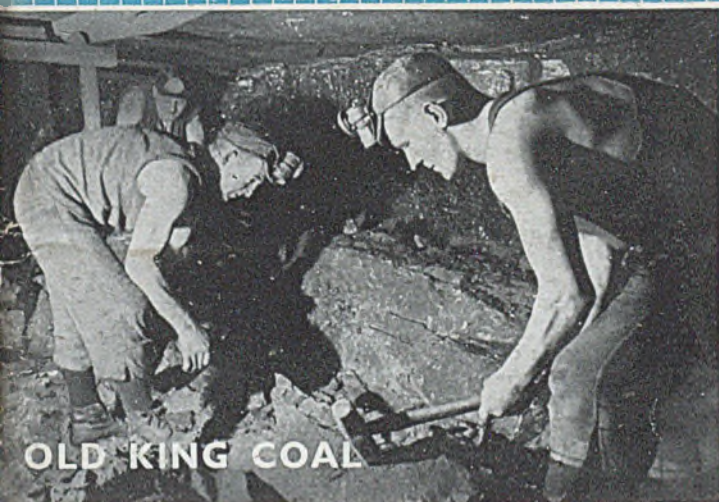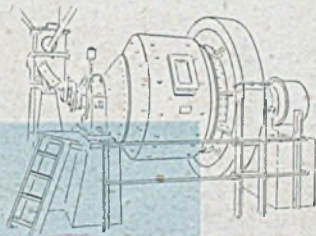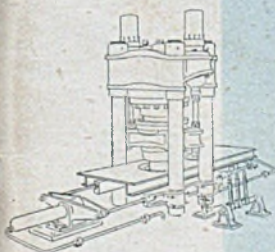# LIGHT METALS

OCTOBER
1944

1'6

OLD KING COAL

Do you know ? . . .

. . . . that just over **four tons of coal** are needed in the production of **one ton** of virgin aluminium ?

First, the production of the necessary pure alumina calls for power, for process steam, and for fuel for calcining. Then, the reduction of the alumina to aluminium absorbs quantities of carbon electrodes, whilst the refining of the crude aluminium pig again uses fuel.

Wherever practicable the National fuel is used, so that the annual call of the aluminium producing industry upon the coal mines of this country attains a significant average.

A

1854

Napoleon III, at the Tuileries banquets which marked the zenith of the Second Empire, made use of "the rare metal aluminium" for cutlery. In the belief that aluminium would be of value for military equipment, he granted funds to further research, but it was not until many years later that the metal was produced in appreciable quantities.

Today the uses of aluminium are many and widespread : tomorrow, it may revolutionise many industries.

Authoritative advice is available on every aspect of the use and fabrication of aluminium alloys — the combined technical experience of a great industry is at the service of intending users

.

UNION CHAMBERS

63 TEMPLE ROW

BIRMINGHAM 2

WROUGHT LIGHT ALLOYS DEVELOPMENT ASSOCIATION

B

1865

——but if she worked in a wartime factory she would also love the good lighting without which she could not keep up her high rate of output.

Incorrect lighting is a drag upon workers' health and dulls enthusiasm, whilst correct lighting promotes increased production. If your installation needs better planning or changes are required to take care of new processes, or extensions are necessary—consult the G.E.C.

Take advantage of the knowledge G.E.C. lighting specialists have gained in helping wartime factories towards full production.

Consult the
G.E.C.
FOR ANY STANDARD OF
iLLUMINATION

C

1445

EDITORIAL OPINION

Favourites—Hot and Not-So-Hot!

FROM any gathering of ordinary folk, pick out 10 subjects for experiment and ask them what they think of aluminium and its future. The odds are that nine of them will give optimistic replies. The metallurgical Press and trade papers, generally, take the same attitude, and rightly so. There is, of course, no denying that a great deal of hard work will be required before many of the ambitious schemes which have been tabled are fully realized in practice. That, however, is merely a matter of time; those who back aluminium have the will, if need be, to push their favourite to the winning post—but get there it shall.

Now metals, like horses, cannot talk. Decisions as to form coming, colloquially, "straight from the horse's mouth" can, we know, at best, emanate only from the trainer, the jockey or the stable boy, and with this we must be content. So, transferring our attention from aluminium to magnesium, we seek the pundits' advice. Informed opinion, however, would seem now to be less unanimous and the voice of the experts less vociferous than that of those backing the senior metal.

Apparent doubt existing in high places finds echo lower in the social scale. Few metallurgists, least of all those concerned with the ultra-light alloys, would deny that, in the consumer field, aluminium supporters frequently grow somewhat cautious when asked to provide testimonials for magnesium. We all of us know the focal points of uncertainty—low corrosion resistance, perhaps, even the fire bogy—it is always the same. The metal is, for no very good reason, viewed warily, like the horse suspected of developing croup at the starting post, or labelled as likely to cross its legs half-way down the course.

Some three years ago, before the expression "post-war planning" had any real meaning, we tackled a name famous in the light-metal industry on this matter. A depressing reply was the result. To-day, with the world political and economic situations fast assuming tangible forms, the experts have taken a slightly more positive stand, but much of their cheerful prognostication is thin, wants foundation, and rings falsely in our ears. There is lacking, on behalf of magnesium, the developmental, creative force which is behind aluminium.

No good purpose is served by ignoring this fact, whatever deep underlying

D

factors may be responsible.   Recent official publications both in this country
and in U.S.A. would tend to indicate a politico-economic background to the
problem.   Meanwhile, however, many a prospective user of ultra-light alloy stands
by, having, willy-nilly, to be satisfied mostly with crumbs.   Fortunately, the
enthusiasm of these people takes a great deal of damping.

L. B. Grant, of the Dow Chemical Co., addressing a meeting in Montreal,
last April, painted a brighter picture.   In a really breezy address, he got over to
his listeners some idea of what is actually being done with magnesium in U.S.A.
Developments already under way, and projected moves, were quite openly
discussed.   It is on this point that we must enlarge.

So often, in the past, there has been reason to complain of the secrecy which
shrouds progress in this country.   How far this is true of the magnesium industry
here at the moment we do not know, but this much is quite certain, "official
releases" of information come far too infrequently and nearly always too late
to be of much value to the go-ahead consumer.   There is little use in trying to
put money on a horse after it has fulfilled its programme for the day : only by
assessing results ahead and judging to-morrow's events can profit be earned.

It is, in fact, high time that magnesium interests in this country took a leaf
from the U.S.A. and German books and followed, in addition, the lead set by
aluminium here and elsewhere.   Some four years ago or so, we explained the
growing need for what we then termed a Magnesium Information Bureau, but so
much has happened since that date that this would no longer be sufficient.   A
Magnesium Development Council, call it what you will, is vitally necessary, not
to promote the use of an untrustworthy material, but, rather, to help in the
obliteration of the memory of what some may be pleased to consider a slightly
speckled past.   The problem is a domestic one and must be settled privately.   In
this, as in so many other industrial crises (for it is no less), to rely on Government
assistance being forthcoming in sufficient measure by an appropriate date is to
court failure : the early history of the present war abounds with telling instances.

The price factor, we believe, is of little real importance at this stage; there is
no reason to suppose that production costs cannot be substantially lowered.   In
point of fact, we do know that the metal is being produced, even in the face of
war-time disabilities, at prices which a few years ago would have been considered
fantastically low.   Let us first get a "Use-more-magnesium" campaign going;
what the consumer must ultimately pay can be decided largely on the results we
achieve.

Contents

*THE FACT that goods made of raw materials in short supply because of war conditions are advertised in
this journal should not be taken as an indication that they are necessarily available for export.*

*SAVE PAPER.—More than ever is paper waste required for our war industries.   Waste paper makes
munitions in a hundred forms—from shell cases to aeroplane parts.*

SIMPLIFYING LIGHT-ALLOY WELDING

From an American Source Comes this Summary of a New Range of Proprietary Filler Rods and Electrodes for Use in the Welding of Aluminium-base Alloys. Reference is also Made to the Welding of Zinc-base Materials

ALTHOUGH, nowadays, the general problem of aluminium welding presents no great difficulty, the wide range of specialized light alloys, and the equally numberless special uses to which these are put, often impose severe limitations on the particular technique and filler rod which may be employed.

Numerous proprietary alloys have appeared on the market with the object of overcoming the troubles experienced in these directions—among them a range put out by an American concern which has issued a summary of its products, the method of using them, and the particular fields for which grades are available.

Considering the properties of aluminium and aluminium alloys, numerous reasons are at once apparent why fusion welding can give rise to difficulty.

    1. High thermal conductivity draws heat away from the weld area.

    2. Refractory oxides are formed when the metal is heated.

    3. Low melting point and melting without show of colour often result in overheating before the welder realizes it.

    4. Susceptibility to cracking at temperature near the melting point (hot-shortness) demands careful preheating.

    5. When overheated, the metal " collapses " without warning.

    6. In the case of heat-treated high-strength alloys, the application of welding heat commonly negatives the superior properties conferred by the treatment.

The effect of these unfavourable characteristics can be eliminated or minimized by welding at lowest possible temperatures. To achieve this, the Eutectic Welding Alloys Co. has developed a number of rods and fluxes for " low temperature " welding of wrought and cast aluminium alloys.

For wrought metals, " Eutecrod 190," a free-flowing alloy that will bond to aluminium sheets and tubing at temperatures from 510-571 degrees C., is available. It will flow through lap joints and form small, neat fillets. It has a tensile strength of 12 tons/sq. in. and good elongation. " Eutecrod 191 " is a similar free-flowing alloy with a slightly lower melting point, designed for joining sheet metal to castings. These two rods have an excellent corrosion resistance and are safe to use, except where a 99.9 per cent. aluminium alloy welding rod is specified.

The welding procedure with " Eutecrods 190 " and 191 is similar to that used for brazing. All oxides and grease should be removed from the weld area, and the parts painted with a water solution of " Autochemic Eutector " flux 190B (for " Eutecrod 190 "), or flux 191 (for " Eutecrod 191 "). Whilst the oxy-hydrogen flame is preferable, a slight excess acetylene
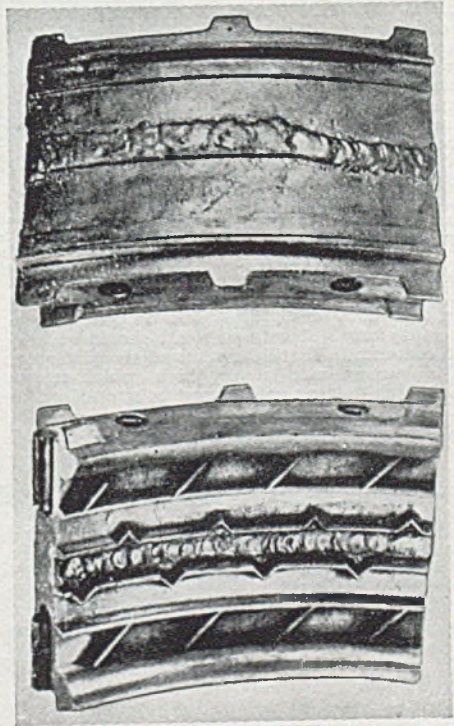
TWO views of an aluminium mould for retreading tyres. Here, a fracture has been made good with "Eutecrod 210," the melting point of which is sufficiently low to effect repair without damage to the adjacent thin intricate sections.

flame with an oxy-acetylene torch may be used, and the weld area heated broadly until the flux melts. On small parts, simple air-gas torches may be used. Melting of the flux is an indication that proper temperature has been reached for applying the welding rod. It is inadvisable

to flow the metal through too narrow a lap—a clearance of .005-.010 in. is desirable.

"Eutecrod 21," used with flux 21, is a higher melting point aluminium alloy welding rod than 190, for bevelled-butt welds, and large fillets on wrought metals, and for joining wrought metals to castings. It would be applied the same as "Eutecrods 210" and 212.

"Eutectrode 2100" is a coated aluminium electrode, used for arc welding wrought metal or castings. It is particularly good for small repairs on heavy castings that would otherwise require extensive preheating. On heavy sections, preheating to only 150-205 degrees C. is necessary to facilitate starting the arc, and avoid cracking the base metal. On these heavy sections, a "U" groove should be formed to permit complete penetration of the weld metal. On light sheet metal, edges need not be bevelled, but they should be spaced about the thickness of the sheet, and clamped on a copper or carbon backing-bar.

"Eutectrode 2100," a coated aluminium electrode excellent for use on light-alloy castings, is used on d.c., reverse polarity only. A very short arc should be held to concentrate heat in the immediate weld area. The burn-off rate is very high, which means that high welding speeds must be maintained to

THE distributor body shown here is cast in light alloy. The fractured parts have been accurately reassembled by arc welding, using "Eutectrode 2100."

zinc-base alloy would be considered satisfactory.

For welding aluminium castings, "Eutecrods 210" and 212 are recommended. "Eutecrod 210" should be used on the common aluminium castings, such as the 5 per cent. silicon-type alloy (alloy 43), and "Eutecrod 212" on castings that require heat treatment after welding. Both of these welding rods will bond to aluminium castings at temperatures from 510-580 degrees C. Each is used with "Autochemic Eutector" flux bearing the same number as the rod.

For welding with "Eutecrods 210" and 212, the castings should be "V'd" out and carefully cleaned in the weld area. A slight excess acetylene flame is used, and flux is applied with the hot end of the welding rod. The weld metal should be applied rapidly in thin layers, extreme care being taken not to fuse the base metal. These welding alloys will bond to castings about 100 degrees C. below melting point of the base metal.

"Eutecrod 19" is a zinc-base alloy for use on aluminium castings and sheets, where small cracks and fine porosity are to be filled in or low spots built up. This rod bonds on the base metal at a temperature of 205-315 degrees C., and is applied without flux. The end of the rod is rubbed on the carefully cleaned and ground

TWO short sections of die-cast zinc-base window guide. These have been jointed, without loss of shape, by the use of a low-temperature filler rod specially formulated for this group of alloys.
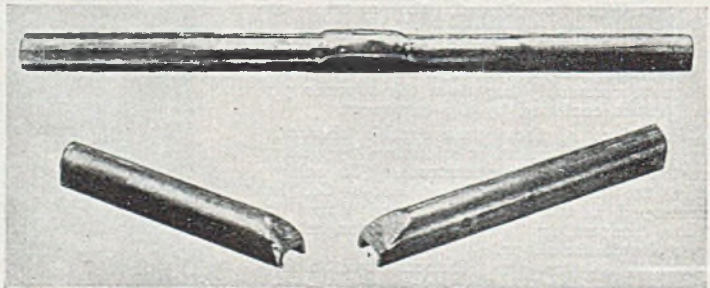
avoid excessive building up. The deposited metal will be sound, and slag easily removed from the weld.

"Eutecrod 199," a new free-flowing alloy, has just been developed for joining aluminium sheet metal at a minimum temperature. This rod flows freely on the base metal at 174 degrees C. It is used with "Autochemic Eutector" Flux 199. It may be used on heat-treated aluminium alloys, where it is necessary to join the parts without disturbing the heat treatment, and where the strength and corrosion resistance of a

or filed metal, thus removing any oxides that may have formed during the heating operation. "Eutecrod 19" does not possess the corrosion resistance of aluminium alloys, so it should be covered with a film of grease, oil or other protective covering.

Reference to this last low-melting-point alloy is of interest, as it raises, once more, the problem of the satisfactory development of what might be termed soft solders for light alloys and the need for materials of this sort possessing higher corrosion resistance than is at present the case.

Thermal Reduction of
ALKALINE-EARTH-METAL OXIDES

W. J. Kroll Presents a Brief History of the Earlier Laboratory Work which Lead, Ultimately, to the Evolution of Practical Commercial Methods for the Isolation of the Alkaline-earth Metals, in Particular Magnesium, by Direct Thermal Reduction from Their Oxides

AFTER the industrial production of magnesium and barium by the thermal reduction of their oxides has been successfully accomplished, it may be interesting to examine the laborious way through which the pioneers went to reach their goal. We do not intend to examine the latest developments that may still be on file in the Patent Offices, as the matter is not yet completely settled; nor shall we refer to the recent furnace constructions, because the " know-how " is only an outcome of the principles discovered a long time ago. The engineering problems entailed have been solved, to varying degrees, in a number of countries, which fact honours those who dared to tackle them. It is intended here to examine chronologically the essential steps accomplished by the individual inventors, up to the beginning of this war, and this only from the point of view of the metallurgist or chemist. A general survey of the literature may be found in Gmelin.[1]

The main steps in the thermal reduction of alkaline-earth metals, including magnesium, have been the discovery of the principle, the use of the law of volatility that stresses the pressure-temperature relationship; the construction of suitable laboratory equipment; the recognition of the fact that the reaction products combine; the use of activators; and, in the case of carbon reduction, the quenching of the furnace gases. This stage was already reached in 1921. The next, and very recent, developments were not connected with chemistry, but consisted of the use of heat-resisting materials not readily available in 1921, the introduction of diffusion-type pumps and, in the case of carbon reduction, the use of hydrogen as a quenching agent.

The first to recognize the volatility of alkaline-earth metals was an American professor at the University of Virginia by the name of J. W. Mallet.[2] He described, in 1877, how he heated to white heat in a coke furnace a carbon crucible filled with CaO, SrO, or BaO, in which was embedded a lump of aluminium, and how, within five to six hours, a large loss of alkaline-earth metal had taken place, whilst the aluminium had disappeared. He stated: " It is remarkable that these metals can be volatilized in a closed vessel, which makes them similar to the alkaline metals."

Cl. Winkler[3] reduced barium oxide with magnesium, but could not separate the reaction products. CaO and SrO behaved likewise. This

he attributed to the formation of lower oxide, for instance Ba_2O. However, it may be that a stable intermetallic compound is produced. The so-called Maquenne mixtures, used as absorbents for nitrogen, which are composed of aluminium plus CaO or magnesium plus CaO, are directly derived from Winkler's experiments.

M. Guntz must be considered as the originator of our processes for isolating magnesium and alkaline-earth metals by reduction with another metal. In 1906, after unsuccessful attempts to produce barium by magnesium reduction, he substituted aluminium for magnesium and operated in vacuum.[4] He used $3BaO + 2Al$ at 1,100 degrees C. in a vacuum maintained in a porcelain tube which contained an iron sleeve, the upper end of which was water-cooled. The same set-up was used in 1910 for producing strontium[5] from a mixture of $3SrO + 2Al$, at a temperature of 1,000 degrees C., in vacuum. This is exactly the same method used to-day for making barium and strontium for getters.

The work was taken up in 1913 by Camille Matignon,[6] who used the Guntz process to reduce $3MgO$ with $2Al$. He operated in a vacuum at 1,200 degrees C., using a porcelain tube with an iron insert cooled at the end. His magnesium recovery was 70 per cent. He claimed that the fusion-electrolysis process for magnesium could be replaced by his vacuum-reduction method. At about the same time, Matignon reduced barium oxide with silicon,[7] and made the important statement that the mixture has to be adjusted in such a way that stable compounds form between the reacted products, for instance, aluminates and silicates. He worked with a mixture to produce $BaO.SiO_2$ and barium metal. Furthermore, he suggested the use of a 90 per cent. ferro-silicon, which is cheaper than the high-grade material. Both of these ideas are embodied in our actual magnesium-reduction processes in which ferro-silicon is used and silicates are formed.

Then the first world war broke out, and it was not until 1921 that we again heard of this process. In 1921, Matignon[8] disclosed the principle of volatility which rules all the equilibrium reactions between $MeO + X$. He suggested CaC_2 as a reducing agent and showed that this reaction proceeds by steps; the first being a reaction of calcium with MgO; the second, at about 1,500 degrees C., the reaction of the carbon with magnesium oxide. Furthermore, he

disclosed the use of CaF_2 as an accelerator.'* He described the reduction of $MgCl_2$, MgO, $MgCl_2$, and plain MgO with CaC_2 at 1,200 and 1,300 degrees C. in a vacuum, and suggested the use of dolomite. From this, the basic principles of the actual metal-reducer processes were all established.

Matignon tried to put his process into practice in the first world war, but failed—why? Here are his explanations:—" The experiments have been prosecuted for over one year without obtaining practical results, due to difficulties with the equipment. We used horizontal iron retorts, clamped for resistance heating, and provided with a condenser extension. Iron collapses even when using hydrogen (externally?) or hydro-carbons. Hydrogen diffuses through the iron walls and the magnesium either becomes oxidized or nitrated. A slow current of argon (inside?) may prevent the collapse of the tube. The retorts lasted one run." If Matignon, in 1915, had known about chromium alloys, his carbide process might have been a success. In 1923, he[10] again demonstrated the reduction of three parts of SrO or BaO with one part of Si at 1,250 degrees C. in a vacuum, and again suggested using ferro-silicon.

The matter remained quiet for about 10 years, when G. Gire[11] published his results on the reduction of MgO with Si. He obtained, in three hours at 1,300 degrees C. in a vacuum, a 50 per cent. magnesium recovery from the mixture $Si+2MgO$. He attributed this low yield to silicate formation, suggested using dolomite, and operated with retorts in a vacuum. The use of dolomite with silicon in a vacuum with formation of $2CaO.SiO_2$ was also suggested in 1935 by the Société générale du Magnésium.[14]

The general relationship between temperature and pressure is given by A. Wacker.[12] This leads to a question of principles: Shall the reduction take place in a vacuum at a lower temperature, for instance, 1,175 degrees C., or at atmospheric pressure between 1,400 and 1,500 degrees C.? An intermediate temperature and pressure is not desirable, as the batch may sinter. At 1,400 to 1,500 degrees C. the slag may be pasty or fluid, depending on the composition. Much attention has been given this matter by the I.G. Farbenindustrie,[13] which has tried to operate with solid slag.

The future of reduction processes at atmospheric pressure depends mainly on the possibility of either fusing the slags or keeping them solid and avoiding magnesium " blue power " formation in the condenser. The most important

experimental contribution has been that of A. Schneider and E. Hesse,[16] who determined the vapour-pressure equilibrium of magnesium when reducing MgO with silicon, and confirmed the formation of magnesium orthosilicate.

Carbon Reduction of Magnesia

Early and unsuccessful attempts to reduce MgO with carbon date back to 1884.[15] Between 1907 and 1924, the physico-chemical conditions were studied by numerous authors, and the fact of the back reaction between CO and magnesium were fully recognized. It was, however, not until F. Hansgirg,[17] in 1932, found a means of quenching the gases and handling the pyrophoric products that the process could become commercial. The equilibrium between MgO and carbon has been studied by Treadwell and Hartnagel.[18]

It will be quite clear from this review that the basic principles governing the successful thermal reduction of the alkaline-earth-metal oxides result mainly from the work of independent investigators, largely in France; the practical application of these principles is due to industry itself. In 1915, Matignon attempted in France to put his discoveries on a commercial basis, much in the same way as has been done in U.S.A. and Great Britain since. His failure was due to a lack of suitable heat-resistant materials and of vacuum pumps of sufficiently high capacity and exhaust power to meet the requirements of the process; these refinements have been realized since his time.

BIBLIOGRAPHY

(1) Gmelin—Magnesium. pp. 133-138 (1937); Barium, pp. 32-33 (1932); and Strontium, p. 35 (1931). (2) J. W. Mallet, " Liebigs Annalen der Chemie," 1877/190/62. (3) Cl. Winkler, " Berichte," 1890/23/125. (4) M. Guntz, " Comptes Rendus," 1906/143/339. (5) M. Guntz and Gallot, " Comptes Rendus," 1910/151/813. (6) Camille Matignon, " Comptes Rendus," 1913/156/1157. (7) Camille Matignon, " Comptes Rendus," 1913/156/1378. (8) Camille Matignon, " Comptes Rendus," 1921/172/381. (9) Camille Matignon and V. Thierry, French Patent 488,735 (1915). (10) Camille Matignon, " Comptes Rendus," 1923/177/1110. (11) G. Gire, " Comptes Rendus," 1932/194/884. G. Gire, French Patents 733,294 (1931), 750,977 (1932); addition 44,063 (1933). (12) A. Wacker, French Patent 802,506 (1936). (13) I.G. Farbenindustrie, French Patent 769,528 (1934); British Patent 413,606 (1934). (14) Société générale du Magnésium—French Patent 800,163 (1935). (15) J. Walter, " Dingler's Polytechnisches Journal," 1884/252/338. (16) A. Schneider and E. Hesse, " Zeitschrift für Elektrochemie," 1940/46/279. (17) F. Hansgirg, " Berghüttenmann, Jahresberichte Leahen," 1934/82/190. U.S. Patent 1,884,993 (1932). (18) W. D. Treadwell and J. Hartnagel, " Helv. Chim. Acta," 1934/17/1372.

---

*The following passages occur in the original patent:—

" Il semble utile aussi de signaler qu'un fondant approprié, par exemple, du fluorure de calcium, pour faciliter la réaction et le départ du magnésium."

" Une faible quantité d'impuretés telles que de l'oxyde de fer, peut même être utile pour faciliter la réaction."

Unfortunately, no specific data are given to indicate how the inventors arrived at this discovery, nor as to the full significance of the additions. Thus, no figures are provided to demonstrate the increased metal yield obtained on using an activator, without which a yield of 40 per cent. metal might be considered good for the calcium-carbide reduction of magnesium oxide, this being raised to at least 80 per cent. in the presence of calcium fluoride. Similarly, activators are required in the ferro-silicon reduction of magnesium oxide.

NEWS—General, Technical and Commercial

Diamond Cutting-tools

WE have received the following letter regarding the account entitled "Machining of Light Alloys With Diamond Tools," which appeared on Page 430 of "Light Metals" for September:—

"We read with interest your article on the machining of light alloys with diamond tools with, naturally, particular interest on the data given for magnesium alloys.

"On Page 432, whilst admitting the possibility of higher cutting speeds, you mention 1,000-1,250 f.p.m. being economical for magnesium alloys, but we have knowledge of speeds up to 3,700 f.p.m. being attained with feeds of .0025-.0005 and a depth of .003. Slight variations of these speeds have given surface finishes between 24 and 6 micro inches on dry machining without any danger of fire. You may also be interested to know that by slightly reducing the cutting speed even finer surface finishes have been produced.

"We would like to call your attention to some very interesting research work which is now in the final stages undertaken by the Institution of Production Engineers with special reference to light alloys.

"Another interesting feature of the September issue is that in not one particular instance do you state the author of the otherwise interesting articles in our sphere. We feel that the value of any technical article must depend upon the authority and status of the author in the same way as a diagnosis depends upon the reputation and experience of the doctor."—L. WHITBURN, for F. A. Hughes and Co., Ltd.

[In his last paragraph, the writer of this letter puts us in an embarrassing position. Much of the matter in "Light Metals" is of a composite nature, with the result that definite authorship is hard to define. Apart from this, however, we feel that technical journals have, in the past, been too frequently used with the object of airing famous names rather than useful knowledge. With this point in mind, we have for long observed what the "Manchester Guardian" termed the "sacred right of anonymity," preferring that our matter should be judged on its merits rather than its authorship be questioned. We cannot, of course, deny there is much sound common sense in what Mr. Whitburn says in the paragraph cited; we have frequently found ourselves at a disadvantage as a result of indulging this whim. Abstractors, for instance, commonly commence their work by digesting "labelled" articles, particularly if they happen to be acquainted with the name attached to them. There are some compensating advantages, however.—ED.]

Aluminium in Architecture

ONE of the earliest uses of aluminium was in ecclesiastical architecture. In 1897 the dome and parts of the roof of St. Joachim's Church in Rome were covered with commercially pure No. 14 gauge aluminium sheets. Subsequently, the new and stronger alloys were used in the construction of spires, windows and their grilles, doors and stair railings.

Other applications in churches have included pulpits, baptismal fonts, candelabra and balda-chines. A church in Pittsburgh, Pa., has a spire composed of a grillework of aluminium castings hung on a steel frame.

