

SOME PRACTICAL PROBLEMS CONNECTED WITH METALLIC CORROSION.

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Report of a Meeting of The Midland Metallurgical Societies held at the James Watt Institute, Birmingham, on 28th September, 1944, when a lecture was given by Dr. Ulick R. Evans on Some Practical Problems Connected with Metallic Corrosion," followed by a Discussion.

Present :- Dr. J. W. Jenkin (in the Chair) and over 100 Members,

Apologies were received from Mr. W. L. Govier, Colonel Cookson, Dr. W. O. Alexander, Mr. A. L. Molineux, Mr. F. E. Stokeld and Mr. H. A. MacColl.

The Chairman, in opening the proceedings, said that by long tradition the Co-ordinated Societies liked to make their initial Meeting of the Session especially attractive by inviting eminent visitors to speak on subjects which they had made particularly their own, It was therefore most fitting that Dr. Ulick Evans should be present this evening to address the Meeting in his own field of Corrosion. The work he had done on this subject was known throughout the world and had for some time been the admiration of his fellow investigators,

LECTURE.

SUMMARY,

Corrosion research is particularly important at the present time, since the solution of certain outstanding problems is likely to decide whether iron and steel will have to be abandoned in certain situations in favour of more expensive materials. Three sets of corrosion problems are being studied in the Cambridge University Corrosion Research Section. These are :—

I.-- Protection of Iron and Steel Carrying Mill-Scale Residues, Rust, Water and possibly Grease. Such surfaces can be protected---

(i) by removing the foreign matter mechanically or chemically; shot-blasting has certain special advantages. An excellent protective system consists of shot-blasting followed by aluminium-spraying from the wire pistol, with a final coat of paint on the sprayed surface.

(ii) by the development of paints suitable for direct application to contaminated surfaces, Of those under study at Cambridge, cementiferous (inorganic) paints and organic paints so richly pigmented with zinc dust as to constitute a conducting layer, have shown promising results. Specimens of rusty steel carrying a single coat of zinc-rich paint applied outside the rust, with a scratch-line penetrating the coat so as to expose the bright steel, have been kept in sea water for two years without the production of any fresh loose rust.

II.--Safe and Efficient Inhibitive Treatment for Cooling Systems.

Whereas cathode inhibitors are usually inefficient, and anodic inhibitors are apt to be dangerous (intensifying attack if added in insufficient amount), it seems likely that the alternate use of the two may provide a combination which is both safe and efficient.

III.--Corrosion Fatigue. Experiments have shown that steel subjected to alternating stresses may have a shorter life if exposed to corrosive conditions for a short period, followed by the exclusion of corrosive influences. than if the corrosive influences operate throughout the whole period of exposure. This emphasizes the danger of relaxing precautions against corrosion even for short

periods. If corrosive influences can be excluded completely, there should be no breakage, provided that the stresses are below the fatigue limit. Zinc-rich paints considerably prolong the life of specimens exposed to alternating stresses in a corrosive environment, although they do not prevent corrosion fatigue altogether.

INTRODUCTORY REMARKS,

Practical Importance of the Solution of Corrosion Problems.

There has probably never been a time when the future of industrial, and engineering methods has depended so much on the solution of certain corrosion problems as is the case to-day. Some practical men are suggesting that the 'Age of Metals' is approaching its end, and that the "Age of Plastics" is about to open. Such an opinion would seem to be exaggerated, since metals have certain properties which plastics cannot reproduce; wherever it is desired to transmit heat or conduct electricity, metallic materials remain a necessity. Others hold that the "Iron and Steel Age" is likely to give place to the "Age of Non-Ferrous Metals." Such an opinion at least merits consideration. The main complaint against iron and steel is that, although admittedly cheap and physically durable, they lack chemical stability. No-one will deny that certain non-ferrous materials may provide real benefits in situations where iron and steel are proving unsatisfactory. The aluminium alloys in particular offer great possibilities, since, apart from the convenience of the low weight/strength ratio, they offer considerable resistance to corrosion in some environments. Nevertheless, it would seem a pity to abandon a cheap and plentiful material for a more expensive one without good cause. Probably most economists would agree that such a policy is hardly likely to lead to an improved standard of living. It is therefore a matter of national, and indeed international, importance to decide whether in some of the situations where iron and steel are to-day causing dissatisfaction in regard to corrosion, the problem could not be solved by applying the understanding of corrosion processes which has been gained in the laboratory during the last twenty years.

Problems of Special Importance. Three main groups of important practical problems are under examination in the Corrosion Research Section at Cambridge University. The policy has been to use the scientific knowledge of the mechanism of corrosion now available in planning methods of avoiding the trouble. Experiments are then carried out to ascertain whether the expectations based on the scientific argument are realised. Such a course provides a prospect of reaching a successful solution more quickly than would be likely by empirical, hit-and-miss methods; moreover it serves as a check upon the accuracy of the views reached in the pure science work, for if the expectations emerging from them are not borne out by experiment, the views clearly require modification.

The three groups of problems are :-

- (1) the protection of steel surfaces which have reached a condition in which ordinary painting methods fail to give protection;
- (2) the evolution of a safe and efficient inhibitive system for rendering cooling-waters non-corrosive;
- (3) the avoidance of cracking due to corrosion fatigue or to various forms of embrittlement,

It is proposed to present a short account of the Cambridge work on these problems, including references - necessarily inadequate - to results obtained elsewhere. Certain gaps in the information provided are rendered necessary by security considerations.

PROTECTIVE COVERINGS.

The Effect of Matter Shut in between Paint and Metal. It is common knowledge that certain painting schemes which afford excellent protection to steel free from mill-scale, rust, moisture and

grease, often give poor results when applied to surfaces carrying these forms of contamination. The most obvious solution is a cleaning operation, which may be either chemical (e.g., pickling). or mechanical (e.g., sand-blasting or shot-blasting). Of these, shot-blasting is 'to-day receiving rather special attention, since, unlike pickling, it avoids wetting the surface, leaves no hydrogen charge and introduces no risk of silicosis to the workers (as does sand-blasting); moreover it brings the surface into a state of lateral compression, which in itself reduces the susceptibility to fatigue and corrosion fatigue. The merits of shot-blasting as a means of obtaining a clean, resistant surface have been advocated, rather particularly by Turner.¹

The superior behaviour of paints applied to cleaned steel - as opposed to a weathered surface - is well brought out by Hudson and Fancutt in their description of certain corrosion tests at Derby carried out for the Protective Coatings Sub-Committee of the Iron and Steel Institute.² Similar conclusions had been reached in the main researches of the Iron and Steel Institute Corrosion Committee,³ and also in the exposure tests organized from Cambridge University which have embraced a number of different painting schemes.⁴ There can be no doubt that the practical advantage of cleaning steel-work before painting is very great; the cost which is not very serious where the process can be carried out on a large scale, will soon be repaid by a lengthening of the period which can be allowed to elapse between repainting

Aluminium-Spraying. If, however, it is decided to clean a steel surface by shot-blasting, it is worth considering whether, before any paint is applied, the surface should not be covered with metallic aluminium applied from the wire pistol. Studies on the protection of steel-work by sprayed metallic coatings have been carried out for many years at Cambridge University,⁵ and both zinc and aluminium have given good results. Each metal can confer, under suitable conditions, protection even at places where the coating has been interrupted by a scratch line, leaving the steel bare. This protection at discontinuities in the coat is electrochemical, and involves the sacrifice of the (anodic) metal coating around the discontinuities; when the coating has disappeared in the vicinity of the scratch-line, the cathodic current density on the exposed steel may fall too low to give protection, and corrosion will then start. Consequently it is desirable to choose a metal for the coat which is corroded just sufficiently quickly to confer cathodic protection on the steel exposed at the gap, but not more quickly than is necessary for this purpose. An aluminium coat is corroded less quickly than zinc, and in certain environments (e.g. immersion in hard water) is not attacked sufficiently quickly to confer cathodic protection on the exposed steel, But in most ordinary atmospheres, aluminium will furnish protection to steel at a discontinuity in the coat, and in such cases it would seem to be more suitable than zinc as a protective covering.

