THE CONSERVATION OF IRON.*

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THE history of the human race might be written in the history of iron. From far back of the early times when man learned to chronicle his triumphs and achievements on tablets of stone, there come down to us the dim traditions of the winning from iron bearing stones of the wonderful metal which was destined to be the greatest instrument of his struggles and of his uplift throughout the ages. Indeed the tablets of stone on which early man recorded his deeds and laws stand as proofs that the development of cutting tools and weapons preceded the art of writing.

Whether as sword, ploughshare, pen, compass needle, or machine, this wonderful and indispensable metal has led men along the paths of conquest, empire and evolution. The historian¹ may well conclude that the saying of Bishop Berkely, "Westward the course of empire takes its way," has received a new interpretation, for the iron industry, the source and sign of material power, which had its beginnings in Asia, the cradle of the race, passed along the Mediterranean into western Europe, crossed the Atlantic Ocean and now finds a home in the valleys of the Rockies and by the Golden Gate to the Pacific. It has made the circuit of the world, and now in the face of an awakened and stirring Orient, thoughtful men are asking if perchance it is preparing for a second cycle.

It is the object of this paper to point out the importance of the conservation of iron in so far as practical methods present themselves for accomplishing results. We may, however, by way of introduction permit ourselves a brief survey of historical data. Herodotus tells us of the early use of iron by the inhabitants of Asia, the Egyptians and other early civilizations. The early traditional writings of the Hebrews teem with allusions to the development of artificers of iron, from Tubal Cain, the first blacksmith of record, to Nebuchadnezzar, King of Babylon, who

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¹ Swank, Iron in All Ages.

in a noted inscription records: "With pillars and beams plated with copper and strengthened with iron, I built up its gates." The prophet Daniel says: "Iron breaketh in pieces and subdueth all things," and "Thou shalt break them with a rod of iron," is the adjuration of the Psalmist.

The earliest steel workers of record were the Chalybians who lived on the southeastern shores of the Black Sea, although other ancient eastern peoples had been almost equally renowned in history and tradition. In the British Museum there are examples of iron and steel tools which are probably more than 3000 years old. The ancient swords of Damascus are famed in song and story and we are told were of such keenness and temper that they could cleave a floss of silk floating in the air or sever a massive iron helm, with equal facility.

Far back, however, of authenticated historical data, the ancient Chinese peoples developed the metallurgy of iron to an art, and this metal is said to have been mentioned in Chinese writings more than 3000 years before Christ. In later times, Pliny the elder, who lived in the first century of our era, testifies as to the excellence of the iron made by the Chinese.

The beautiful iron monument of Kutab Minar near Delhi, India, is of great antiquity, although its exact period is in doubt. Randolph, an American who visited Delhi in 1874, records that he attempted to secure a few grains from the base of the monument for analysis but that it completely dulled two cold chisels worked by his servant without producing any marks on the base of the pillar.² Although this extraordinary statement taxes our credulity, there can be no doubt that the old, hand wrought, charcoal smelted irons were of a grade of excellence that modern steel makers find it difficult to attain. It is also noteworthy here that the iron column of Delhi has resisted the corrosive influence of the atmosphere for many centuries, with no protective coating beyond that which nature may herself have provided. In regard to density, homogeneity, temperability and resistance to corrosion, the fame of the older metals has come down to us, and in truth there is a mass of testimony to prove that inferior qualities began first to seriously show themselves contemporaneously with the introduction of the great modern pneumatic processes used in manufacturing both iron and steel.

² Swank, *Iron in All Ages*, p. 9.

We live, however, in a practical age and it is essential that we should consider our great industrial problems from a practical view-point. No sensible persons would venture to propose a return to the old hand worked methods of manufacture, for modern conditions could not support such an industry. In the old Wootz and Catalan processes, very pure magnetite and hematite ores, first pulverized and thoroughly lixiviated and washed were used. They were then little by little puddled out by burning with charcoal in a pit or oven and subsequently beaten and forged by patient industry to the desired form. It seems to be a law of Nature that her materials should respond to the manipulations of the hands of man and acquire properties that machinery cannot give. As an example of this, we have only to remember the everlasting qualities of the hand worked lacquers and enamels of the Orient and compare them with the machine and brush laid coatings of our own industrial processes. The poet Virgil who lived before Christ has drawn a picture which brings vividly to mind the intense manual labor involved in early metallurgical operations:

^a As when the Cyclops, at th' almighty nod,
New thunder hasten for their angry god,
Subdued in fire the stubborn metal lies:
One brawny smith the puffing bellows plies,
And draws and blows reciprocating air:
Others to quench the hissing mass prepare:
With lifted arms they order every blow,
And chime their sounding hammers in a row:
With labored anvils Etna groans below.
Strongly they strike; huge flakes of flames expire:
With tongs they turn the steel and vex it in the fire.