Aluminium Collapsible Tubes

BY recent amendment to the War Production Board's conservation order M-115, civilians in the U.S.A. can now purchase shaving cream, tooth paste, ointments, sulfa drugs in jelly and other such pharmaceutical items in aluminium collapsible tubes without turning in a used tube for the new one. This is largely a result of the seven-fold war-time expansion of aluminium production in U.S.A. The principal restriction now is man-power to produce the tube material and tubes. Said George J. Stanley, vice-president and general salesman, Aluminum Co. of America: "While it is our intention to make every effort within our power to help eliminate a war-time hardship which has been felt by every man and woman in America, the manufacture of collapsible tubes at our Edgewater, N.J., works, and the blanks we will supply to other manufacturers for the making of aluminium tubes, will be determined by the amount of competent help which can be obtained without diverting man-power from essential war production."

New Laboratory Apparatus

WE have received from Griffin and Tatlock, Ltd., a series of pamphlets detailing new laboratory apparatus. Of principal interest is the anti-vibration balance table, designed to permit even the most delicate balance to be used in the neighbourhood of industrial equipment and apparatus giving rise to high intensity vibration of high or low frequency.

A further pamphlet deals with what is referred to as a super-hard glass-cutting knife, the cutting element of which is a cobalt-chromium-tungsten alloy. Leaflet G.T. 1342 describes apparatus for the determination of benzole, toluene and phenols. Leaflet 1343 gives details of a vibratory ball mill of new design for use in rapid grinding of materials to a finely powdered form. In this apparatus, the pot (which normally rotates in balance to give a more cascading effect of the balls) runs on an out-of-balance device to produce a deliberate hammering effect.

The Griffin and Tatlock apparatus for the determination of nitrogen in steel by the Kjeldahl method is described in leaflet 1344.

New W.L.A.D.A. Appointment

IT is announced that Mr. J. D. Beddows, B.Sc., has been appointed metallurgist and technical assistant to Dr. E. G. West, of the Wrought Light Alloys Development Association. The appointment had become necessary owing to the increasing expansion of the Association's work. Mr. Beddows, who graduated at Birmingham University in 1931, has held a number of important posts in industry.

Putting Mg on Post-war Map

UNDER the title "Dow Company Looks Ahead—Chemical Company Explores New Uses for Magnesium," "Business Week," for September 2, 1944, featured the following summary:—

"Dow Chemical Co. stockholders who visited the company's Midland (Mich.) general offices for their annual meeting last week were given a preview of products Dow plans to offer for post-war sale in what it hopes will be a market of 'free customers.'

"*Light Castings.*—Included also were two war product exhibits; extruded magnesium alloy used for rocket-launching tubes on fighter 'planes and magnesium-alloy castings for a jet-propulsion aircraft engine. None of five large castings for this engine weighs as much as 100 lb. The entire engine, said to develop 8,000 h.p., weighs only 1,800 lb., of which 450 lb. consist of magnesium castings.

"A relatively prosaic product with post-war tonnage possibilities that created a stir of questions and discussions was a magnesium-alloy wheel for a passenger automobile. It was patterned after a steel wheel built for the 1942 model Chrysler Imperial.

"*In Testing Stage.*—Dow technical men emphasized the magnesium wheel was experimental—it hasn't yet been fully tested or sold to any manufacturer.

"However, it does offer a possible saving in unsprung weight. Designed to be as strong as the steel wheel, which weighs 20 lb., the magnesium wheel weighs only 8 lb. Dow designers also have been working on plans for a magnesium-alloy brake drum, with cast-iron brakeband surface, which might weigh 17 lb. in place of 30 lb. for the conventional steel brake drum.

"Thus, the magnesium wheel and brakedrum assembly might reduce unsprung weight by 25 lb. per wheel, without changing design, and riding qualities might be improved by changing the proportion of sprung to unsprung weight.

"*May be Competitive.*—Magnesium aircraft wheels have proved satisfactory, Dow technicians say, and they argue that there is no reason why magnesium eventually can't compete with steel automobile wheels on a direct price basis. Meanwhile, they acknowledge that two important hurdles will have to be surmounted: Design must be proved in test applications (which is said to be true of any wheel design) and mass-production techniques and machinery will have to be developed.

"Arithmetic of magnesium automobile wheels is completely speculative, but impressive. A 6,000,000-car year, which some manufacturers visualize, using four 25 lb. magnesium wheels per car, would use this country's total war-time capacity of 250,000 tons a year. Production has already been cut 50 per cent., and a further cut to 10,000 tons monthly is expected in the industry.

"*Would Lift Restrictions.*—From a practical viewpoint, neither Dow nor any of the other magnesium producers expect magnesium demand to catch up with capacity for some time, which is the explanation of Dow's current fight (B.W.-August 19, 1944, p. 7) to secure removal of all restrictions on use of this light metal.

"To illustrate minor uses which might be multiplied indefinitely, Dow technicians say that there is a shortage of door-knobs; that they can be made from magnesium as well and as cheaply as from any other material; and that small manufacturers won't start the long unexplored journey through Government red tape to start the door-knobs rolling. Yet there is a machine which with one operator can produce 600 an hour.

"*New Aircraft Use.*—Another magnesium innovation was an I-beam for aircraft construction, a structural member the company feels may be adapted to all kinds of post-war building jobs.

"Although there were other exhibits such as plastic soles and heels (which it is claimed won't make black marks on floors), non-breakable plastic bottles, and other plastic and chemical specialities, the exhibits seemed heavily weighted with magnesium, indicating the company's pre-occupation with its development possibilities.

"*Not Profitable Yet.*—Company officials say magnesium, by itself, still isn't a money-maker for Dow; that it continues to depend on co-production of other materials such as chlorine."

Gravity Die-casting Practice

THE process of gravity die-casting is but one example of a successful technique which has been amply demonstrated in the war-time production drive and which, further, should be utilized by progressive engineering concerns in peace-time production.

In the past there has been an unfortunate tendency for engineers to look upon the production of gravity die moulds as a purely engineering job, whilst the best work has been done by those foundries that realized the necessity, in the design stage, for a combination of engineering skill and knowledge of the founder's craft. Too often this state of affairs led to jealously guarded process secrets in individual design departments and foundries.

In "Gravity Die-casting Technique," by Geo. W. Lowe (Hutchinson's Scientific and Technical Publications), published at 9s. 6d., the author has performed a service in bringing the fundamentals of die design into the light of day, and producers and users should be grateful to him. Scattered articles, often on specialized aspects of the subject, have appeared, from time to time, in the technical and trade Press, but here we are presented with a complete account of die production. The intricacies of the art are made quite clear without recourse to technical jargon, and with no assumption on the part of the author that his readers are other than practical engineers. Vague and often unwarranted flights into metallurgical science have, commendably, been strictly avoided.

From the nature of the subject it cannot be expected that the last word has been said—last words have a knack of being said over and over again; the gravity die-casting process is a developing art. Users of castings should, therefore, continuously explore the possibilities of gravity die-castings; this study will assist designers, production engineers and buyers to acquire a knowledgeable background. The addition of an index would improve the general usefulness of the book.

TRAINING FOR INDUSTRY

THE recent booklet,* by Twyman, and a brochure† issued by Birmid Industries, Ltd., deal with the important question of the entry of the boy into industry: the first particularly from the point of view of the optical instrument industry and the second from that of metallurgical industries. Both are concerned with the initial training of the boy leaving school to fit him to take his place in the labour market.

The Birmid scheme for apprenticeship is actually in operation and has evidently received the closest attention and minutest care of those responsible in the companies comprising Birmid Industries, Ltd. The scheme is open to boys of 16 who have reached School Certificate standard and covers a period of five years: in the first stage of three years the boy (aged 16-19) is to receive a general knowledge of his craft and a working knowledge of the basic technical background. During these three years the companies arrange and pay for a sandwich course at the appropriate technical college; the second stage of two years is to be a period of specialization, giving the apprentice an opportunity for making the most of his particular abilities. At the end of the apprenticeship facilities will be available to selected apprentices for further specialized training. Boys leaving school at 14 not having reached School Certificate standard may register as "apprentice-trainees," and the companies provide a school continuation course, so that they will be qualified for an entrance examination for apprenticeship at 16 years. At 19 apprentices will be expected to qualify for the Ordinary National Certificate, the City and Guilds Certificate or the Technical College Diploma, and at the end of the apprenticeship take the Higher National Certificate or Final City and Guilds Certificate. For apprentices who show that they will benefit from them, special courses are available in other works, at the foundry school or other technical institutions, or a degree course at a university. No premuim is required; a form of agreement is entered into; scales of pay are to be agreed by the Employers' Federation and the trade unions; holidays are arranged. During the first three years of the course, in addition to technical subjects, three hours per week is to be given to English subjects, covering industrial history, industrial administration, economics, geography and citizenship, and also précis, report and essay writing, and during the last two years two hours per week is set aside for "management."

The scheme deserves the highest commendation: it offers the boy, who has made full use of his time at school until the age of 16, a real opportunity by training in manual dexterity, physical effort and use of brain power to become a really useful member of the metallurgical engineering industries and, at the same time, will fit him, by the development of initiative and imagination, to become a sound citizen. In addition, the scheme will ensure that there is always a sufficient number of young men in every way fitted to carry on the exacting and highly skilled business of the modern metallurgical engineering industries.

Mr. Twyman supports the need for apprenticeship wholeheartedly and has given the subject very careful consideration. The outline of his scheme is clear and concise, and is followed by detailed considerations on which it is based. He follows apprenticeship from its earliest days in 1300 down to the problems of the twentieth century. The scheme differs from the Birmid Scheme on the questions of age and educational qualifications: Mr. Twyman insists that a boy should become an apprentice at 14, and that there should be no educational qualifications. He supports the need for the earlier age by saying: "There is a general neglect of the fact that at the age of 14 many normal boys become impatient of learning unless they see some useful result" and, later, "there are psychological reasons why the normal boy should take his first step into manhood by entering into paid occupation among professionals somewhere about the age of 14." These are surely very equivocal statements on which to base an argument. He then examines the sentimental reasons (as he calls them) for deferring the school-leaving age, one of which he states is "to acquire a sense of citizenship." On this he posits the following question: "What better initiation and education could there be than to become a citizen: to enter into a contract—the very foundation of civil life; to earn's one's living; to acquire the qualification for the franchise; and to aim early to support a wife and children?" In his curriculum for the apprenticeship course for five years no time whatever is allotted for the study of any non-technical subject. Mr. Twyman has complained only three pages earlier "that in postponing the school-leaving age to 15 and later to 16 the education authorities are relegating this country permanently to the amateur class in crafts. Surely we are going to relegate the country to amateurism in citizenship if the only background the apprentice has for this great responsibility is the meagre learning he has received at school until 14, to which nothing whatever is to be added during his apprenticeship—as well give a boy a bat and ball and hope he will one day play cricket for England without any guidance or tuition." Mr. Twyman may aim "primarily at the prosperity of British industry," but unless industry does something more to train a boy's character and develop his outlook than giving him an opportunity of earning a living, "the welfare of those working in industry cannot be achieved." Industrialists are too apt to overlook the fact that the prosperity of British industry can only be founded on a society in which the spiritual as well as the material sides of human nature have been fully educated (i.e., drawn out). Assuming that Mr. Twyman is correct in thinking that a boy should start in industry at 14, it is essential that during the 60 months' training as an apprentice time should be found for dealing with that part of the human boy which is to develop his standard with his fellows and his manners towards the world.—H. C. B. PHILLIPS.

---

*"Apprenticeship for a Skilled Trade," by F. Twyman, F.Inst.P., F.R.S. (Charles Griffin and Co., Ltd. 5s.)

†"Training for the Metallurgical Engineering Industries." (Birmid Industries, Ltd.)

ECONOMIC REVIEW

The Following Account of the Immediate Post-war History and Current Development of Spain's Aluminium Industry is Presented in the "Deutsche Allgemeine Zeitung," Monday, June 5, 1944

AS a result of the war, neutral countries in Europe have become faced with increasing difficulties regarding supplies of raw material; particularly is this true in the case of metals, because before the war Europe was, to a large extent, dependent for its supplies of metal proper, and raw materials for metal, upon imports from overseas. Deliveries from such sources are becoming less and less frequent as hostilities continue. Apart from direct hindrances, represented by wholesale destruction of world shipping, the parts played by the growing metal requirements of the Allied nations and the Navicert system are not to be ignored.

Thus non-belligerents are likely to find it impossible to maintain their imports at a level corresponding with metal requirements for the entire duration of the war. For this reason European countries have tended, more and more, to interest themselves in the question of domestic light-metal production, as, in this way, they appear to possess a more favourable chance of meeting the demands made upon their resources.

Even in Spain, aluminium production to-day has assumed a far greater significance than was previously the case. In considering the Spanish problem, due attention must be paid to the fact that, as a result of the Civil War, metal requirements had increased very considerably, and that aluminium, on technical military grounds, has come to occupy a position of importance much higher than a few years ago. That this would be so became clear to the Spanish authorities during the Civil War, hence domestic bauxite resources, so far little used, were declared items of strategic value, although native deposits of this mineral were formerly not used to any extent.

Until recently, Spain's aluminium requirements could be met by a very minor domestic production. Prior to the outbreak of the present war, the aluminium output there stood at round about 1,000 tons per annum with 1,300 tons in 1935 as a peak figure. In 1936, output reached only 800 tons. Since that date, no production figures have been available.

Spain possesses bauxite deposits in the provinces of Barcelona, Taragona, Navarra, Cadiz and Seville; it is not fully known whether all of these will prove economical to exploit. Prior to the Civil War, some 2,500 tons of bauxite were mined per year, but the whole of this was taken up in the manufacture of aluminous cements. In 1934, local bauxite production completely stopped, and Spain's aluminium producers relied entirely on alumina imported from France. Even if the stepping-up of its bauxite production cannot, perhaps, be quite so rapid as might appear desirable for the nourishment of a really progressive aluminium industry, nevertheless Spain, like Switzerland,

need, normally, not be seriously troubled, as it is able to buy from France.

The most important Spanish producer of aluminium is the Aluminio Español S.A., the plant of which, at Sabinago, in Huesca, had, before the war, a capacity of about 1,500 tons per annum. This company had then, for some short while, been granted permission by the authorities to reconstruct and modernize its plant, in order to make possible an output of up to 2,000 tons a year. Official permission was given in September, 1943, for the newly founded Sociedad General Español de Aluminio to erect a further aluminium extraction plant, also with a capacity of about 2,000 tons a year. This permission was granted to the company, however, only on condition that it used, in the main, bauxite of domestic origin. Furthermore, it was stipulated that production must commence not later than August, 1944. The capital of the new company amounts to 21 million pesetas and, at a later date, is to be raised to 75 million pesetas.

The Institute of National Industry was asked by the authorities, in 1943, to form yet a further company for the production of aluminium, capital for this undertaking to be subscribed mainly by the Institute.

This plan was duly put into effect in conjunction with the well-known Spanish copper concern, Sociedad Español de Construcciones Electromecanicas (S.E.C.E.M.) of Cordova. The new company is known as "Empresa National de Aluminio S.A.," its capital is 40 million pesetas, 25 million being subscribed by the Institute of National Industry and 15 million by S.E.C.E.M. The plant of this new company will commence operations some time in September, 1945, with an output capacity of about 5,000 tons a year. The precise location of the plant has not yet been decided upon.

Thus, according to present plans Spain can reckon on a domestic aluminium production of 9-10,000 tons per year. This figure is, in itself, not particularly startling. Nevertheless, it represents a considerable easing of the burden of those responsible for providing the country with sufficient metal to get on with. Furthermore, the mere fact that the metal is produced at home will result in saving in transport and will satisfy the growing demands of the electrical industry, for example, for a substitute for copper, supplies of which have been affected, even in Spain itself, by difficulties arising directly out of the war.

As an outcome of this development it appears that the question of production of necessary cheap power must now be studied—i.e., Spain's water-power resources must be assessed and turned to use. These have been estimated at 4,000,000 h.p., but, until now, only 1,400,000 h.p. of the total has been utilized.

Aluminium and Magnesium in the Electrical Industries

By
B. J. BRAJNIKOFF

In this Section of his Account, Continued from "Light Metals," 1944/7/223, the Author Describes Aluminium Production at Alcoa Plants and at Arvida, and the Electrical Equipment Associated with it

54 AL. 19 STEEL   54 AL. 7 STEEL   30 AL. 19 STEEL

| 30 AL. | 26 AL. | 6 AL. | 6 AL. |
| 7 STEEL | 7 STEEL | 7 STEEL | 1 STEEL |
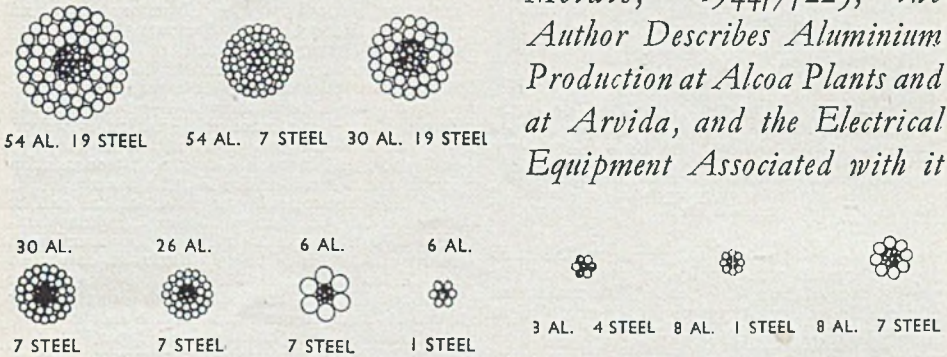
Fig. 1 (Above).—Diagrammatic cross-sections showing forms of standard types of Alcoa steel-cored aluminium cable.

3 AL. 4 STEEL   8 AL. 1 STEEL   8 AL. 7 STEEL

| 12 AL. | 16 AL. |
| 7 STEEL | 19 STEEL |

Fig 2.—Apart from standard types as shown in Fig. 1, Alcoa also manufacture, to order, special forms of steel-cored aluminium cable. Some cross-sections are shown here.

DISCUSSION on the application of aluminium to high-voltage transmission systems would not be complete without brief reference to progress in its development and utilization in U.S.A. practice. Here has been gained the widest experience in the construction of overhead lines operating at 220 kV.

The following account represents an attempt to illuminate some fundamental points concerning the design, construction and operation in U.S.A. of high-voltage transmission lines, with special attention being paid to 220 kV. systems with steel-cored aluminium conductors. Details are based on the latest U.S.A. practice, as furnished by technical data supplied by the Aluminum Co. of America. At this concern's works, which may claim the largest output of aluminium conductors for any one organization, there is concentrated, also, about 80 per cent. of the world's production of aluminium.

Increasing cost and relative scarcity of copper are bound to be felt acutely in American electrical practice, as the development of this branch has reached there an unprecedented level. As would be expected, steel-reinforced aluminium cables have provided the solution to the problem, and are now utilized to the largest possible extent. The commencement of their application in the U.S.A. dates back to 1906-1907, but their widest use has been attained only since 1920, after practical experience of many years had dispelled doubts associated with the initial period of their adoption.

At the present time, nearly 50 per cent. of newly constructed transmission lines in the U.S.A. is equipped with steel-cored aluminium conductors; the application of those consisting of aluminium alone amounts to less than 1 per cent. of the total number of newly built lines and serves, exclusively, low voltage systems.

In the construction of steel-reinforced aluminium cables for normal spans, the Aluminum Co. of America has recently worked out a definite ratio for steel to aluminium, in which steel constitutes about 40 per cent. by weight of the entire section of the cable; there are indications that all observed breakdowns of lines occurred in cases where conductors exhibited a steel ratio less than this figure.

Alcoa's conductors are usually of definite standard cross-sections, but, for different specific requirements, it undertakes production of cables of any other construction, as illustrated in Figs. 1 and 2.

In calculating the mechanical strength of conductors, the designer has to take into account not only the cross-section of steel, but also the cross-section of aluminium. The distribution of
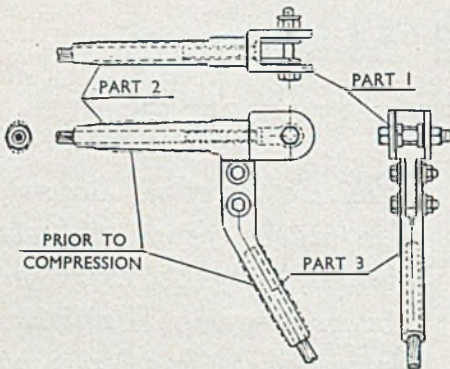
Fig. 3.—Clamp used in U.S.A. for erection of steel-cored-aluminium-cable systems. Fastening of the steel-core and its aluminium envelope is effected by means of a compressing operation performed in a special hydraulic press at a working pressure of 100 tons. The general arrangement of the press is illustrated in Fig. 4.

stresses in both materials depends on the ratio of their moduli of elasticity as well as on the various temperature coefficients. The maximum permissible tension for aluminium is accepted in the neighbourhood of 9 kg./mm.²

In the initial period of application of steel-reinforced aluminium cables, steel of average quality was used, but, subsequently, Alcoa, on the basis of experience of later years, passed on to the use of a high-grade steel of special composition having a tensile strength of 140 kg./mm.² with from 4·5 per cent. elongation.

During the past few years has been introduced a supplementary method for the treatment of aluminium cables by means of stretching prior to the erection. Nowadays, however, American practice prefers to omit this as marked elongation of the cable can take place only after reaching the limit of the calculated mechanical loads; the probability of this happening under actual service conditions is not great. In the event of experiencing such conditions, it is simpler to offset their results by retightening the conductors.

Recently great attention has been paid by the American concerns to the problems of vibration of conductors. This, in some instances, has been the cause of failure of overhead lines. Of late this question has been extensively studied, and it has been shown that vibration in conductors is due to the local wind action and is effected exclusively in a vertical plane.

Of the many different methods proposed to reduce mechanical overstressing of the conductor due to vibration, the simplest and most reliable is that of winding the cable in a suspension clamp by means of wires of variable cross-section. The winding is applied to a cable segment 1.6 metres long, reckoning from each side of the clamp; such a braiding arrangement acts as a cushion and thus protects the conductor against excess tension, by absorbing forces due to local bending caused by the vibrations. Moreover, the winding also prevents damage to conductors by arcing in the event of flashover across the string of insulators; this is especially important in the absence of guard-rings.

As regards apprehensions with respect to the corrosion of the steel core with consequent reduction of the mechanical strength of the cable, it should be emphasized that their application in the United States, extending over a period of some 25 years, laboratory tests and service in Europe, have demonstrated that no dangerous attack takes place.

An interesting case on record occurred in one American overhead line. As a result of a flashover, all the aluminium was burnt off a short length of steel-reinforced cable which, however, was still held in position by means of the steel core only, and in such a way that transmission continued to function for about a month.

As to the electrical properties of the cables, it is usual in the design to take into consideration only the conductivity of the aluminium component. The technical aluminium employed for the conductors in the U.S.A. is of 99.4 per cent. purity; its conductivity is from 60 per cent. to 61.3 per cent. that of the international standard specimen of annealed copper.

In U.S.A. is undertaken the construction of aluminium cables of three types: (1) Those with a guaranteed conductivity of 60 per cent., with actual conductivity within the limits 60 per cent. to 61 per cent.; (2) those with guaranteed conductivity of 61 per cent., and (3) those made of aluminium of superior quality, with guaranteed conductivities of 61.1 per cent., 61.2 per cent. and 61.3 per cent.

Normal prices are quoted for those with a guaranteed conductivity of 61 per cent., cables of a lower or higher guaranteed conductivity are, of course, priced with respective rebates or additions to the normal cost.

Returning now to the problem of the computation of the mechanical strength of steel-cored aluminium cables, it should be pointed

Fig. 4.—Transportable hydraulic press used for fixing clamps (as shown in Fig. 3) to steel-cored aluminium cable.
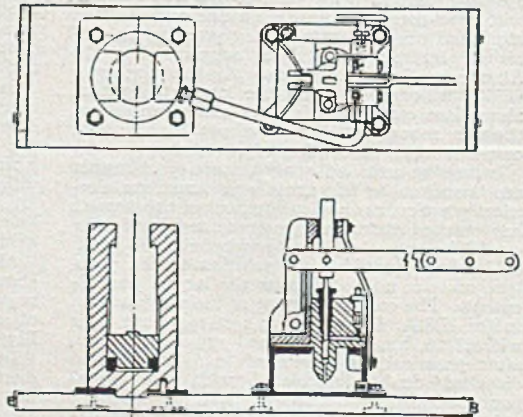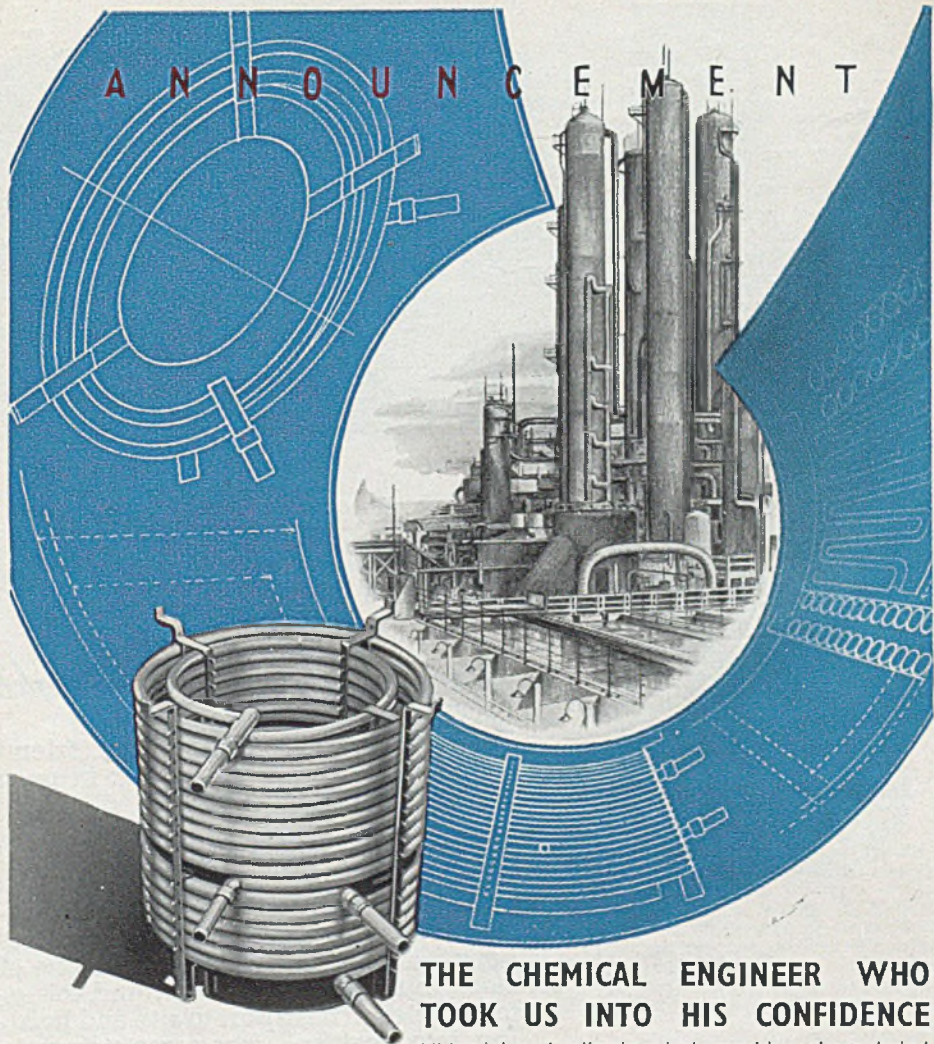
F

The art of carrying weight

Were the baskets heavier, our friend on the left would be slower in pace and carry fewer.

The moral is that excessive weight hampers mobility.

Take for instance a Jib Crane constructed of Reynolds Light Alloy Sections. It is equal in strength to one of steel, but infinitely lighter, and therefore easier in transport to site and hoisting into position. The same principle applies to this telescopic Tentpole in Reynolds Light Alloy Tubing—with a 6ft. extension and weighing only 12 ozs. a boon to holiday makers.

. . . . just two examples of the way Reynolds will " materially " influence the near future.

