J. wire is a proved success.

The finest stationery paper is made from linen (flax), but inferior papers contain cotton scrap and shoddy, (torn-up fabrics). Wood pulp papers have now largely replaced cotton papers and are universal for News sheets and the like.

Vulcanised Fibre is often prepared by treating sheets of paper with zinc chloride solution, and then compressing the gelatinised sheets. It is not a first class insulator. If the fibre is to be in direct contact with metals, no soluble chloride must be retained, because it is deliquescent and will lead to corrosion trouble.

Presspahn, which is used mainly as a "spacer" and in washers, consists of paper which has been dipped in shellac and pressed into sheets.

Empire Cloth is now specified as a covering for coils and similar purposes. It consists of fine linen cloth impregnated with highly-boiled linseed oil and dried.

16. *Wool, Silk, Artificial Silk and Iso-Electric Tussah.*

Next come two animal fibres—wool, which is the hair of sheep; and silk, which is exuded by the silk worm. Manufactured or artificial " silk," and specially treated silk, must also be dealt with.

Wool (see Figs. 6 and 9), is generally tubular and often curly. It presents a somewhat scaly appearance on the outside and contains an internal medullary (or marrow-like) substance. The fibres vary from $1\frac{1}{2}$ to 12 inches in length and from $\frac{1}{2}$ to 2 mils in diameter. Sheep's hairs are of fairly uniform diameter throughout, but lambs' hairs taper to a point. A wool braiding has the very valuable property of not permitting the spreading of a flame; its fumes indeed have slight fire-extinguishing properties. It is much used as the outer braiding of flame-proof wire.

There have been isolated cases of serious trouble with moth grubs destroying the wool covering of flame-proof jumper wires. It is probable that any extension of this trouble could be stopped by lightly painting the braiding with " green oil," which is not likely to cause damage to either indiarubber or enamel. It seems worth considering whether the braiding of all new wool-covered wire should not be impregnated during manufacture by either alum or ammonium phosphate or ammonium sulphate. Now that wires are covered with either indiarubber or enamel, no corrosion trouble is likely to ensue.

Silk, i.e., natural silk, (see Figs. 7 and 9), is obtained from silk worms, which may be either cultivated or wild. The worm's spinning glands secrete two colourless liquids which unite into a double yellowish thread of silk as they emerge from the glands. This construction accounts for the wavy formation and for the nodes which are visible in the microscope. The wild product is relatively coarse and brownish, and is called *Tussah silk*. *Spun silk* is made from floss silk, which is the waste after reeling—possibly 45%. Spun silk is specified as being allowed for the first braiding next to telephone instrument cord conductors; tussah silk for the first lapping on house telephone and unexposed instrument-connecting cords, and for the first two layers on the conductors of switchboard cords; but in both cases, cellulose acetate rayon is a preferable alternative, which is generally used.

Artificial Silk, (see Figs. 8 and 9), is now called "rayon." It is produced in three older forms by the cellulose nitrate, cuprammonium, and viscose processes—and by the latest and most important process from cellulose acetate. The product of the viscose (or regenerated cellulose) process absorbs moisture too readily for telephone purposes. A suitable cellulose acetate rayon makes a first class insulating covering. The cellulose acetate is suitably dissolved and squirted through very fine holes into alcohol or the like; it emerges in the form of fine silk-like threads. These rayon threads are thicker than natural silk, and so feel harsher; but they are stronger and have a better gloss. Rayon is an excellent silk substitute for which there are nowadays innumerable uses in every-day life. Wood pulp is the usual source of the cellulose.

Iso-electric tussah silk is produced from natural tussah silk by a new process. The tussah is washed in a very weak acid which renders it so neutral that it is capable of forming salts with either an acid or a base. This increases the insulation resistance of tussah some 50 to 100 times.

Taking the insulation resistance of Viscose and natural cotton as a standard at, say, 80% humidity, natural tussah would have about ten times, iso-electric tussah and natural silk about 1,000 times, and cotopa and the very best cellulose acetate rayons some 10,000 times this insulation resistance.

There may be occasions when it is desirable to distinguish between fibres of cotton, silk and artificial silk. They can easily be distinguished with a microscope on the lines indicated in the figures, or by a simple chemical test. In caustic potash cotton is insoluble; pure silk dissolves to a colourless solution; and artificial silk gives a yellowish solution. If a flame be applied to natural silk, acrid vapours are given off, and a dark-coloured nodule is formed on the end; cotton smoulders when burning and gives a white ash.

MISCELLANEOUS.