The Nineteenth Century ushered in the age of steam and from this point the history of iron exerts an even more potent influence than before over the development of the human race. The names of Watt, Stevenson, Bessemer and Siemens will never require bronze monuments to perpetuate them, for as long as iron is made or moves they will be remembered.

It was significant that the steam-engine, the locomotive and the great pneumatic process for steel making should have appeared at almost the same moment, as though indeed an over-

^a Quoted from Swank, *loc. cit.*

shadowing Providence had a deep laid design for the industrial future of the race. It is a curious thought too that experience and tradition teaches us that all the gifts of Nature or Providence have penalties attached. The Golden Age told this truth in song and story, as in the Hebrew tradition of the banishment from Eden, or in the Homeric legends of the Greeks. And now, in turn, the Iron Age exacts its penalties and the gigantic industrialism of modern man threatens the future with its penalties.

FIG. I.

Curve showing the production of iron ore, pig-iron, and steel in the United States, 1870 to 1910, in long tons.

Probably no one who has not made a special study of the conservation of iron has a fair conception of the problems which the question presents.

I have chosen for my theme to-day the presentation of this subject, along a line which I venture to hope will bring out the relation of iron conservation problems to the general subject of intensity of growth in civilization. I have chosen to begin my analysis from the year 1870, because from this date on there

begins the steep rise in what for want of a better characterization I shall call the intensity curves of civilization.

In order to simplify my purpose and because the statistics are more readily available, I have confined myself to the data which applies only to the United States, but these may be taken as fairly indicative of the world's curves.

Intensity curves on staple products in the U.S. from 1870 to 1910.

As it is impossible to include in a tabular or graphic representation all the staples, the production and consumption of which may be taken as the measure of intensity, I have made an arbitrary selection in order to illustrate my point. I start with the premise that the necessities and the energies of human life can be very simply analyzed. Food and clothing, the prime human

necessities, can for our purpose be represented by wheat and cattle,⁴ sheep and cotton, and the source and sign of material energy by iron. Gold, the measure of value and medium of exchange, is included, for reasons which are sufficiently obvious, and finally the growth in population is also shown.

I first present in Fig. 1 the curve showing the growth in the production of iron ore, pig-iron and steel, the data having been compiled from the figures furnished by the U. S. Geological Survey.

In Fig. 2 I show the curve in production of the various staples mentioned in the preceding paragraph. I have not in this table shown the fluctuations in production, from year to year, but for the sake of convenience in demonstrating my point have drawn straight lines for the production in 1870 and in 1910. In order to show the statistics of the different staples graphically, it has been necessary to adopt the arbitrary plan of counting population, sheep and cattle by tens, instead of by units, and also to express the growth in wheat production in hundred bushels instead of in one bushel units. By adopting this expedient, we are enabled to start all of the productions from a more or less common starting point, somewhere between two and six million units. As will readily be seen, iron ore and pig-iron are shown in tons, cotton in bales, gold in ounces, live animals and population in tens, and wheat in hundred bushels. The statistics on cotton, wheat, sheep and cattle are from bulletins of the Bureau of Statistics, U. S. Department of Agriculture; the figures on population from the U. S. Census Report.

Although all the intensity curves are ascending, the iron curve is a veritable Mt. McKinley whose topmost peak is still unknown and unexplored. The total production of pig-iron in 1910 was 27,290,545 gross tons against 25,795,471 tons in 1909, an increase of 1,503,074 tons, or over 5.8 per cent. It is, however, when contrasted with the increase in population that the iron statistics come out most strongly. The per capita production of pig-iron in the United States has increased more than 1000 per cent. since 1850. If the rate that was recorded in the last decade is in any degree approximated in the present, the per capita production will exceed one-half ton before 1920 is reached.

⁴ The cattle statistics used refer only to milch cattle.