TUBES RODS SECTIONS
SHEET AND STRIP IN
"HIDUMINIUM"
ALUMINIUM ALLOYS

REYNOLDS

REYNOLDS TUBE CO. LTD. &
REYNOLDS ROLLING MILLS LTD.
BIRMINGHAM. 11.

out that, in American practice, the checking up of the values of sags to meet the contingency of local overheating due to short circuit is not done, even in the case of very powerful networks. The term " sag" denotes the vertical component of the deflection of the conductor from a straight line connecting its two supports, which are on the same level.

The weight of the wire has a direct bearing upon the behaviour of the line, being one of the important factors in the study of sags and tensions in the conductors. For a given deflection in a span, the tension in the cable is practically in direct proportion to the load per unit length of the cable, this load consisting of the weight of the cable itself, plus its ice or snow coating, plus (vectorially) wind loading. As a rough indication of the mechanical advantage of any conductor material, we may take the ratio between its tensile strength and weight; tension in a conductor for a given span is, approximately, in inverse proportion to its sag. In computing sags and tensions in conductors, it is usually assumed that the cable is perfectly flexible, with a uniform distribution of loading over its whole length, thus attaining the shape of a catenary.

first of all, to put on the conductor the outer part of the clamp and to cut back the aluminium wires to a length somewhat exceeding that of the inner part of the clamp designed for holding the steel core. Then the steel core is fitted in and subjected to compression in the hydraulic press. Following this, the outer part of the clamp is slid on to the fastened cable and, after insertion of the binding bolt the whole assembly is again compressed in the press. Owing to high pressure employed in the process, perfectly reliable connection is attained, and the guaranteed strength of the clamp constitutes 95 per cent. of the maximum strength of the cable.

Connection of the two clamps on to the anchor support is realized with the aid of a separate suspended loop fastened to the tightening clamps.

Besides the devices described, overhead lines equipped with steel-cored aluminium cables also make use of erection clamps of the usual type. In this case, with the object of protecting the conductor from damage, special aluminium linings are fitted. The cost of both types of clamp is the same.

Clamps, very simple in construction and dependable in service, are also made for taps.

Fig. 5.—Connector for steel-cored aluminium conductors. This diagram shows form before and after attachment has been effected by compression.

As has been stated in the previous section of this study, recent trends on the Continent of Europe have favoured the adoption of conductors made entirely of special aluminium-base alloys (such as " Almelec," " Aldrey," " Montegal," which, in addition to about 98.7 per cent. of aluminium contain silicon, magnesium and iron) in preference to steel-reinforced cables. With equivalent conductivity in terms of their cross-sections, conductors consisting of these alloys possess, in comparison with those of copper, 50 per cent. more mechanical strength with 46 per cent. less weight. The cost of such conductors, on a weight basis, is, approximately, 50 per cent. higher than that of steel-cored aluminium cables.

However, notwithstanding the obvious advantages of conductors produced from aluminium-base alloys, American designers still display a conservative attitude to their application, apparently waiting for further performance results based on their exploitation in Europe.

Clamps and Connectors

Peculiarities inherent to the construction of steel-reinforced aluminium cables have necessitated the introduction of suitable tightening clamps, and of connectors of special types.

Tightening clamps, as manufactured by the Aluminum Co. of America, consist of three parts, one of which serves for securing the steel core, another of aluminium, and the third for connecting the loop, as depicted in Fig. 3.

In order to fasten in the cable it is necessary,

Where aluminium is joined to copper conductors, special aluminium clamps with copper bushings should be employed. In this event, one of the grooves of the clamp is copper-plated, with the aim of preventing electrolytic corrosion. Although reaction between this copper coating and the body of the clamp may still take place, it very soon ceases on account of the formation of a thin layer of oxides on the surface.

Suspension clamps for steel-cored aluminium cable differ from clamps of the ordinary type by the provision of a larger aperture for enclosing the conductor complete with protective layer of aluminium braiding. Sliding clamps, which automatically open in the case of rupture of the cable, are now in wide use; over one-third of the newly built transmission lines in the U.S.A. are equipped with devices of this type. In particular, the application of such sliding clamps (opening on deflection of the string of insulators beyond an angle of 40 degrees to the vertical plane) has proved highly beneficial in service on one of the largest American overhead lines—the recently constructed Conowingo 220 kV. transmission system in Pennsylvania.

Splicing of steel-cored aluminium cable is carried out with either twisted-sleeve connectors (for joining small conductors) or by means of connectors of a special design, as illustrated in Fig. 5, for joining separately the steel core and the aluminium envelope; jointing of the individual parts of the cable is also realized with

the aid of the compression process in a special hydraulic press. The total length of such a connector for a cable 2.5 cms. in diam. is 750 mm., its weight being 2.7 kg.

Insulation Problem in Overhead Lines

A very important problem in the exploitation of high-voltage overhead lines is the question of reliable insulation. The application of suspension insulators in the form of a string of multiple elements, along which exists a non-uniform potential gradient, promoted the adoption of special protective devices such as horn gaps and guard rings. Furthermore, the proximity of a powerfully charged cloud induces a charge on the wires; then, when the cloud is discharged by a flash of lightning, the induced charge on the conductor becomes free and travels off in both directions along the conduc-

ANCHOR SUPPORT Nº 1

Fig. 6 (above).—Erection of steel-cored aluminium cables in an anchored span. By tightening the free end of the cable by means of an erecting clamp, the conductor is given the calculated tension, whilst on the intermediate supports it remains suspended on pulleys. Fig. 7 (right).—Temporary guying of intermediate supports in erection of steel-cored aluminium cables.

tor in the form of a progressive wave of very high-peak e.m.f. These progressive waves, on account of their very steep frontal pressure, are particularly dangerous in the case of overhead lines.

However, despite the fact that the prevention of ill-effects from these excess pressures constitutes a very urgent technical problem, progress so far appears mainly to be confined to attempts to improve available protective devices. For example, in recent years on the overhead lines of the Union Gas and Electric Co., in the State of Ohio, there appeared horn gaps of a new construction, consisting of insulating tubes enclosing ejectable fuses. On the occurrence of arcing between the horn and a lower guard ring, the resulting short-circuit to earth burns out the fuse, which is blown from the insulating tube, thereby breaking the arc. This process, as is shown by oscillograms, takes place within half a period, so that relays have no time to act, and, therefore, operation of the line is not interrupted. Under actual service conditions for over three years, these horn gaps have prevented 70 per cent. of all registered cases of arcing involving line failure.

On the other hand, another school of thought considers the application of any protective devices unnecessary. Conowingo transmission

line, Pennsylvania, uses neither horn gaps nor guard rings.

Erection Technique

In determining the distance between the rows of the line supports in a flat area, it is customary in American practice to ignore any contingency arising as a result of the collapse of a support. The swinging of overhead cables in a flat area is regarded as synchronous; experience has shown that movement of air layers takes place in the form of a wide current, simultaneously affecting all conductors. For mountainous regions, where there is likelihood of a whirling motion of air masses, the possibility of asynchronous swing with a phase difference of 90 degrees is taken into account.

There exists no uniform rule in American practice with regard to the character, or width, of the right of way for overhead lines. Each individual case is determined by the degree of importance of the network, economic considerations, topographic features of the route, and other relevant factors. Again, there exists no standard span between the anchored supports of the line in the U.S.A.; in practice there is a tendency towards its increase. There are spans between anchored towers from five kilometres to seven kilometres long, having rigid supports interposed between them. The average number
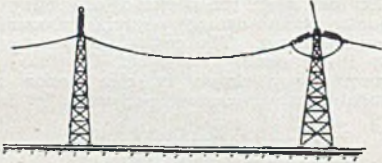
ANCHOR SUPPORT Nº 2

TEMPORARY GUYING

of anchored pylons in relation to the general number of line supports fluctuates between 7 per cent. to 15 per cent. In terms of the costs of aluminium and other constructional materials in the U.S.A., the length of economic span for overhead lines operated at 220 kV. in a flat area lies between 300 metres and 320 metres.

When it is clearly advantageous to do so, American engineers do not hesitate to adopt, in individual cases, spans differing appreciably from the normal. An interesting example of this character is the passage of the 150 kV. transmission line over three large valleys in California, where the length of the average span reaches 1,580 metres, the length of neighbouring spans being 1,100 metres and 600 metres. Notwithstanding such long spans, the clearance space between the circuit conductors for this line has been kept normal, namely, 6 metres. The recent tendency in American practice in the construction of important transmission lines, is to arrange individual circuits on separate lines of supports, avoiding the use of towers supporting double-circuit cables.

In the design of intermediate supports, the usual ratio of the height of the tower to the width of its base is accepted in U.S.A. as equal to 4.5-5. The foregoing ratio, according to standard methods of design and permissible

loads in American practice, gives the most economical solution of the problem, i.e., the minimum weight of line support.

According to U.S.A. standards in the calculation of the line supports, the factor of safety in relation to the tensile strength of the material employed is taken as equal to three. The usual construction material is mild steel of normal quality with a tensile strength of about .40 kg./mm.[2]

In computation of compression members in regard to longitudinal bending, American practice accepted the three different values for the ratio of a free length of the structural rod to the minimum radius of inertia: (1) For rods employed in the base—120; (2) for working rods in the lattice—160; (3) for structural rods—200.

Turning to the question of foundations for the line supports, it should be noted that in U.S.A. there are not infrequent cases of the use of iron anchors in place of reinforced concrete foundations. In the construction of the 220 kV. Conowingo transmission system, there were used for the making of the reinforced concrete foundations special conical forms fabricated from thin sheet iron; these, in some instances, were left, together with the foundation, in the ground, on account of difficulties encountered in their extraction. As to methods of anchoring the support to the foundation, American practice uses embedding of the base members in the concrete foundation, or the securing of the support by means of special foundation bolts.

The following is the standard procedure in U.S.A. for the assembly and erection of line supports as well as for repairs of steel-cored aluminium cables:—At the works producing the construction material for the supports there are usually made complete sets of the various structural elements, such as angle-iron corner members as well as other sections, including those used for the flat strip bracing, cut to the required length and furnished with drilled holes. These complete sets of prefabricated component parts are conveyed to the place of installation, where the support is assembled by means of bolts; as a safeguard against unscrewing of nuts, the thread on the protruding end of the bolt is hammered down. After this the assembled support is erected and installed at the appropriate point. It has become common in recent years, sometimes, prior to the raising of the support, to fit this latter with strings of insulators, the whole being erected together.

Unwinding of the steel-cored aluminium cable is performed with the aid of a tractor, and for arranging conductors in one horizontal plane the following method is used:—The drum is fastened to the anchor support, and a free end of the cable drawn by the tractor. To allow the passage of the middle conductor through the opening of the intermediate tower, the tractor is stopped, the end of the cable detached, and then drawn through the opening by means of a special pulley, after which the end of the cable is again attached to the tractor, which proceeds to pull it farther until the next intermediate support is reached. When the whole length of the cable has been unwound from the first drum, the second drum is brought in its place and is dealt with in a similar fashion.

Joining of the ends of unwound cables is effected by means of the connectors already described. Erection work is carried out directly on the ground by a group of three operators. With experienced personnel, the work takes about 15 minutes. The weight of the hydraulic press used to close the clamps, together with the pump is 85 kg.

After the cable has been unwound to the length of the entire anchor span, one end is fastened to the tightening clamp, this operation being performed on the ground, then the clamp with the attached cable is hoisted and secured to anchor support No. 1 by joining it to the string of insulators, as illustrated in Fig. 6.

Further, the conductor, with the help of the erecting clamp, is securely fixed on the nearest intermediate support of a given anchored span, which support, in its turn, is temporarily guyed to prevent collapse. Finally, the clamp with the attached conductor is raised and fixed securely on to the second anchor support by joining it to a string of insulators. Following this, the cable on the neighbouring intermediate support is released and then suspended in the clamps of the other interposed supports of the anchored span under consideration. Prior to the fitting of the cable into the clamps, it is wound with a special protective wire braiding as described previously.

In the next anchored span these operations are repeated in the same sequence and, subsequently, on the anchor tower there is installed a cable loop connecting the conductors of the two contiguous anchored spans.

With the object of regulating the tension in the conductor in the anchored span, there is sometimes fitted between a string of insulators and the cross-arm of the anchor tower either a length of cable or a chain consisting of from three to four links.

In unwinding steel-cored aluminium cables from the drums, no special measures are taken to protect them from damage on the ground, whilst the general precautions against injuries by stones, gravel, rough handling, etc., in the course of the erecting operations remain the same as those observed in the case of copper conductors.

In splicing the cables and in fitting them into the erecting clamps, special care should be exercised in order to ensure that both the conductor and the component parts of the clamp be as clean as possible. At this juncture it may be of interest to touch upon certain questions relating to the exploitation of overhead lines in the U.S.A.

To maintain constant observation of the working of the transmission line, there are placed along the route at intervals of 12 to 20 miles huts for the line personnel, each post usually accommodating not less than two agents, one of whom must always remain on duty at the telephone.

Inspection of the line is carried out weekly, in the course of which there are carefully examined every support, the structural components anchored to the foundations, the state of conductors and insulators, etc. Weekly inspection is, in American practice, found to be preferable to daily examination on account of the fact that in the daily tour attention may be dulled by fatigue, with the result that certain details, which might lead to serious consequences, are overlooked. After stormy weather

it is customary to make a special inspection of the line, subjecting it to particularly careful examination.

The line personnel is provided with binoculars and portable telephones. When required, a qualified repair party is sent to the spot affected, for which purpose there are kept in readiness specially equipped mobile workshops on a suitable road adjacent to the overhead line.

Progress in Development of Aluminium in North America

The application of aluminium conductors in the U.S.A. is practised on a colossal scale; thus, already in 1939, the quantity employed in networks there had reached approximately 1,365,000 kilometres, including over 160,000 kilometres of aluminium lines laid in that year for the purpose of electrification of agriculture, and more than 1,600 kilometres of steel-reinforced aluminium cables used in construction of the 220 kV. Bonneville Dam transmission system, as well as many other enterprises.

implied raising the annual production capacity of all works belonging to Alcoa in 1941 up to 200,000 tons of metal.

Another noteworthy development in the light metals industry of the U.S.A. is the aluminium plant of the Reynolds Metals Co.,[4] which is unique in that it starts with low-grade bauxite ore, processes it to alumina, reduces the oxide to metal, and converts it into the rolled sheets, bars, rods, and other shapes, the whole manufacture being carried out in one continuous straight-line flow of materials, thus combining three plants in one.

Situated close to the parent enterprise of the Reynolds Metals Co. at Louisville, Ky., this works, known as the Listerhill plant, has been erected near to Wilson Dam on the navigable Tennessee River at Muscle Shoals, Ala., commencing aluminium production in 1941; with installation of additional rolling mills in 1943, plant capacity has now more than quadrupled the original plans, and the limit of growth is not yet in sight.

Fig. 8.—General view of the alumina plant at Arvida. Buildings at the right are devoted principally to storage and subsidiary treatment of bauxite by-products. Buildings at the left are concerned chiefly with the preparation and storage of the alumina itself.

To meet such gigantic demands from the electrical industries alone (not mentioning aircraft, sea and land transport, and numerous other fields of use for aluminium), the Aluminum Co. of America, following the completion in 1939 of the $26,000,000 construction programme, was induced to embark on the new scheme of accelerated expansion, involving the investment of $30,000,000, to be realized in 1940.

In 1941 there should have commenced the operation of the newly built electrolysis plant at Vancouver, Washington, which was designed to give, initially, 14,000 tons of metal per annum, using alumina brought from the Alcoa works at Mobile, Alabama, and employing energy derived from the Bonneville Dam hydro-electric power station on the Columbia River.

Among other fundamental objectives of the Alcoa expansion programme,[3] the following should be noted: (1) Exploitation of bauxite deposits in Dutch Guiana, with an initial output of about 500,000 tons of bauxite a year, in addition to increased shipping of bauxite from Latin America (Brazil). (2) Expansion of the alumina works at Mobile, Alabama, and at East St. Louis, Illinois. (3) The introduction of technical improvements in a number of hydro-electric installations on the Little Tennessee River, and increase in production of the aluminium works in the State of Tennessee.

The realization of this programme would have

Migration of Aluminium from Pittsburg to Arvida

Pittsburg was the cradle of aluminium production in the Western Hemisphere. Here, Arthur Davis, one of the pioneers of the aluminium industry, in conjunction with the inventor of the process, Martin Hall, spent many anxious days working out the technique for the electrolysis of alumina dissolved in the cryolite bath. Now, the works at Arvida, Canada,* the world's largest aluminium plant, should undoubtedly be regarded as one of the major achievements of the aluminium industry in North America.

The industrial crisis in 1929 considerably held up the full construction programme of this great enterprise, designed at the time to produce yearly up to 300,000 tons of metal. On completion, the original project was to comprise works for the production of alumina, the electrode factory, and plant for the electrolytic reduction of the oxide of aluminium to metal.

As the primary raw materials required for the aluminium industry are lacking in Canada and its home market capacity for aluminium products is very limited, the principal reasons for erecting the plant at Arvida have been, mainly, based on the abundance and low cost

---

* See "Light Metals," 1939/2/249.

of the hydro-electric power obtainable on the spot.

The Arvida Hydro-electric Installation

The hydro-electric power station at Arvida is situated on the Saguenay River, which is the left tributary of the River St. Lawrence, approximately 350 kilometres to the north of Quebec. The works, as well as the townlet adjacent to it, are located on the plateau by the Saguenay River, which is navigable to ocean shipping up to Port Alfred, a few miles from the plant down the river. A railway line 35 kilometres long joins the harbour with the works, which, in addition, is connected with Quebec by a single-track line. Communication with Arvida by car is possible only by a road which, for several hundred kilometres, passes through a dense, wild forest.

The hydro-electric power is derived from dams built on the Saguenay River and its tributaries. Lake St. John, the area of which exceeds 1,000 square kilometres due to the large number of rivers that empty into it, forms a gigantic natural reservoir. A part of the hydro-electric energy supplies the local network with current, which feeds the aluminium plant, excess power being transmitted to Quebec by means of the high-voltage overhead line running through an entirely uninhabited region.

The following fundamental data on the Arvida hydro-electric installation are of interest:—Volume of water, 5,660,000,000 cubic metres; area of the reserve water (Lake St. John connected by the Saguenay River with the River St. Lawrence), 1,035 square kilometres; power capacity of the turbines already erected, 800,000 h.p.; projected, 2,050,000 h.p.

The turbines are of the vertical type, operating three-phase generators at 60 r.p.m., with a capacity of 65,000 h.p. each at 13,200 v. The current is stepped up to a pressure of 154 kV. in two stages, and is transmitted to the aluminium plant, where it is stepped down and converted into direct current at 600 V. and 6,000 A. by means of a converter of 3,600 kW. capacity.

The Alumina Plant

The imposing scale of the Arvida enterprise may be gauged from Fig. 8, presenting a general view of the new alumina plant. On the right may be seen a number of buildings housing processing equipment employed in the storage and treatment of liquors and solutions, filtration of red mud, and decomposition and washing of hydrates. The buildings on the left are designed for the storage, filtration and calcination of the hydrated oxide, and include a large rotary kiln.

Production of alumina at Arvida is based on the Hoops-Hall process, using a high iron bauxite shipped from Port Mackenzie, British Guiana, to Port Alfred on the estuary of the Saguenay River, whence it is brought to the plant by rail.

The bauxite, after crushing to pass a 6 mm. screen, is dried in rotary kilns, after which it is mixed with quartz, sand and coke, or anthracite powder. This mixture is then sintered in a Dwyte-Lloyd machine to give a product which, in addition to aluminium oxide, contains 22 per cent. of Fe_2O_3 and 12 per cent. of SiO_2. Subsequently, the sinter obtained in this way is

treated in large three-phase arc furnaces of a capacity of 15,000 kVA.

The furnace electrodes (91 cm. diam.) are of the Söderberg continuous type, and are produced from petroleum, coke, tar and pitch. The electric furnaces employed are of the vertical, tipping, batch type with double walls for water cooling. The openings for introducing the charge are situated between the three electrodes. Over the furnace is fitted a dome, also water-cooled, which collects gases released in the process to the amount of 2,000 cubic metres per minute, and directs them to the electrical precipitation for removal of dust.

The furnace charge consists of 7-9 tons of sinter and lump coke, and is heated for four hours. As a result of the reducing reaction, there are formed ferro-silicon and alumina, the latter being discharged by blowing in the molten state with a current of air and steam at pressures up to 15 atmospheres. In this way there is produced alumina with a particle size of a few mm., which is next treated with 8 per cent. sulphuric acid. The resulting precipitate contains:—

SiO_2—from 0.15 per cent. to 0.08 per cent.;
Fe_2O_3—from 0.15 per cent. to 0.094 per cent.;
Ti^2O^3—from 0.25 per cent. to 0.16 per cent.;
CaO^2—from 0.4 per cent. to 0.02 per cent.

The content of Al_2O_3 reaches 99.64 per cent. The proportion of titanium in alumina obtained by the Hoops-Hall process depends on the amount of iron originally present in the charged material, but is always higher than in alumina produced by the wet method. A great advantage of the Hoops-Hall process lies in the possibility of utilizing low-grade bauxites with a high silicon and iron.

When alumina for aluminium of low titanium content has to be produced, it is obtained by the Bayer process.

The Electrode Works

Petroleum coke, shipped to Arvida from Texas, contains from 8 per cent. to 10 per cent. of volatile matter. Reduced in size to about 6 mm. granules, it is heated to incandescence in electric furnaces of the resistance type to remove the volatile constituents and to increase its resistance to oxidation. The general arrangement of the Arvida electrode plant is illustrated in Fig. 10.

The furnace consists of a simple cylindrical vessel with water cooling, which houses two pairs of carbon electrodes. Charging is effected by means of two feeders and discharge is carried out from the bottom with the aid of a bucket transporter with controllable speed, the material being transferred to bunkers.

The furnace is impermeable to both air and foreign gases, and an ascending current of cold hydrogen with 10 per cent C.O. abstracts from the descending mass of coke the last traces of volatile components.

The surface area of each pair of electrodes equals 1.2 × 2 square metres. The electric current, supplied by two independent circuits at a pressure of 80-90 V., passes from one electrode to another through a layer of coke, which is thereby strongly heated.

The throughput time of the coke in the furnace is regulated by controlling the speed of the bucket transporter. The temperature level

maintained between the electrodes reaches, approximately, 1,100 degrees C., being, of course, influenced by the current of cold gas. The output of the furnace depends on the content of volatile matter, but an average value is of the order of 0.7 ton per hour. The material issued from the furnace is allowed to cool and is then comminuted and sieved.

The electrode mixture consists of 70 per cent. of baked coke, 18 per cent. pitch, and 12 per cent. crushed electrode ends. This mixture, after being rendered plastic in the mixing mills, is moulded into blocks in a hydraulic press under a pressure of 4 tons/sq. m., and then subjected to heating in resistance furnaces, as shown in Fig. 11.

The furnace unit, the length of which is 42 metres, is fed with current from both ends by means of copper electrodes connected to aluminium bus-bars. The furnace floor is made of a compact, non-conducting mass, the walls being of refractory brick. The anode blocks are placed from one end of the furnace chamber to the other in rows of five, every electrode being embedded in a layer of loose coke. The furnace roof consists of a layer of granulated coke. Each furnace is charged with approximately 150 tons of moulded block material, that is, roughly, 2,700 electrodes at a time. Power is supplied as two-phase current to a capacity of 2,000 kW.; the electrical pressure, which at the commencement of the operation reaches 190 V., falls at its termination to 90 V. The electrodes are

kept in the furnace for a period of 26 days, during which, for five-six days, they are being actually heated by the current, whilst during the remaining 20 days they are allowed to cool off; the time required for charging and discharging the furnace is five days.

A factor of exceptional importance with regard to avoiding the development of cracks in the finished products is cooling rate. The heat-treated anodes possess a cross-sectional area of 31×41 cm.[2] and are 32 cm. high.

The Electrolysis Plant

According to the final designs, the aluminium plant at Arvida will, on the completion of its construction programme, have installed equipment capable of yielding up to 300,000 tons of metal per annum. Each series of baths comprises 110 cells, each of which is fed with current of 28,000 to 30,000 A., with a working pressure at the terminal clamps of 5-6 V. The baths are of a rectangular shape and are situated in rows parallel to one another, with the longer side arranged at right angle to the bay.

One end of each bath is fitted with an outlet through which, every two or three days, the aluminium is tapped into a ladle placed in a pit near by. The other end of the bath is in close proximity to the cell of the next row. In the passage formed between the two rows of cells are installed the hoppers for feeding the baths with alumina. Such an arrangement economizes in floor area, but the cell arrange-
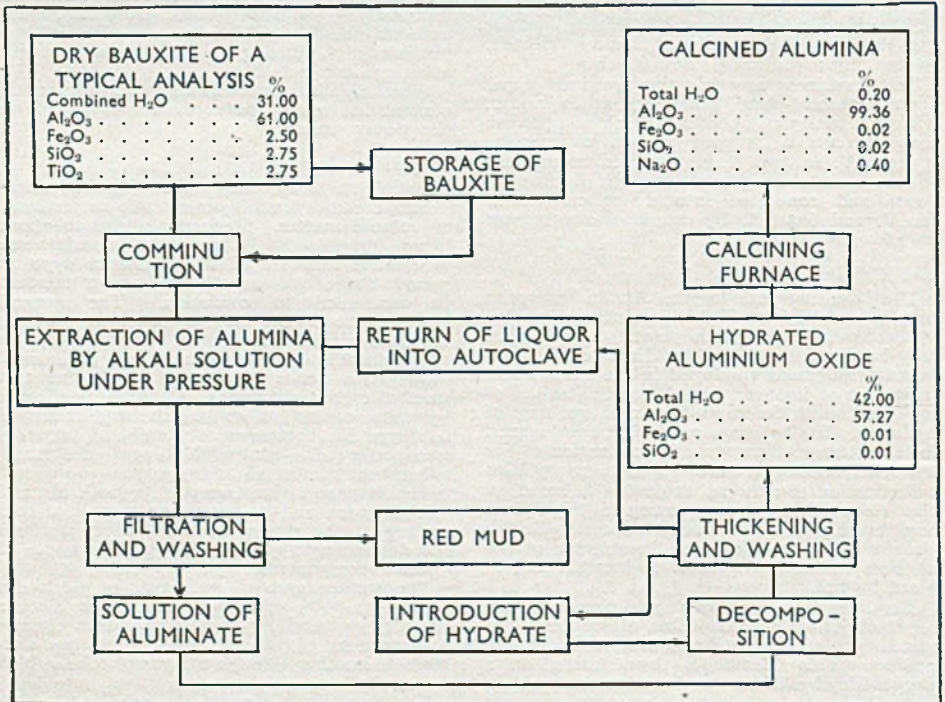
Fig. 9.—Flow sheet for production of alumina by the Bayer process.

ment, as practised in Europe, is probably to be preferred as, in this case, when the cells are placed lengthwise along the bay (i.e., touching each other at the narrow sides) they are more easily accessible to works personnel.

The aluminium tapped from the baths into the ladles is then poured from the latter into a resistance furnace, the chrome-nickel heating units of which are arranged along its roof. The metal, on completion of its treatment in these furnaces, is next cast into ingots of the standard sizes. Electrical furnaces are also employed for the production of aluminium-base alloys.

From this account it will be seen that the use of electricity is practised at Arvida on an exceptionally vast scale. Besides electrolysis proper, other operations as, for example, the melting of aluminium and heat treatment of its alloys, the heating of the petroleum coke and the baking of electrodes, are all carried out in electrical furnaces.

It might be instructive to consider, at this point, the production of alumina from low-grade materials instead of from bauxites. It is, at

of the present war electrodes for the reduction cells were invariably made of petroleum coke, supplies of which were ample, and access to which was easy. The war, however, saw, first, difficulties arising in regard to the importing of the petroleum coke and, secondly, with regard to supplies of the material itself.