As a result of early laboratory work at Cambridge, it was decided to expose outdoors a number of aluminium-sprayed steel specimens at stations representing urban, marine, country and mixed atmospheres. This set of tests was started by Britton in 1931, and, at three out of the four stations, lasted seven years, The spraying was kindly carried out by Mr. W. E. Ballard. In cases where no paint was applied outside the aluminium-sprayed coats, there was some deterioration of the coating, which was seriously altered at the London station, but no rust had appeared anywhere. In cases where a single coat of cheap iron oxide oil paint had been applied outside the sprayed aluminium layer, the condition was almost perfect (apart from soot) after seven years' exposure - even in London.

These tests were terminated just before the outbreak of the war, and the results suggested that a promising method of protecting steel would consist in aluminium-spraying followed by a coat of paint. Practical experience, accumulated during the period of hostilities, has confirmed this. Interesting results, which may now be mentioned, have emerged in connection with the protection of cylinders containing hydrogen for balloon barrages. These cylinders have to be exposed to all

sorts of conditions - including marine and tropical atmospheres - and, since it is essential to reduce weight to the minimum, they have relatively thin walls, so that a small amount of pitting would have serious consequences. Fortunately, however, the protective system indicated has proved reliable, and reports of the state of cylinders exposed to severe conditions have been most encouraging.⁶

Paints for Uncleaned Surfaces. The cleaning of steel surfaces by shot-blasting or pickling is only economical where the process can be applied on a large scale. In small jobs, the application of paint to steel-work which carries residual mill-scale, rust, moisture and frequently oil, often cannot be avoided. Two types of paints have been considered at Cambridge which, at least in some cases, seem to afford hope that the painting of surfaces to-day considered as "unpaintable" may become a practical possibility in the not too distant future.

The first type - the **cementiferous paints** - have been developed within the Cambridge University laboratory, but it is not permissible to discuss them to-day, except to say that, being based on an aqueous vehicle, they will automatically take up any moisture which is present on the surface, that they are specially suitable for use on rusty steel and that with certain modifications, they can be made to emulsify, and thus render harmless, small amounts of oil or grease present on the surface.

The second type - the **zinc-rich organic paints** - has been developed more or less independently at different places, and indeed certain zinc-rich organic paints are to-day on the market. Much of Mayne's work⁷ at Cambridge has been devoted to studying the mechanism of the protection afforded by such paints even when applied to rusty steel surfaces, and to over-coming some of their defects.

Mayne has found that any paint coat pigmented with metallic zinc dust can be regarded as an electrical conductor if the zinc-content is sufficiently high, so that the individual particles of zinc are pressed into contact with one another. This is true, whatever vehicle is used. But with certain vehicles, such as linseed oil, the mixture containing the necessary proportion of zinc dust is incapable of being brushed out on metal, and must be applied with a palette knife, which is, of course, not a practical proposition. If the vehicle be polystyrene or chloro-rubber, mixtures possessing the required zinc-content are easily brushable; the films after drying contain about 95 per cent. by weight of metallic zinc.

If such paints are spread out on clean, bright steel, and a scratch-line is pierced through the coat after it is dry, and if the specimen is then immersed, say, in sea water, the steel bared at the scratch-line receives cathodic protection, just like steel carrying an electro-deposited or sprayed coating of metallic zinc. There is nothing surprising about this, since all parts of the zinc in the paint coat are in electrical contact with one another, and the particles at the base of the coat will be in electrical contact with the clean steel. But it is also found that if these zinc-rich paints are applied to rusty steel, protection is still provided at a scratch-line. Mayne's electrical studies⁸ have shown the reason for this. Although in the opening stages there is no electrical connection between paint coat and underlying steel, such a connection develops later, because the zinc at certain places reduces the rust to metallic iron (or possibly to magnetite), so that a conducting bridge is formed through the rust coat, connecting the zinc and the steel basis. Since there is good lateral conductivity along the paint, a limited number of these bridges will serve to put the whole paint coat in effective connection with the basis, so that the cathodic protection at discontinuities is easily understood.

An interesting feature of Mayne's electrical studies is that zinc-pigmented coats which are found to be in electrical contact with the steel basis in the early stages often cease to be in contact later. This is probably due to the fact that the zinc particles in the innermost layer of the coat become used up, so that the connection is broken. Nevertheless protection of the steel continues, probably because, during the earlier period whilst the connection still existed, zinc hydroxide was deposited on the

exposed steel as a cathodic product of the electrolysis of zinc chloride (formed by the anodic reaction), so that any iron salts formed subsequently at such places will be precipitated by the zinc hydroxide as **adherent** rust in physical contact with the metal. This adherent rust will possess a protective character, and will smother further passage of iron into solution, so that the loose, non protective type of rust characteristic of uncoated steelwork is not formed. The formation of adherent, protective rust in long-continued experiments at a scratch-line on specimens painted with zinc-rich paints and immersed in sea-water has been observed in the laboratory,

Whether or not the explanation given is completely correct, it is a fact that specimens of rusty iron carrying a single coat of zinc-rich polystyrene paint, with a scratch-line pierced through the coat so as to expose bright steel, have been partially immersed in sea water in the laboratory for about two years without the formation of any loose rust. Specimens carrying two coats of similar paint have been exposed by Dr. Harris on a raft in the sea at Millport for about two years. And are practically uncorroded. There is some fouling on them, but it is actually much less than on specimens carrying two coats of commercial anti-corrosive paint followed by a commercial anti-fouling coat, since here intense corrosion has set in and the rust has pushed away the anti-fouling coat. The fault would seem to lie less with the commercial anti fouling preparation than with the so-called anti-corrosive coats on which it has been applied, since the same commercial anti-fouling preparation applied upon a cementiferous coat (which has prevented the under-rusting) has successfully stopped fouling. Nevertheless it is too early to assert that these new paints can solve the problems of marine painting, and indeed in their present form they suffer from certain defects, one being a tendency to develop blisters in some situations.

Blistering. It is an unfortunate fact that several high-duty paints, otherwise satisfactory, are prone to blistering. Mayne has devoted some work to the study of blisters, which he finds can be developed on steel coated with a clear lacquer and immersed in sea water; thus they are not confined to paints pigmented with metallic zinc, although for reasons stated later such paints are especially susceptible to the trouble.