Table I gives the total and per capita production of the last seven census years:

A Spanish statistician ⁵ has recently published an interesting review of the question of the iron ore supplies of the world. To bring home the far-reaching importance of the matter, he draws attention to the fact that the annual production of iron has risen from 5 million tons at the middle of the Nineteenth Century to nearly 61 million tons in 1909, and for this about 140 million tons of ore were consumed in that year. This author points out that there is no reason to suppose that the world's output of iron has reached its maximum point but that on the contrary it is likely during the coming decades that the rate of the annual increase in production will be fully maintained and probably

TABLE I.

Calendar years	Population of United States, number	Production of pig-iron, gross tons	Per capita production, pounds
1850.....	23,191,876	563,755	61.6
1860.....	31,433,321	821,223	63.6
1870.....	38,558,371	1,665,179	105.6
1880.....	50,189,209	3,835,191	178.0
1890.....	62,979,766	9,202,703	318.1
1900.....	76,303,387	13,789,242	386.8
1910.....	91,972,266	27,298,545	664.7

surpassed. He assumes the world's production of iron in 1920 will be 93 million tons produced from about 217 million tons of ore, that is to say, that if this forecasted rate of increase in the production of iron is realized, the present annual world's output of iron ore will be required to be increased about 88 million tons.

We must now turn to the consideration of the resources which must stand the drain that modern intensity is putting upon them. At the Eleventh International Geological Congress at Stockholm, which met last year, there was presented a lengthy report ⁶ upon the amount and distribution of the world's supply of iron ore. Practically every country where iron ore is worked is represented. The total known supply of iron ore of the world is estimated on Table II.

⁵ J. de Lazurtegui, *Ensayo sobre la cuestión de los Minerales de Hierro* Ayer, Hoy y Mañana, Bilbao, 1910, pp. 1-145.

⁶ *Iron Ore Resources of the World*, Stockholm, 1910.

The *Journal of the Iron and Steel Institute* comments upon Table II as follows: To what extent the future of iron will become dependent upon low grade ores is shown in this report. The actual reserves of rich ores containing 60 per cent. of iron are estimated at 1300 million tons, and the potential reserves at 687 million tons. Four-fifths of the known and recorded rich ores are contained in the deposits of northern Sweden.

As has already been stated, it is the object of this paper to consider the conservation of iron principally from the stand-point of our own immediate problem in the United States. The statistics already given show very clearly that the annual production of iron ore may very possibly reach the 100 million ton mark if the present general tendency towards increase is maintained for a few more decades. If we could assume that this figure would not be surpassed but would become an upper limiting value, the

TABLE II.

	Actual reserves		Potential reserves	
	Ore, metric tons (millions)	Iron, metric tons (millions)	Ore, metric tons (millions)	Iron, metric tons (millions)
Europe.....	12,032	4,733	41,029	12,085
America.....	9,855	5,154	81,822	40,731
Asia.....	260	156	457	283
Australia.....	136	74	69	37
Africa.....	125	75	many thousands	many thousands
Totals,....	22,408	10,192	123,377	53,136

situation would hold no menace for the western hemisphere for many generations yet to come. The actual and potential ore reserves of America given in Table II are sufficient even at this rate to last nearly one thousand years, and we may as well admit that we need feel little responsibility in regard to our remote descendants who may exist in ten centuries from the present era. With respect to the United States and the situation which children now born will have to cope with, we are, however, vitally concerned. Mr. John Birkinbine,⁷ in an interesting article on the "Production and Resources of the Lake Iron Region," has published some valuable figures. He gives the total contribution to

⁷ The Mining World, vol. xxxiii, No. 10, p. 417.

the iron ore supply of the United States made to the close of 1909 by each of the ranges included in the Lake Superior district, which produces about 80 per cent. of all iron ore mined in the United States.

Mesabi	195,703,424
Marquette	91,903,991
Menominee	71,313,115
Gogebic	60,820,503
Vermillion	29,125,385
Total	448,966,418

Birkinbine also states that a report was issued in 1908 by the Minnesota Tax Commission, which claimed that a conservative estimate of the available iron ore lands in the lake iron region showed a reserve of 1,192,500,000 tons of iron ore, the bulk of which is on the Mesabi range.