17. *Mica, Quartz, Asbestos, and Slate.*

Mica, quartz, asbestos (all crystalline), and slate are four wonderful natural materials, which are inorganic, *i.e.*, are not the product of once-living matter. Mica provides the largest and thinnest or flattest, *i.e.*, the most sheet-like crystals known; asbestos the longest and thinnest, *i.e.*, the most thread-like crystals; slate provides large slabs, which are mechanically strong. All have unique combinations of qualities which make them of special utility in connection with electricity and heat. Slate is unfortunately an unreliable material.

Mica, the greatest natural insulator, need only be considered in three forms:—phlogopite (amber mica), found largely in Canada; muscovite (white mica), coming mainly from India, but also from many other places; and the manufactured micanite derived from these two. Silica, alumina and potash are the main common constituents. Mica is a transparent, inert and non-inflammable substance; it has extraordinary dielectric properties as it will resist about 4,000 volts per mil of thickness; and it will withstand high temperatures. Phlogopite can be employed up to about 1,000°C; the harder and much less flexible muscovite up to about 500°C. The use of mica in lightning protectors and commutators, not to mention lamp chimneys, is generally known.

Micanite is built up into many forms from mica with other admixtures, *e.g.*, into "hard plate," hot moulded or cold moulded insulating sheets, and so on; and in combination with paper, cambric or silk into micafolium and other materials specially useful as wrappings for large machines. Micanite has an average dielectric strength of 800 volts per mil of thickness—twice that of bakelite and most ebonite.

Quartz or fused silica is generally similar to mica, but is much superior to it as regards power factor at high frequencies. It is therefore used for the insulation of high-quality condensers, especially those used for radio purposes.

Asbestos, the greatest natural non-inflammable heat-resister and heat-retainer, is found in two main groups called amphibole and serpentine. Chrysotile, in the serpentine group, is much the most useful and important form, being lighter, softer, stronger and more flexible. It is found chiefly in Canada, near Quebec. Each fibre is one complete crystal and may be 4 inches long; it is markedly smooth and extremely fine, the diameter being about 30 micro-inches (thousandths of a mil). It can readily be built up into forms such as paper, fabrics, braiding, sheeting, string, etc., so that its heat-resisting or lagging properties can best be utilised. Combined with a suitable clay, cement or bitumen, it has exceptionally good powers of insulation and dielectric strength even at extremely high temperatures.

Slate, which is found in many localities, can readily be cleaved into slabs of almost any thickness. Slate slabs are relatively cheap, are mechanically strong, are non-inflammable and have fairly good insulating properties. Slate is unrivalled for power switch-boards and other heavy work of that kind. Where a really high standard of insulation is necessary, it is usual to varnish the surface and to insulate each contact with some additional insulating material. Ebonite or bakelite collets are often used for this purpose—an excellent protection against metallic veins which are not infrequently found. Slate is often used for small fuse panels and the like, but bakelite is now a formidable competitor.

Slate contains, chemically, about 60% silica and 20% alumina, and is built up naturally from clay and shale by intense pressure and high temperature. The best electrical properties are obtained with "mica slate," where there has been almost complete metamorphosis of the clay. Slate should not absorb more than 0.2% of water and should withstand 250°F for 12 hours without cracking.

18. *Bakelite and Ebonite.*

Bakelite is an insulating and moulding material, mainly developed since the war. It has now become of very great importance in the electrical industry. From it are made not only very elaborate and beautiful mouldings, but also laminated materials, cements, varnishes and lacquers. It will even produce gear wheels which are durable, as well as silent, under quite heavy loads.

A description of bakelite mouldings is such a catalogue of good qualities as to read like an advertisement! These mouldings are markedly light in weight, yet they are mechanically very strong; they are fairly rigid, yet not brittle, and they can be drilled, tapped and otherwise machined; they will not support combustion on their own account, and—particularly if suitably stoved—they have high dielectric and heat-resisting properties; they are non-hygroscopic and give excellent surface insulation indefinitely; they are odourless and are unaffected by water and most chemicals; they will accommodate almost any kind of insertion during the moulding process, thus saving much expense in subsequent fitting work; they will follow very intricate moulds clearly and sharply and with an accuracy of about 4 mils per linear inch; they can be produced with a great variety of really permanent colour effects, all with a good lustre not needing polishing; and they have a hard surface which does not show bloom, neither does it discolour or deteriorate with age—a valuable asset in telephone apparatus. Fig. 10 on page 47 gives typical figures for some of the physical and electrical properties of these invaluable bakelite mouldings.