The cause of the blistering is apparently as follows. Electro-chemical principles indicate that the migration of cations to the cathodic points and of anions to the anodic points causes the concentration below the lacquer to become locally higher than in the liquid outside.⁹ At the cathodic points the product, sodium hydroxide, tends to loosen the paint, as shown in the author's early work,¹⁰ and the difference of concentration between the cathodic points below the lacquer and the sea water outside is largely relieved by water being drawn inwards through the lacquer by osmosis, causing the coat to swell up into a blister. At the anodic points, the product is ferrous chloride, which will not loosen the coat, so that the concentration difference cannot be relieved by osmotic intake of water, but must be relieved by the diffusion of ferrous chloride outwards through the lacquer. Thus at the cathodic points there arise loose blisters full of alkaline liquid--as Mayne has observed -- whilst at the anodic points there is no loosening of the coat, but a production of adherent rust nodules.

Blistering is particularly liable to occur on painted steel near the water-line, since the locally good supply of oxygen makes the water-line zone cathodic, so that alkali is here produced in excess. It is especially characteristic of paints pigmented with zinc or aluminium, since in such cases the steel is itself cathodic towards the pigment. Consequently the alkali is formed between the paint coat and the steel basis, and the zinc-rich paint itself rises as a blister.

In other cases the zinc-rich coat may remain adherent, but the coats covering it may rise. This sometimes occurs when the zinc-rich coat is covered with a commercial anti-fouling paint containing a copper compound, In such a case, metallic copper is likely to be deposited at the junction between the coats. and the alkali formed at the cathode of the cell zinc/copper, being

liberated between the two paint coats, often causes the anti-fouling paint to rise in blisters, the zinc-rich paint remaining adherent. This tendency of an anti-fouling coat applied on a zinc-rich coat to blister has proved a serious drawback to the use of zinc-rich organic paints on ships, but it is believed that the trouble is capable of being overcome. If so, the zinc-rich paints should play a very valuable part in preventing marine corrosion of steel.

Although the mechanism suggested probably accounts for the blisters met with on the special paints under study at Cambridge, it must not be assumed that it is the only, possible cause of blistering. Vernon and Wormwell,¹¹ whose work on marine corrosion is of very special interest, write :-- "In conditions of rapid movement of painted steel specimens in sea water (natural or synthetic) small blisters usually appear before there is any sign of corrosion anywhere on the specimen. When a blister breaks, the steel beneath is at first bright and uncorroded, remaining so for one or two days and then beginning to rust." If there are several different causes of blistering the problem of prevention clearly becomes more difficult.

SOLUBLE INHIBITORS.

Safe and Dangerous Inhibitors. It is well known that certain substances such as potassium chromate, sodium hydroxide or sodium phosphate, when added to water in sufficient quantities, render it completely non-rusting, so that iron remains bright indefinitely in water thus treated. Unfortunately, if the addition of soluble inhibitor is insufficient to stop corrosion entirely, the attack is actually intensified. As pointed out by the author in a theoretical paper,¹² this is generally inevitable where the inhibitor is one which acts by suppressing the anodic reaction. If an anodic inhibitor is added in insufficient quantities, so that the corroded area is diminished, then, if the corrosion rate were controlled purely by the anodic reaction, the corrosion rate would be diminished in the same proportion as the corroded area, and the intensity of attack (the corrosion per unit area of the part affected) would be unchanged. But if the corrosion rate is controlled even in part by the cathodic reaction, the rate of attack will diminish less quickly than the corroded area, so that the intensity of attack will actually be increased. This intensification of attack by insufficient additions of soluble inhibitors is particularly dangerous if the water contains chlorides. For the amount of inhibitor needed to stop attack is then greater, owing to the penetrating power of chlorine ions, and the localized attack will be met with at a higher total concentration where the rate of total corrosion will be greater.

This intensification of attack by insufficient additions of inhibitors is a serious practical problem where chromates or alkali are added to prevent corrosion in cooling system. Even when the additions may appear to be adequate, intense corrosion may set in at inaccessible crannies, or under heaps of settled debris - places unfavourable to the necessary replenishment of the inhibitive chemical, which is consumed in stifling corrosion. Under such conditions, perforation of a cooling tube or jacket may occur more quickly than if no inhibitor had been added at all. Consequently there is to-day great hesitation in recommending this type of soluble inhibitor.

The same theoretical argument which predicts that intensification may arise from the use of anodic inhibitors in critical amounts, indicates that no corresponding danger attends the adoption of cathodic inhibitors. Unfortunately, cathodic inhibitors are inefficient in the sense that even when added in excess they fail to stop corrosion entirely; moreover, there are special circumstances where even cathodic inhibitors may intensify attack.¹³ Thus it would seem at first sight necessary to choose between anodic inhibitors, which are efficient but not safe, and cathodic inhibitors, which are reasonably safe but not at all efficient.

Combination of Anodic and Cathodic Inhibitors. Theory suggests that if cathodic and anodic inhibitors were used in conjunction, a system might be evolved which was both safe and efficient.

An attempt has been made to use chromic acid and magnesium hydroxide simultaneously. the mixture being known as “basic magnesium chromate.” Experiments at Cambridge by Thornhill¹⁴ indicated that this combination had certain attractive properties. Under conditions where heat was being transmitted to the liquid through the steel, it caused no intensification even if added in insufficient quantities to stop attack entirely; furthermore it proved capable of putting a stop to rusting, even where it had already been allowed to start before the inhibitor was added. Unfortunately, under stagnant conditions, in the absence of thermal circulation, the inhibitor was found to be “dangerous” in the sense used above; when it was added in insufficient quantity, the loss of thickness, as measured with an electrical micrometer devised by Thornhill for the purpose. was worse than that caused by the same water not treated with inhibitor.

Attempts were then made to use anodic and cathodic inhibitors alternately, and here the results are more hopeful. Thornhill has found that if a steel specimen is immersed on alternate days (1) in natural water containing small amounts of potassium chromate¹⁵ (an anodic inhibitor) and (2) in the same water containing zinc sulphate (a cathodic inhibitor), both inhibitors being present in amounts insufficient. to stop corrosion altogether, the corrosion tends to fall off with time and may after some weeks become negligibly slow. At this point it may be possible to keep the steel in natural water containing no inhibitor at all and some days elapse before corrosion sets in again. When it often does, it often starts at a point not previously attacked, so that the tendency is to spread out corrosion, rather than to intensify it. Results suggest that this method of inhibition will enable small amounts of chemicals to be used without serious fear of intensification even when attack is not prevented completely. The matter is still under study, and different natural waters behave somewhat differently, but there is at least. some prospect that the researches may lead to the “safe and efficient” inhibitive treatment which has so long eluded discovery. .

CORROSION FATIGUE

The Problem. It is generally agreed that fatigue is responsible for a considerable proportion of the more dangerous allures met with by engineers. Provided that corrosive influences can be excluded. it should be possible avoid fatigue even under conditions of alternating stress, simply by ensuring that stresses are every everywhere below the fatigue limit of the material selected; the fatigue life should then be infinite. Unfortunately if corrosive influences are present, there is no fatigue limit; probably most. engineering fatigue failures are really due to corrosion fatigue in the early stages, although later the crack may extend by pure fatigue.