Dr. C. W. Hayes, the well-known statistical expert of the U. S. Geological Survey, has given an extremely interesting review of the iron situation.⁸ He says in part: "If the average rate of increase by decades should be continued, it would require the production in the next three decades of 6,088,000,000 tons of ore. But the ore supply now available in the United States is estimated at 4,788,000,000 tons, which is only 78 per cent. of the amount needed on this assumption. It is evident, therefore, that the present average rate of increase in production of high grade ores cannot continue even for the next thirty years, and that before 1940 the production must already have reached a maximum and begun to decline, and a very large use must be made of low grade ores not now classed as available. The second condition, with its consequently greatly increased cost of iron, is the only thing which can prevent a decline in the iron industry, measured by the amount of pig-iron produced within the next thirty years, unless there is in the meantime very greatly increased importation of foreign ores."

Dr. Hayes, however, further points out what I wish to emphasize here, that it is impossible to accurately predict the date of exhaustion of the iron ore supplies and that any attempt to do so is wholly unprofitable and unwarranted. It will readily be

⁸ Mineral Resources of the United States, 1908, U. S. Geological Survey.

seen that there are too many factors which enter into this problem, both from the stand-point of political economy and technical development, the tendency of which is not always determinable. It is, however, safe to say that an analysis such as has been attempted in this paper should do good by stimulating more careful study by the public generally of an interesting situation which undoubtedly exists. The normal intensity flow as shown in Fig. 2, which in a sense measures the growth of humanity and civilization in the United States, may be considered to be that which is bounded by the lines for cattle and cotton. The intensity curves for iron, as can clearly be seen at a glance, are out of all proportion to the other staples which in their aggregate may be taken as a measure of modern development.

Another interesting feature of the iron conservation problem which is frequently overlooked is the relation between iron and coal. It is estimated that every ton of iron ore produced requires about four tons of coal or its equivalent in fixed carbon to convert the ore into merchantable iron and steel. An ultimate annual consumption of 400 million tons of coal per year for this purpose alone is therefore to be anticipated in the not distant future.

In presenting this paper on the conservation of iron, there has been no intention on the part of the author to approach the subject in a pessimistic or malthusian attitude of mind. The world is working out other problems and it will undoubtedly work out this one. The exhibition and application of energy or even the very existence of the human race without iron is unthinkable from the stand-point of our present knowledge. In the main, the problem is one for the political economist and as this phase of the subject carries us onto ground somewhat unfamiliar to the writer, we will pass to the technical side of the discussion. It would seem, however, that free entry of raw materials into this country is sure to be demanded in the near future, whether some of us like it or not. The high grade ores of northern Sweden, of Asia, of South America, and of British North America will be as necessary to our industry as to that of our national competitors. From this point of view perhaps the wise statesmanship which is seeking to bring about reciprocity with our American neighbors has not been as highly appreciated as it deserves, by large numbers of our people.

From the technical stand-point, the conservation of iron pre-

sents interesting problems which we will now proceed to briefly consider. The tendency of iron to oxidize or rust is inherent in its nature. The rusting of iron is essentially a process of slow combustion which is annually burning up an untold and unknown quantity of this precious metal. Forest fires in one great blazing conflagration can destroy hundreds of millions of dollars worth of valuable timber. Kindly Nature assisted by the arts of man can cause the forest to grow again, but no partnership between industry and Nature will ever again reclaim the iron that has fallen away to rust. If it were possible to obtain statistics capable of showing even approximately the quantity of iron which annually burns to rust, they would probably astonish us. Unfortunately, such statistics will never be available. It is not even possible to obtain reliable data in regard to the quantity of iron which goes to the scrap pile each year. It is, of course, well known that a very considerable quantity of selected scrap goes back to the furnace to be used again, and in even the best open-hearth steel practice about 50 per cent. of the total charge consists of high grade scrap. In addition to this, low grade scrap is used for common castings and for other purposes, but in spite of all this there must be a vast quantity of junk which is destined never again to become serviceable to man.

I quote from an interesting article in a recent issue of one of the great New York newspapers: "An enormous quantity of new iron is continually being mined and manufactured and apparently added to the world's stock of material, and yet the available pile of usable metal does not rapidly increase. The fact is that only a small portion becomes permanently available stock. Not more than a quarter of the world's iron is used a second time, and not more than a quarter of this goes through a second scrapping. Where does it all go? We get many suggestions as to where and how the iron is dissipated, or, as we say, consumed; this consumption being as complete and final for the portions considered as the consumption of coal or wheat. In the processes of manufacture, in the melting and forging, there is burning of metal, and in all the cutting operations of the shops there is waste, only the larger chips representing recoverable material. The dissipation by wear is more rapid than one would think. Dr. Soper, in a recent valuable paper before the Boston Society of Civil Engineers, says that he found that, by actual

record of material replaced, there was produced in the New York Subway, from the brake shoes alone, one ton of iron-dust per month per mile. The waste of wheels and rails was not so easily ascertainable, but it is to be added to this.