Bakelite is manufactured from carbolic acid, (phenol, $C_6 H_5 OH$) and formaldehyde (H C H O). These substances can be suitably combined to form an intermediate liquid "Bakelite Resin A," which passes later to the "B" form,—an inert, *soluble* and *fusible* solid. If "Bakelite Resin B" be heated it melts at about 120°F, and if the heating be continued after melting, this moulding material curiously enough will eventually harden again, this time into an *insoluble, infusible,* amber-like substance called "Bakelite Resin C." This pure form can be improved by the incorporation during manufacture of various selected fillers under strictly controlled conditions. Wood flour, for example, can be incorporated to give added mechanical strength with inappreciable increase in weight; or asbestos may be added to provide materials noted for their powers of resistance to heat and to shock, though in these materials the water absorbing powers of asbestos may lead to low insulation.

Powerful hydraulic presses are required for the moulding process. They are usually heated by steam, and give pressures of 500 to 2,500 lbs. per sq. inch. Highly finished moulds are necessary, and these are of course expensive; but the very exceptional all-round qualities of the product and the adaptability of the process to repetition work on a large scale enable mouldings to be made which are really cheap. This is specially the case when it is remembered that practically no subsequent finishing or fitting is needed.

Sheet bakelite (laminated) is made by impregnating sheets of paper with bakelite varnish and curing in a hot press. Such sheets can readily be punched. They have good insulating properties and their uses are manifold. They are, for example, proof against hot plates and so on and are not easily scratched. High grade bakelite sheet is much harder than ebonite and is mechanically superior to it for such purposes as selector banks and relay spring assemblies where the plastic nature of ebonite is liable to cause the assembly to become loose. It is cheaper than ebonite, but the surface insulation is satisfactory only when the natural polish from the press is retained; sheared edges of cut-up strips, and ground faces, may however be varnished. Moulded bakelite sheets, (not laminated), are also obtainable. They have higher insulating qualities, but are considerably more expensive.

Ebonite is a vulcanised rubber compound which for many purposes is being superseded by bakelite. Its main advantage over bakelite seems to be its greater resilience; it has also a lower dielectric constant (or specific inductive capacity), about 3 as against 4. It is produced from rubber which has been hot-vulcanised with considerable quantities of sulphur, and with minerals selected as required. If the (combined) sulphur of vulcanisation is as low as 20% of the total weight, the ebonite is very pliable, but not very strong; if the sulphur be raised to 30%, the ebonite is very strong, but distinctly brittle. An addition of 5% carbon black has been found to prevent surface deterioration and the consequent loss of colour and of insulation under high voltages. This used to give serious trouble. Ebonite can be produced in only a few colours, and it has none of the heat-resisting powers of bakelite. It is very brittle if slightly over-vulcanised, and bakelite would probably be better for ear-caps, mouthpieces and the like. In simple forms of mouldings, ebonite is at present about half the price of bakelite per pound.

Switchboard plugs afford a striking example of progressive steps in insulation. For years these plugs were assembled with ebonite insulating parts. Then a moulding process was developed, by which the whole plug was bound together by bakelite insulation being forced in. Now, in place of the bakelite, cellulose acetate insulation is similarly employed as it is more amenable and leaves no air pockets.

19. *Waxes.*

Paraffin wax is used for making solid joints in P.C. Cable, and for filling slots in base boards, etc. It has excellent insulating powers and is quite inert. This wax consists of a mixture of the higher members of the paraffin group, which has the general formula $C_n H_{2n+2}$. In this formula n varies from 1 to about 30. Paraffin wax, being thus a mixture of a homologous series, can be produced with any specified melting point within certain limits. The Post Office specifies wax which melts at 50°C and which is strictly neutral.

Beeswax is used for waxing wires which are laced out, so that it must be light enough in colour to allow the identification colours of the conductors to show through. It is of course a naturally occurring wax, of which the main constituents are 85% melissic palmitate and 12% cerotic acid. The melting point obtained is from 62.5° to 64.0°C.

Wax polishes are selected polishes which will not show finger marks when tested on a French polished surface. They consist of varying mixtures of Beeswax and Carnauba and paraffin waxes, with a thinner such as turpentine or white spirit.

20. *Sound-absorbing Substances.*

The need is being felt more and more for substances which will deaden the effect of noise in Instrument rooms, Phonogram rooms, Telephone cabinets, etc. Felt has been used for many years. More recently much success has been obtained with special porous substances such as cabot quilt, which consists of treated dried seaweed; with celotex, which is a special form of cellular wood; and with other similar materials. "Insul," a British-made wood product, is claimed to be equally successful and not to be subject to attack by certain insects. Paint being an efficient sound reflector, absorbing surfaces must not be painted; and the general absorption is much increased by suitable slots and indentations in the surface.