The Danger of Brief Exposures to Corrosive Conditions. The mechanism of corrosion fatigue is under scientific study at Cambridge by Tchorabdj, whose results, although at first sight academic, have led to one conclusion of considerable practical importance. Tchorabdj uses a two-stage procedure somewhat different from the well-known method of McAdam. In the first stage he subjects his specimens (actually steel wire) to alternating stresses in presence of potassium chloride solution (a special feeding device maintains a clear-cut ring of liquid on the wire at the chosen point), After this (corrosion fatigue) stage has proceeded for the required time, the flow of liquid is stopped, the specimen cleaned and wiped dry, and alternating stressing (at the same stress range) continued in the absence of corrosive liquid, until the specimen breaks. The time needed for breakage in the second stage is a measure of the residual strength left in the steel after the corrosion fatigue has done its work.

Since Tchorabdj works below the fatigue limit, the life in the absence of a corrosion stage should be infinite. But he finds that a short exposure to corrosive conditions may reduce the total life to a

few hours. If the corrosion fatigue stage is continued for a longer period, the total life again increases. In other words, a short exposure to common conditions may be as dangerous or more dangerous than a longer exposure. The practical application of these results is obvious. If in some machine, vehicle or structure corrosive influences can be continuously excluded, alternating stresses involve no danger provided that they do not exceed the fatigue limit. If during a comparatively short period, vigilance is relaxed, and corrosive influences gain access to the metal, corrosion fatigue will set in and the crack will continue to extend even if shortly afterwards the precautions are renewed and corrosive influences once more excluded. The insidious character of corrosion fatigue becomes evident.

The Prevention of Corrosion Fatigue. It becomes a vital necessity to discover methods of combating corrosion fatigue and here considerable work has been carried out by Huddle, whose experiments¹⁶ show that corrosion fatigue life can be considerably prolonged by painting with zinc-rich paints of the organic or cementiferous type. Specimens of mild steel, subjected to an alternating stress range of +/-10 tons/sq.in. And a frequency of 1250 rev./min, in sea water break after 1.7×10^6 cycles. If the specimens are painted with zinc-rich polystyrene paint, the life exceeds 8.4×10^6 cycles. His results suggest that the protection, although partly mechanical, is partly electrochemical, and can thus operate at gaps in a coat. It seems likely that the failures due to corrosion fatigue could be rendered less frequent by protective measures of this character, although it cannot be claimed that the trouble has been overcome. Moreover, protection by painting is not applicable to bearing surfaces, or other places where there is no clearance.

OTHER PROBLEMS.

Policy Regarding Corrosion Problems. There seems to be a reasonable prospect of obtaining in the not too distant future at least a partial solution of the problems already mentioned. Other corrosion problems exist. or will arise in future, perhaps suddenly. — It would be useful to know how far Concerns (whether Government Departments or Private Firms) intend to tackle corrosion problems within their own laboratories, and how far they propose to parcel them out to laboratories which specialize in such problems, In the former case, there will be a demand for men with research experience in corrosion. and it is very doubtful whether there is anywhere a means of meeting that demand. Certainly at Cambridge the only possible reply to-day to a firm which enquires for a trained corrosion investigator is that, if the firm cares to endow a piece of research for. say. two years, it can at the end of the period have the first claim on the man who has carried it out. It is, of course, possible that the situation may soon radically change, but, if there is prospect of the demand continuing, there should be a plan to meet it; and if such a plan exists to-day, it is unknown to the author.

Conditions of Work in Laboratories Engaged on Industrial Problems. Whilst the subject of the supply of young University men to industrial posts is under discussion. a few general remarks may perhaps be permissible on the sort of conditions which will best enable such men to carry out useful work; these do not refer exclusively to men engaged on corrosion problems. Some hesitation is felt in introducing this subject, but it is probably as important to the Department or Firm as to the young men that the matter should receive attention, since clearly a keen scientist will better serve his employers if he remains a keen scientist instead of degenerating into a weary hack.

The young man leaving the University has usually an up-to-date knowledge of his subject, based on the interest which he feels in it and which has given him the urge to study it. He lacks, of course, technical experience, and is likely to be of limited value to his employers until this experience is gained; if, after a few years, he has gained experience and still possesses an up-to-date knowledge, he will be of great value. If he has not kept abreast of advances made in his subject, his value will be no greater than when he took up the post. Now he will only keep up with his subject if he

remains so interested in it that he still feels the urge to read and think about what appears in the journals; if he is made to work long hours in the Works Laboratory, with little or no access to libraries, returning home tired in the evening, it is certain that he will not read in his own time, or, if he does still read, he will do so unintelligently.

For this reason alone, it would seem that a system of long and inelastically regulated hours in a Works Laboratory is simply bad business. But there is another reason for maintaining conditions of work which will keep the scientist fresh and alert. Each of us occasionally experiences a "brain-wave" - the arrival of some inventive idea which suggests how what, by any obvious procedure, will require a week, can be accomplished in a day. On purely financial grounds, brain-waves are things worth cultivating, but they occur most often when the brain is fresh, and comes back to a problem after a period of relaxation. I believe that the practice of giving young scientists two weeks holiday a year is a sure way of restricting brain-waves to a minimum, and that the doubling of this period would pay for itself in the quickening of inventive faculties.

After all, the Corrosion Fatigue of Metals is a minor tragedy compared to the Corrosion Fatigue of Men.

APPENDIX.

METHOD OF STUDYING THE ELECTRICAL CONNECTION FROM A ZINC-PIGMENTED PAINT COAT THROUGH THE RUST LAYER TO THE STEEL BASIS.

Current Method. If a horizontal plate of zinc or zinc-coated steel is covered with filter paper soaked in sea water and a freshly cut edge of a steel strip is pressed vertically on to the same paper, both horizontal and vertical steel being joined through a reversing switch to a milliammeter, a current will flow in a direction indicating that the zinc is anodic towards the steel strip. If instead of a zinc plate, a steel plate covered with **old**, compact rust as a result of outdoor exposure is used, the rusty steel will be found to be cathodic to the freshly cut edge. If a zinc-pigmented paint has been applied outside the rust on the steel plate, the latter will be found to be cathodic if the zinc is out of contact with the steel basis; but if conducting bridges exist penetrating through the rust layer, and establishing good connection between coat and basis; the zinc-painted steel will be anodic. This simple test serves to indicate whether the currents flowing will be in the sense calculated to confer cathodic protection upon the bright edge of the vertical strip and furnishes some idea as to whether the paint coat is likely to offer electro-chemical protection to bare steel which may become exposed at some scratch-line penetrating the coat. Unfortunately the magnitude of the currents, and even (in border line cases) their direction, depend somewhat on the history of the strip previous to the test, and Mayne has preferred to use a potential test furnishing results which are probably more reproducible, °

Potential Method. If a piece of clean steel is painted with zinc-rich paint, so that there is perfect contact between zinc and steel, and perfect exclusion of the sea water from the rust layer, the potential measured on a potentiometer against, say a calomel electrode should be similar to that of solid zinc. If the paint is applied outside a coat of old rust, in such a way that there is no contact between zinc and steel basis, and if the sea water can penetrate through the zinc coat to the conducting part of the rust below, the potential should be the same as that of uncoated rusty steel. In intermediate cases, where the electronic resistance (R) of the metallic bridges connecting steel and zinc coat is of the same order of magnitude as the electrolytic resistance (Z) of the liquid paths penetrating the zinc coat to the compact rust below, then the potential will (Fig. 1) lie between that of zinc (Z) and that of rusty steel (S),