"The same rate of iron-dust production was estimated for the elevated railroads, while the same process was also in operation on the surface roads and, more slowly, of course, with all running vehicles. On the big railroads account is kept of the weight of the cars in use. A large number of steel hopper cars showed an average loss of weight of 702 pounds the first year, with continuous losses, not always at the same rate, for subsequent years. Some of this loss, of course, was due to wear and some to rust. The rusting of iron goes on always, and in some extensive lines of manufacture, as for instance wire fences, and the various iron articles in domestic service, the entire output ultimately goes to rust. Old iron lies around everywhere, some of it too small and much of it too insignificant to be individually noticed, slowly disintegrating, some of it going into the air, some into water, and some into the soil, and through these media into untraceable combination and activities. Dr. Soper, in the paper referred to above, says that he has never found any dust anywhere in New York which had not iron in it."

What seems to be necessary on the technical side of the iron conservation problem, is some inventive development which will assure a more permanent quality in the iron and steel which is manufactured into serviceable forms. A certain amount of wear and tear and unavoidable waste there will always be, but it is by no means impossible that metallurgical and technical development will in the future reduce the wastage to a reasonable minimum. If the great modern steel structures could be looked up as practically permanent, we should have the comfortable assurance that many tons of iron and steel once won from the ore represented a practically permanent addition to the wealth of the world. Great progress has been made within the last few years in the understanding of the corrosion problem and in the art of protecting iron and steel from rapid decay. Several years ago the writer had the honor of presenting before The Franklin Institute a paper on the "Electrolytic Theory of Corrosion." This theory has found a direct application to the manufacture and production

of protective coatings both in the form of paints and of other metals, and careful, systematic tests of these new ideas of protection are more and more strongly corroborative as time goes on. Much remains to be done, however, before the full protection of iron and steel against corrosive influences may be considered a problem solved. The electrolytic explanation of corrosion has shown why it is that hastily made, badly segregated steel rusts more seriously and more quickly than pure, carefully made metal. This knowledge has led to a new development in the metallurgical industry of this country. Processes have been worked out, by means of which iron of extraordinary purity and most excellent quality is now made in open-hearth furnaces on the large scale of operation usual in steel making. The purity of these products is equal and even superior to that of the best Norwegian and Swedish charcoal irons, and there is no question but that they fill a long felt want for a great many industrial purposes. No claim can be made that these pure irons are absolutely rust resistant, but their particular value along this line seems to be that they are slow rusters and that being practically free from impurities, the bad effects due to segregation are reduced to a minimum. It is not always the fact that iron or steel rusts but the manner of its rusting which constitutes a special danger. Just as a chain is no stronger than its weakest link, so also a piece of iron in service may be ruined and discarded even if more than 99 per cent. of its mass and surface is still in good condition. The even texture of the rust which forms upon these pure irons and the absence of pitting effects is one of their prominent characteristics. When provided with an efficient protective coating in addition to their own slow rusting qualities, they appear to be a decided step in advance in the achievement of rust resistant iron. As a basis for the manufacture on a commercial scale, of comparatively cheap and very highly rust resistant alloys, these pure irons hold out a great promise. There are whole series of binary and ternary alloys of iron which have not yet been thoroughly studied even on the laboratory scale. It has already been reported that certain ternary alloys of iron, nickel and copper started from a pure iron base are non-rusting.⁹ There is always the hope that a commercial unrustible alloy with the

⁹ Clamer, Proc. Am. Soc. for Testing Materials, x, 270 (1910).

strength and valuable physical properties of steel will solve the problem of a permanent industrial metal.