Again, recourse was had to materials of a lower grade, such as, in former times, might have been considered uneconomic in use, principally because of the pre-treatment they would require to render them suitable for the purpose in view. Special anthracite dusts, purified by flotation, have been used in place of petroleum
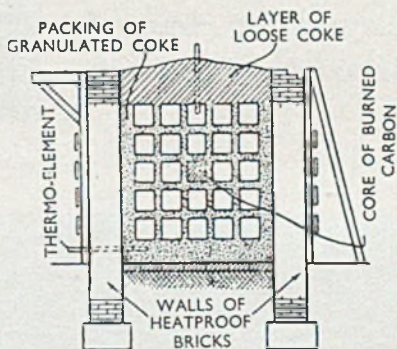
Fig. 11 (above).—Diagrammatic cross-section of resistance furnace for the heat treatment of carbon electrodes at Arvida. This plant is operated on a batch basis, the duration of treatment per batch being in all about 26 days.
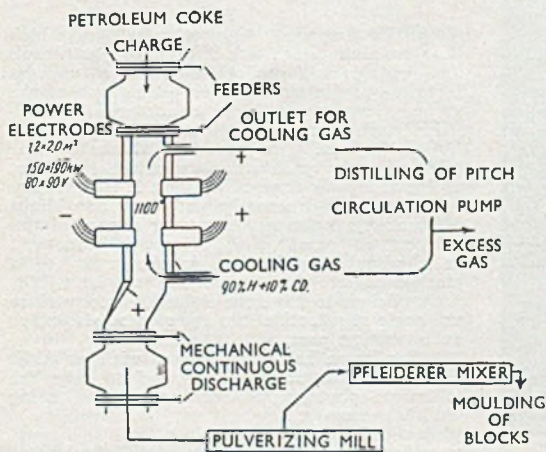
Fig. 10 (left).—Flow sheet illustrating production at Arvida of carbon electrodes for aluminium reduction cells.

the moment, impossible to gauge the extent of the use being made of these raw materials, and the nature of the techniques utilized for their treatment. However, in general, sources of aluminium, such as clays of various degrees of impurity and labradorite, entail operations more numerous and more intricate than those required by high-grade bauxites. Plant requirements are more extensive and energy consumption is certainly greater.

If the present trend develops, and such raw materials do become seriously considered as sources of commercial aluminium, it is likely that, again, considerable claims will be made upon electrically operated equipment of all types, to a degree greater than is at present the case.

Somewhat similarly, perhaps, additional calls will be made upon electrical power in connection with the production of a material, or materials, suitable for electrodes. Prior to the outbreak

coke and, after subjection to treatments evolved for the purpose, appear to have proved satisfactory.

From the standpoint of the present account, the only feature of interest here lies in the fact that, once more, handling and treatment requirements imply increased power consumption, thus emphasizing still further the intimate connection between the electrical and light-metal industries.

(To be continued.)

REFERENCES

(1) *Whittaker;* "*Canadian Chemistry and Metallurgy,*" *January,* 1936. (2) "*Metallurgist,*" *No. 12 (108),* 114-119, 1938. (3) *Hobbs;* "*Metal Progress,*" 1941/7/68. (4) *Lee;* "*Chemical and Metallurgical Engineering,*" 1943/5/145.

LIGHTING FOR PHOTO-MACROGRAPHY OF ALUMINIUM ALLOYS

H. Chadwick, B.Sc., Discusses Technical Difficulties Entailed in the Photographing of Large Flat Areas of Metal which have
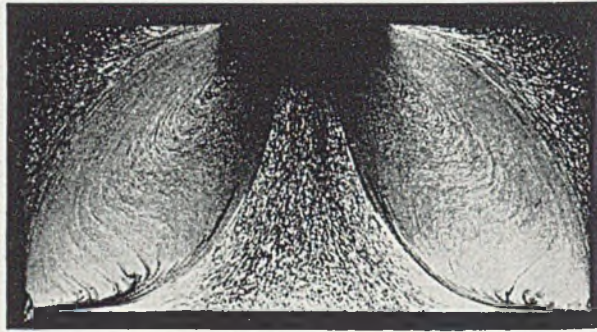
Fig. 1.—Extrusion discard lit by oblique light, the lower portion of the specimen being nearer to the source of light. (Equivalent magnification in reproduction = ¼ linear.)
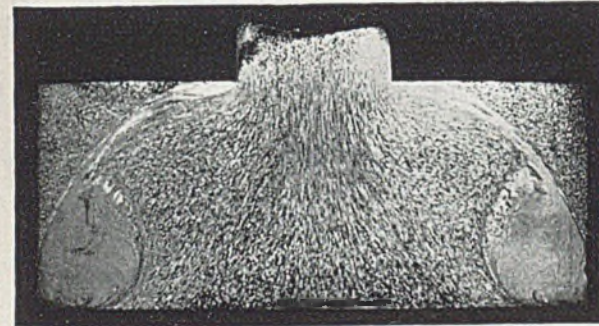
Fig. 2.—Extrusion discard of same size as that shown in Fig. 1. Illumination here is by light reflected from overhead white screen. (Equivalent magnification in reproduction = ¼ linear.)

been Subjected to Macro Etching. Experiments to Determine a Satisfactory Lighting System for the Purpose are Described
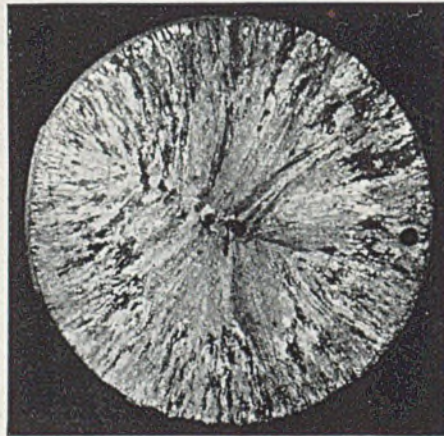
Fig. 3 (Above).—Section of billet with macro etched surface illuminated by diffused light. Compare with Fig. 7, opposite. (Equivalent magnification in reproduction = ⅓ linear.)

LARGE flat areas of most metals, of which aluminium is one, are difficult to photograph and obtain a reproduction with a uniform intensity of illumination. A photograph of the surface may be considered as composed of individual reflections of the source of illumination by each grain. In order to obtain a clear picture of the grain structure of the specimen, as shown up by these reflections, it is necessary to use a high-contrast plate; thus any slight difference in light intensity over a part of the subject, so small that it passes unnoticed in a visual examination, is shown up to a marked degree. But, as will be seen later, it is not sufficient to have the lighting uniform since the angle of reflection into the camera also plays an important part.

A Sanderson half-plate camera with an Aldis f./7.7 anastigmatic lens was used to take the following photographs, contact prints being taken from the plates. The camera was fixed to a vertical slide, the subjects being placed on the floor immediately below. The height

of the camera was adjusted to give an image of a correct size when focused.

The first attempt at lighting was to use the overhead room light, a 100-watt lamp enclosed in a diffusing shade. The light was 9 ft. from the ground and above a point 5 ft. from the specimen, throwing light on it at a steep angle. Fig. 1 is a photograph of an extrusion discard, 9 ins. by 4 ins., obtained by this method of lighting, using a Kodak P25 plate, exposed for 4 mins. with an aperture of f./16. The illumination could not be otherwise than even, no shadows or reflections were allowed to fall across the subject, so one is led to conclude that the change in the angle of the light is responsible for the irregularity of the photograph. The lightest part of the specimen is nearest the lamp. If two lamps are used, one on each side, then the subject lights up in two places, leaving the centre dark.

In order to make the lighting more even and to fall from every side, a white cartridge paper screen, 2 ft. square, was placed
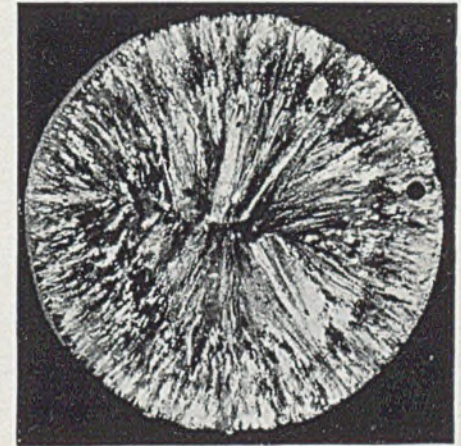
Fig. 7.—Illustrated above is the macro etched billet section forming the subject of Fig. 3, but illuminated, in this case, by vertical light. (Equivalent magnification in reproduction = ⅓ linear.)
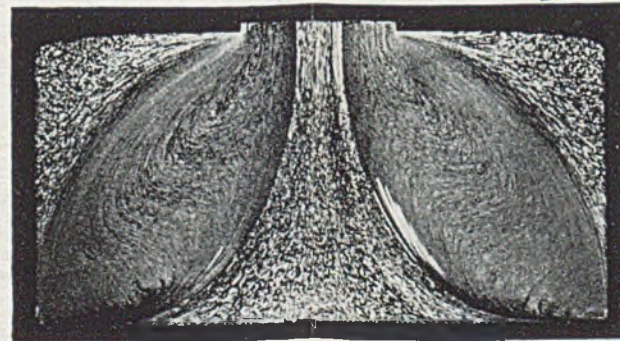
Fig. 4 (Left).—Large specimen with diffuse illuminators as in Figs. 2 and 3, but with additional reflectors at each end. (Equivalent magnification in reproduction = ⅓ linear.) Fig. 5 (Above).—Photo-macrograph obtained using the vertical illuminator. (Equivalent magnification in reproduction = ¼ linear.) Fig. 6 (Right).—Further example showing results obtained by use of the vertical illuminator. (Equivalent magnification in reproduction = ⅓ linear.)
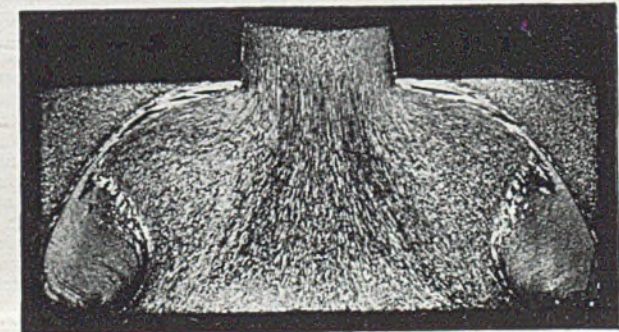
above the subject and illuminated from above by two 100-watt lamps. A small hole was made in the screen for the lens. Thus a photograph of the reflection of the white screen in the surface of the smoothed and etched specimen was obtained. The lighting was not quite uniform, so instead of two lamps above, four lamps were placed underneath at the corners of the screen, each surrounded by a reflector, so that no light should fall directly on the subject. The lamps had to be so placed that any light which entered the camera did not fall directly on the plate, but it is not necessary completely to shield the camera from the lamps. The hole for the lens, in the middle of the screen, must be as small as possible, otherwise a dark patch is produced in the centre of the photograph—again due to reflection; about $1\frac{1}{2}$ ins. square is the most that can be allowed. Figs. 2 and 3 are examples of photographs taken on Kodak P25 plates with exposures of 3 mins. and an aperture of f./32, using this type of lighting. Fig. 2 is another extrusion discard of the same size as the one shown in Fig. 1, while Fig. 3 is a section taken from a billet, 9 ins. in diameter. Fig. 4 is a larger sample, 18 ins. long by 9 ins. wide, and required, in addition, two other sheets of cartridge paper, one at each end, reaching from the square overhead reflector to the floor. Without these additional reflectors the ends of the subject were insufficiently illuminated or, as it might be put, the ends reflected the darker portions of the room, round the camera, as the overhead reflector did not extend sufficiently far to cover them. The plate and exposure employed were the same as for Figs. 2 and 3.

Effect of Rotation

If an etched specimen be rotated, the intensity of the reflected light from any particular grain varies as the angle of the incident light alters. Thus in the above type of diffused lighting, it would be possible for the majority of the grains to reflect light of a high intensity into the camera, because light is falling from many angles, tending to give a uniform picture and destroying the detail. If parallel light be allowed to fall on the specimen from the side, the structure is shown up distinctly, but as we have seen, the lighting appears uneven, the cause being attributed to the difference in the angle of the light which illuminates the side nearer the lamp from that which illuminates the rest. In order to minimize this difference the light was made to fall vertically, using a large vertical illuminator. This was constructed from a sheet of good quality glass, 3 ft. long by 2 ft. wide, held in a frame at an angle of 45 degrees to the horizontal, the details of which are shown in Fig. 8. This was placed underneath the camera in such a way that light from a 100-watt lamp 10 ft. away was reflected down to the subject. The wall or a screen behind the reflector must be painted a dull black and have a uniform surface, since this also comes in the field of the camera and any irregularity appears superimposed on the subject. A screen must also be inserted between

the lamp and the specimen to shield it from direct illumination.

Figs. 5, 6 and 7 are examples of photo-macrographs taken by this method, and are of the same specimens as are shown in Figs. 1, 2 and 3 respectively. Kodak B20 process plates were used for all three photographs, with an exposure of 4 mins. and an aperture of f./16.

All the photographs shown were printed on Ilford S4.1P papers.

The sample shown in Fig. 4 was tried under the vertical illuminator, but, whilst the centre was reproduced distinctly, the ends were dark. Ten ins. diam. was found to be the limiting size of specimen for the lighting equipment used, since greater than this the light illuminating the sample deviates too far from a parallel beam; the edges of the specimen appear dark because the light falling here is reflected away from the camera. If more than one lamp were to be used, the lightning would be more even, but the object of using a vertical illuminator would be defeated. Unfortunately the accom-
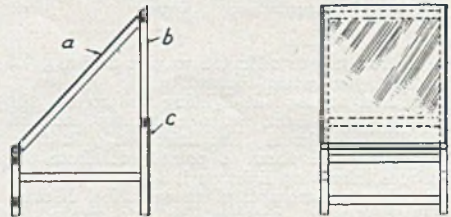
Fig. 8.—Constructional details of the vertical illuminator referred to in the text. This is constructed from a sheet of good quality glass 3 ft. long and 2 ft. wide, held as shown in a frame at an angle of 45 degrees to the horizontal. In use, it was placed underneath the camera in such a way that light from a 100-watt lamp, 10 ft. away, was reflected down to the subject. The screen behind the reflector is painted a uniform dull black. In practice, a screen is inserted between the lamp and the specimen to shield it from direct illumination.

modation available rendered the carrying out of experiments with the larger specimens impossible, but if it be desired to photograph larger specimens, two methods of lighting can be suggested. The first is to use a lamp farther away, using as a rough guide, a foot distance for every inch in diameter of the sample. This ensures that the light, when it reaches the specimen, although weaker in intensity, approximates more to a parallel beam. The exposure must be increased to compensate for this reduction of the illumination in the proportion of the square of the distances of the lamp. The second method would be to use a large parabolic aluminium reflector behind the lamp, the reflector being a little larger than the specimen, with the lamp at the centre of focus, in order to give a parallel beam of light. The use of the reflector would increase the intensity of illumination, cutting down the exposure required. In this case, the distance of the lamp would make very little difference to the intensity and about 10 ft. should be suitable.

Aluminium in
The Chemical Industries

*After Concluding, from "Light Metals," 1944/7/358, an
Account of the Action of Alkaline-earth-metal Salts upon
Aluminium, the Effect of Heavy-metal Compounds is Briefly
Summarized. The Effects of Some Organic Materials are then
Considered. Following the Completion of this Section, the
General Suitability and Availability of Aluminium-base Alloys
for Chemical-engineering Purposes are Reviewed. An Examina-
tion of Practical Instances Completes this Part of the Study*

THE concluding paragraphs in the previous instalment of this discussion dealt with the action of calcium- and barium-chloride solutions, and of calcium hypochlorite, on aluminium. It was stated that, in general, the action of alka-line-earth-metal salts is less pronounced than that of salts of the alkali metals.

Lime and baryta (calcium oxide and hydroxide and barium hydroxide) attack aluminium and the metal can seldom be used in contact with these materials. The *sulphates* of calcium and barium and moist *calcium oxalate* cause some corrosion, but the *carbonates* and *calcium hydrosulphide* have no effect. *Calcium sulphide* causes very slight general corrosion (no pitting) and aluminium may satisfactorily be used in contact with horticultural spraying mixtures containing 2-20 per cent. calcium sulphide together with a little iron sulphate or lead arsenate.

Calcium carbide does not corrode aluminium, but *carbide mud* gives rise to a vigorous attack unless the metal be protected by M.B.V. treatment.

Dry *aluminium chloride* may be stored and transported in aluminium vessels, but moisture gives rise to the formation of hydrochloric acid and the metal is then attacked. *Aluminium sulphate* is corrosive, although *basic aluminium sulphate* is safe at all concentrations and temperatures. *Potash alum* and *aluminium nitrate* are practically without effect on aluminium (unless free nitric acid be present). *Aluminium formate* causes no corrosion and aluminium has given satisfactory service in equipment for the production of this compound.

Heavy Metals

The behaviour of aluminium in contact with solutions of salts of the heavy metals depends on the difference in potential between it and the metal of the salt in that particular solvent. This difference is often considerable and aluminium is attacked, the corrosion being intensified by increase in temperature. The oxygenated salts show less tendency to attack the metal, but when their solutions contain or liberate free acid, attack takes place imme-

diately. In many cases, however, it is possible to decrease the attack by means of appropriate coatings.

Aluminium is unsuitable for use with solutions of *copper sulphate* and *other copper salts,* because copper is deposited from them on to the aluminium. Wherever the copper is deposited electrolytic action commences, giving rise to pitting of the aluminium. The M.B.V. film impregnated with grease or wax gives satisfactory protection from the action of copper sulphate solutions up to 5 per cent. concentration.

When chalk is added to copper sulphate solutions, an adherent crust is formed which lessens the corrosion of the underlying metal.

The silver salts, zinc chloride, tin chloride, lead nitrate, basic lead acetate and *ferric chloride* are also dangerously corrosive. Aluminium is not attacked by dry *zinc oxide* and only slightly by solutions of *zinc sulphate.* Aluminium sheet has, for many years, been used for the cathodes in the electrolytic production of zinc. Aluminium is only slightly attacked by saturated solutions of *ferrous sulphate,* and it may be used in constructing the reservoirs and other apparatus employed in the spraying of fruit trees. At high temperatures, ferrous sulphate is oxidized to *ferric sulphate* which attacks aluminium.

Mercury and *mercury salts* are very detrimental. Mercury causes electrolytic corrosion of the metal and, further, once mercury or a mercury salt has wetted the surface, an amalgam forms, which rapidly hydrolyses to aluminium hydroxide; the mercury is thus freed for further amalgamation, and the process of deterioration goes on rapidly. Great care always has to be exercised in the use of mercury thermometers, especially glass types, which are prone to breakage and which, therefore, may constitute a menace to aluminium plant. Vapour pressure instruments, bimetallic instruments or thermocouples should be employed.

Solutions of *chromic acid* attack aluminium. Nevertheless, aluminium cathodes are used in the baths for anodic oxidation by the chromic-acid process as the normal action is prevented

by a film of hydrogen; aluminium drying trays are used in the manufacture of chromic acid. The unalloyed metal is sometimes used for the exhaust ducts of chromium-plating plants; it is not greatly affected by chromium-plating solutions (Table 8, p. 356). *Chromates* are generally without adverse influence, and aluminium vessels are used for chemical chromate treatments such as the M.B.V. process. Because of its good resistance to the action of *chromium sesquioxide*, aluminium is employed in equipment for the drying of this compound.

The Action of Some Organic Materials on Aluminium

Hydrocarbons. The saturated and unsaturated hydrocarbons have no action on aluminium, and the resistance of the metal towards other substances which are frequently found as impurities in the crude hydrocarbons or are used in admixture with the refined products, as well as the possession of other favourable characteristics, have led to the use of aluminium in a number of branches of the hydrocarbon solvent, fuel and allied industries. Thus, aluminium and its alloys are employed for the construction of tanks for the storage of crude and refined petroleum products with high sulphur content and for the handling of *sulphurous gases in oilfields;* in petroleum distillation plant and frequently in equipment for the blending of *petroleum fuels (tetraethyl lead* has no effect on aluminium); for the construction of steamheating coils and other apparatus in the manufacture of *paraffin and ceresin waxes* and in plant used in the treatment, blending and emulsification of these materials.

Alcohols. The *Aliphatic alcohols*, including *glycerin* and *ethylene glycol*, are practically without effect on aluminium except under the following conditions:—

1. If the water content falls below 0.01 per cent. a vigorous reaction may take place. This is, of course, far below the water content of alcohols normally employed either in industry or in the laboratory, and this danger is most unlikely to arise, particularly as alcohols are hygroscopic and, if specially prepared to be water-free, rapidly absorb sufficient moisture to prevent reaction unless the greatest precautions are taken.

2. The influence of small amounts of impurities, acids, alkalies and especially tannin, is very marked and may lead to corrosion in many cases where there would otherwise be no attack.

3. *Aqueous solutions* are slightly corrosive, the extent of attack varying inversely with the molecular weight of the alcohol, but is seldom serious, and it may be prevented by anodizing.

4. Complex mixtures, such as certain *alcohol/benzine motor fuels* may give rise to corrosion. Attack may be connected with the water content of the fuel and can be prevented by anodizing or by the addition of inhibitors to the fuel, as is done in aircraft fuel systems.

Generally speaking, aluminium may be regarded as satisfactory in contact with alcohols, but tests should be carried out in particular cases since, in the presence of only traces of certain impurities, or with certain complex mixtures, anodizing may be necessary to ensure satisfactory freedom from attack. Aluminium is regularly employed in the form of extruded bottles for the storage and transport of alcoholic solutions of perfumes and essences. Not only does the use of aluminium preserve the colour and purity of the product, but it also reduces transport costs and enables small quantities of the solutions, often of considerable value, to be sent by express or registered transport, which would not be possible with heavier or less robust containers.

Ethers, uncontaminated by acids, are without action on aluminium. The *amines,* having properties resembling those of ammonia, behave somewhat similarly in contact with aluminium. The *primary amines* are the most basic and probably the most corrosive but, as in the case of ammonia, an adherent protective layer is soon formed which, if not destroyed by, for example, an inorganic base or a halogen salt, protects the metal from further attack. Thus, aluminium is suitable for the construction of cooling equipment used in the production of methylamine. No precise information is available regarding the effect of the secondary, tertiary and quaternary ammonium compounds.

Fatty Acids. The fatty acids vary quite widely in their behaviour towards aluminium but, in general, acids of commercial purity have very little action, particularly at normal temperatures. Occasionally there is an initial relatively vigorous reaction, but in most cases this falls off rapidly to a minimum constant rate of attack. Attack is least with fatty acid solutions at concentrations just below that at which they are anhydrous and increases with dilution. It is of academic interest to note that, in the complete absence of water, a violent reaction may ensue, as in the case of the alcohols.

Aluminium is used extensively in industries treating fatty acids at normal temperatures in the construction of storage tanks, and so on, and prevents the darkening and discoloration inseparable from the use of other metals such as iron and copper. Attack by *acetic acid* decreases with increasing concentration up to 99.5 per cent. acid *(glacial acetic acid)* and is small at normal temperatures. There is a marked increase in attack as the temperature is raised, but it still remains very small for concentrations between 90 and 99.9 per cent. acid. Sodium chloride increases attack at all temperatures; potassium bromide and potassium sulphate increase attack at elevated temperatures; potassium iodide and potassium nitrate have no accelerating influence at any temperature. M.B.V. treatment gives some protection. Attack by *acetic anhydride* is not great and can be reckoned as 0.00025-in. penetration per year for metal of normal purity in contact with acetic anhydride at room temperature.

Aluminium finds a number of uses in the manufacture of acetic acid. Where mercury is employed as a catalyst, serious attack of aluminium equipment is to be expected, resulting from traces of mercury left in the acid.

Aluminium acetylation equipment is employed in the cellulose acetate silk industry, coming into contact with both acetic anhydride and acetic acid. The small proportion of sulphuric

Table 9.—Nominal Physical Properties of Metals.

Metal	Specific gravity	Thermal conductivity, cal. cm. cube, °C. per sec.	Specific heat, cal. per gm. per °C.	Specific resistance at 20°C. in microhms/cm. cube	Approx. tensile strength, tons/sq. in.
Aluminium	2.7	0.504	0.214	2.85	10–15
Beryllium	1.83	—	0.425	—	—
Copper	8.9	0.89	0.097	1.77	25–30
Iron	7.8	0.15	0.12	10–15	6–20
Lead	11.4	0.083	0.031	20.8	0.8–1.1
Magnesium	1.74	0.376	0.250	4.35	9–14
Nickel	8.9	0.145	0.115	10.7	28–56
Silver	10.5	1.00	0.056	1.66	18–20
Tin	7.3	0.155	0.054	13	2
Zinc	7.2	0.265	0.092	6–6.5	7

acid added to the mixture does not exert any corrosive influence on the metal.

Aluminium tanks and wagons are widely used and aluminium drums generally advocated for the handling and transport of both acetic acid and acetic anhydride.

The higher homologues of acetic acid (propionic, butyric, valeric acids) behave somewhat similarly.

The *higher fatty acids (oleic, margaric, palmitic, stearic, etc.)* are generally quite inert to aluminium even after prolonged contact at their boiling point. Completely water-free acids react violently, producing irregular pitting, but only traces of water are needed to eliminate this hazard. There is some evidence to show that the aluminium/silicon alloys are more resistant than pure aluminium.

Formic acid is an exception to the rest of the fatty acids. It attacks aluminium fairly readily, causing pitting, the attack increasing with temperature and concentration up to a strength of about 25 per cent., after which it is independent of concentration. At very high concentrations (above 95 per cent. at 20 degrees C., above 30 per cent. at 50 degrees C.), there is a tendency towards the formation of a superficial protective crust but, nevertheless, aluminium is not to be recommended for use with formic acid, except under very special circumstances, as in the rubber industry. Artificially thickened oxide films are dissolved by the acid and, therefore, offer no protection. Proprietary solutions for descaling steel often contain formic acid, and these should be used with care in the proximity of aluminium.

The esters of the fatty acids *(ethyl, butyl and amyl acetates* and *ethyl oxalate* have been particularly examined) are neutral liquids used in industry as fruit essences, perfumes, intermediate products and solvents. They have little or no action on aluminium, a state of affairs which appears to be uninfluenced by the presence of small amounts of acetic and sulphuric acids employed in the esterification process. Aluminium is a most suitable metal to employ in the handling, processing and transport of these materials as it introduces no contamination to impair the odour, colour and taste of the product.

Aldehydes *(formaldehyde, acetaldehyde, paraldehyde, metaldehyde)* and ketones (ordinary acetone in particular), in the pure state, are substantially without action on aluminium and the metal is generally safe to use

with them, but impurities and water content must be watched. These materials, and especially the aldehydes, are easily oxidized to produce acids which, in certain cases (formic acid), may give rise to corrosion. Thus, a content of 0.2 – 0.4 per cent. formic acid in formaldehyde may be dangerous in the cold. This is a factor to be considered. In practice, however, aluminium has given considerable satisfaction in the storage and transport of *formaldehyde* and is preferred to other metals as it causes less decomposition of the aldehyde. Aluminium piping and cooling apparatus have been used for a considerable time for concentrated *acetaldehyde. Crotonaldehyde*, though itself unaffected by contact with aluminium in the cold, gradually darkens and deposits a brown substance at elevated temperatures; the aluminium shows no change in surface appearance.

Halogen compounds of the hydrocarbons. Most of these *(ethyl chloride, ethylene chloride, dichlorethylene, trichlorethylene, perchlorethylene, chloroform, carbon tetrachloride)* have no action on aluminium when dry. In the presence of moisture and light, however, they mostly decompose to a small extent with the formation of small amounts of the corresponding halogen acids (hydrochloric acid, hydrobromic acid) which leads to corrosion and, on occasion, violent reaction. Aluminium can only be used safely with these materials under conditions which prevent decomposition. As would be expected, the chlorine compounds produce a greater attack than the bromine compounds and these, in turn, more than the iodine compounds.

Aluminium is not attacked by water-free concentrated *ethylene dibromide* at normal temperatures. At boiling point, however, ethylene dibromide dissolves aluminium very rapidly, especially in the presence of traces of water.

Bromoform and *iodoform* do not attack aluminium owing to the protective action of the natural aluminium oxide film. If this film be destroyed, the metal is attacked immediately. The resistance of aluminium may be increased very considerably by reinforcing the natural film by chemical or electrolytic methods.