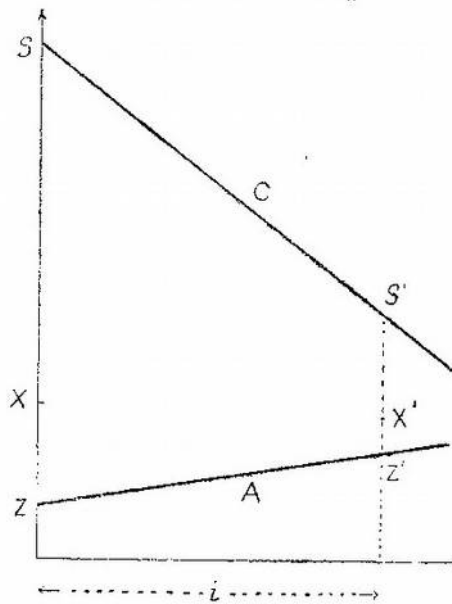


Figure 1.

and if $(R+\zeta)$ is so high that the current flowing between zinc and steel is small, it will fall at such a point, X, that

$$ZX/XS = R/\zeta$$

In the more general case where the current flowing is sufficient to cause polarization, the two potentials will move towards one another, as shown, by the polarization curves A and C, thus diminishing the resultant E.M.F. The current strength will attain that value, i , which will leave a residual E.M.F., represented by the intercept $Z'S'$, equal to $i(R+\zeta)$, since this value is just sufficient to force current i through the resistance $(R+\zeta)$. The potential taken up will be represented by the point X' on the intercept such that

$$Z'X'/X'S' = R/\zeta$$

It follows that any change which improves the contact between zinc coat and steel basis (diminishing R) will, provided that r is not altered, cause the potential to move towards that of zinc, whilst any change unfavourable to the bridging will, given constancy of ζ cause it to move in the opposite direction. Thus the shift of potential with time gives information regarding changes in the connection between zinc-rich coat and steel basis.

Before throwing the meeting open to general discussion, the Chairman invited Professor T. Turner to propose a vote of thanks to the Lecturer, to be seconded by Dr. J. C. Hudson.

DISCUSSION.

PROF. T. TURNER. It is a great pleasure to me to be able to be present at this first Meeting of the Session. It is a long time since I had an opportunity of being among you, and one remembers how many old friends one had and, I hope, still retains in this district. To-night we have been privileged by the presence of one whose name is familiar wherever corrosion is studied. It matters not in what part of the world you go, you will find people who have read and very often carefully studied the work of Dr. Ulick Evans. This work appears to me to follow in the lines of the great discoveries. In connection with research, we may sometimes want to settle some particular question - some little difficulty that we have in the work, That is one kind of research. The other is what is commonly called "fundamental research." Fundamental research is very often conducted by private individuals

with very simple apparatus and with very small funds. When some remarkable discovery has been made and it comes to be applied. then we require expensive apparatus, large manufactories and: big pay-rolls. Take Faraday for example. A few bits of wire, a few glass or earthenware cells. probably a little sealing wax, some cotton. That was practically all he had. and from these very simple things he was able to deduce the laws which were afterwards of such wide and general application. I remember that Dr. Ulick Evans began, perhaps twenty years or more ago, with a number of small experiments with test tubes. Then there were beakers, and small pieces of metal, and we rather wondered what this was going to come to. He seemed rather to be playing, but he was doing the fundamental work, and you will have seen how it has grown in the same way as other great investigations until it has become applicable in so many directions and has such important connections with the well-being of the whole world. It is all the more important because we are using up our metals. Take copper, for instance. We are extracting more copper than ever before, hut we do not put anything back. That metal is being lost except in so far as we recover it from scrap; and so with tin and ether metals. To conserve the metals is, or should be, the object of the metallurgist. The metallurgist should make metals; he should work metals: he should conserve metals.

I ask you to support a very hearty vote of thanks to Dr. Evans for coming so far and for giving us so interesting a lecture and for teaching many of us a good deal in his address this evening.

DR. HUDSON. It is a great pleasure to me to support this vote of thanks, and also a matter of pride that I should follow Professor Turner whom we are very glad to see again in Birmingham.

We have had a most interesting talk and have learnt a great deal from it, It will not be necessary for me to allude again to the eminent position which Dr. Evans occupies in, the corrosion field. At the same time he combines the art of very excellent experimental technique with an equally good facility for instructing others and a great willingness to help all and sundry who are interested in this subject. We ourselves have over a number of years benefited in many respects by the advice he has given us oh numerous occasions.

With reference to tests in sea water of zinc-rich coats; we have conducted tests on some of these coatings and I think it is fair to say that their life, to destruction, would certainly be of the order of two years or more in sea water. Dr. Evans refrained from. giving figures for ordinary commercial paints, but I think it would be fair to say that if tested under equivalent conditions less than 25%, of them would have a life exceeding six months. That is not meant to be any aspersion on the paint manufacturers, because many of those paints are only meant for maintenance purposes and not for the initial priming of steel. We have found in our work that zinc dust is a very valuable constituent of anti-corrosion paints, particularly for under-water use, but there are certain difficulties. First of all, with the high concentration of zinc dust, you will find that the tins will blow up if the medium of the paint is not carefully selected. That can be overcome by using zinc-dust paints as a two-component system. The alternative is to use a special medium in which this hydrogen evolution does not occur, and that, I think, is one of the great advantages of the polystyrene type of vehicle. We have found that aluminium is also a useful constituent for these paints, and I should like to ask Dr. Evans whether he has ever tried flake aluminium in the paints in the same way that he has tried zine dust.

(The vote of thanks proposed by Professor Turner and seconded by Dy. Hudson was carried unanimously, and the Chairman threw the Meeting open to discussion)

MR. BALLARD. In those very early days mentioned by Professor Turner, when the first experiments were made on very small samples, I remember that we sprayed steel sheets with aluminium and obtained some rather striking results. Work on these specimens was continued at Cambridge and by Dr. Sutton at Farnborough. and the subsequent work has been described by Dr. Evans. One point which I think should be mentioned is that we are continually hearing it said, by engineers particularly:-- "Yes: but that was done in a test tube or on a sample 2in. Square!" We know that in many cases it is very difficult to match up tests on small samples with what will happen in practice, but that is not always true and I think we should not fall into the error of thinking that because tests are done on a small scale they bear no reference to the bigger tests which will be carried out in commerce afterwards.

I would like to ask one or two questions with reference to the polystyrene vehicle for zinc-carrying paints. I can understand that it is a very good vehicle, especially if the polystyrene is of fairly low molecular weight, but. I am rather surprised to hear that it is so good from a practical point of view because polystyrene is a very excellent non-conductor, and therefore it seems strange that it should be a good vehicle for a paint which depends entirely for its use on the zinc or aluminium particles being in electrical contact. I should have thought that some of the plastics which will absorb water would have been more effective. Its success is probably due more to the fact that one can load up the polystyrene with a large percentage of the metallic powders rather than to any other factor.