One difficulty that has been met with and overcome in the manufacture of these pure metals lies in the fact that when the attempt is made to burn out all the ordinary impurities that produce segregation, the iron itself is likely to be burned. When this has occurred, the oxygen content of the resulting metal will be high, and segregation of the oxide is almost certain to take place. Fortunately this difficulty has been overcome, and pure iron can now be made with as low an oxygen content as the best steels. On analysis by the Ledebur method of combustion in hydrogen, the writer has examined samples of these pure irons which run as low as 0.015 oxygen. It is probable that an oxygen content of from 0.03 to 0.04 might be considered allowable in metals of this type.

Another project that is interesting along the line of preservation is the study of possible methods of treating structural steel on a manufacturing scale so as to give it a practically unrustible surface. There are a number of processes that have been proposed and some of which are now in use for bringing about this result. The well known Bauer-Barff and Wells processes depend upon already oxidized surfaces. One promising field is along the line of alloying the surface after the steel has already been rolled and shaped. Others again depend upon rolling oxide into the surface and giving the surface another working between specially designed rolls, such as in the Speller process. It is true that all these expedients add to the cost of the products, but, in view of the importance of the problem, it is probable that within reasonable limits the cost will not be a factor.

It is well known that serious damage can be done to structural steel by electrolysis caused by stray currents from high potential electric service lines. In fact, it is perhaps not too much to say that electrolysis threatens the destruction of millions of dollars worth of property in this country. After a few more serious object lessons have been met with by engineers, it is likely that any expedient that promises to reduce the dangers will be welcome. The writer has himself recently been called upon to inspect and report on a full reinforced concrete structure which cost \$400,000 to build about four years ago and which has been ruined by electrolysis from escaped railway currents. If this form of

steel tuberculosis is going to attack the great reinforced concrete buildings of the present day, the ultimate damage will be appalling.

The principal methods which are used on a large scale at the present time for the protection of steel consist in the various types of so-called protective coatings. We may consider these under the separate headings of metallic coatings and paints. The electrolytic explanation of corrosion has proved most useful to the technology of protective coatings. The various processes for zinc deposition have been more used than any others. Zinc on theoretical grounds is the most protective metal, owing to the fact that it is strongly electro-positive to iron and will therefore protect it at its own expense as long as it is kept in contact with it. In one very important respect, the subject of zinc protection has not been understood by engineers, manufacturers, and others who are responsible for the production and purchase of galvanized material. It has been generally supposed that any cracking or crazing of the zinc coatings would invite corrosion by allowing moisture and the atmosphere to penetrate to the underlying iron. The effort to overcome this supposed difficulty has led to the application of thin, light coatings of zinc. On the Isthmus of Panama there have been found examples of galvanized sheet that were left there by the French when they abandoned the workings. This galvanized sheet, which must be some thirty to forty years old and which has been exposed under very trying conditions, has steadfastly resisted corrosion. It is true, of course, that these old examples of galvanized sheet were probably hand dipped and were provided with very heavy and efficient zinc coatings. It could not be claimed that the machine galvanized sheet as made to-day would last anything like as long as this, under the same conditions. An example of misdirected zeal on the part of those responsible for specifications for galvanized steel wire has recently been brought to the writer's attention. A specification under which a very large quantity of wire was to be bought stated, among other qualifications, that the wire must be capable of being closely wrapped around another wire of the same diameter, without showing cracking or crazing at the bends. Now, zinc as has been stated, is electro-positive to iron, and when the two metals are in contact, the iron will be protected even if it is entirely exposed and bare. This point has been very clearly brought out

as the result of systematic investigations by the writer and others, and it can be demonstrated by anyone who wishes to take the trouble to solder pieces of zinc and iron together and submit the couple to corrosive influences. Inspection shows that the bare, cut-off ends of galvanized wire do not rust on exposure. Why, then, draw specifications which only succeeded in excluding heavy coatings of zinc, simply because these show cracking and lifting at sharp bends? It would be far better for engineers to specify within possible limits the actual weight of zinc which their galvanized material is to carry, but in default of this it would be better at the present time to buy material that cracks and crazes on severe bending tests than to draw up specifications to preclude this condition.