Dibasic acids and hydroxyacids *(oxalic, maleic succinic, lactic, tartaric, citric,* malic acids)*. These acids and their solutions have only a slight action on aluminium at ordinary temperatures. The attack, which is largely independent of concentration, increases with rise in temperature and becomes much more pronounced at 60-70 degrees C. However, it can

nearly always be reduced to negligible proportions in the presence of colloids or fats which act as inhibitors; the action of lactic acid, for example, is retarded in the presence of milk. In some cases, artificially produced aluminium oxide films may give some added protection; they are ineffective in the case of citric acid. Dibasic and hydroxy acids are contained in many fruit juices but, in considering the possible action of the latter on aluminium, it must be remembered that the action of fruit juices may be very different from the actions of the individual acids present. Aluminium equipment has given considerable satisfaction in the processing of fruits and fruit juices and is being used to an increasing extent for the packaging of such foodstuffs.

Glucose *(grape sugar)* and **pure lactose** *(milk sugar)* are without action, but aluminium plant is unsuited to the production of the latter as *crude milk sugar* contains acids which attack the metal. *Albumen and gelatine* have no action on aluminium; equipment in this metal has given every satisfaction in the production of gelatine for human consumption.

The action of *glues* on aluminium depends on their composition. Usually, they are without action on aluminium if neutral, but if acid or alkaline, they cause some pitting of the metal. Glues containing hydrochloric acid or salts of mercury, and casein glues containing phenol or copper caseinate, also attack the metal.

Tests for the action of a glue on aluminium should be thorough and exhaustive, since corrosion may not commence for some time. This fact is of special importance with glues for attaching aluminium foil to paper, cardboard, etc. A number of suitable glues are available, witness the quantities of aluminium foil which are backed with glued paper and cardboard.

Carbohydrates have no effect on aluminium. This metal is largely used in the construction of plant for the manufacture of nitro-cellulose and cellulose acetate. In the form of lacquers, these materials are used for the protection of aluminium against corrosion.

Aromatic Compounds

Benzol, toluol, the light and heavy *petrols* and mixtures of benzol and absolute alcohol containing 10-25 per cent. of alcohol have no action on aluminium. Aluminium and its alloys are used in process equipment, storage tanks, tank cars, etc., for benzol and petrol.

Amino compounds. The aromatic bases are generally weaker than those of the aliphatic series, and their action on aluminium, though resembling that of the primary aliphatic amines, is still less severe. At normal temperatures, the rate of attack is insignificant, but it becomes more pronounced at higher temperatures. Thus, *aniline,* which has no action on aluminium at normal temperatures, gives rise to a violent reaction near the boiling point, especially if the aniline be water-free. *Salts of the aromatic amino compounds* have the same action as the acid with which they are combined; thus, *aniline hydrochloride* attacks aluminium as strongly as hydrochloric acid and *aniline sulphate* causes some attack even at normal temperatures.

Acetanilde is without effect on aluminium.

The action of *phenols* on aluminium is approximately the same as that of weak acids.

At normal temperatures their action is practically negligible; aqueous solutions at 60-80 degrees C. have only slight action on the metal.

Water-free phenols have no action on aluminium at normal temperatures, but at higher temperatures they attack the metal vigorously. The action may be stopped by the addition of water.

Aluminium appliances in contact with mixtures of carbolic acid and formaldehyde, at temperatures up to 10 degrees C., have given satisfaction. Plant for the handling of phenol has been regularly employed for many years.

Resorcinol, hydroquinone and the *trihydric phenols (pyrogallol* and *phloroglucinol)* are without action on aluminium.

Picric acid may be melted in aluminium vessels but the metal is unsuitable for plant used in its manufacture.

Aromatic acids and esters. The *aromatic acids* generally have no action, or only a very slight action, on aluminium *(benzoic, phthallic, dry crystalline salicylic* and *gallic acids).* Aluminium is used satisfactorily in the construction of equipment for the sublimation of benzoic acid and in vessels for the crystallization of phthallic acid; the iron content of the metal should be as low as possible. Aqueous solutions of pure *tannic acid* have very little action on aluminium, but industrial mixtures containing tannin sometimes cause trouble and the metal should not be used without previous tests of a practical nature.

The action of the *aromatic esters* depends on the properties of the acid radical. Thus, in the presence of water, *benzoyl chloride* attacks aluminium at normal temperature, whereas the water-free chloride is without action. At the boiling point of benzoyl chloride, the metal is rapidly dissolved in both cases.

The *sulphonic acids* corrode aluminium to an extent depending on their concentration and the temperature. Although attack is practically nil in cold dilute solutions, aluminium is not recommended for use in contact with these products.

Terpenes and camphors. *Turpentine, menthol, camphor* and *eucalyptus oil* have no action on aluminium. These products form the basis of a great number of costly essences and perfumes and aluminium is much used in rectifying and distilling apparatus and, in the form of bottles, for transporting the essences. A slight reaction which occurs between aluminium and *Eau de Cologne* may be prevented by M.B.V. treatment.

The *aromatic ketones* and ethereal solutions of the *aldehydes* have no action on aluminium but, in the presence of water, *benzaldehyde* attacks the metal strongly.

Resinous materials. *Rosin, shellac, copals, kauri gum* and the *synthetic resins* have little or no action on aluminium and the metal is frequently employed in the construction of the plant employed in the manufacture of synthetic resins and in the processing of rosin, kauri gum and the copals for use in the paint, varnish and lacquer industries. The absence of any substantial reaction between the metal and the material being processed and the lack of any catalytic oxidation of the resin by the metal, together with the fact that any corrosion products produced are colourless, result in the production of paler products, which is an

important advantage in the manufacture of coating compositions.

Rubber has no action on aluminium, and light metals are largely used for such purposes as vulcanizing apparatus and moulds for shaping. The value of aluminium for this purpose lies in the light weight of the equipment and accessories made of it, in the brilliancy of colour and desirable surface imparted to the moulded rubber products due possibly to the non-adhesion of vulcanized rubber to aluminium.

Aluminium pans are used for coagulating rubber latex by means of formic acid. This is one of the few instances in which aluminium is used satisfactorily in contact with formic acid. Its success in this instance is probably due to the formation of a thin film of rubber which isolates the metal surface from attack by the acid.

Aluminium is employed for the basis of the anodes used in the electro-deposition of rubber. By itself aluminium is not entirely satisfactory, as it gives rise to excessive anode gassing, but this difficulty is overcome by zinc-plating the aluminium anode. The thickness of the coating determines the ZnO content of the rubber, and the evolution of gas bubbles indicates that all the zinc has been used up.

Furfural, indole and *isatin* have no appreciable effect on aluminium. A great number of *alkaloids* have no action on aluminium, and in many cases the metal may be used satisfactorily in their preparation, drying, etc. Preliminary tests are, however, advisable. *Naphthalene* and *tetralin (tetrahydro naphthalene)* have no action on aluminium. Care needs to be taken in the use of aluminium in contact with *naphthols* as, although there is no attack under normal conditions, a violent reaction may take place at elevated temperatures, particularly under water-free conditions. *Naphthylamine* attacks aluminium vigorously.

Anthracene and *anthraquinone* have no action but *anthranilic acid* attacks aluminium. Very extensive tests on over 300 of the *dye-stuffs* used in the dyeing industry have indicated that in a number of cases aluminium may be employed advantageously. The general conclusions reached are as follows:—

(a In vat dyeing, the necessity of operating in a very alkaline bath leads to corrosion of aluminium.

(b) The dyeing of animal fibres in acid baths, using acid dyes, is carried out in the majority of cases quite satisfactorily, but in some cases the colours themselves are not sufficiently stable to enable aluminium to be recommended.

(c) In the case of basic dyes, which are particularly employed in printing, aluminium does not modify the shade of the dye in the majority of cases, but tests should be made in each case.

(d) The dyeing of cellulose fibres, cotton, linen and the other vegetable fibres, with direct dyes, may be carried out in aluminium vats, the metal having no action on the dye.

In addition to its use in actual dyeing operations, aluminium is quite extensively used for plant employed in the manufacture of the dyes themselves.

Soaps. Satisfactory use is made of aluminium in the soap industry for storing fatty acids and for wrapping shaving soaps, etc. Hard soaps have no great effect on aluminium, but soft soaps give rise to vigorous attacks which may be inhibited by the addition of sodium silicate.

Moist *tobacco* is apt to cause some slight corrosion of aluminium which is believed to be due to the presence of tannic acid; *nicotine* itself has no action on aluminium. The amount of moisture normally present in tobacco, cigarettes and cigars is not sufficient to give rise to any trouble, and aluminium is widely used for the packaging of these products both as linings for wooden boxes for overseas transport and as foil wrappings inside cardboard containers. Trouble is occasionally experienced in tropical and sub-tropical climates during the rainy season.

The summary presented lists a large number of chemical materials, together with their action on aluminium. From it some idea may be obtained of the probable behaviour of the metal in a particular operation or process in the chemical industry. But inertness is not the only consideration and the chemical engineer needs to know something of the mechanical and thermal properties of the proposed materials, their cost, the forms in which they are available and the ways in which they can be manipulated to produce the often complicated apparatus required in the chemical industry.

The following is a brief consideration of the physical and mechanical properties of the light alloys, their machining and forming characteristics, weldability and other relevant features.

The availability, physical and mechanical properties of aluminium alloys of interest to the chemical industry. Some idea of the several types of aluminium alloy produced and the wide range of forms in which they are available will have been gained during the reading of the earlier part of this article. The information already given will, in this section, be supplemented mainly by tables of physical and mechanical properties.

One of the most important advances made by the aluminium industry since its inception at the end of the 19th century is in the improvement in the quality of the commercial unalloyed metal. This is now produced commercially with the very high purity of 99.5 per cent. minimum aluminium, impurities being mainly a few tenths per cent. of iron and silicon, with occasional traces of other elements, such as manganese and copper. This is a very high level of purity for an element like aluminium, which, during extraction conditions of temperature, is highly reactive and presents problems in deoxidizing, and removal of retained elements, far more exacting than is the case with the heavier metals.

High purity is of considerable importance in so far as resistance to corrosion practically always increases with increasing purity. The introduction within the past few years of super-purity metal having an aluminium content of about 99.99 per cent. is, therefore, of considerable potential interest to the chemical industry. Experiments have shown the super-purity metal to possess quite outstanding resistance in many cases, although there are, to date, few published

Table 10.—Properties of Aluminium Sheet and Strip Materials.

Material	Temper	Copper	Manganese	Magnesium	Silicon	Iron	Titanium	Nickel	Chromium	Other elements	Ultimate tensile strength, tons/sq.in.	Elongation, % on 2 ins.	Hardness D.P.N.
Commercial aluminium 98% min.	Soft	—	—	—	1.0 ⎫ 1.75	1.0 ⎭	—	—	—	0.25	5.0-6.5	50 min.	30 max.
	Half hard	—	—	—			—	—	—	—	7.8-8.5	40 min.	30-40
	Hard	—	—	—			—	—	—	—	9 min.	30 min.	40 min.
Aluminium 99.5% min.	Soft	—	—	—	0.3 ⎫ 0.5	0.3 ⎭	—	—	—	—	5.0-6.5	50 min.	30 max.
	Half hard	—	—	—			—	—	—	—	7.0-8.5	40 min.	30-40
	Hard	—	—	—			—	—	—	—	9 min.	30 min.	40 min.
Aluminium 1¼% manganese	Soft	—	1.0-1.5	—	1.0 ⎫ 1.75	1.0 ⎭	—	—	—	0.25	6-8.0	20 min.	30 max.
	Half hard	—		—			—	—	—	—	8-10.0	6 min.	30-45
	Hard	—		—			—	—	—	—	10 min.	4 min.	45 min.
Aluminium 10% silicon	Soft	—	—	—	9.5-13.0	1.0	—	—	—	0.10	5.0-8.0	50 min.	40 max.
	Half hard	—	—	—	—	—	—	—	—	—	8.0-10.0	40 min.	45-55
	Hard	—	—	—	—	—	—	—	—	—	10 min.	30 min.	55 min.
Duralumin	Heat treated	3.5-4.5	0.4-0.7	0.4-0.8	0.7	0.7	0.3	—	—	—	24 min.	15 min.	110 min.
Aluminium/magnesium alloy (7%)	Soft	—	0.6	6.5-7.5	0.5	0.75	—	—	—	—	20 max.	20 min.	65 max.
	Hard	—	—	—	—	—	—	—	—	—	20 min.	12 min.	100 min.
Aluminium/magnesium alloy (1 to 6%)	Soft	1.0	1.5	1.0-6.0	0.7	1.5	—	1.5	0.5	—	12.5 max.	20 min.	50 max.
	Hard	—	—	—	—	—	—	—	—	—	12.5 min.	10 min.	60 min.

records of its industrial application. Perhaps its greatest disadvantage is that of softness, for it is considerably softer than aluminium of commercial purity in the soft condition and is, therefore, easily damaged by scratching or abrasion. Its mechanical properties are lower than those of the commercially pure metal, too, but this can be overcome readily by the use of a duplex or clad metal in which a core of commercially pure aluminium or of an aluminium alloy is faced on one or both sides with a thin sheet of super-purity metal. The use of such duplex metals is to be recommended, too, in the interest of economy as the super-purity metal is relatively expensive. These clad materials are of considerable interest to the chemical industry and more will be said about them later.

Alloys. In addition to the commercially pure metal, a number of light aluminium alloys are available.

Each of these alloys is designed with a view to improving one or more specific characteristics of aluminium, without detracting from other properties, or with the minimum loss in these other directions. They thus increase the field of applicability of the material. They are all well defined by official specification or by trade designation. Their particular additional merits, as well as their limitations are, therefore, clearly known. In consequence, no confusion arises in choice of material, and designers and draughtsmen have a clear course before them.

In this respect, again, a markedly better situation exists than is the case with many other metals of which manufacturers are rather loath to disclose compositional data alongside mechanical and physical properties. In such cases, rule-of-thumb designing tends to result, and chaos is caused in large engineering organizations which attempt competitive purchasing.

It cannot be too strongly emphasized that, in any equipment, rarely are the same properties required in all the members of that equipment. Therefore, for each component part, the most appropriate metal or alloy must be selected. All-aluminium plants or equipments are, therefore, visualized, with the right grade of metal to suit each component according to its function, and with fabrication or manipulability taken into consideration. Thus containers and tanks for the pro-

cessing, storage or transport of food products would use the high-grade, unalloyed aluminium, but supporting structures would utilize high-tensile alloys. Further, the latter would be appropriately chosen from wrought sectional forms or from castings. Similarly, in electrical work, bus-bars and conductors need to be in high-purity, high-conductivity material with minimum stress, that is, soft tempers, but structural work and panels can take advantage of the alloys to obtain the degree of strength or stiffness desired in particular cases, whilst castings can be extensively used in alloys most suited to give the dimensional accuracy and soundness of structure required without prime consideration to compositional features.

Uniform standards of purity in conjunction with an understanding of the metallurgy involved and the use of modern methods of production enables the metal and its alloys to be provided in wrought forms, sheet, strip and foil, rod, bar, tube and section, drawn or extruded, to a close degree of exactitude not only throughout a batch, but also through the same piece. This precision refers to dimensional tolerances, to mechanical properties of strength and temper, as well as to chemical properties of resistance to corrosion and electrical quality of conductance or resistivity.

Heat Treatment

The mechanical properties of aluminium alloys are increased by cold working, such as by rolling, deformation or hammering, or by heat treatment. From the point of view of the attainment of maximum mechanical properties, aluminium alloys may be classified into three groups according to the manner in which this increase in mechanical properties is obtained. The groups are those which are not susceptible to heat treatment, generally known as " strain hardened " alloys, those attaining their strength by a single heat treatment and which age and harden spontaneously at room temperature, and a final group which is susceptible to a single solution heat treatment, but which requires a subsequent low-temperature precipitation treatment to develop maximum mechanical properties.

The chemical engineer is not required to know very much about the heat treatment of aluminium alloys. In point of fact heat treatment is nearly always carried out by the manufacturer (in the case of castings and forgings) or by the fabricator (in the case of sheet products) and needs careful control of a number of variables and considerable experience to obtain satisfactory and consistent results.

It is, however, important for the chemical engineer to be aware of the existence of these three groups of alloys and to understand the broad outline by which the method of heat treatment is carried out and its effects on mechanical, chemical and physical properties because of the obvious influence on his choice of alloy for specific purposes. Thus, components which are to be highly stressed and which are not required to possess maximum chemical resistance would be designed for production in a heat-treatable alloy. On the other hand, heat treatment may cause warping of large areas of small cross-section and, for the manufacture of such components, a non-heat treatable alloy would be chosen wherever possible.

So far, no alloy has been produced which has sufficiently high intrinsic mechanical properties due to its composition alone, to compete with the heat-treatable alloys, although certain of the aluminium-magnesium alloys approach closely to this ideal and are used for stressed parts.

The first group consists, therefore, mainly of low- to medium-strength alloys, the greater part being pure or commercially pure aluminium which may be said to form the backbone of the domestic spun-hollow-ware trades. It should not be inferred from this, however, that these alloys are suitable for only unstressed parts, as many of them, particularly in the harder degrees of temper, are eminently suitable, and are much used, for parts in which a high degree of rigidity and strength is required.

Heat-treated Alloys

Those of the heat-treated types falling into groups two and three, constitute the high-strength aluminium alloys and are normally used for the construction of parts and components where stresses are liable to be high. In general, the double heat-treated types have a higher proof stress and ratio of proof stress to ultimate stress than have the single heat-treated alloys, and may, therefore, often be stressed rather more highly. Pure aluminium, like other pure metals, is not, in the accepted sense of the term, susceptible to heat treatment, for the only effect of heating the metal is to soften it.

Physical and Mechanical Properties of the Aluminium Alloys

A primary recommendation of aluminium and the aluminium-base alloys is that of lightness and, in weight per unit volume, they may be regarded as one-third of that of the common structural metals, iron, copper, brasses, bronzes, tin, zinc, stainless steels and nickel silvers, and one-quarter that of silver and lead. The specific gravities of the common metals are given in Table 9.

Low specific gravity enables the use of lighter supporting members and foundations in fixed plant. In movable apparatus and in containers for transport purposes the advantages of light weight are even more obvious. Aluminium is suitably employed for many of the rotating and reciprocating components in chemical plant, in which capacity its low inertia represents a considerable saving in vibrational stresses and also in fuel consumption.

The thermal conductivity of aluminium is approximately three times that of iron, tin and nickel; twice that of zinc; six times that of lead; half that of silver and more than half that of copper. The thermal capacity of aluminium is relatively high, however, due to the high specific heat of the metal.

Taking into account the slightly thicker sections which are generally necessary when aluminium alloys replace stressed members in steel or bronze, etc., it can be said, as a very rough approximation, that the heat capacity of an aluminium component is about the same as that of a corresponding component in iron or copper-base metal. A high heat capacity is an advantage or disadvantage according to the circumstances of each particular case. Materials of high heat capacity require more fuel to raise their temperature through a given range, but they generally, although not always (because heat loss may depend on design, and on the

Table 11.—Properties of Aluminum Rod, Bar, Tube and Section Materials.

Material	Temper	Composition, %									Ultimate tensile strength, tons/sq. in.	Elongation, % on 2 ins.	Hardness D.P.N.
		Copper	Manganese	Magnesium	Silicon	Iron	Titanium	Nickel	Chromium	Other elements			
Aluminium 99% min.	As extruded or drawn	—	—	—	0.5	0.6	—	—	—	0.10	7.0 min.	40 min.	35 min.
Aluminium 10% silicon	As extruded or drawn	—	—	—	9.5–13.0	1.0	—	—	—	0.10	8.0 min.	40 min.	40 min.
Duralumin	Heat-treated	3.5–4.5	0.4–0.7	0.4–0.8	0.7	0.7	0.3	—	—	—	20 min.	8 min.	100 min.
Aluminium/magnesium alloy (7%)	—	—	0.6	6.5–7.5	0.5	0.75	—	—	—	—	20 min.	15 min.	80 min.
Aluminium/magnesium alloy (1 to 3%)	—	—	1.5	1.0–3.0	0.7	0.7	0.2	0.35	0.5	—	11 min.	18 min.	60 min.

Single figures for composition in both tables indicate maximum values.

colour and polish of the surface), cool more slowly and fluctuations in the source of heat cause correspondingly smaller fluctuations in temperature. Thus, dangers due to draughts or overheating are much less real.

Possession of a high thermal conductivity is a very great advantage where heat transfer, which forms an essential part of nearly all chemical processes, is desired; the greater its speed, the greater the economies in fuel and time which can be effected. The individual properties of all the common metals are markedly influenced by alloying elements or by the presence of impurities, so that no broad interpretation of figures given in an accompanying table should be made.

Alloys Groups

Aluminium alloys in common use can be divided into a fairly small number of groups on an application-composition basis and tables are presented giving the major mechanical properties of the most important of these classes. Thus, Table 10 refers to sheet and strip materials, including ordinary and high-purity aluminium t. silicon and the copper-bearing alloys, 10 per cent. silicon alloy, duralumin, 7 per cent. magnesium alloy such as MG7, and the low magnesium alloys such as D2 and Birmabright. Table 11 refers to bars, tubes and sections, in aluminium, 10 per cent. silicon alloy, duralumin, and the magnesium alloys. Table 12 covers a small range of casting alloys, the copper alloys, 10 per cent. silicon alloy, copper/nickel/silicon/magnesium alloy, and copper/silicon alloy. Table 13 refers to rivets and wires for riveting in aluminium, magnesium alloys and duralumin.

In the chemical industry plant needs would largely be satisfied with aluminium itself for sheet and fabricated work, aluminium, aluminium-silicon or duralumin for structural work involving the use of sections and aluminium/ silicon, aluminium/copper, or aluminium/ silicon/copper for castings. This, of course, does not cater for motor and pump components and highly stressed components that can usefully be served by heat-treatable aluminium/copper/ magnesium/silicon/nickel alloys, of the RR and Y types.

Figures given in accompanying tables are obtained from the standard specifications (mostly B.S.I. and D.T.D.), the number of which is far greater than the number of groups into which we have divided the alloys. Often one of these specifications covers several rather different proprietary alloys. Therefore, the data given are of a nominal nature for well-recognized general-purpose materials and must be taken only as an indication of the values usually obtained. Quality of manufacture of a product, especially in the case of castings, has quite an important bearing on corrosion resistance. Segregation, inclusions, cavities and blow-holes are potential sources of weakness at which corrosion may commence. It follows that attention must be paid to quality of manufacture as well as to composition of alloy.

Availability of Aluminium Alloys

Aluminium wire and sheet are normally supplied in thicknesses or diameters from 0.0010 in. to 0.5 in. Various types of stranded conductors and steel-cored aluminium cables are made for electrical purposes. Round rod is supplied in

sizes from $\frac{1}{8}$-in. to 6-in. diam. and hexagon rod for screwing and machining up to 2-in. diam. Special free-cutting aluminium alloys are supplied, the corrosion resistance of these being slightly inferior to that of the general run of aluminium alloys.

Bar and strip for electrical purposes are made in a wide variety of sizes up to 6 ins. in width and up to $\frac{3}{8}$-in. thick. Flat aluminium sheet is supplied in all gauges down to No. 30 S.W.G., but for gauges less than No. 16 S.W.G. it is more economical to order the metal in coil form. Coiled strip is supplied in all widths up to a maximum of 36 ins., according to gauge and in maximum lengths corresponding to a normal maximum weight per coil of approximately 60-180 lb., according to width. Aluminium circles are supplied in all popular gauges and in diameters from 1 in. to 72 ins.

Tubes and pipes are made with outside diameters 3-16 in. to 10 ins., and for safe internal pressures up to some 1,700 lb. per sq. in., according to size. A variety of pipe fittings and aluminium nuts and bolts, screws and rivets are made in various sizes and alloys.

The availability of extruded aluminium sections is of the greatest importance to the chemical industry. Such forms as square, octagonal, oval, rectangular and split tubes, gutterings, drip plates, lap plates, cappings and tread plates have obvious applications; less obvious, but equally important, is the use of other sections designed primarily for the building industry in the construction of assemblies and for structural members.

Sheet embossed with a pyramid or fluted pattern is useful for tread plates and draining boards. Aluminium foil is in use in the chemical industry for the heat insulation of plant and for the wrapping of products.

The principal forms in which aluminium is normally supplied have been indicated. In many cases, other forms and sizes outside the ranges quoted can be supplied to order without much difficulty or extra expense. It does not take into account war-time developments, which are quite likely to increase not only the types of aluminium semi-manufactures, but also the range of sizes in which they are available.

Clad Materials

We have previously mentioned the clad materials. These are available in a wide range of different cores and facings, according to the specific purpose for which they are required. The object of clad materials is to combine the strength of a strong core with resistance to corrosion afforded by a mechanically weaker, but chemically more inert, facing metal. The action of the facing is two-fold; first, it protects the core by preventing contact with corrosive media and, secondly, even when damaged or at bolt or rivet positions, it still protects the corrodible core electrochemically. Moreover, in the case of super-purity metal facings on a core of commercially pure aluminium, this protection extends to a large degree to the strong alloy rivets themselves and to the sheared edges of the sheet.

Manipulability of Light Alloys

So far, we have justified the use of light alloys in the chemical industry from the points of view of corrosion resistance, physical properties and availability. But, having ascertained that the material can be obtained in a suitable form and being satisfied as to its mechanical, physical and chemical suitability for the job, the chemical engineer still requires to know something of its manipulability in order that he may judge its suitability for forming to the required design and for assembly and co-ordination along with other components to produce a complete unit of plant or apparatus. It is not necessary for the chemical engineer to be in possession of all the facts regarding the manipulability of the light alloys, but it is important for him to have a clear idea of their capabilities and limitations from the points of view of machining, forming and assembly. What follows is, therefore, a very brief summary of the working characteristics of the light alloys.

Sheet Metal Work

The replacement of steel sheet and panels by aluminium does not usually call for any alteration in plant layout or the type of labour employed. The same tools and machinery can be used for cutting, rolling, beating and planishing; the skilled panel beater in steel finds aluminium easier to work because of its malleability. Primary curves are obtained by rolling and the secondary curves are worked in by puckering or by sand-bag beating. Alternatively, panels of moderate convexity can be raised to the required shape by means of a wheeling machine.

Shaped panels of standard design may be produced on power-driven or screw presses. For this work, aluminium, being soft and malleable, requires only a quarter to half the pressure needed for steel, which results in an important saving in tools, machines and power.

Because of its ductility, aluminium is particularly suited for all types of forming operations, and can frequently be worked into shapes which are too complicated for economical production in other metals. Deep cup-like shapes are produced by deep drawing, using punches and dies of highly polished hardened tool steel. The number of operations required to produce, a cup of a given size in aluminium is comparatively small; an even more important factor contributing to the economy of press working is the fact that intermediate annealing is rarely necessary in dealing with thin gauges. With suitably designed passes, even heavy gauges will stand a surprising degree of deformation without cracking. Alloys containing magnesium, manganese and chromium, either singly or in combination, have good deep-drawing properties. The power requirements are generally rather more than for pure aluminium but, at the same time, increased deformation is possible, and the strength of the finished cup is greater.

Adequate lubrication is important for pressing and for deep drawing. For most purposes, a cheap vaseline or lard oil is recommended, but paraffin is quite suitable for shallow pressing and drawing and for stamping and blanking. Both sides of the blank, as well as the punch and dies, should be covered with lubricant.