PART 2. CLAY PRODUCTS.

In out-door telephone construction work a very important part is played by open line insulators, underground ducts and similar articles which are in the main manufactured from clay products. Cement also is derived mostly from clay. Some of these clay products will now be described,—chiefly from the "material" standpoint.

SECTION 4. OPEN LINE INSULATORS.

Every ordinary line insulator, of whatever material it be made, is required to give an insulation resistance of 10,000 megohms measured from water surrounding the insulator both to water in the crown and also to water in the space between the inner and outer sheds. The test is made with a reflecting galvanometer at about 300 volts, with the edges of the insulators artificially dried; the water will have stood at a level ½ inch below the edges for at least the previous 12 hours, so as to penetrate minute cracks or porous material. The thread for the spindle is of a special non-symmetrical type for reasons lost in obscurity, but probably not unconnected with the old and inaccurate wooden lathe used by the original inventor. Partly due to this rather intricate thread, and partly due to relatively high average humidity, glass insulators are not used on telephone lines in this country.

Composition insulators can most conveniently be included here, though they are not clay products.

21. *Composition Insulators.*

Composition insulators have three advantages:—They are cheap, they are not easily broken, and they can readily be moulded into forms, such as for leading-in insulators, which are a difficult proposition in porcelain. For such special cases they are an established success; they have still to prove their durability as ordinary line insulators. Those made a few years ago were a complete failure; many of them were based on coal tar pitch, which was quickly eroded and led to early breakdown. Those now being made are claimed to be, and seem to be, far superior. Bitumen, with considerable blending of petroleum pitch, forms the base in many cases; asbestos fibre, which ought to be in *short* lengths, is the other important ingredient. It is necessary to guard against the water-absorbing powers of asbestos. Great pressures—100 tons or so on a single insulator—are used to give a close body; the presses are generally heated. The body, when new, is certainly non-porous and is an excellent insulator; time alone will show whether it is to be regarded as a first class durable open line insulator. These insulators take appreciably longer to charge electrically than do porcelain insulators, due to some combination of capacity and electrification. Recent research has shown that as a consequence their effective resistance to alternating voltages (at 10 volts 800 p.p.s. between spindle and line wire) is many times, perhaps 30 times, lower than with porcelain, even than with unglazed porcelain.

22. *Porcelain Insulators.*

Porcelain undoubtedly provides the finest possible main line insulators. They can be made of any desired size and can be glazed white or brown; they are completely inert and weather-proof and will endure so long as they remain unbroken. One of the principal materials used is china clay or kaolin, a hydrated silicate of alumina of the form ($Al_2 O_3$, $2 Si O_2$, $2H_2 O$), which is obtained mostly from Cornwall. Clays have the property of being plastic when wet, so long as they retain their combined water. Other ingredients are added to give toughness and easy vitrification; and the whole is ground and sifted. The " slip " thus produced is caused to flow past permanent magnets, which remove all magnetic particles. The insulators are then shaped either by throwing or by pressing followed by turning, and the threads are cut. They are next dried slowly and later fired in a kiln which must cause fusion so as to ensure a vitreous body. Handling is much reduced and the process expedited if a rotary continuously-fired kiln be used. A leadless glaze is applied and the process is arranged in some works so that only the one firing is necessary, in others so that a second firing is given at a lower temperature. This glaze, which is mainly a kaolin wash, may " craze " after some years; but the glaze merely retards the accumulation of dirt and does not affect the insulation directly. In fact experiments are in progress to see whether it is possible to use unglazed porcelain insulators, with a probable saving in cost varying from 5% in some cases to as much as 20%. This will increase competition with the composition insulators, which themselves have a surface which is not really glazed. So far the unglazed porcelain insulators have proved equal to the glazed.

The finished insulator should be completely vitreous, with an absorption of water less than 0.001%. A spot of ink on a newly-broken surface should retain its shape and leave no stain when wiped off with a damp cloth,—a useful rough test. Alternating current tests have shown a flash-over from spindle to groove at some 40,000 volts without puncture of the very strong body. The slightest carelessness in the firing will lead to a porous body or to definite cracks—and, of course, low insulation. Every maker undertakes to issue only insulators which have been proved good by electrical tests. Most of these insulators are despatched direct from the works to the job, and check tests are made on a small proportion of them after receipt. Serious notice is taken if these check tests reveal faults in manufacture.