Next to zinc, the metals most used to protect iron are tin, lead, and the alloys of these two metals which are used in the production of *terne plate*. Theoretically speaking, neither tin nor lead should ever be used for the protection of iron, for instead of being, like zinc, electro-positive to iron, they are electro-negative. It will therefore be seen that any crack or opening in a protective coating of tin will lead to rapid destruction of the iron at the exposed spot. It appears to be almost impossible to apply a tin coating to the surface of iron, that is free from minute openings known as *pin holes*. It is for this reason that so much trouble is experienced with the various types of iron which depend upon tin as the protective agent. If a perfectly homogeneous coating of tin could be put upon the surface of iron, the protection might be considered efficient, in spite of the fact that tin is electro-negative to iron, but this would simply be for the reason that tin in itself, when pure, is not a corrodible metal. In contact with iron, however, the burden of attack is thrown upon the iron in the couple, and iron in contact with tin will corrode more rapidly than when left to itself.

Copper, as well as lead and tin, has been proposed as a protective coating for iron, but is open to exactly the same criticism, as it is one of the metals which is strongly electro-negative to iron. Among the electro-positive metals which have not been mentioned, we find both aluminum and magnesium, but up to the present time no alloy of these metals has been evolved, which is suitable in its physical characteristics, even if the cost were not considered prohibitive.

In the field of paint coatings, very great progress has been made in the protection of iron and steel within the last two years.

Four years ago the writer called attention to the fact that the action of the pigment portion of a paint coating, in either promoting or retarding corrosion, had been overlooked.¹⁰ Previous to that time, the attention of engineers and paint technologists had been principally directed to the production of combinations of pigment and vehicle so designed as to be good excluders of moisture and to have other desirable qualities as then understood.

It has already been suggested in this paper that the element iron has been endowed with some very extraordinary properties which especially fit it for the intensive service of mankind. Among these characteristics which it possesses to a unique degree, we may include its power of hardening or taking a temper and the wonderful property of becoming magnetic. Still another wonderful characteristic may be defined as that of passivity or the power of being thrown, by contact with other substances, into a passive condition. The passive condition is not a stable one, nor is it possible by any means to render iron passive and to maintain it in this condition out of contact with the passifying agent. The fact remains the same, however, that while in the passive state iron loses one of its principal characteristics of being extremely active chemically and therefore becomes for the time being uncorrodible. The phenomenon of passivity has been known and studied for many years, and much literature exists on the subject. It is interestingly summed up in the article on iron in the Eleventh Edition of the *Encyclopædia Britannica*, which has just been published, but time will not allow of a discussion of the subject here. It will suffice to say that the best agents for producing and maintaining the condition, that have been put to practical test for paint coatings, are the slightly soluble chromates and other substances which when acted on by water produce a distinctly alkaline reaction. Pigmentary substances which produce a condition of passivity on the surface of the iron are now generally known and spoken of as inhibitive, because although they cannot be expected to entirely prohibit the rusting of iron, they do serve to maintain the passive condition and therefore check or retard corrosion. A very interesting series of tests involving these prin-

¹⁰ Proc. Am. Soc. for Testing Materials, vols. vii and viii, 1907-8.

ciples has been carried out by the American Society for Testing Materials in co-operation with the Paint Manufacturers' Association of the United States. A number of iron and steel panels treated with paint made from various pigmentary substances, have been exposed to the action of the atmosphere and elements at Atlantic City, N. J., for three years. The latest available report of these tests, which has been published, states that the inspection of the tests has shown that those pigments whose protective value depends upon the value of chromate inhibition, as well as those which produce basic reactions in water suspension, have given a good account of themselves on the test panels. Progressive paint technologists and engineers are now availing themselves of the results of the many investigations which have recently been published along these lines, and a most decided improvement may be expected in our ordinary methods for preservation of iron and steel.

The object of this paper has not been to present new data in regard to the preservation of iron and steel but to briefly summarize and review the general conservation problem. There can be no question that much of the iron which has been allowed to fall into the condition of irretrievable rust or gone to the scrap pile, from which it is unlikely to be again removed and made serviceable, might have been saved if the corrosion and preservation problem had been properly understood by engineers and technologists responsible for its care. It has only been of recent years that engineers have realized that it was unsafe to bring in contact in one construction metals of unlike electrochemical properties. It is, however, true that much destruction of iron has been occasioned by lack of knowledge of this one thing, for even different types of iron and steel will rust each other when connected together and exposed to the action of corrosive influences in the air or water. An Institute of Metals has recently been founded in England, for the special purpose of considering just such important industrial problems as those here referred to. In summarizing this paper which has been written in the hope that it will serve to stimulate general interest on the part of thoughtful persons to the importance of the iron conservation problem, it has been shown that iron, the cheapest and most abundant of the industrial metals, is, after food and clothing, the most indispensable substance which enters into the life-history