The dies employed for blanking are usually of cast iron with a hardened steel insert, and punches are frequently unhardened tool steel. If only a small number of blanks is required and the stock is thin, mild steel may be used for the

Table 12.—Properties of Aluminium Casting Alloys.

| Material | Composition, % | | | | | | | | | Ultimate tensile strength, tons/sq. in. | Elongation, % on 2 ins. | Hardness D.P.N. |
	Copper	Manganese	Magnesium	Silicon	Iron	Titanium	Nickel	Chromium	Zinc			
Aluminium 8% copper	6.0-8.0	—	—	0.7	0.8	0.2	—	—	0.1	9.0 min.	3.0 min.	80 min.
Aluminium 5% copper	4.0-5.0	—	—	0.9	0.7	0.25	—	—	—	15 min.	8 min.	80 min.
Aluminium 10% silicon	0.1	0.5	0.6	10.0-13.0	0.6	0.2	—	—	—	14 min.	8 min.	50 min.
Aluminium/copper/nickel/magnesium silicon alloy	0.8-2.0	—	0.3-0.8	2.0 3.0	0.8 1.4	0.3	0.5/1.5	—	—	22 min.	—	100 min.
Aluminium/copper/silicon	2.0-4.0	0.7	0.15	3.0-6.0	0.8	—	0.35	—	0.2	10 min.	2 min.	40 min.

Single figures for composition indicate maximum values.

dies; even these are said to be capable of 70-100 hours' working on pure aluminium without retouching.

Metal spinning is an invaluable practice for the forming of components of chemical plant from aluminium sheet on account of the cheapness of the chucks employed as compared with the high cost of press dies. Thus, where only a small quantity of articles is required, or where the size of the component is large or the shape excessively complicated with a re-entrant outline, it will be more economical to produce these by spinning than by press drawing. Blanks as large as 6 ft. in diameter may be spun in a cheap form of lathe, whereas the press required to deal with such a size of blank would be excessively costly.

Spinning is sometimes employed as an adjunct to the press, the latter being used to produce the first shaping, and the more complicated working being done on the lathe.

Annealing

Aluminium sheet of hard temper, or sheet which has been hardened by cold working, can be restored to the soft highly ductile condition by a simple heating to about 350 degrees C. (662 degrees F.). Only a few minutes' exposure to this temperature is necessary, and the sheet is afterwards cooled either naturally in the air or by quenching in water. The method employed for heating depends upon the nature of the work. In panel beating, for example, where the work is often cumbersome in size or form, the usual method is to employ a portable gas blowpipe, which is played over the work until the required temperature, as judged by some rough-and-ready workshop test, is attained. A common method is to rub the work with a dry match-stick from time to time, the heating being stopped when the metal is hot enough to char the wood.

In more precise processes, such as press work, where a large number of articles of all the same shape and size are to be annealed, a large muffle furnace is commonly used.

Some care is necessary to ensure that the metal is not overheated during annealing, as this causes abnormal grain growth.

Casting

Many of the aluminium alloys (but, in general, not the pure metal) are suitable for casting in sand or chill moulds or by the pressure die-casting process. They do not cast as easily as brass or cast iron but, on the other hand, their founding is not so difficult as that of many of the special coppers or high tensile and corrosion resisting irons and steels. Their special difficulties are now well understood by the several companies which specialize in aluminium foundry work and castings in aluminium alloys may be specified with confidence for use in the chemical industry.

Forging

Pure aluminium forges excellently, but is not strong enough for anything but small parts, or those where chemical properties rather than strength are of prime importance. The great majority of forgings are carried out in the strong alloys, particularly the heat-treatable type, and these find only very limited use in chemical plant.

Machining

Light alloys are amongst the most easily machined of metals available to the chemical industry. Tool wear is small and machining speeds are very high. Quite good work can be done with an ordinary woodworking lathe but, wherever possible, it is recommended that faster machines be installed and advantage be taken of the specially designed tools which have been developed for the purpose; in this way very considerable economies can be effected.

The good machining properties of the light alloys are of advantage to the chemical industry in the production of parts of complicated profile by machining, an operation which may be economically or even technically impossible in cast iron or one of the bronzes, and a difficult and expensive matter in steel.

The pages of " Light Metals " and the technical publications of the aluminium producers and suppliers give many recommendations as to tool speeds and forms. It is not proposed to encroach on this field here except to say that, in general, speed should be high and feed light for a fine finish, whilst tool profile should be such as to allow for greater ease of chip removal than is customary with tools designed for the machining of brass and mild steel. In repetition work, threads are sometimes formed by a process known as thread rolling, in which hardened steel rolls having threads cut upon them are pressed into the aluminium, raising a corresponding thread by squeezing the metal. This process can be applied to screws up to 2 ins. or so in diam.

Jointing the Light Alloys

Satisfactory joints can be made between components in light alloys by riveting or by welding, and, in most cases, without the need for expensive apparatus. This is most important, as the production and maintenance of satisfactory liquid-tight, and sometimes gas-tight, joints is a primary necessity of the chemical industry. The riveting of aluminium and aluminium alloys does not present any difficulty and is already widely practised in the chemical industry. In order to avoid any possibility of bimetallic corrosion, it is desirable that only light-alloy rivets should be used to join light-alloy sheets. Rivets are available in both pure aluminium and in the strong aluminium alloys; they are usually driven cold and for rivets up to 5-16-in. diam., even in the strong alloys, they may be driven in the same way and with the same tools as for steel. Hot driving may also be employed and, where the amount of work to be done justifies the installation of special plant, it is an advantage to purchase a machine which closes the rivets with a squeeze rather than by a series of blows. Duralumin rivets must be driven within two hours of solution heat treatment and quenching before precipitation sets in, although this period of two hours may be lengthened to a day or more by storing in a refrigerator after quenching. When driving a long line of rivets, it is advisable to drive them at random rather than progressively along the line, to avoid spread and distortion of the work. The overlap of a riveted joint should not be less than four to five times the rivet diameter for pure aluminium, but for duralumin this may be reduced to two to three times, depending on the thickness of the sheet; reduction of this overlap may lead to the production of a wavy edge to the sheet. For thin sheet-metal work, the depressed type of riveting provides a substantial increase in strength. In this system the edges of the metal around the rivet hole are punched to form a countersunk depression, and the interlocking of the depressions in the two sheets increases the strength of the joint by as much as 30 per cent. The use of a countersunk rivet provides a flush surface on one side when the joint is complete, which is frequently an advantage in the chemical industry where minimum interference with flow and the avoidance of protuberances which may interfere with cleaning and with the removal of deposits is frequently required.

Homogeneous, liquid-tight joints may be made in aluminium and its alloys by hammer, autogenous, electric arc or electric resistance welding. Hammer welding, as its name implies, is carried out by hammering the two metals together at 50-100 degrees C. below the melting point, when they are somewhat soft. The joints are entirely homogeneous and, in the case of pure aluminium, are of about the same mechanical strength as the surrounding metal.   Corrosion resistance is good. Hammer welding is not often employed, however, and autogenous welding is the process in most common use. In this process, the edges to be jointed are melted together along with a rod of the pure metal or of the same alloy as the edges themselves, so that the joint contains no added heavy metal. A weld of this type is not, therefore, subject to deterioration with age, it is reliable as to strength and it can be so finished that its presence is undetectable. Oxy-acetylene or oxy-hydrogen flames may be used as the source of heat, and a flux is employed to remove the natural oxide film which is always present on the surface of the metal and which would normally prevent the molten edges from flowing together.   The success of the process depends to a large extent on the quality of the flux employed, which must provide efficient removal of the oxide film; of equal importance to the success of the welded joint is the prevention of flux inclusions in the weld and careful choice of flux, skill in the performance of the operation, and washing away of excess flux with hot water and a brush after welding are essential. Fluxes are highly corrosive to aluminium, and attack on the metal may result from traces which are left behind. To assist in the prevention of entrapped flux, butt joints should always be made in preference to lap joints; in addition, sounder welds are usually obtained in butt joints.

It must be borne in mind that the weld metal is in the as-cast condition, which the parts to be welded are hardly likely to be, so that, in consequence, the mechanical properties of the weld metal will be lower than those of the components being joined. It is possible to improve the properties by hammering and annealing but, in the case of alloys, it is sometimes necessary to employ heat treatment. In this event, the maximum advantage of heat treatment is obtained by first breaking down the cast structure by means of hammering.

Electric arc welding, electric resistance welding, spot welding and seam welding are all possible with the aluminium-base light alloys. Soft soldering is not recommended as a method of jointing light metals except in those very rare instances where jointing by other methods is not practicable. On the other hand, for hard soldering, use may be made of alloys containing at least 90 per cent. aluminium and, in such cases, the danger of reduced corrosion resistance at the solder joint and of bi-metallic corrosion in the presence of water, is greatly diminished. The use of a flux is essential, and there are a number of satisfactory brands on the market. After completing the joint, any residue of flux should be carefully removed by washing with hot water and a stiff brush. Reaction soldering is of interest. The solder is a chemical mixture which is spread on the parts to be jointed and heated by a blowpipe to about 200

Table 13.—Properties of Aluminium Wires and Rivets.

| Material | Temper | Composition, % | | | | | | | | Ultimate tensile strength, tons/sq. in. | Elongation, % on 2 ins. | Hardness D.P.N. |
		Copper	Manganese	Magnesium	Silicon	Iron	Titanium	Nickel	Other elements			
Commercial aluminium 98% min.	As drawn	—	—	—	1.0	1.0 (1.7)	—	—	0.3	7.0 min.	40 min.	35 min.
Aluminium 5% magnesium	As drawn	—	0.6	4.5-5.5	0.5	0.5	—	—	—	16 min.	18 min.	80 min.
Aluminium 7% magnesium	As drawn	—	0.6	6.5-10.0	0.5	0.5	—	—	—	27 min.	15 min.	100 min.
Duralumin	Heat-treated	3.5-4.5	0.4-0.7	0.4-0.8	0.7	0.7	0.3	—	—	25 min.	8 min.	100 min.

Single figures for composition indicate maximum values.

degrees C. A chemical reaction takes place which results in the deposition of pure zinc in a molten condition on the aluminium surfaces to be joined. The zinc flows readily between the edges and alloys with the aluminium forming an excellent joint mechanically. Being a bi-metallic joint, it is less satisfactory chemically, and it should not be exposed to corrosive conditions. Further developments in the field of soldering are to be anticipated after the war.

Bolted Joints

Wherever possible, bolts and screws should be of the same composition as the metal to be joined, in order to avoid the risk of forming corrosive couples. If other metals, particularly brass and bronze, have to be used, then care should be taken to protect the joint from moisture; this minimizes the danger of corrosion. Aluminium nails, bolts and screws are readily obtainable, but it is advisable to avoid the use of fine threads where bolts or screws have to be withdrawn or replaced frequently.

Seam Joints

Seam joints should be avoided so far as possible and, in any case, only used where no serious stresses are imposed. Sheets should be in the annealed condition. Special jointing systems have been devised for aluminium tubes and pipes. These will be described later.

Applications of Light Alloys in Practice
1.—In the Handling of Solids

Aluminium alloys are used in a small number of applications in the winning and processing of crude ores and other solid materials in the chemical industry. Unfortunately, many ores are highly abrasive and the softness of the light alloys precludes the possibility of their application in every direction in the mining and treatment of the ores, advantageous though that might be from the points of view of avoiding contamination and discoloration. Perhaps the only notable exception in this regard, which might be quoted, concerns the utilization of the stronger alloys for accessory equipment such as mechanical excavators and shovels, where, on account of their low weight, they have proved of considerable practical importance. These uses, however, are not strictly within the scope of the chemical engineer.

The light alloys have found application in such items as mine cages, dredger booms, buckets and wheelbarrows. Lightweight mine cages reduce power requirements and do not necessitate such heavy construction in the derricks. The employment of light-alloy dredger booms and crane buckets enables a heavier useful load to be carried without increasing the size or power of the rest of the plant. Economies effected in this way greatly outweigh the original extra cost of the light-alloy equipment.

In one case, where shiploads of sodium nitrate had regularly to be unloaded, it was found that the steel cargo bucket could be replaced by an aluminium bucket of 50 per cent. greater capacity without increasing its total loaded weight. This meant that, without any alteration to the rest of the plant, and with no increase in the rate of power consumption, the speed of discharge of the ship was increased by 50 per cent.

The use of light alloys in such items as buckets and wheelbarrows for hand use is an obvious advantage in face of the limitations of human effort. In a few cases, where soft materials have been handled, spades and shovels have also been made in light alloy and have shown a considerable economy in human effort. Apart from weight saving, the use of light alloys for these and similar items is sometimes dictated by purity requirements of the product, for example, in the handling of sulphur, or by the necessity of avoiding sparking or contamination by copper or other heavy metals in the case of unstable materials such as explosives. Aluminium screens and perforated sheet are used for the grading and screening of some crushed ores and powdered products, whilst trays of welded sheet aluminium are employed for drying many types of solid product.

II.—In the Handling of Liquids

The Storing, Handling and Distillation of Water

Water is the prime requisite of the chemical industry. Sometimes it is employed for carrying off sludges or for washing-out purposes, and its purity may not be of great importance. In other cases, and this includes a large percentage of processing operations, the particular chemical treatment may demand the use of water of known high purity, that is, generally, distilled water. The chemical engineer is, therefore, greatly concerned with the effect of water on the materials chosen for the construction of chemical plant.

Information has already been given regarding the influence of waters of different purity on the light alloys. As a summary, it may be said that aluminium should be used for the storage and handling of natural waters only after practical tests have indicated its suitability in that specific instance. Many natural waters contain iron salts; alternatively, water may pick up rust in the course of its passage through the chemical plant. In either case, such iron-bearing waters should not be handled in aluminium. Agitation, bubbling, etc., must be considered in the tests, as aerated water may not behave in the same way as still water.

Temporary hardness in water is generally less dangerous than permanent hardness and does not usually cause attack of aluminium unless there are appreciable amounts of chlorides and, particularly, sulphates also present. In the concentrations met with in industrial waters, sulphate impurities are frequently more troublesome than chlorides although, when dealing with solutions of these two salts, chlorides are the more dangerously corrosive. Water rich in magnesium chloride is decidedly corrosive to aluminium when hot.

Reduction of permanent hardness involves the replacement of the calcium and magnesium ions in the water by sodium and potassium ions. The latter being the more reactive towards aluminium, it follows that water softened artificially by a process involving ion exchange is usually more corrosive than the unsoftened water.

Detailed consideration has been given to the whole subject by H. Lichtenberg in an article on the action of water on aluminium published in "Korrosion u. Metallschutz," 1940/16/251 (summary and commentary in "Light Metals," 1943/6/420).

It is stressed that, while the impurity ingredients in water are contributory to corrosion, in fact they may be the determining factors, many other influences have to be considered. Often, some of these factors may be obscure. Among those that have to be considered are:— Impurities in the aluminium itself, temperature, aeration, and metallic contamination, especially copper, picked up by the water in its course, particularly through pipe systems, to the position where used. In consequence, consideration of data provided by water analyses does not necessarily yield all that is required to predict serviceability or to explain failures and, upon occasion, it has proved to be even misleading. This emphasizes the need for practical tests.

As far as gaseous impurities are concerned, Lichtenberg considers that water containing oxygen attacks aluminium slightly at first, particularly at the air-water-metal interface, after which dissolution of the metal becomes inhibited due to the formation of protective coatings, whilst water containing carbon dioxide does not attack aluminium.

Considering the influence of ions of dissolved salts, he concludes that chlorides accelerate attack on aluminium; sulphate ions, particularly those from acid sulphates, produce a uniform etching attack; the presence of heavy metal salts is very harmful, soft waters are more active than hard waters.

Distilled Water

There appears to be practically no action at all between aluminium and distilled water and, partly for this reason, and partly because of the economy and manipulability of the metal compared with the other resistant metals, e.g., tin and silver, it is of considerable importance in the manufacture and handling of distilled water, and its use in this connection is rapidly growing.

Distilled water is one of the most important materials in fine chemical manufacture, being necessary for many processing operations. On a commercial scale, it is usually produced by boiling water in special vessels internally heated by steam coils, and condensing the distillate in long metal tubes which are cooled externally by a stream of water. These condenser tubes have to be constructed in a material which is substantially unaffected by condensed steam, or the distilled water becomes contaminated again. Metals such as iron, galvanized iron and copper are, therefore, out of the question. In addition, a suitable material for the construction of condenser tubes must possess a high thermal conductivity to ensure rapid heat transfer. Aluminium is quite satisfactory in this respect, its thermal conductivity being approximately three times that of iron, tin and nickel, and not greatly inferior to that of copper and silver (approximately half that of silver and more than half that of copper). Formerly, copper coated with tin was employed, but condenser tubes may equally well be made of aluminium, and they give just as good service.

Aluminium offers a distinct price advantage over tin-coated copper; in many instances it also offers important chemical advantages following on the very low pick-up of aluminium and the catalytic inactivity of the metal ions so picked up as compared with those of tin and especially copper. Thus, it has been found that water condensed in aluminium tubes causes less decomposition of hydrogen peroxide than does distilled water condensed in tubes of any other metal. Aluminium-condensed distilled water is, therefore, almost exclusively employed for the dilution of hydrogen peroxide to the usual pharmaceutical and industrial concentrations.

An interesting aluminium water distillation plant was installed at the Mallinckrodt Chemical Works (America) a few months before the war started. It is of particular interest partly because of its large capacity and partly because its installation was only commenced after a small aluminium system had been set up and had proved to be superior to the systems previously employed. The Mallinckrodt Chemical Works are makers of pharmaceutical, laboratory

and photographic chemicals. All these materials must be extremely pure and distilled water of high purity is required in most stages of their processing.

The plant installed contains a triple effect still from which the distilled water passes to four aluminium storage tanks of 2,000 gallons capacity each, arranged in pairs so that two tanks are in use while two are being cleaned. This continuous cycle of cleanings was adopted to ensure all possible freedom from contamination by dirt and foul matter. These tanks are situated at ground level and the distilled water is pumped from them to a 2,000-gallon distributing tank on the roof. The pipe line is in 3S aluminium alloy (1.25 per cent. manganese, remainder aluminium), the main line being 3 ins. in diam. and the distributing lines of smaller cross section according to their required capacity. Part of the line is carried underground, and precautions had to be taken to prevent corrosion.

The storage tanks were constructed of welded 3S alloy plate, protected by bituminous paint where they stood on a concrete base. Loose covers were fitted in two sections to allow for easy handling. Effective insulation was provided between the tanks and the feed lines whilst a definite break was arranged between the tanks and the still. Besides eliminating electrical contact, it was considered that a short fall from the still to the tank would aerate the water and reduce the possibility of reaction with the metal. The pipe fittings were made in aluminium alloy B214 (3.75 per cent. Mg 1.75 per cent. Si, remainder Al), standard pipe thread being employed. The pump fittings and valves were made in bronze.

Another interesting aluminium distilled water system was installed at the Kansas State College in 1940. The still was of the Barnstead type with a capacity of 50 gallons per hour and the feed was taken to a 1,000-gallon aluminium storage tank. It was found that, by using pure aluminium for the tank and distributing pipes, with aluminium and silver faucets, a plentiful supply of distilled water with a conductivity of 10^{-6} reciprocal ohms was made available throughout the building.

There are only two of the more recent aluminium distilled-water installations fabricated in aluminium; particulars of others will be found in " The Aluminium Industry," Vol 2 (Edwards, Frary and Jeffries), and elsewhere.

A point which needs emphasis is the need for an all-light-metal set-up. It is unsafe, for example, fitting aluminium storage tanks if the distributing lines be of copper. The condensers, storage and distributing tanks, pipe lines, valves and taps should all be in aluminium to achieve the best results. For condensers and pipe lines, cold or hard-drawn tubing, extruded and drawn from a hollow billet, can be produced in seamless runs up to about 20 ft. long. Tubes in aluminium, or even in many of the higher strength alloys, are very ductile and are readily formed into coils of intricate design. Perfectly satisfactory jointings of aluminium tubes in header plates can be made by a number of methods, one being first to expand the tube on to the header plate and then swage to the back neck, thus preventing any possibility of leakage. Alternatively, a welded joint can be made.

Bolted joints with gaskets should, so far as possible, be avoided, in distilled water systems; where their use is imperative, rubber gaskets or thicker grades of aluminium foil in the soft condition may be more satisfactory than impregnated gaskets which may cause contamination of the water. Storage and distributing tanks are best made of welded aluminium sheets. The life of apparatus of this kind is usually in excess of 10 years, depending, of course, on the gauge of metal employed. Aluminium piping and taps will be considered in detail later.

Steam

Aluminium is not to be recommended for use in the production of steam. In the first place, the mechanical properties of light alloys are not suitable for high-pressure installations, whilst coke fires must be used with care or hot spots may be formed and the area soon holes. This danger is accentuated by the inevitable deposition of scale, which possesses low heat conductivity, in an uneven layer on the walls and bottom of the vessel. Corrosion by the scale and by the dissolved salts present in the water is accelerated by the elevated working temperature, and the variable nature of the available water makes it difficult to provide any kind of protection.

Aluminium paint, however, is of the greatest value as a protection against corrosion for internal and external surfaces of iron boilers. It is silvery in colour and high in reflectivity for visible light, factors which make it additionally welcome in poorly lighted boiler rooms. It also provides some measure of heat insulation, although heat insulation of much greater efficiency is obtained by the use of crumpled aluminium foil. Aluminium tubing is not widely used for steam, although it is much used for other vapours and gases.

Aluminium Piping in Chemical Plant

For the handling of many types of fluid aluminium pipe lines are, without question, the most efficient and, in the long run, the most economical of the systems at present open to the chemical engineer. Their efficiency is due to three factors: First, the chemical resistance of the metal towards the fluid being carried and the consequent absence of pipe corrosion, pipe blockage and contamination of the product; secondly, the ease with which pipe lines in aluminium may be welded to provide joints of approximately the same mechanical strength and chemical resistance as the rest of the pipe line; thirdly, due to the absence of weak spots in the line, the incidence of breakdowns is greatly reduced. Repair may be a serious matter where inflammable or unstable products are being carried, and inevitably causes, at least, a partial closure of the plant.

Their economy is explained by savings under these headings combined with the ease and cheapness with which the pipe lines may be installed, and the fact that special fittings in aluminium alloy can be fabricated on the job with a cutting and welding blowpipe. No other system of piping—iron, galvanized or tinned iron, copper, glass or ceramics—can show all these advantages.

DETERMINATION OF SURFACE QUALITY[1]

Account, after Heyes and Lueg, Describing a New Sensitive Photo-electric Method for the Evaluation of Surface Finish. Results of the Method are Compared with Those Obtained by Other Techniques
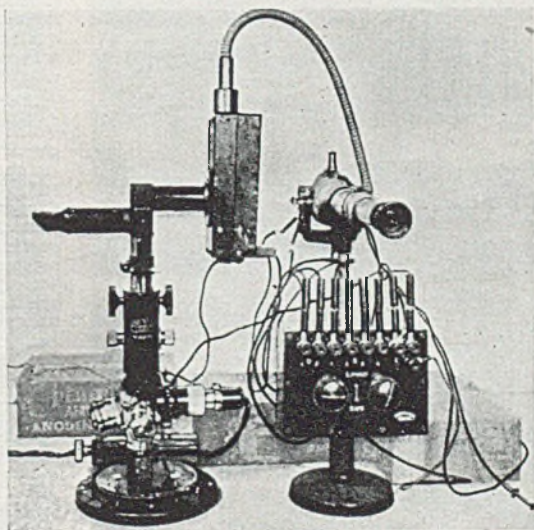

Fig. 1.—After Heyes and Lueg, showing apparatus set up for determination of surface finish.

THERE are many methods for examining and measuring surface quality; a list of those employed prior to 1936 is contained in G. Schmaltz's " Technische Oberflächen-kunde,"[2] whilst among recently published methods, those of Perthen[3] and v. Trentini[4] may be mentioned.

Previously existing methods, however, are not completely satisfactory and the requirements of an adequate technique can be summarized as follows:—

1. The method should allow the examination of very rough as well as of polished surfaces.
2. The technique should be applicable to flat, cylindrical and spherical faces.
3. Different stages in machining should be recognized easily.
4. The arrangement should be easy to handle and suitable for any workshop.
5. The arrangement should be standardized in such a way that different
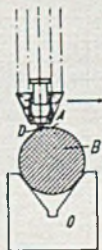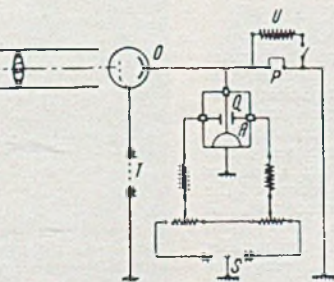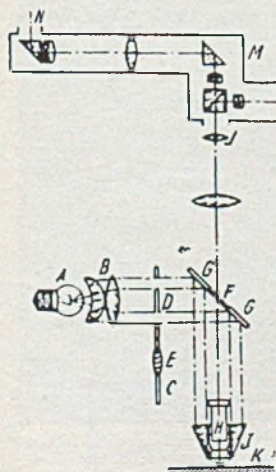
Fig. 2 (above, left).—Diagram of photometer used for determination of surface quality: A, point source of light; B, condenser; C, slide; D, diaphragm; E, convergent lens system; F, translucent part of mirror; G, opaque part of mirror; H, objective; J, condenser; K, surface of test piece; L, eye piece; M, binocular attachment; N, eye piece; O, photo-cell; P, earth; Q, electrometer suspension; R, knife edges; S and T, batteries; U, resistance.

Fig. 3 (above, right).—Measurement of surface quality of cylindrical test piece: A, point to be focused; B, cylindrical test piece; O, Vee block; D, focused point.
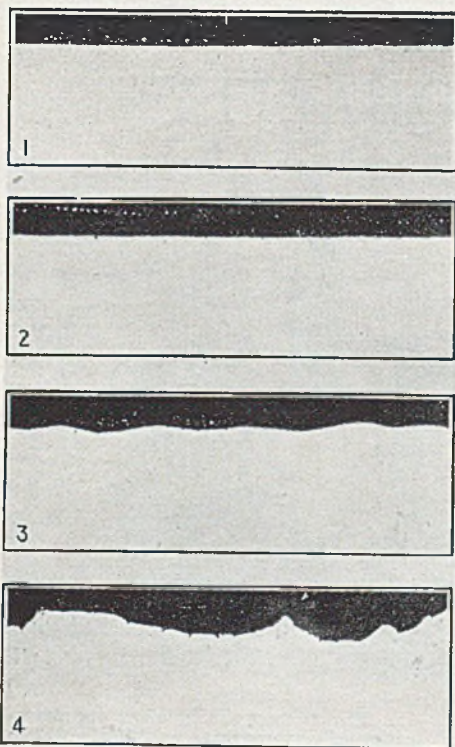
Fig. 4.—Surface profiles of steel test pieces (equivalent magnification in reproduction = 150 diams.): 1, polished; 2, ground; 3, turned; 4, after sand-blasting.

instruments give corresponding results relating to the same surface.

6. The result must correspond to the roughness measured by an absolute method.

The technique described in the following account has been developed in the light of these requirements.

Description of the Method

If light be directed on to a well-polished metal surface and examined with a metallurgical microscope with light-ground illumination, most of the light is seen to be reflected into the microscope, apart from the reflection losses at the lenses and at the surface of the test-piece. If the surface shows scratches or traces of the working process, however, a proportion of the incident light is reflected or deflected and will only partly enter an objective with small aperture. The rougher the surface, the smaller will be the amount of light entering the microscope.

With dark-ground illumination the light is directed upon the metal surface at such an angle that no directly reflected light can enter the objective. This is only possible for the light reflected or deflected at a suitable angle on the rough parts of the surface. A smoothly polished surface will reflect or diffuse only a small amount of light with dark-ground illumination, whilst a rough surface reflects or diffuses more light.

It is possible, therefore, to obtain a good idea of surface quality by measuring the light leaving the objective with both kinds of illumination. It is particularly useful for defining the quality as a quotient of light-ground to dark-ground illumination or for defining roughness as the reciprocal of the quotient. In this method, fluctuations in the source of light have only minor influence on the result.

Description of the Measuring Arrangement

The apparatus in Fig. 2 is based on the concepts outlined; the source of light is a point A; the light passes through condenser B and a slide C with openings, one of which holds a diaphragm D, whereas the other one houses a convergent lens system E. The first position of the slide which is shown in the diagram represents dark-ground illumination, and the centre part of the beam is screened off. Thus the translucent centre part of mirror F remains unexposed to the light. The opaque part of the mirror G, however, reflects the peripheral rays in such a way that they are directed through condenser J at a certain angle of incidence upon the surface of the test-piece K. Condenser J surrounds objective H. The rays, reflected or deflected on the surface K, enter objective H, pass the translucent part of mirror F and leave the microscope by the eye-piece L. The binocular attachment M directs the rays partly into eyepiece N, and partly upon photo-electric cell O. By means of eye-piece N, the surface is brought into focus and a photometric arrangement connected to photo-electric cell O allows the determination of the intensity of the light.