23. *Stoneware Insulators and Battery Jars.*

Stoneware Insulators, (sometimes called earthenware insulators), are made in a manner generally similar to that above described; but the clay contains other ingredients, and particularly oxide of iron and additional silica (sand). Common salt is used to give the glazing, merely by being thrown on to the fires in the kiln. Stoneware insulators when they are good are very good indeed; but it appears to be much more difficult than in the case of porcelain to ensure that every single insulator shall be highly vitreous and therefore reliable. Cases not infrequently occur where individual insulators develop low insulation after a few months. This appears to be due to invisible cracks which develop from internal stresses set up during possibly abnormal shrinkage—it may be a very slow and prolonged shrinkage; or perhaps vibration during handling or transit may be the last straw in these cases; another theory is that the glaze covers up the trouble for a time and later breaks down. Shrinkage, as well as vitrification, is a difficult factor to control in all such work; it is reduced by the addition of previously fused material which has been ground to powder. Stoneware is slightly less strong mechanically than porcelain.

Battery Jars (stoneware) are made from the same materials in a generally similar way. Except that the water is kept two inches from the edge, they have the same test.

SECTION 5. UNDERGROUND DUCTS AND BRICKS.

24. *Stoneware Ducts.*

Self-aligning stoneware (often called earthenware) ducts are another example of vitrified clay products. They are glazed inside and out with volatilised common salt, and in fact are made on very similar lines to stoneware insulators, though for ducts no special efforts are necessary to obtain high insulating or non-absorbent properties. Each bore must be smooth, to avoid damaging the cable, and must be reasonably straight, its curvature not exceeding 3/16 inch on a 2 foot length. It must take a 2 foot mandril $\frac{1}{4}$ inch less in diameter than the nominal bore, and a gauging disc 3/16 inch less (working size 20 mils larger). Water-tight joints are facilitated by lining the spigots and sockets with carefully shaped Stanford's composition. These two linings should fit so well that one duct, when pressed on to another, will lift it straight up off the ground. The composition consists of 2 parts each of boiled coal tar and sharp sand or ground pottery, and 3 parts of sulphur. It should remain hard at 140°F. In making the linings for multiple ducts it is essential to avoid giving them a slight twist due to some eccentricity in the jointing machine. To detect this trouble, which becomes cumulative and thus causes a slow but steady rotation of a line of ducts, lines of 20 ducts are laid down on a level surface every day at the works; they must lie flat and straight. Each multiple duct is marked with a black mark on one particular face as it comes from the machines; this mark should always be laid downwards.

As a test of porosity, absolutely dry samples of broken duct must not increase in weight by more than 5% when submerged in cold water, the temperature of which is raised to boiling point and kept there for one hour. As regards strength, a single way duct must carry 30 cwt. per ft. run—a multiple duct 2 tons—when crushed between two wide blocks which lie along the length of the duct. The lower block is 2 feet long and the upper one 1 ft. long; felt washers or sand are used to distribute the load.

Jointing compound—or "compound number 6,"—which is used in completing the jointing of ducts in the trench, consists of equal quantities of coal tar and French chalk, with 6% stearine pitch. A new luting compound called Revertex is now under trial and seems likely to be markedly successful. It is easy of application, it can be applied to wet material and it has great mechanical strength. It is a rubber composition made by Revertex, Ltd., and is used in the form of a mixture of 40 parts latex and 60 parts of ciment fondu by weight. It should be used within 1½ hours of mixing—a somewhat troublesome restriction.

Insufficient care is often taken in handling these ducts in trucks and on the road as the "joints," particularly the spigot joints, are very easily damaged. Ducts should not be stacked on their spigot ends.

Ducts are issued direct from the works and attention should be called to any case where a duct does not show an approval mark consisting of a broad arrow and two letters in paint. Red paint is used on straight ducts and green paint on those slightly curved.

25. *Bricks.*

Red wire-cut bricks are sometimes used for Jointing Chambers. They are made from clay containing probably 5% of oxide of iron. These bricks, though well burnt, are not kilned at a high enough temperature to cause vitrification, and they are not glazed. (The material, in fact, resembles that of earthenware or fire-clay ducts which are used for special purposes embedded in concrete—not in the bare earth, as they are salt-glazed on the inside only). These red bricks under compression will stand about 200 tons per sq. foot. The Post Office specifies that they shall absorb not more than 10% of water after 24 hrs. immersion.