It is very clever to invent a paint which can be put on a very rusty surface. I know and you know what Dr. Evans means when he says that here is a paint which can be used under difficult conditions. It appears to me that many engineers will draw another conclusion, and that instead of putting it on weathered steel or steel which is only comparatively rusty, they will expect this paint to be equally effective on steel with humps of scale on it and from which the scale will drop off complete with paint. I have been for many years interested in corrosion, and the more years that I go the less opinion have [of the engineer and the corrosion problem, I wonder whether it is not dangerous to invent paint which can be put on to dirty surfaces, because I expect the next thing will be that they will take a strip of steel from the hot-rolling mill and paint that !

Before sitting down, I would like to express my sincere appreciation for all these talks given by Dr. Evans. He not only knows his subject but can also "put it over."

MR. RODFORD. I have listened with very real interest to the lecture, but after hearing Mr. Ballard's remarks and as an engineer who is faced at the present moment with the problem of painting many thousands of steel castings and steel fabrications which owing to war conditions have been stored out in the open, I would be grateful to have any advice which Dr. Evans can give me. Briefly. the position is that the ordinary types of paint which the Ministry of Supply will allow us to use are mostly oil-base paints containing rather high proportions of natural resin and pigment. The great trouble is that with a single coat of paint of such a description, we find that when the machines have been standing in packing cases for some time the paint is no longer on them. I was immediately interested when Dr. Evans mentioned paints which could cover steel bearing mill scale and rust and give reasonable protection.

It seems to me that the most important property of any paint is that of adhesion, and provided the large chunks of mill scale and rust had been removed there would be a great outlet for such a paint provided it had good adhesion, particularly as many of the machines to which I have referred have to be used on board ship where fire risks are a very important factor. It would appear that a paint containing a great deal of metal as pigment would reduce these fire risks. Therefore, if Dr. Evans would care to enlarge on the bond which he has used for these corrosion resisting paints of the polystyrene type. the information would be of very great assistance to Industry.

MR. T. D. SMITH. I would like to thank the lecturer very much for the extremely clear way in which his subject has been presented, particularly as I have just had the unenviable job of translating forty-two pages of a closely written paper on corrosion! It is interesting to note that the principle of anodic protection is used in the aluminium clad alloys of the Duralumin type. While an aluminium coat of high purity is used to protect the high strength material underneath the coating. On the main subject of the lecturer's remarks I am afraid I shall have to put my question in the form of a paradox; that is when is corrosion not corrosion? I ask this because if you take plain aluminium or zinc, and steel, and clean them and expose them to the atmosphere, oxidation takes place, but in the one case it progresses continuously whilst in the other case a coating is formed which prevents further corrosion.

Finally, I would like to endorse Mr. Ballard's remarks on the value of corrosion tests.

DR. PRICE. My first question relates to the reduction of scale which is underneath the zinc coating. Dr. Evans says that the iron oxide is reduced to iron. If he has any views on the subject of how that reduction occurs. I personally would be interested. Is it, for instance, that the zinc itself is converted to oxide in some way? If so, I would hardly have thought there was sufficient conduction within the film to allow that to take place.

Secondly ; the lecturer referred to adherent scale that was formed when the zinc coatings were perforated, and underneath there was this layer of rust. I wondered whether this could be an iron zincate formed in direct contact with the surface, Perhaps Dr. Evans could give us his views on this point.

MR. C. E. BEYNON. As one who has been associated with some research work on corrosion, I would like to mention two instances where the results were successful. The first problem concerned the tarnishing of tinplate, known as "yellow stain," and by applying Dr. Evans' well-known theory we were able to explain the appearance of the stain and also suggest means of preventing it.

The other problem was corrosion of aero-engine Induction pipes made of aluminium alloy welded together (assembled from 6 or 8 parts). These were submitted to us covered with a white powder deposit. On examination we found potassium was present, which suggested that the powder had come from the flux. We were well aware of the well-known and dangerous effects of chlorides, particularly on aluminium oxide films. I wonder if Dr. Evans can give us a simple explanation of this poisonous effect of chloride ions ?

To-day we received a letter from the research chemist of a well-known industrial organisation. in which he mentioned that he was coming to the conclusion that mathematicians should inherit the earth. They have invaded the field of physical metallurgy and have given us indications that alloying nowadays must be regarded not as an indication of new metals but an indication of new valency electrons. . . . You cut right across the equilibrium diagram, I mention all this because I feel there are two generalisations in inorganic chemistry which need some explanation ,

(1) **Periodic classification**, which has been used to enable non-metallurgists to understand the modern atomic theory:

(2) **The electrochemical series**. I have often wondered why it should happen that two neighbouring elements in the periodic series (e.g. copper and zinc) should be so far apart in the electrochemical series.

Presumably. with regard to the alloys, the theory was introduced with the idea of putting forward a tentative suggestion; namely, that the face-centred cubic metals do not seem particularly keen on

accumulating electrons, whilst on the other hand a body-centred cubic metal like sodium or iron is only too anxious to lose them, Is there any application of this modern explanation to the subject of corrosion? This may be rather an academic point in view of the fact that Dr. Evans is dealing with the practical application of corrosion, but I think there are many people for whom the only way of tackling a practical problem is by starting with the academic.

MR. TOLHURST. I have listened with very great interest to Dr. Evans' remarks, and as an engineer I agree with Mr. Ballard that if you are going to put a coating on, it should be put on as clean a metal as possible, I venture to suggest, however, that it is not always possible and sometimes not advisable, because in the case of (say) coal mining machinery you get the abrasive action of the coal on the plate and however much trouble and expense you go to in putting on the paint, the abrasive action removes it,

I would like to ask Dr. Evans what his experience has been with copper-bearing steel. We heard of it shortly after the last war. We had some fine reports on it, but were rather chary of working it ourselves because we had no personal experience. Some of our customers tried it. and in the meantime we made some experiments with samples of copper-bearing steel, some wrought iron and some mild steel which we put out in the packing shed. We expected the copper-bearing steel to show up best. About a week later we examined these samples (which were quite uncoated), and the copper-bearing steel was smothered with rust, the ordinary steel did not show much sign of rusting and the wrought iron was O.K. I took them inside later and was surprised to find, with the copper-bearing sample, that although it had a surface rust there was no pitting. The mild steel was deeply pitted but the wrought iron was fairly free from pitting. After that we felt more inclined to recommend copper-bearing steel for mining machinery, and only within the last week we have had a letter from a customer to say that the samples made from copper-bearing steel have definitely withstood the wear and tear much better than ordinary mild steel. If Dr, Evans could say anything about this, I would be greatly obliged.

MR. DUNLOP. To-night Dr. Evans has described the use Of paints containing metal powders on parts required to resist wet corrosion, May I ask if he has had experience of the use of similar materials on dry corrosion, e.g. to resist oxidation at elevated temperatures? It is quite a usual practice to paint the outside of furnaces with aluminium paint. I wonder whether Dr. Evans has any other materials to suggest, suitable for painting parts to withstand oxidation at high temperatures,

MR. HEATHCOAT. I would like to ask whether the metal-bearing paints are suitable for use in dipping tanks. The particular problem in which I happen to be interested is one where it is not possible to either brush or spray. The parts are resistance welded assemblies and are not accessible, and protection can only be obtained by dipping. I am wondering whether the metal dust would settle at the bottom of the tank, or whether it would remain in reasonable suspension in the mixtures suggested. I have tried zinc chromate with good success, but perhaps the metal dust would be better.