With light-ground illumination, the diaphragm D is replaced by the convergent lens system E. The light is thus directed on the translucent mirror F and from there through objective H upon the test surface K. The rays reflected from the surface pass the translucent mirror F,
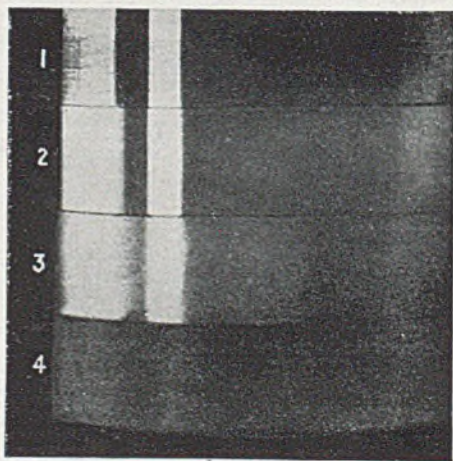

Fig. 5.—Steel test pieces of different surface quality (about half actual size): 1, polished; 2, ground; 3, turned; 4, after sand-blasting.
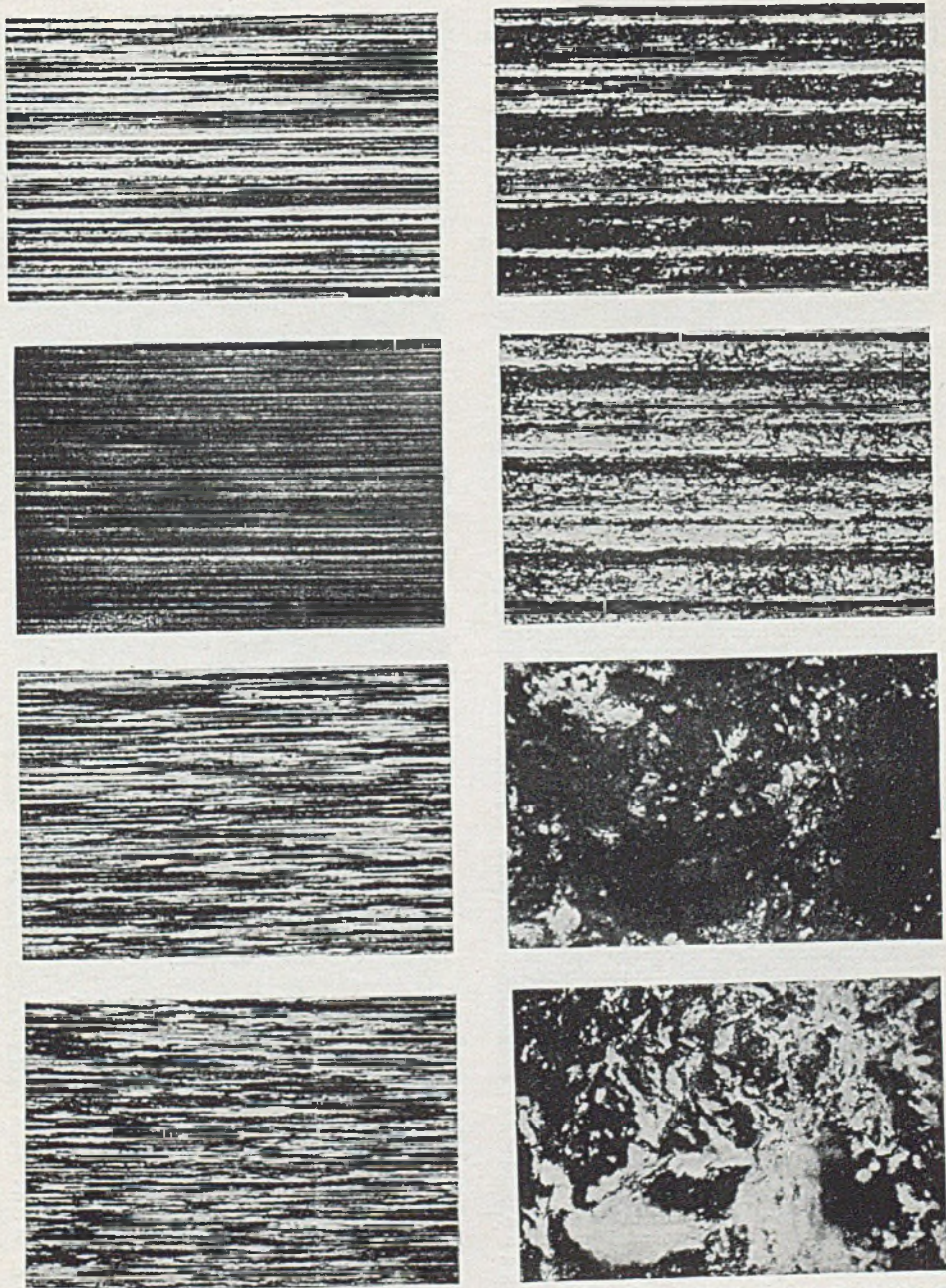
Fig. 6.—Surface structure of steel test pieces after subjugation to various methods of finishing (equivalent magnification in reproduction 75 diams.): Uppermost, left.—Polished, light-ground illumination. Immediately below is shown the same specimen with dark-ground illumination. The reproductions below those already referred to are of a ground specimen with light and dark-ground illumination respectively. Uppermost at the right is shown a turned specimen with light-ground illumination, the same specimen with dark-ground illumination being presented immediately below it. The last two reproductions at the right are those of a sand-blast steel specimen with light-ground and dark-ground illumination respectively.

enter the eyepiece L and are separated into two fractions by the binocular attachment M. The intensity of these fractions is determined in the same way as described for dark-ground illumination.

If the surface quality of cylindrical faces is to be determined, care should be taken to ensure that the optical axis of the microscope coincides with the diameter of the test-piece, and for this purpose the test-piece may be placed in the V-groove of a suitable block (Fig. 3). In order to focus the highest point A, the objective is first raised, then lowered slowly and at the same time moved to and fro in the direction indicated by the arrow. The point first coming into focus will correspond to point A.

Result of the Tests

The method was first tested on four chromium-steel wheels of 100 mm. diameter (about 4 ins.) and 20 mm. thickness. The cylindrical surfaces were finished in different ways. Test-piece 1 was polished, test-piece 2 fine-ground, test-piece 3 turned, and test-piece 4 sand-blasted. Cross-sections of the ground specimen of the test-pieces are shown at 150 dias. magnification (Fig. 4). The segments cut from the wheels for the purpose were embedded in Wood's metal and carefully ground and polished.

The illustrations do not show any traces of the working processes on polished and ground test-pieces. With turned and sand-blasted test-pieces, however, the influence of the working process on the surface can be clearly seen. Fig. 5 is a view of the test-pieces arranged according to surface quality; the lower sand-blast test-piece does not show any reflections, those on the turned test-piece are weak, those on the ground test-piece clearly marked, and the polished test-piece shows very pronounced and defined reflections. On close inspection the polished surface shows a certain amount of grooving.

Fig. 6 shows the surfaces of the test-pieces at 75 dias. magnification with light- and dark-ground illumination. The graduation in smoothness from the sand-blast test-piece to the polished one can clearly be seen. Unfortunately the reproductions do not convey the exact values with regard to the different types of illumination, but the structure of the surface can easily be recognized.

In order to compare the present method with those previously used, the four test-pieces were examined by light-slit method of Schmaltz at the laboratories of the Technical College (Technische Hochschule), Aix-la-Chapelle. The values for the roughness found by the light-slit method are given in Table 1 (Nos. 1 to 4), together with the results of the photometric method.

As photometric measurement is based on the ratio of a photo-electric current with light-ground to that with dark-ground illumination, it is not necessary to find the absolute values of such a current. The current passed by the photo-electric cell is proportional to the value $\frac{100}{T}$, T being the time required to charge the photometer condenser system. From this value the steady, feeble current due to reflection and diffusion in the microscope itself has to be deducted, because its value does not depend on the surface quality of the test-piece. With dark-ground illumination there was no such measurable steady feeble current.

In order to obtain a mean value for the surface quality, five different surface areas were measured each time and, on each one, five measurements with light-ground and with dark-ground illumination were made. The results agree with one another very well. For example, in the measurements with light-ground illumination on the polished test-piece the mean error
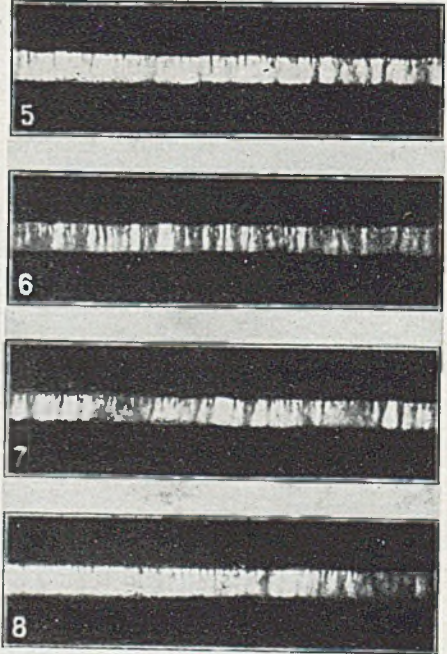

Fig. 7.—Surface quality by the light-slit method: 5 — 1.3μ; 6 — 2.5μ; 7 — 1.5μ; 8 — 0.8μ
(1μ = 0.001 mm.)

was 0.5 per cent. The results given in the last column but one of Table 1 show that, with increasing surface smoothness, the mean values of the quotients of the photo-electric currents drop from 21.16 with the sand-blast test-piece to 3.04 with the turned test-piece; to 0.833 with the ground specimen, and to 0.0736 with the polished test-piece. Nevertheless, the quotient obtained with the polished test-piece does not yet represent the ultimate in surface quality, for with a flat, highly polished sample, for instance, a quotient of 0.00279 was obtained. In general it can be stated that the better the surface the smaller the quotient.

It is remarkable how well the photometric quotients agree with the values found by the light-slit method and given in the last column. They amount to 22.3 μ with the sand-blast test-piece, 4.8 μ with the turned specimen, and 1.1 μ with the ground test-piece. No value was obtained with the polished test-piece. The values found by the light-slit method indicate
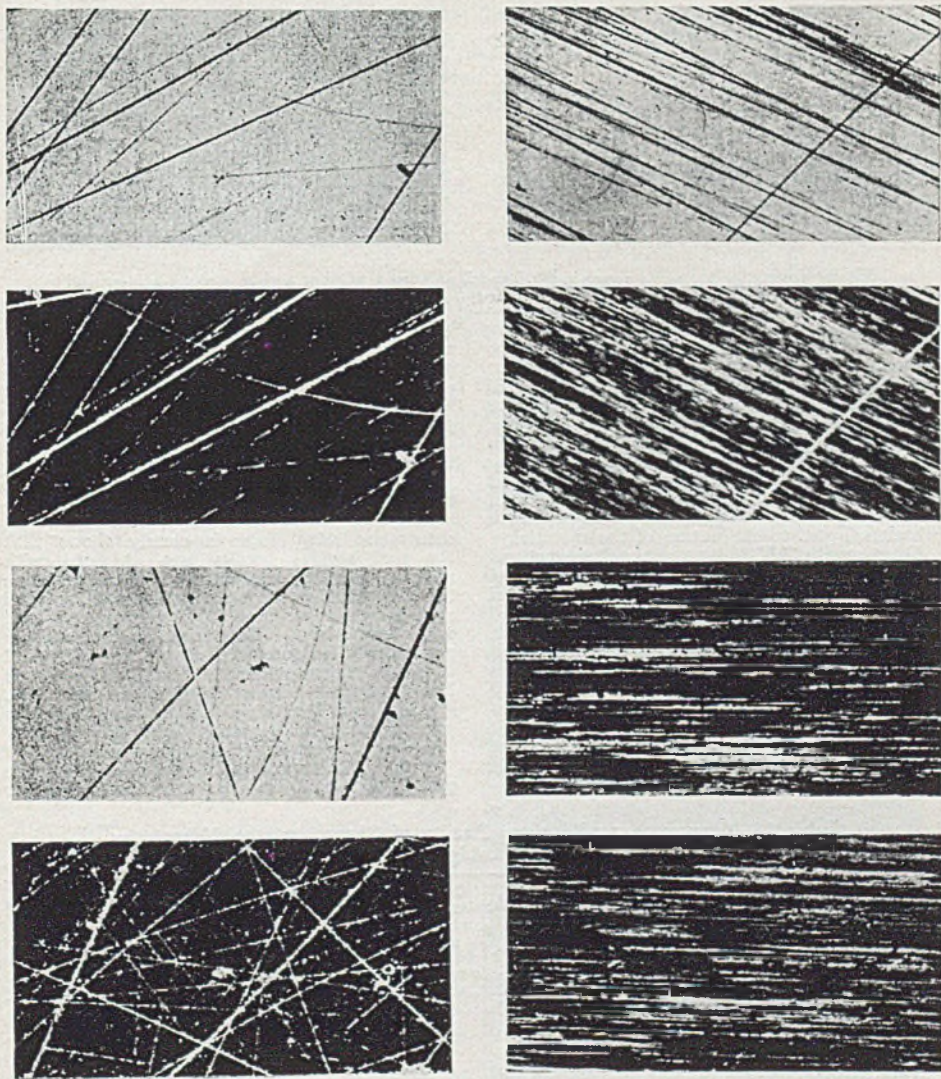
Fig. 8.—Surfaces of different quality (equivalent magnification in reproduction 75 diams.): Uppermost illustration at the left shows surface of plug gauge quality with light-ground illumination, reproduction below being the same surface with dark-ground illumination. The lower pair of reproductions at the left are of a surface of gauge block quality with light and dark-ground illumination respectively. The uppermost reproductions at the right are of a lapped surface with light-ground and dark-ground illumination respectively, lower pair of illustrations being of a finely ground surface with light-ground and dark-ground illumination respectively.

the distance of the highest point of the surface from a line through the deepest point ($1 \mu = 0.001$ mm.).

Although it may be a mere chance that the values of the two last columns are nearly identical, the conclusion is justified that the photometer can be gauged by the light-slit method. This is one of Schmaltz's conditions for a so-called "integral method," where the result is influenced by all face-elements of the measured surface. The slit-method shows only an image of the surface-micro-geometry in one direction.

The results with the light-slit and the photometric methods indicate that they are equally suitable for measuring rough faces. For the
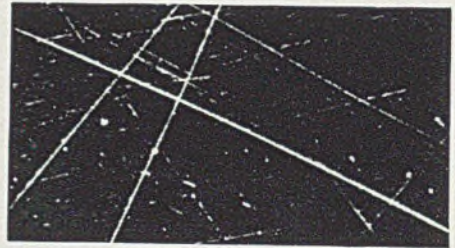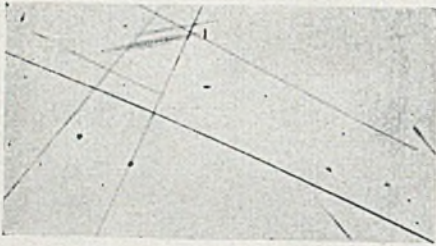
Fig. 9.—Completing the series shown in Fig. 8 and illustrating a polished surface seen by light-ground (left) and dark-ground (right) illumination respectively.

measurement of higher quality surfaces, the photometer is, however, definitely superior, because it can be used for measuring polished test-pieces which are beyond the capacity of the light-slit method.

A series of further tests were carried out in order to investigate whether differences in the surface quality of cylindrical test-pieces could be determined by the photometric method. The test-pieces were ground with abrasive wheels adapted to the nature of the material.

Four steel wheels of 75 mm. diameter and 10 mm. in thickness were examined. The steel contained 0.19 per cent. C, 24 per cent. Cr. and 22.6 per cent. Ni. The cast steel was turned first, heated and quenched in water from 1,100 degrees C. All wheels were subsequently ground with grinding wheel 1 (depth 0.15 mm.) and finish ground with one of the grinding wheels Nos. 1 to 4 (depth 0.1 mm.). Particulars are given in Table 2.

Table 3 (Nos. 5 to 8) also shows that the results obtained with the light-slit method and those obtained with the photometric method

are in close agreement. The best surface quality by both methods was found on test-piece 8 and the roughest surface on test-piece 6. Between these values lie those for test-pieces 5 and 7. Considering the exactness of the light-slit method (0.5 to 1 μ), the values with these two methods agree very well with one another.

In order to obtain a better comparison of the two methods with this series of tests, the surfaces were illuminated from the side. A comparison with Table 2 clearly shows that the best surface quality was obtained with grinding wheel 4, which is particularly suitable for the grinding of V_2A steel (stainless steel containing 0.1 per cent. C, 18 per cent. Cr and 8 per cent. Ni). The result can readily be understood, because the chromium-nickel-steel used has a composition similar to V_2A steel. The roughest surface was produced with grinding wheel 2, which is generally used for grinding plain carbon steel. Fig. 7 shows light-slit photos taken on test-pieces 5 to 8.

It was also intended to measure the surface quality with a stylus, but the wheels were too

Table 1.—Measurement of Surface Quality of Chromium-steel Wheels by Photometric and Light-slit Methods.

Test-piece	Spot measured	Charging time in secs. with light-ground illumination mean value T	$\frac{100}{T}$	$\frac{100}{T}$ — steady feeble current = i_1	Charging time in secs. with dark-ground illumination mean value T	$\frac{100}{T} = i_2$	$\frac{i_2}{i_1}$	Mean value of quotients	Maximum height H light-slit method
1 polished	1	10.58	9.45	8.36	161.6	0.619	0.0740		
	2	10.71	9.34	8.25	173.1	0.578	0.0701		
	3	10.71	9.34	8.25	165.9	0.603	0.0731	0.0736	Not measurable
	4	10.73	9.32	8.23	155.6	0.643	0.0781		
	5	10.62	9.42	8.33	165.6	0.604	0.0725		
2 ground	1	13.49	7.41	6.32	19.91	5.02	0.794		
	2	14.25	7.02	5.93	19.82	5.05	0.852		
	3	14.54	6.88	5.79	19.98	5.04	0.865	0.833	1.1μ
	4	14.00	7.14	6.05	20.66	4.84	0.800		
	5	15.28	6.54	5.45	21.51	4.65	0.853		
3 turned	1	30.84	3.24	2.16	14.28	7.00	3.24		
	2	30.54	3.27	2.19	13.70	7.30	3.33		
	3	28.93	3.46	2.38	14.38	6.95	2.92	3.04	4.8μ
	4	30.30	3.30	2.22	15.23	6.57	2.96		
	5	28.32	3.53	2.45	14.85	6.73	2.75		
4 sand-blast	1	75.37	1.327	0.247	20.93	4.78	19.35		
	2	78.20	1.279	0.199	20.82	4.80	24.12		
	3	76.75	1.303	0.223	20.42	4.90	21.97	21.16	22.3μ
	4	73.73	1.356	0.232	20.69	4.83	20.82		
	5	73.67	1.357	0.233	22.00	4.55	19.53		

Table 2.

Test-piece	Grinding wheel No.	Description of grinding wheel			Diameter mm.	Surface speed ft./sec.
		Grain	Hardness	Purpose		
5	1	100	LM	Steel alloy, general	400	92
6	2	80	MN	Steel	350	81
7	3	80	Jot	Steel alloy (W.F. 100)*	400	92
8	4	60	Jot 8/5	Steel alloy (V₂A)†	400	92

* Poppet-valve steel (special alloy), Krupp.   † Stainless steel, 18% Cr, 8% Ni and 0.1% C (Krupp).

big for the apparatus available. The results obtained are particularly valuable with the finest machined surfaces.

The Rheinmetall-Borsig A.G., Düsseldorf, submitted five cylindrical steel discs (the flat faces of which showed surfaces of different quality) to examination by this method. The composition of the steel was that commonly used for gauges. The details concerning the surface quality are given in Table 4 (Nos. 9 to 13). The light-ground and dark-ground images in Figs. 8 and 9 show the more or less smoothed surfaces. With the exception of test-piece 12, the roughness of which was measured by the light-slit method to be 1.2μ, it was not possible to find the surface quality values of other test-pieces by either the light-slit or the stylus method. Fig. 10 shows the light-slit photos of the surfaces and Fig. 11 the stylus curves of the same test-pieces. Only with the ground test-piece 12, it will be noticed, can minor unevenness of the order of 1μ be seen.

It is somewhat to be regretted that no details are given of the construction and operation of the particular type of stylus machine employed to produce the images reproduced in Fig. 11. Inherently, any mechanical method of this sort must suffer from severe limitations, these being dictated by inaccuracies of motion in the moving parts of the apparatus. At the same time, however, there have recently been developed exceedingly delicate pantographic devices, provided with a precision-finished diamond stylus capable of executing micro-writing of the minutest order; machines of this type, operated to give surface magnification, should be applicable to the evaluation of small differences in finish.

It is likely, should this prove possible, that mechanical equipment of this type would find extensive use in tool-room and precision machine-shop practice, provided that a sufficiently robust design could be evolved to withstand the general handling it would receive on service.

The photometric method described gives results which can be distinguished clearly from one another, as can be seen from Table 4 (Nos. 9 to 13). The best surface quality was observed on polished test-piece 13. The mean value of the quotients of the photo-electric currents with light-ground to that with dark-ground illumination in this case is 0.0206.
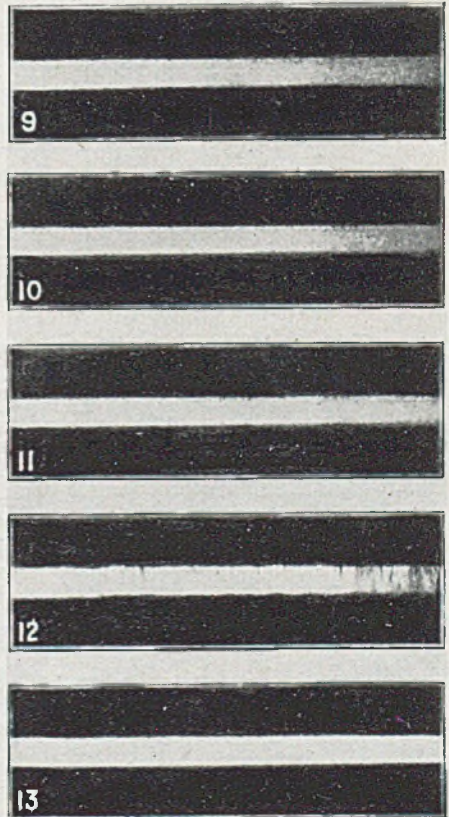
Fig. 10.—Determination of surface quality by the light-slit method of surface finish by different methods: 9, plug gauge (not measurable); 10, gauge block (not measurable); 11, lapped (not measurable); 12, finely ground (1.2μ); 13, polished (not measurable).

slightly inferior is the surface quality of plug gauges (test-piece 9, mean value of quotients 0.0268). With test surface corresponding to the quality of gauge blocks (test-piece 10), the

Table 3.—Measurement of Surface Quality of Chromium-nickel-steel Wheels by Photometric and Light-slit Methods.

Test-piece	Spot measured	Charging time in secs. with light-ground illumination mean value T	$\frac{100}{T}$	$\frac{100}{T}$ — steady feeble current i_1	Charging time in secs. with dark-ground illumination mean value T	$\frac{100}{T} = i_2$	$\frac{i_2}{i_1}$	Mean value of quotients	Maximum height H light-slit method
5	1	21.37	4.68	3.30	12.18	8.21	2.49		
	2	21.88	4.57	3.19	12.18	8.21	2.57		
	3	23.22	4.31	2.93	12.70	7.87	2.69	2.59	1.3μ
	4	22.53	4.44	3.06	12.31	8.12	2.65		
	5	22.14	4.52	3.14	12.37	8.08	2.57		
6	1	23.48	4.26	2.88	11.23	8.90	3.09		
	2	23.84	4.19	2.81	11.08	9.03	3.21		
	3	23.22	4.31	2.93	10.58	9.45	3.23	3.19	2.5μ
	4	23.08	4.33	2.95	10.96	9.12	3.09		
	5	22.98	4.35	2.97	10.12	9.88	3.33		
	1	22.88	4.37	2.99	12.30	8.13	2.72		
	2	23.81	4.20	2.82	11.19	8.94	3.17		
	3	23.31	4.29	2.91	12.82	7.80	2.68	2.91	1.5μ
	4	23.58	4.24	2.86	11.40	8.77	3.07		
	5	22.53	4.44	3.06	11.24	8.90	2.91		
	1	21.13	4.73	3.35	15.94	6.27	1.87		
	2	21.35	4.68	3.30	15.16	6.60	2.00		
	3	21.48	4.66	3.28	16.81	5.95	1.81	1.88	0.8μ
	4	22.13	4.52	3.14	18.07	5.53	1.76		
	5	22.22	4.50	3.12	16.36	6.11	1.96		

Table 4.—Measurement of Surface Quality by Photometric and Light-slit Methods.

Test-piece	Spot measured	Charging time in secs. with light-ground illumination mean value T	$\frac{100}{T}$	$\frac{100}{T}$ — steady feeble current $= i_1$	Charging time in secs. with dark-ground illumination mean value T	$\frac{100}{T}$	$\frac{100}{T}$ — steady feeble current $= i_2$	$\frac{i_2}{i_1}$	Mean value of quotients	Maximum height H light-slit method
9 surface quality of plug gauges	1	3.79	26.39	23.60	116.12	0.861	0.621	0.0263		
	2	3.72	26.88	24.09	117.02	0.855	0.615	0.0255		
	3	3.78	26.46	23.67	120.53	0.830	0.590	0.0249	268.10^{-2}	not measurable
	4	3.79	26.39	23.60	108.90	0.918	0.678	0.0287		
	5	3.93	25.45	22.66	112.09	0.892	0.652	0.0288		
10 surface quality of gauge blocks	1	4.11	24.33	21.54	65.15	1.535	1.295	0.0601		
	2	4.19	23.87	21.08	76.54	1.307	1.067	0.0506		
	3	4.27	23.42	20.63	61.51	1.626	1.386	0.0672	545.10^{-2}	not measurable
	4	4.21	23.75	20.96	75.17	1.330	1.090	0.0520		
	5	3.99	25.06	22.27	84.09	1.189	0.949	0.0426		
11 lapped	1	4.07	24.57	22.24	24.33	4.110	3.888	0.175		
	2	3.93	25.45	23.12	29.05	3.442	3.220	0.139		
	3	4.12	24.27	21.94	24.51	4.080	3.858	0.176	163.10^{-2}	not measurable
	4	4.25	23.53	21.20	25.75	3.883	3.661	0.173		
	5	4.12	24.27	21.94	28.25	3.540	3.318	0.151		
12 finely ground	1	7.89	12.67	10.34	14.20	7.04	6.82	0.660		
	2	7.91	12.64	10.31	14.96	6.68	6.46	0.627		
	3	7.83	12.77	10.44	14.19	7.05	6.83	0.654	629.10^{-2}	1.2μ
	4	8.03	12.45	10.12	14.13	7.08	6.86	0.678		
	5	7.63	13.11	10.78	17.01	5.88	5.66	0.525		
13 polished	1	3.37	29.67	27.34	113.42	0.882	0.660	0.0241		
	2	3.55	28.17	25.84	128.33	0.779	0.557	0.0216		
	3	3.31	30.21	27.88	141.51	0.707	0.485	0.0174	206.10^{-2}	not measurable
	4	3.29	30.40	28.07	133.90	0.747	0.525	0.0187		
	5	3.27	30.58	28.25	121.32	0.824	0.602*	0.0213		

quotient rises to 0.0545, with the lapped test-piece 11, to 0.163 and with the ground test-piece 12, it reaches its maximum value of 0.629.