Staffordshire blue bricks are a superior type of brick containing about 10% of oxide of iron. They are about three times as strong as, and five times less porous than, red wire-cut bricks. Though the latter are acceptable for brickwork man-holes and other brickwork jointing chambers in foot-ways, Staffordshire blues are specified for such brickwork chambers in carriageways.

Concrete or reinforced concrete is the normal construction for joint boxes or man-holes; bricks are used only in special cases, such as where the ground cannot be kept open long enough for the concrete to set properly, or where the boxes are of irregular shape.

Section 6. Cements.

The last clay product to be dealt with is cement, which is much used in the construction of telephone kiosks, and manholes, and concrete work generally. The first aspect to consider is the function of cement in the formation of concrete, as this function controls the special properties to be looked for when a cement is selected for any particular work.

In addition to any iron reinforcement used, concrete consists of ballast, (such as pit shingle, gravel or broken granite), sand, cement and water. In what follows granite will be taken as a typical ballast. Broadly speaking, the granite provides the strength; the sand fills up part of the voids left between the pieces of granite; neither granite nor sand undergoes any chemical change in the process; the finely powdered cement and the water make a thin liquid which covers and adheres to every piece of granite and every grain of sand; and finally the cement and water enter into *chemical combination* and produce eventually a hard crystalline solid substance. It is important that every particle of cement shall have sufficient water available to enable it to join in the solidified compound. The new solid substance produced, (hereafter called solid cement), binds together the whole mass of granite, sand, cement and water into a single solid block of great strength,—particularly great in compression.

For the cement to have a proper chance to function as it should, the sand and ballast must be clean and sharp and of well graded sizes and there must be no sulphur-producing ingredients. Sulphur in the presence of moisture readily produces dilute sulphuric acid, which slowly and relentlessly eats away the concrete by chemical action. For this reason particular care should be taken to avoid slag, coke, breeze and ashes in the ballast.

It has been found by experience that tests of sample briquettes made from neat cements, provided that they have been treated in standard ways, give test results which apply relatively also to concretes made from the same cement in the same way. Full strength is not obtained with neat cement because there is insufficient room for the crystals to form. For test briquettes it is preferable to use cement mixed with three parts of special Leighton Buzzard sand. The single word "cement" hereafter refers only to the unhydrated powder, *i.e.*, before mixing with water; after mixing, the "liquid cement" is in a state of constant transition to "solid cement." The finer the particles of cement, the more rapid will this transition be, and the stronger the product. Cold weather slows up this action, and if the liquid cement be frozen, all normal solidifying action is suspended. The need for storing cement in a really dry place is obvious.

In addition to cheapness the following are important qualities:—

(*a*) Particularly for manholes, rapidity of hardening. This property is quite different from rapidity of initial setting.

(*b*) Particularly for kiosks, the production of a surface which is uniform and pleasing, and which can be painted or stippled with lasting success.

(*c*) The power of resisting sulphur in the water and elsewhere.

(*d*) Water-proofing qualities.

These properties will be considered in turn for Portland cements, including rapid hardening Portland; and for special cements, including aluminous cements and waterproof cements. First, however, some account will be given of stipple.

Stipple is merely a pigment-oil paste, made from selected materials. The pigment is tinted zinc oxide and the medium is a tung oil base. The stipple, which can best be applied by a short fibred brush, dries in about 1½ hours. It is essential that the coat applied be absolutely continuous, otherwise the " weather " will soon get behind it and peel it off. When properly applied the life should not be less than two years.

26. *Portland Cement.*

Portland cement, (so called from its resemblance to Portland stone when set with water), consists broadly of a mixture of chalk and clay which has been calcined and ground to an extremely fine powder. The chalk is mainly calcium carbonate; the clay is a hydrated silicate of alumina with a variety of impurities, especially oxide of iron, and with important variations in the quantity of alumina ($Al_2 O_3$) present. Some natural marls are found to have the chalk and clay already mixed in the right proportions.

The "calcining" is so called because calcium oxide (lime) is released from the chalk, and is thus set free to seize the silica and alumina in the clay and convert them to calcium silicates and calcium aluminates. The whole process is rather complex and is extremely critical as regards temperature, aeration and admixture of moisture, but the final product is nowadays very uniform and reliable.

Rapid hardening Portland Cements have a slightly increased proportion of alumina and are ground still more finely. In some cases perfectly reliable rapid-hardening Portland cement concrete has been made which after three days is almost as hard and strong as ordinary cement concrete after twenty-eight days; and its final hardness and strength are greater.

White Portland Cement for facing purposes can be produced from carefully selected ingredients, almost free from oxide of iron. It sets off colour work clearly and in beautiful contrast.