of man. A very recent authority has said of iron ¹¹: "Iron is a very Proteus. It is extremely hard in our files and razors and extremely soft in our horseshoe nails which in some countries the smith rejects unless he can bend them on his forehead. With iron we cut and shape iron; it is extremely magnetic and almost non-magnetic; as brittle as glass and almost as pliable and ductile as copper; extremely springy and springless and dead; wonderfully strong and very weak; conducting heat and electricity easily and again offering great resistance to their passage; here welding readily, there incapable of welding; here very infusible, there melting with relative ease. The coincidence that so indispensable a thing should also be so abundant, that an iron-needing man should be set on an iron-cored globe, certainly suggests design. The indispensableness of such abundant things as air, water, and light is readily explained by saying that their very abundance has evolved a creature dependent upon them, but the indispensable quality of iron did not shape man's evolution, because its great usefulness did not arise until historic times or even, as in the case of magnetism, until modern times."

Whereas it has been shown that the great increase in the per capita consumption of iron by the human race is but a part of the general advance in wealth and civilization, it has also been shown that the intensive use of iron is out of all relation or proportion to the increase of intensivity in the use of the other materials which go to make up the necessities of the race and of civilization. It must, of course, be admitted that the causes of this great increase in the use of iron may be found in the diversion of mankind from purely agricultural to manufacturing pursuits, for nearly all machinery must necessarily be made of iron. Again we have to take into consideration the displacement of wood by iron for ships and bridge building, the use of iron beams, columns and other members used in the construction of modern buildings; the growth of steam and electrical railways, as well as the introduction of iron fencing. In conclusion, it is interesting to note that the three great nations which are the principal iron producers of the world and which are so closely related by ties of blood—Great Britain, the United States and Germany—produced in 1907 81 per cent. of the world's pig-iron and 83

¹¹ Encyclopædia Britannica, 11th Ed., 1910, vol. xiv, p. 801.

per cent. of its steel; and moreover the four great processes by which practically all the irons and steels are made, namely, the puddling, crucible, the acid and basic varieties of the Bessemer, and open-hearth processes, as well as the great mechanical methods of forging and rolling iron and steel, were invented by Anglo-Saxons, with the possible exception of the open-hearth process in which Great Britain must share with France the credit of the invention.

Gases Occluded in Copper Alloys. G. GUILLERNIN AND B. DELACHANAL. (*Comptes Rendus*, cli, 881.)—From the examination of several special forgeable brasses, bronzes, a phosphor-bronze and two samples of tin, it is concluded that: 1. Special brasses retain occluded from 1 to 30 times their volume of gas, chiefly hydrogen, carbon monoxide and dioxide. 2. In sound castings the gas is almost entirely hydrogen. 3. In unsound castings a larger portion of carbon oxides occur. 4. Hot rolled bars contain less gas than castings. 5. The hydrogen in sound pieces, even when in notable amount, has no injurious effect on the mechanical properties of forgeable brasses. 6. Phosphor-bronze contains very little gas, chiefly carbon dioxide and hydrogen, phosphorus, as in cast-iron and steel, seems to diminish the solubility of hydrogen in the metal. 7. Commercial tin contains a small volume of hydrogen and carbon oxides. 8. None of these metals exhibit the phenomenon of "spitting."

Alloys of Tellurium with Cadmium and Tin. M. KOBAYASHI. (*Zeit. anorg. Chem.*, lxi, 1.)—Thermal analysis shows that tellurium and cadmium combine to form the compound TeCd , which melts at about 104°C . but exists in the melts only in equilibrium with an excess of tellurium. With tin, tellurium forms the compound, TeSn , melting at 780°C . and this forms a eutectic with tellurium containing 86 per cent. of the latter and melting at 393°C . Neither compound forms mixed crystals with its components. Cadmium dissolves tellurium up to 1.2 per cent. at 700°C ., and the solubility is probably greater at higher temperatures.

Purification of Waste Water from Pulp Mills. J. G. ROEST. (*Chem. Wochblad*, vi, 106.)—It is well known that clay will remove impurities from liquids. Experiments on its use as a purifier of waste water from pulp mills show that $1\frac{1}{2}$ per cent. of potter's clay is sufficient to precipitate suspended impurities from the waste water. The precipitated waste has an appreciable value as a fertilizer.