Considering the results of the different series of tests it may be stated that the photometric method is superior to both the light-slit and the stylus method. On turned and ground surfaces the exactness of measurement is the same; the photometric method, however, is more rapid because the two other methods require photographs to be made, especially if high accuracy be essential. On surfaces of high quality the photometric method is superior to the two other methods, because it alone gives values that can be used.

Summary

A photometric measuring method is described for the indication of surface quality on flat and cylindrical test-pieces. With it a determination of the surface quality of rough and polished faces is possible. The agreement between the new method and those previously in common use is established for surfaces of medium quality. For surfaces of high quality the new method gives results more accurate than those previously used.

10 ——————

11 ——————

12 ——————

13 ——————
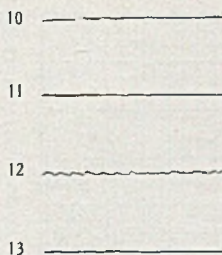
Fig. 11.—Stylus curves of surfaces of different quality: 10, gauge block quality; 11, lapped; 12, fine ground (1.2μ); 13, polished. Equivalent magnification in reproduction 1,500 diameters.

REFERENCES

(1) *Josef Heyes, Werner Lueg, " Ein neues Verfahren zur Kennzeichnung der Oberflaechenguete von Werkstoffen," "Kaiser Wilhelm Institut für Eisenforschung,"* 1942/24/31. (2) *G. Schmaltz, " Technische Oberflaechenkunde," Berlin,* 1936. (3) *J. Perthen, "Maschinenbau,"* 1936/15/669. (4) *B. v. Trentini, " Die Werkzeugmaschine,"* 1941, p. 152, No. 6.

Light Alloys in
Metal Rectifiers and Photocells

Continuing from "Light Metals" 1944/7/458 a Discussion on Photocells. The Copper - oxide and Caesium Types are Here Dealt With

Fig. 84.—The Nivoc E.P.L. Selenium rectifier.
(Courtesy Becker, London.)
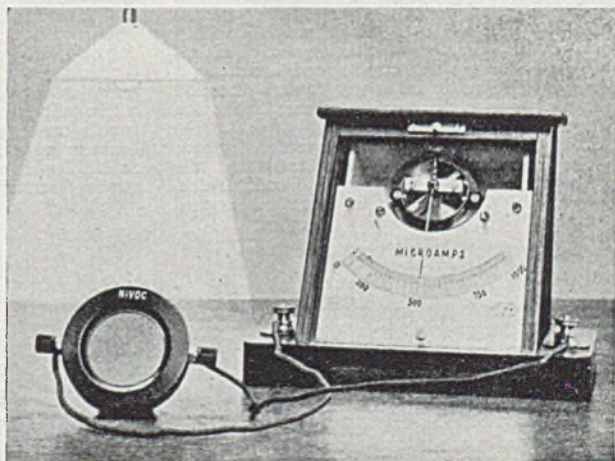
Copper-oxide Rectifier Photocell

REFERENCE has already been made to the construction and principle of the copper-oxide rectifier photocell. Its manufacture as far as the copper/cuprous-oxide combination is concerned proceeds along lines closely similar to those followed for the rectifier itself. It entails, therefore, selection of a grade of copper of suitable purity, grain size and surface condi-

tion, its oxidation under controlled conditions of heat treatment and the removal of the surface layer of cupric oxide. Beyond that, processing is similar to that for the selenium rectifier photocell. Thus the next step is the application of a transparent metal counter-electrode, usually of gold, silver, platinum or palladium, by the cathode sputtering process, leaving the peripheral margin free from this coating. Then the collecting ring of fusible

Fig. 85.—Characteristics of the 45 mm. Nivoc E.P.L. photocell. Current generated for various intensities of incident light is given for different values of external resistance.

with the selenium-rectifier photocell, but that in the copper/cuprous-oxide photocell there is a red and infra-red colour response with the cut-off at the red end of the visible spectrum exactly at the point where light transmission of the cuprous oxide begins. The cuprous oxide consequently must act as a filter. With the counter-electrode, the maximum colour response is approximately in the middle of the visible spectrum, but for the copper/cuprous-oxide photocell the colour response is not so wide as for the selenium photocell, and does not extend beyond the visible range. In commercial applications it appears, therefore, as though the selenium rectifier photocell is likely to command the field.

The production of rectifier photocells is obviously a specialized manufacture, entailing a high degree of technical control, electrical, chemical and metallurgical, as well as instrument precision. It is to be noted therefore that these cells are produced mainly by large electrical concerns of high repute with research, development and control facilities at their disposal. Some of these producers as follow:—In America, The Western Electrical Instrument Corporation and The General Electric Incd.; in Germany, The Süddeutsche Apparate—Fabrik; in France, Le Matériel Téléphonique; in this country, The Westinghouse Brake and Signal Co., Ltd., Evans Electroselenium, Ltd.

Regarding uses, there are a thousand and one general applications. The first obvious possibility is the starting, stopping, or automatic actuation of a moving element, by breaking the continuity of a beam or pencil of light. In this function, the photocell operates in conjunction with a relay, meter or other electrical device. The automatic opening of doors is a typical example, theatre, cinema and hotel doors being typical cases, and one-way doors of service rooms in restaurants being a really useful application. It leaves the hands free for waiters to handle trays, etc., safely, and avoids the tiring business of pushing the door with the shoulder or kicking it with the foot. The same utility application arises in large factories through which light electric trucks operate; often it is

alloy is sprayed on, and finally a coating of clear varnish or lacquer may or may not be applied to all but contact surfaces.

Williams and Thompson (J. Inst. Elec. Eng., May, 1941) refer to the photo-electric properties of the cuprous-oxide Cu/Cu_2O couple. They point out that the photo-current which on closed circuit flows when the cuprous-oxide surface is exposed to light, is internally in the direction from copper to cuprous oxide, whereas when the transparent counter-electrode is present, the direction internally is from the counter-electrode to the cuprous oxide. They state that the photo-voltaic effects without the counter-electrode are of similar order to those experienced

Fig. 86 (above).—The colour sensitivity of Nivoc E.P.L photocell for wavelengths 400-800 $\mu\mu$. Plotted also is the sensitivity curve for the human eye. Filters can be embodied in the cell to narrow response band to correspond more nearly to that of the eye.

Fig. 87 (right).— Current developed in two commercial photocells of French origin for various intensities of illumination and an external circuit resistance of 20 ohms.
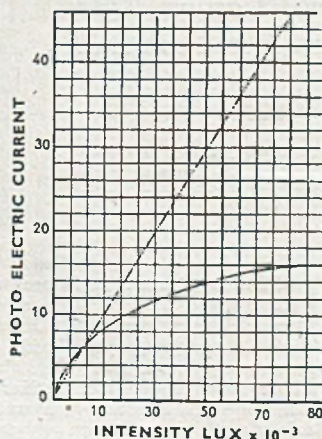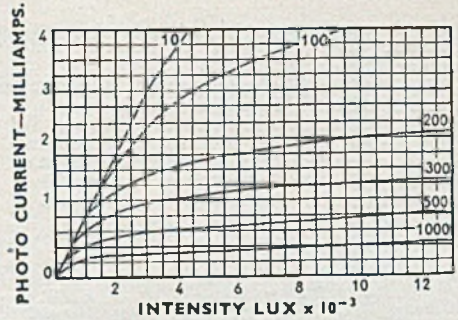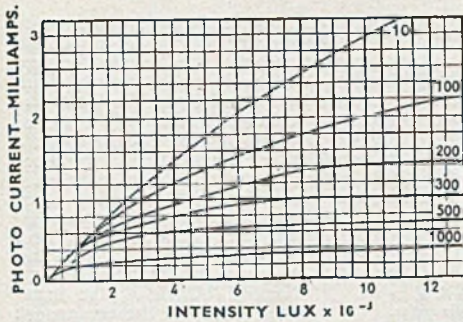
Fig. 88 (above).—Cell as in Fig. 87. Current developed for a range of external resistance values and over a range of light intensities. Fig. 89 (above, right). —Another type of selenium photocell of French origin showing current output with light intensity for a range of external resistance values. Fig. 90 (below).— Three commercial photocells of French origin showing power output against resistance of external circuit at intensity of 500 Lux. Fig. 91 (right).—Typical spectral sensitivity curve for selenium rectifier photocell (French origin) compared with average sensitivity of the eye. Fig. 92 (below, right).—Curve showing open circuit emf. in relationship to intensity of light ; effective surface area 10 cm.^{2} (cell of French origin).
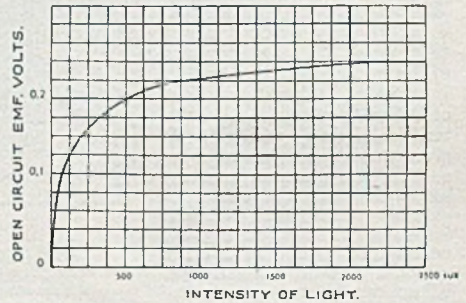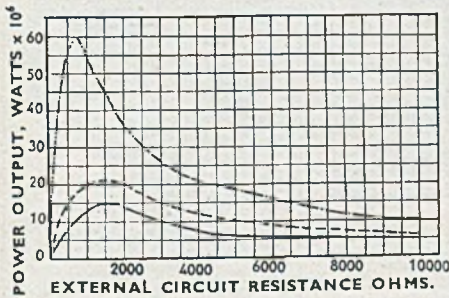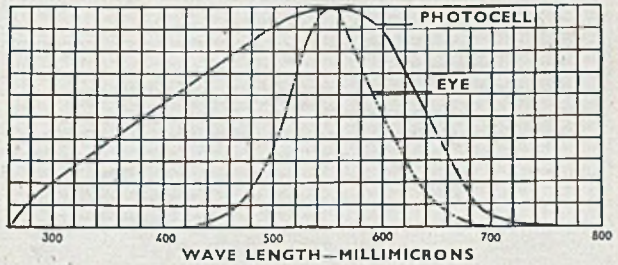
noted that the truck driver is left to " ram " the door with his truck, which is dangerous to pedestrians and disastrous to doors. Control of conveyorized systems, for example, for handling food packs, components and the like in numerous industries, is practicable. Objects can be automatically counted or diverted from one channel to another by photoelectric means. Feed or breaks in feed can be controlled or detected. Automatic starting or stopping can be devised.

General light control is another primary field of exploitation. Artificial lighting in schoolrooms and other assembly places can be controlled from daylight intensity. Black-out systems can be automatically operated, and this gives the possibility of general automatic or remote control operation of shutters or blinds.

Burglar alarm systems can be devised quite easily, and on the same principle, devices for announcing arrival of cars at petrol stations, of customers at counters or visitors in hotels,

can be designed, either in conjunction with an audible warning such as a bell, or a visual sign such as an electric light.

The foregoing are a few of the purely utilitarian applications. The more purely scientific applications are not neglected. Photography is one of the most important, not only with respect to exposure-metres but also for the operation of high-speed camera shutters. The determination of density of photographs, or portions of them, is made easily possible, as, for example, the measurement of intensity of spectral lines in spectographs, this being used in quantitative spectrographic analysis. They are also used in photo-electric fluorimeters for estimating the concentration of fluorescing solutions. Chemical applications include gas analysis. Thus automatic apparatus for determining carbon dioxide in various atmospheres and giving an automatically operated alarm, visual or audible, has been marketed. In this, the air is passed through a liquid containing a

pH colour indicator, and through the latter a beam of light falls on a photocell which operates the electrical circuit.

The rectifier photocells consist of the cell element mounted in appropriate fashion in a case, its electrodes connected to terminals, and from these connections are taken to the external circuit, which may be a sensitive meter or other device. Fig. 84 taken from " The Nivoc Supplement " for April, 1939 (a publication of

Fig. 93 (left).—Photocell L.M.T. type 3001A, of Le Materiel Telephonique, Paris, to illustrate mounting and terminating.

It need not be stressed that the mounting into which the photo-electric couple is embodied, and the external means for effecting electrical connections, are aspects virtually divorced from the construction of the cell itself. So far as the cell mounting is concerned, the only essential characteristics are that it should be of such a design as not to interfere with the performance of the unit in service, and should be sufficiently robust, vapour-proof, damp-proof, etc., to meet any exigencies of service in field or laboratory. These requirements are dictated by the necessity for avoiding any chemical attack at the interfaces (edge) of the component parts of the combination, as such corrosion might, in time, conceivably affect the performance of the cell.

(To be continued)

Fig. 94 (left).—Photocell L.M.T. type 3002A, of Le Materiel Telephonique, Paris, showing further system of terminating.

W. and J. George, Ltd., and F. E. Becker and Co.), shows the Nivoc E.P.L. cell, which typically illustrates this point. In relation to this particular cell, Fig. 85 shows the characteristics of the 45 mm. size. It gives the current generated for various intensities of incident light with different values of external resistance. Colour sensitivity is shown in Fig. 86, which also gives the average response for the human eye. Filters can be embodied in the system to narrow the band of response for the cell to correspond more nearly to that of the eye.

The French concern mentioned exploited rectifier photocells (and caesium photocells) for a full field of applications. They also marketed the complete apparatus for many purposes, e.g., relay combinations, gas analysis apparatus, light measuring equipment, pocket luximeters, colorimeters, light control equipment, etc. These rectifier photocells are of the selenium type and are not confined to steel base plates, but also include aluminium in this function. These commercial cells are very important and are already produced in great numbers. Their development and manufacture, however, are very much in their infancy and, naturally, a great future is to be anticipated. Consequently, graphical representation of characteristics of commercial cells is of more than passing interest, and those shown in these pages are taken from a French technical publication.

Fig. 95 (right).—Photocell L.M.T. type 3003A, showing mounting with union-type fixing.
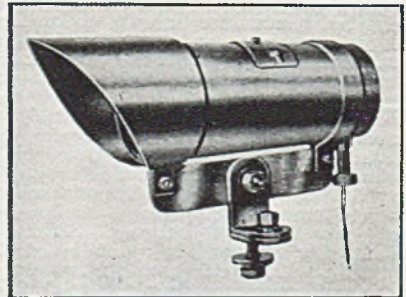
Fig. 96.—Photocell L.M.T. type 3003D, of Le Materiel Telephonique, Paris, with some more elaborate mounting.

The Thermionic Type of Photocell

The photoelectric tube is a two-electrode assembly similar in construction to a radio receiving valve. The electrodes are anode and cathode, the latter being the larger and the one having electron-emitting properties. Photo-electric emission is a surface effect and, there-fore, the modern tendency in design is to use a cathode of large area coated with a thin layer of electron-emitting substance. The cathode base is oxidized silver or oxidized copper. It is thin, of the order of o.o10 in. in thickness; pure silver itself need not be used, and some-times a silver-coated metal is employed. The light-sensitive properties are given by a coating of another element, and as these cells are usually used with visible light, choice of element is restricted to the following series: Sodium, potas-sium, rubidium, caesium, lithium, strontium and barium.

Various considerations can, and do, dictate the particular choice of element in practice. Apart from photoelectric efficiency, amenability to commercial pro-duction methods of tube manufac-ture is perhaps the most important feature. This entails evaporation or distillation of the element, usually in glass equipment; this last factor precludes lithium, strontium and barium, of which

the boiling points are too high for handling conveniently in this manner. Probably the commonest type of modern thermionic photo-cells uses caesium, the cathode consisting of a layer of this element on an oxidized silver surface, the cathode being silver throughout, or silver-clad, or electro-silver-plated base metal. Some caesium oxide is, probably, inevitably present. However, films of rubidium on oxidized silver and films of potassium upon oxidized silver or oxidized copper are also used. The behaviour of most of these alkali and alkaline-earth metals as getters for residual gases was dealt with in a

The sealing of the electrodes into a glass seal, mounting in a glass tube and treatments of pumping, sealing, etc., will closely follow the technique of normal valve-tube production. The final photoelectric tube may be left as a high vacuum type or it may be " gas-filled." The latter signifies the presence of a little inert gas to give a small pressure; the gas is one of the rare gases of the atmosphere, usually argon, but, alternatively, helium. Cells of this type are sensitive to visible light, particularly the red end of the spectrum, and to infra-red. The high-vacuum variety of tube exhibits a constancy of characteristics and linear relationship between photoelectric current and intensity of incident radiation, specially suiting it to applications in which reproducibility of measurements is an important factor. On the other hand, the gas-filled variety can, in comparison, give higher emission current for the same intensity of light, suiting it more to instances where detection of

WAVE LENGTH OF INCIDENT LIGHT—ANGSTROM UNITS

light is the primary objective. In some types of television camera, a mosaic comprising a num-ber of photoelectric spots upon an appropriate base is employed.

As for rectifier photocells, special techniques have to be employed in the development and manufacture of the thermionic type of photo-

	(a)	(b)	(c)
Normal anode voltage	90 volts	20 to 120 volts	90 volts
Maximum anode voltage	120 volts	180 volts	90 volts
Maximum anode current..	10 micro-amp.	100 micro-amp.	10 micro-amp.
Effective surface area	20 sq. cm.	20 sq. cm.	20 sq. cm.
Sensitivity at 90 volts and with light source temperature 2,710 degrees K.	60 micro-amp. per lumen	20 micro-amp. per lumen	100 micro-amp. per lumen

previous article on the subject of getters and gettering,* and it will be appreciated that, in their application to the cathode in the photocell, residual gases will be dealt with, and traces of oxide in the coating become inevitable.

* See "Light Metals," 1944/7/34 ; 77.

cells. Production to-day is fairly generally established, e.g., The British Thomson Houston Co. in this country, Le Materiel Telephonique in France, and The General Electric Co. of America are outstanding. A wide range of types is made and developments are always proceeding.

typical products of the French company use caesium-coated cathodes with gas filling and are characterized according to the data tabulated on the previous page.

A typical curve showing sensitivity with wave length of the incident light is given in Fig. 97. The best response is in the red and infra-red regions and from the data given a sensitivity up to 100 micro-amperes per lumen from a light source of temperature 2,710 degrees K. with 90 volts anode voltage is obtainable.

Photoelectric relays employ these caesium phototubes. The General Electric Corporation specializes in such equipment, and finds for it many applications, such as the sorting of articles on a basis of size or for starting or stopping intermittent operations. These photoelectric relays comprise three essential parts, including

tude to actuate a thyratron tube, by which means further amplification is secured. The thyratron tube has a cathode, grid and anode, but is gas-filled and, in consequence, its operation is different from that of the pliotron tube. Electrons passing from cathode to anode collide with the gas molecules, cause ionisation and, consequently, reduce the potential drop between anode and cathode to relatively low and substantially constant value. A small thyratron tube is thus able to pass a current of the order of amperes as compared with milliamperes in small pliotron tubes. Again, the tube does not pass anode current when the grid potential is more negative than a certain critical grid voltage (which is related to the anode voltage), but it does pass current from anode to cathode when the grid potential is raised above the critical value. Once this current is set up, the grid ordinarily exerts no further control over it as long as the anode voltage continues positive,
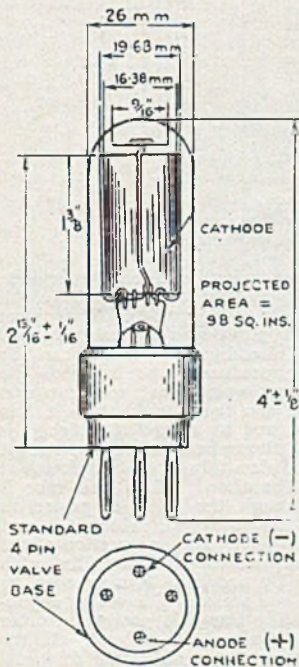
Fig. 98 (Left). — Diagram showing construction and dimensions of a caesium photocell. *(Courtesy of the British Thomson Houston Company, and "Chemical Age."*
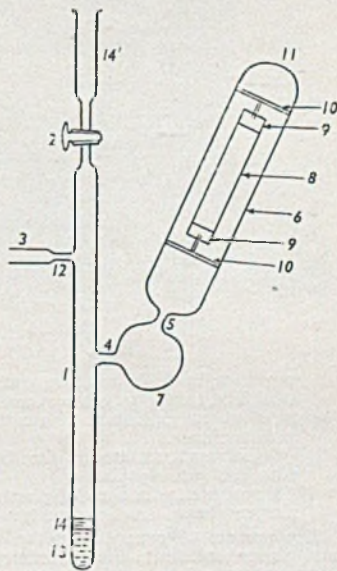
Fig. 99 (Right).—Apparatus for introducing an alkali metal, such as caesium, rubidium, etc., into a protective container according to B.T.H. patent B.P. 296,347.

the light-sensitive or phototube, a system for amplifying the phototube current, and a relay circuit for opening and closing an electrical circuit which controls the operation desired. The phototube is a gas-filled (argon) caesium-coated cathode type in order to obtain the maximum output for a given intensity of light. This current is amplified by passing it through an impedance of suitable value and the resulting voltage is applied to the grid of a pliotron tube. In the latter a stream of electrons is maintained from cathode to anode by means of a heated filament in the conventional manner. The grid is situated between these other two electrodes. The grid current need only be small, because a small change in grid voltage produces a pronounced effect upon the pliotron current. The resulting pliotron current is of sufficient magni-

that is, it cannot stop or modulate the anode current. On the other hand, if the anode voltage be made negative with respect to cathode, the current stops and the grid can then regain control and can prohibit the starting of current when the anode again becomes positive. If alternating current is applied to the anode circuit, the grid can regain control once per cycle when the anode voltage is negative, and the anode current can effectively be started and stopped by proper manipulation of the grid voltage. If direct current be applied to the thyratron, as it is by means of a rectifying tube in some systems, the anode circuit must be opened by an external relay or switch after each operation of the device. This information, together with detailed operating data, is given in the G.E.C. leaflet No. GEA-2536.

Apart from applications of the types already mentioned, the American concern, Photoswitch Incorporated, have applied phototube devices in

a number of important problems, especially in industry. The following include some of these specialized uses:—

Counting on loading chutes and conveyors, remote and automatic, traffic counting, counting in can-and-box box manufacture.

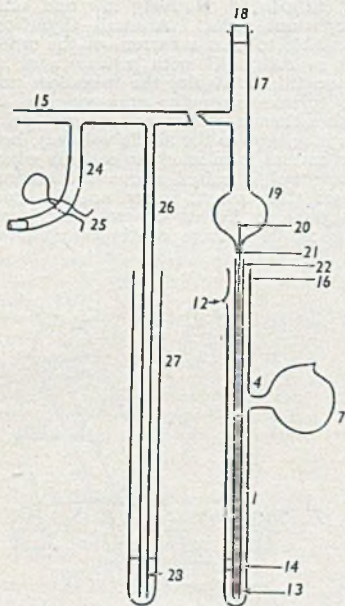Control of motors in wire drawing, thread breaking in textile works, speed com-

Fig. 100 (left).—Further details of apparatus described in B.P. 296,347. (See Fig. 99.) Apparatus for transferring alkali metal from protective casing into capilliary. (A description of the apparatus will be given in the succeeding part of this account to appear in the November issue of "Light Metals.")

Fig. 101 (right).—Enlarged view of part of the apparatus illustrated in Fig. 100. Here the capilliary (20) is shown being filled, the container with the alkali metal being for the purpose, immersed in an oil bath (29).
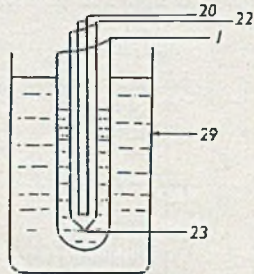
pensation in cable winding, drawing presses and heat-treatment conveyors.

Safeguards operation of guards on presses and machines.

Signal systems, traffic, fire, burglar, shipping and gate signals.

Inspection, idle time of plant, grading on size or shape, smoke density.

Equipment, of course, has the usually long and almost indefinite life customary with light electrical apparatus, with the normal exception of a limit of a minimum of 1,000 hours on the thermionic tubes. Equipment is relatively small and inexpensive.

The simple construction of the caesium photocell is shown in Fig. 98, which is taken from the metallurgical section of the "Chemical Age," February 3, 1944, p. 143. It is there included by courtesy of The British Thomson-Houston Co. in an article on the alkali metals in alloys by O. P. Einerl and F. Neurath. The simplicity of construction is misleading because the introduction of the alkali metal, usually caesium, is probably one of the most intricate operations in vacuum-tube production, and demands the extreme of ingenuity. Consequently, specialized means are devised for the purpose, and it is interesting to note that B.T.-H. patents dating back 15 years cover the procedure. The caesium (or rubidium) is produced from the chloride by reduction with metallic calcium, and its preparation and filling into capillary tubes for use in

the photocells is all carried out in the specially designed apparatus with the metal protected from atmospheric deterioration by means of vacuum or an inert liquid. Again, more stable alloys are referred to, alloys from which the alkali metal can easily be liberated by evaporation.

B.P. No. 296,347, 1929, assigned to The British Thomson-Houston Co., covers improved methods and apparatus for handling the readily oxidizable metals of the alkali group. The procedures apply not only to caesium, but also to the other members of the group, rubidium, lithium, sodium and potassium. The patent points out that when one of these alkali metals has to be stored in a capillary tubing and is destined for use in high-vacuum electron discharge devices, then it is absolutely essential that the alkali metal be free from all impurities. The object of the patent is to provide an improved method and apparatus whereby this ideal can be achieved. The procedure is as follows:—The purified alkali metal is placed in a container and covered by means of a liquid with which it does not readily react, and by means of which it is protected against atmospheric oxidation, etc. A capillary tube is placed in a casing closed at its lower end. The closed end of this tube is then inserted through the layer of protective liquid into the alkali metal, which is kept molten for the purpose. The end portion of the casing is removed and the capillary filled with the alkali metal by suction. It may then be removed and its end sealed. The casing is provided with a readily frangible portion in order to facilitate the removal of its end. If the capillary is of opaque material, such as metal with which the alkali metal does not react, then it is desirable to provide a gauge in order to follow the process of filling. This is done by using a second capillary of the same internal diameter as that to be filled, connecting it in parallel to the same suction device and having its open end immersed in a liquid of the same specific gravity as that of the alkali metal.

It is indicated that the preferred way of filling the first container with the oxidizable alkali metal is to distil it in directly under vacuum, and then to cover it with its protective layer of liquid while still under vacuum.

Fig. 99 shows apparatus for introducing the pure alkali metal into the container, Fig. 100, its introduction into the capillary, and Fig. 101 an enlarged view of a portion of the device in Fig. 100.

(To be continued)

International Regatta at Spithead. Kaiser's yacht 'Meteor' wins International Cup for Schooners. August 7, 1911

WHEN WE WERE YOUNG

Three years later the Kaiser was an entry in another International Regatta, but he won no prizes. And now the same nation under another leader has challenged the world for mastery. We've lived in stirring times since Cellon was founded in 1911. Not only in politics and arms have there been turmoil and commotion; industry has had its revolution, science has advanced out of all relation to its past progress. So, Cellon's career has been set in a period of change, advancement and improvement. Its position in industry shows that it has kept pace with affairs, despite these turbulent interruptions.

CELLON LTD., KINGSTON-ON-THAMES.   TEL.: KINGSTON 1234 (5 lines).
Thorp-Hambrock Co., Ltd., Montreal, Canada. Cellon Corporation Pty., Ltd., Sydney, Australia.

CELLON
CERRIC CERRUX

The perfect finish

CELLON

CVS-514

--- MISCELLANEOUS ---

MONOMARK Service. Permanent London address. Letters
redirected 5/- p.a. Write BM/MONO92, W.C.1.   84/3124

EDITORIAL & BUSINESS ANNOUNCEMENTS

ALL instructions, matter and passed proofs for all
kinds of advertisements must reach the Head Office
of "LIGHT METALS" by the 10th of each month to
ensure insertion in the following month's issue.

"LIGHT METALS" is published in London, England,
towards the end of each month.

Head Offices: Bowling Green Lane, London, E.C.1.
Inland Telegrams - - - "Pressimus, Smith, London."
Cables - - - - - "Pressimus, London."
Telephone - - - Terminus 3636 (Private Exchange).

SUBSCRIPTIONS — United Kingdom or abroad:
12 issues for 20s. post free; pro rata for fewer numbers.