27. *Special Cements.*

Aluminous cements, which incidentally are quick-hardening, are of particular value where the surface has to be stippled or painted, as with kiosks. Portland cement concrete surfaces always carry more or less free alkali, which react with the oil in the paint, and lead to lifting of the paint. The final result is generally stripping of the paint, apart from probable alterations in colour. Aluminous cements are considered to avoid, or at any rate to reduce, this trouble. Much care is necessary with them, however, to avoid too rich a mixture, otherwise severe stresses are set up in the concrte, probably leading to deformation; also the surfaces must be frequently wetted during hardening because of the considerable heat emitted by the chemical action. For aluminous cement concrete the moulds must have a really good finish because, unlike Portland cement concrete, the surface cannot readily be faced up or repaired. Not even very small quantities of Portland cements should be mixed with aluminous cements. These aluminous cements were originally specially designed for their powers of resisting waters containing sulphates. They are appreciably dearer than quick-hardening Portland cement,—and of course than ordinary Portland cement. As regards the main constituents, the percentages for Portland and aluminous cements respectively are approx.:—Silica, 21.5 and 8.0; alumina, 6.7 and 43.25; oxide of iron, 2.6 and 8.0; and lime, 64.9 and 38.7.

Waterproof Cements are produced by the addition to ordinary cements of about 2% of such compounds as Pudlo or Medusa. These compounds are of a greasy nature and in an extremely fine state. They thus assist to close up very minute pores—though all first class concrete ought to be watertight. Absorption should be reduced to below 1%, from possibly 3% to 6%. The strength is not affected.

Coloured Cements are very useful where it is desired that concrete structures shall blend with surrounding buildings. The colours are nearly always of mineral origin, such as oxide of iron or chromium. They must not cause chemical action with the cement, nor be adversely affected by constituents of the concrete. Using coloured cements it may even some day be possible to make reinforced concrete pillar boxes in "natural" Post Office red; such concrete would not, of course, need painting!

Retarding liquids are now available for producing ornamental finishes on concrete work. These liquids are painted on to carefully selected portions of the faces of the moulds. When the concrete is removed from the moulds the corresponding concrete parts will be found to have their surface still soft. A stiff brush will then remove some of the facing cement and allow the granite to show through. By such methods very attractive colour effects can be obtained. Gypsum ($Ca\ SO_4$, $2\ H_2\ O$) is generally used for this purpose; up to 2% of calcium chloride has a similar effect.

CONCLUSION.

This paper has given some striking examples of post-war progress in devising improved materials for the use of communication engineers. Consider recent developments from one basic substance alone, namely, cellulose acetate. From it are produced an excellent and convenient insulation for telephone plugs; extremely good insulating rayon fabrics for covering telephone cords; and flexible, hard and durable enamels and lacquers which for many purposes are unsurpassed. Bakelite is another striking and important example of progressive development,—a process which engineers may reasonably hope to see extended in many probably unexpected directions by modern scientific and industrial research.

In conclusion, it should be remembered that the bounty of Nature is not infinite,—wonderfully generous though it be. An engineer has no right to use any natural product when one more plentiful will meet all reasonable requirements. Price will guide him to some extent, but he must not forget that though a new material is likely to be expensive during development, it may eventually become abundant and relatively cheap. There is the fullest scope for his ingenuity and intelligence in selecting the cheapest adequate materials without neglecting to encourage progress in every useful direction.

APPENDIX I.

PIGMENTS.

For the various colours indicated below the Post Office normally uses the pigments listed. In the names given for these pigments any word in italics is usually omitted in trade descriptions. A " lake " is a synthetic aniline dye, coupled with a base (or body) such as barytes or alumina.

White. White lead (basic lead carbonate), tinted with ultramarine as required, is most used. Lithopone, *zinc* sulphide white, zinc *oxide* white, *lead* sulphate white, stannic oxide, and titanox are also used.

Red. Red oxide of iron and aniline lakes are most used. Vermillion and red lead also are available.

Green. Chromium oxide. Brunswick green and aniline lakes. Cheap Brunswick greens are unreliable.

Stone. White lead tinted with ochre and burnt umber. Zinc oxide may be used in place of white lead.

Black. Carbon black, with a body such as barytes or chalk; or a lake.

Lead. As for " Stone," but tinted with carbon black.

Chocolate. Chocolate-coloured iron oxide.