In some exploratory tests being made recently, a proprietary lacquer was being used both in the clear form and in two pigmented varieties. I thought I would try zinc chromate in the clear one. I heavily pigmented the lacquer with this and stoved the material at 400°F., and after 100 hours the metal was still bright in the cabinet. Probably that method would be much too expensive to use commercially. If these metallic paints could be used as dipping paints. it would be very interesting for the problem I have in mind.

A MEMBER. As one who used to attend Dr. Evans' lectures twenty years ago, I am always very interested in what he has to tell us, One point that struck me about the paints he has mentioned was that they were mainly intended for ships and bridges and ironwork generally on which a fairly rough sort of finish only is required. In Birmingham perhaps one of the most important trades is the

manufacture of motor-cars. And there we are very interested in protection from rust. I should like to have something which would stand crushing and bending without rusting away. but it is also essential that the finish is smooth and slick. I wondered whether Dr. Evans would consider that these types of paint were likely to be used for and would much increase the life of motor-car bodies, or whether that is a long way off yet.

MR. REGAN. I would like to ask if the vehicle in zinc coatings is necessary at all. Could the effects of a zinc coating, which have been described to-night, be equally or better achieved if the zinc were applied electrolytically ?

MR. JENNINGS. There is one point on which I think we should all like information; that is, on the question of the sprayed coatings. What was the purity of the aluminium. Or zinc metal used and what was the method of spraying? We know that there are three methods - the wire process, the powder process, and the molten metal process.

MR. STANTON. I am rather interested in corrosion as a long-term policy, and wondered whether Dr. Evans could give us any information about the point at which the coating really breaks down. I am mainly concerned about the metal sprayed coatings. Has Dr. Evans any data on the actual area of exposed steel on which corrosion does not take place ?

Mr. Sachs. Dr. Evans mentioned, when he was discussing the theory of protection by zinc coatings of rusty surfaces, that the surface was covered by zinc hydroxide. Iron salts get mixed up with the zinc hydroxide and they form a protective oxide layer. Is it possible to make the normal loose rust into a protective layer by holding it on the surface or, as it were, entangling it by some kind of chemical like zinc hydroxide ?

DR. BAMFIELD. One thing Dr. Evans did not emphasize is that there are are lots of different processes for preventing corrosion, and most of them have their uses. It is up to the user to decide which process he is going to adopt; not only on the basis of the corrosion protection afforded, but on the suitability of the process and the cost. He may decide on metal spraying, galvanising or painting, or on some particular treatment followed by painting, but it depends on many different factors including the size and shape of the article and the use to which it will be put.

DR. JENKINS. There must come a time when you have to strike a balance.

DR. EVANS. I should like to thank the Chairman, and the proposer and seconder of the vote of thanks, very sincerely for their extremely kind remarks. and to thank all those who have taken part in the discussion, I am sorry that Professor Turner had to leave early, as I should have liked to thank him while he was here for the very great kindness he has shown me, not only this evening but on many other occasions during the last twenty-one years. He came to me after the first paper I ever gave on corrosion, and encouraged me to continue the work, I particularly appreciated the fact that my name was mentioned to-night in conjunction with that of Faraday, and I was also very glad that Professor Turner made a reference to the fact that it is one of the duties of metallurgists to study the conservation of metals. I fully agree. I think we cannot go on using up materials recklessly in the present way, and that will have to be brought more and more to mind as time goes on.

I was extremely interested in and very grateful to Dr. Hudson for the particulars he gave regarding the probable life of different types of paints. I fully agree that the keeping power, in the pot, of these new zinc-rich paints is extremely important, and although I have no comparative particulars, I think that the zinc-rich polystyrene paint is going to be pretty good in that way. We have not made very much use of aluminium in paints recently. Some of the early work which Britton and I did on aluminium pigmented paints was not entirely encouraging, but I think that was probably our fault. I

agree with Dr. Hudson when he says that the introduction of aluminium into these paints may be very useful indeed.

I appreciate very much what Mr. Ballard said about the possibilities of small scale tests. I agree that in the past there has been rather a tendency to say that you cannot get much out of small scale specimens. Whilst there is something to be said for these objections. I think we have learnt a good deal from work on small specimens. and that on the whole this work has been justified by observations in service on a large scale.

With regard to the question of polystyrenes and the use of very bad conductors as a vehicle for them: it is absolutely necessary to have a vehicle of such physical properties that the zinc dust particles can be brought into metallic and electronic contact with one another. We must get electrons across from the zinc particles to the steel. That really means we have got to have something which will stick the zinc particles together fairly effectively, so that they are in contact with one another in some part of their periphery. It would be no use trying to make up for lack of electronic contact by giving a vehicle which would have electrolytic conductivity. One could, of course, obtain it by using some plastic which absorbs water readily, but that would not give us a complete circuit.

We have got to deal with a cell, if we want a current to flow, and we join zinc and iron with an iron wire, we must have the two paths; the "electrolytic" on which the ions go, and the "electronic" (or metallic) along which the electrons go. You cannot make up a discontinuity on the electronic path by joining up odd things in a drop of salt water. That would not give you the current. Remember, we must have the two paths, so there is no advantage in introducing water-absorbent plastic; and as a matter of fact the vehicles which have the necessary physical properties to give you a specific situation are best obtained by polystyrenes or chlorinated rubber, which are heavily absorbent. Actually, the paints are fairly porous when they are put on. They appear to get less porous, no doubt as a result of the volatile part evaporating, probably through the precipitation of zinc hydroxide through the pores which are thus filled up.

I agree that we must not try to paint surfaces with a lot of adherent scale. I am relying on hand or mechanical wire brushing first of all, before the paints are put on, but the surfaces need not be cleaned by shot blast or anything difficult like that.

The question about the painting of castings stored out the open would take another lecture to answer. One gathers that these are machine parts, and I am not at all sure that the paints I have been describing would be suitable. As regards the question of fire risks, some of the cementiferous paints, which are completely inorganic after drying, are being considered in this connection. We have two classes - one when heated strongly cracks right off. There is another which can be put on steel, made red hot, placed under a tap, made red hot and quenched again and stands up quite well. There must therefore be some application for these paints in connection with fire risks, but I do not think they are going to be much used for machine parts when there is any question of a definite clearance; and for that reason I am not answering a later question. I am not very optimistic about their use in the motor-car industry, although I may say that one company has asked for samples. It was for a rather special purpose. and I have not heard the result.

I was asked why the corrosion product on some metals was adherent and on others non-adherent. There is an electro-chemical answer to that. In general. where the corrosion product is the direct anodic product it will be adherent. Thus in the case of lead and a sulphate solution the corrosion product will be adherent and protective before you can see it: whereas in the case of iron, the corrosion product (rust) is formed by interaction between the —anodic/cathodic products (ferrous chloride and soluble pentoxide) which meet and give you a very loose material.

Taking iron in phosphorous pentoxide solution, where the anodic product would be soluble, you get very little corrosion because it is smothered by the appearance of iron phosphate in the early stages, Taking iron in zinc sulphate solution; here the cathode product (zinc hydroxide) is a soluble body and tends to slow down the corrosion, Dr. Price suggested that this body was iron zincate. I have suggested this at a Galvanising Committee meeting. One meets the same type of film on certain varieties of galvanised coatings, and I suggested that it was a spinel in which the di-valent element is zinc, I regard it as zinc ferride. but I think I ought to regard it as ferric zincate. In that case we merely differ on nomenclature, and I think probably Dr. Price is right.

As regards reduction of the zinc oxide; I am really not quite sure, but think it is very much more likely that it is due to the reduction of iron salts which are practically always present in atmospheric rusts, and agree that is the thing to visualise. The thing is, we do seem to be getting a contact bridge through the rust coat.

I was very interested in the question of the differentiation of rate of corrosion in tinplate, which I read about when the work on it was published.

In reply to the question as to why chloride. Particularly, is fatal for aluminium oxide coatings; there is no doubt that chlorine ions can get through oxide coatings or films. Britton and I measured the penetrating power of different ions actually through films of aluminium and found that chlorides came at the top of the list. Iodides and bromides were very much the same, It is a fact that chlorine ions do cause your protective films to break down in practically every case,

There is a tremendous number of electron theories of passivity, and they flourish at the present time in America. We do not agree with the theories put forward, but it is clear that electrons have something to do with the question. The matter of the periodical classification I have dealt with elsewhere to some extent, but it is too complicated to embark on now. As regards the question of body-centre or face-centre lattices, I am not sure that the question should not be the other way round - not so much that certain lattices tend to loose electrons, as the fact that the rearrangement of the electrons may facilitate the formation of certain lattices. This is a matter which has been discussed a good deal by physicists lately.

As regards copper-bearing steels in mining machinery; I am very glad (and am sure Dr. Hudson is glad) that these copper-bearing steels came out well in the end after a bad start. I myself have had a similar experience of two materials: that which started best behaved worst in the end.

Particularly in atmospheric exposure tests where an electrolytic iron and steel are compared, the steel will be found to be completely rusty when the electrolytic iron has only small rusty patches. much of it being still bright, in the early stages; but if you leave it there for a year or so, you generally find that the electrolytic iron has rusted more than the steel.

With regard to paints for elevated temperatures; we are thinking of some of the cementiferous paints in connection with that, but it was not their original purpose.

In answer to the question of keeping pigments in suspension; it is necessary, of course, to choose your vehicle with the proper physical properties, but there is a fair choice. The reason why I recommend zinc chromate is that it is an inhibitor and will protect discontinuities in a similar manner to which potassium chromate when added to water prevents rusting, It is not due to cathodic production as in the case of the zinc rich paints.

As one of the speakers suggested, the paints I have mentioned are intended for a rough finish. At the moment I hold out no hopes of getting paints for smooth finishes.

Zinc would be better if applied electrolytically, but it is not on every occasion that you can put everything into a plating bath, Where you could apply the coat by hot galvanising, that would probably be more advantageous still. The point of zinc rich paint is that you can apply it when the article is in situ,

With the regard to the purity of the aluminium; we tried several degrees of purity when we were spraying these aluminium coats, including what was then called "E.P." (extra purity aluminium). But it would not be regarded as very high purity nowadays. It did seem to behave rather better than the commercial aluminium, but there was not a very great difference. As regards the method of application, all the coatings used in these tests were applied by the wire process, Dr. Hudson, has made coats applied by various processes, and he has shown that the wire process is the best. for certain metals at any rate. I would certainly prefer it for aluminium. I agree that applying the paint by dipping the welded assemblies, as mentioned by Mr. Heathcoat would be advantageous. For the inside of a narrow-mouthed bottle I fancy it would be more a question of pouring the paint in and rotating centrifugally.

What area can be exposed before the coating breaks down ? It depends so much upon the electrolyte and the thickness of the layer of liquid wetting the metal. Most of our experiments were done with scratch lines.

In reply to Mr. Sachs, I am afraid it is not possible to make ordinary rust protective by entanglement with zinc hydroxide. The rust was precipitated within the zinc hydroxide; it never had been loose, ,

I agree with Dr. Bamfield's remarks, I am glad he brought out the point that the user will have to choose according to the suitability of the material for the article that has to be protected, and there also has to be a balance between the economic factors involved, as Dr. Jenkin remarked.

(Dr. Evans thanked the Chairman and all those who had taken part in the Discussion, and was heartily applauded in return),

END OF MEETING.

REFERENCES.

1. T.H. Turner, *Proc. Inst. Mech. Eng.*, 1943, **149**, 773;1944, **150**, 97.
2. See Brochure "Protective Painting of Structural Steel," 1941 (Iron and Steel Inst.).
3. Conveniently summarised by J. C. Hudson, 'The Corrosion of Iron and Steel,' 1940 (Chapman and Hall).
4. S.C. Britton and U. R. Evans, *J. Soc. Chem. Ind.*, 1930, **49**, 173T ; 1932, **51**, 211T ; 1936, 55, 337T; 1939, **58**, 90.
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6. Information kindly supplied by Dr. H. Sutton, of the Ministry of Aircraft Production.
7. J.E.O. Mayne and U.R. Evans, *Chem. Ind.*, 1944, p. 109,
8. For electrochemical basis, see Appendix.
9. This may seem to conflict with the statements made in electrochemical textbooks that there is a drop in concentration around the electrodes. Such a drop will only occur when the electronic reactions remove the ions from solution; for instance, when nickel chloride solution is electrolysed between platinum electrodes, the cations are removed as metallic metal and the anions as chlorine gas, causing a diminution of concentration at both electrodes. If, how ever, sodium chloride is

electrolysed between iron electrodes (with attack on the iron at the anode), neither cation nor anion is removed and the migration will cause an increase of concentration both at anode and cathode.

10. U.R. Evans, *Trans. Electrochem. Soc.*, 1929, **55**, 243.

11. W.H. J. Vernon and F. Wormwell, *J. Iron Steel Inst.*: discussion on paper by U. R. Evans, "Progress in the Corrosion Research Section at Cambridge ,

12. U.R. Evans, *Trans. Electrochem. Soc.*, 1936, **69**, 273. See also experimental work by E. Chyzewski and U. R. Evans, *Trans. Electrochem. Soc.*, 1939, **76**, 215.

13. See two papers by R. \$. Thornhill and the author to be delivered at the forthcoming American Symposium on Soluble Inhibitors.

14. R.S. Thornhill (with experimental work by A Shadbolt), *J. Iron Steel Inst.*, 1942, **146**, 83P.

15. Sodium chromate would be used in practice. Moreover the water would not be treated with chromate and zine salts on alternate days. Probably the first inhibitor would be added in equivalent concentration C_1 and allowed to expend itself until the concentration had fallen to a value C_2 at which inhibition was highly incomplete; the second inhibitor would then be added in amounts sufficient to establish a concentration C_1 (allowing for reaction with the residue of the first inhibitor) and permitted to expend itself until its concentration had dropped to C_2 , after which the first inhibitor would be added, and so on.

16. A. U. Huddle and U. R. Evans, *J. Iron Steel Inst.*, Advanced Proof, Oct., 1943.