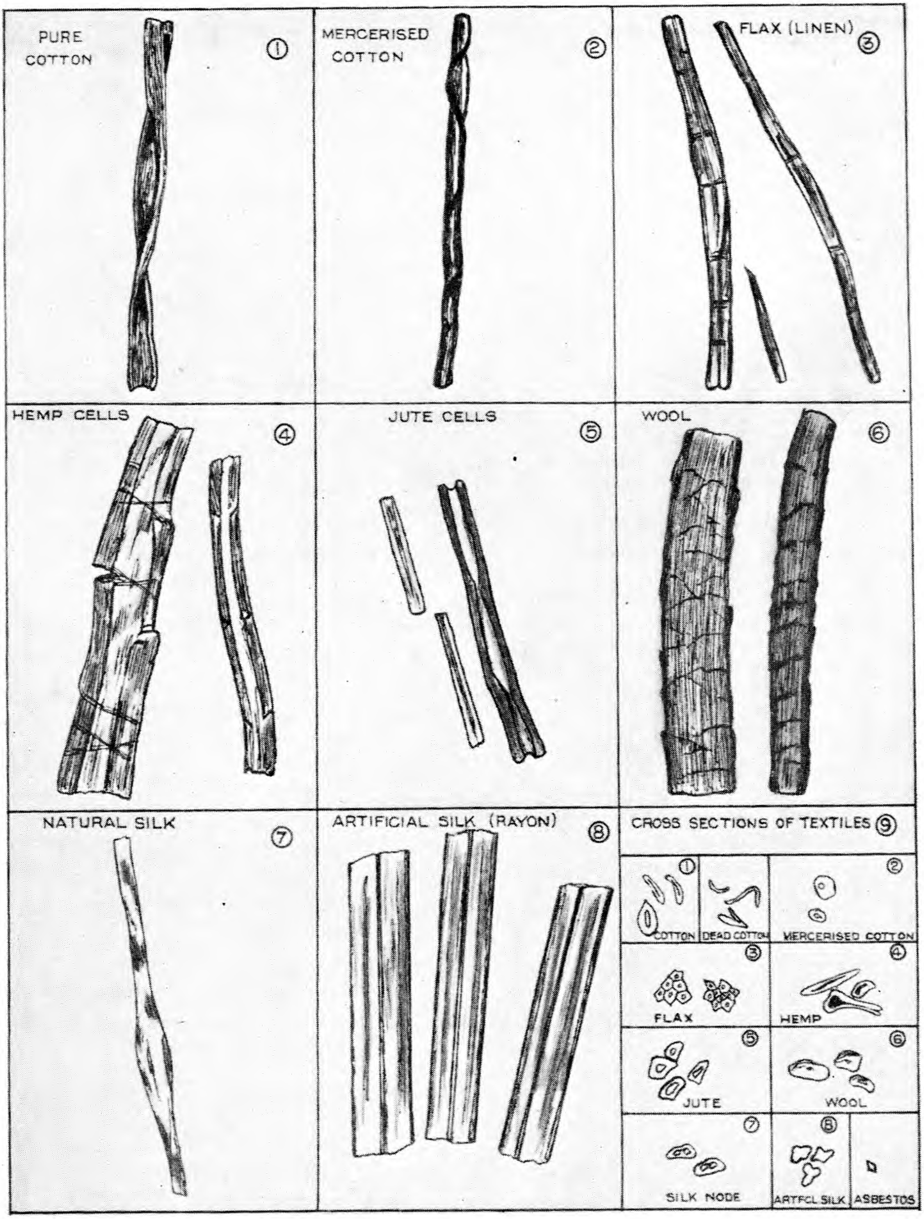
Blue. Prussian blue (ferrocyanide of iron), and ultramarine.

Yellow. Chrome yellow and ochre.

APPENDIX 2.

INDEX.

APPENDIX 3.



FIGURES 1 TO 9.

MOULDED FORMITE — BAKELITE — WOODMEAL MATERIAL (10)

APPROX. PHYSICAL DATA.

Specific Gravity	1.3
Weight per cubic inch	·76 oz.
Tensile Strength	5000 lbs. per Sq. Inch
Compressive Strength	30000 " " " "
Transverse Strength	12000 " " " "
Brinnell Hardness	40
Coefficient of Expansion	·000016 per °F.
Will withstand continuously	450° F.

APPROX. ELECTRICAL DATA.

Dielectric Strength at 60° F.	450 Volts per Mil. Thick
Surface insulation over 1/4" at 60° F.	10,000 megohms to Infinity.
Insulation resistance 2500 Volts at 60° F.	Infinity.
Specific inductive Capacity	4·0

FIGURE 10.

Printed by Birch and Whittington. 10, Station Rd., Epsom.