steel, which would indicate that it was injurious when steel was heated to comparatively high temperatures. It frequently occurs with manganese silicate (slag) and it segregates together with phosphide of iron in the form of ghosts. In this case it may be very injurious to steel, and especially so where the sulphide is spread out into threads or ribbons by rolling the metal.

Sulphur, when added to soft cast iron that is low in sulphur, increases the strength of the metal, partly by closing the grain and partly by increasing the combined carbon. Owing to this tendency to increase the combined carbon and form an iron carbide, it has a hardening effect on the metal. Its effect on the tensile strength of steel has not been definitely settled, but up to 0.10% it does not alter the elastic ratio, elongation, or reduction of area to any extent. The actual percentage of sulphur at which steel ceases to be malleable or weldable varies with other ingredients. Each increment of manganese raises it, and it is lowered if the steel ingots are cast too hot.

Attention is being turned to the effect of sulphur, noted in the preceding paragraph, and the old theory that sulphur should be reduced to a mere trace in steel is beginning to be doubted, as some of these effects could be made beneficial if the injurious effects could be overcome. Some recent investigations have led to the belief that the oxides are the real source of weakness and failures in steel, and if these can be removed, the injurious effects of sulphur can at least be nullified, with the probability of its being made beneficial.

According to the old theory, 0.08% of sulphur made crucible steel absolutely worthless for welding, forging, rolling, etc., but I have recently seen samples of crucible steel that had the oxides reduced to a minimum, and the sulphur at 0.08%, that were forged under the steam hammer without any signs of checks. A piece of this same steel which contained 0.60% of carbon was welded onto machinery steel to form the cutting edge of an axe, and apparently the weld was perfect, as there was no signs of a crack when it was ground to shape. This axe was stood on an anvil with the cutting edge up, and given 20 blows with a heavy sledge before the edge broke, and even then the weld was not harmed.

Another test was to drift a hole 4 inches in diameter in stock $1\frac{1}{2}$ inches thick and 4 inches wide without destroying the drift. In still another test a $\frac{3}{8}$-inch set stood 200 blows from a 12-pound sledge without breaking. This same set was then used in the daily work at the mill until it was worn out, and it outlasted two sets made from stock steel. The tensile strength was a little better than the ordinary in this high sulphur steel.

The sulphur content was carried still higher in later tests and it was found that with sulphur up to 0.13 per cent. no injurious effects were apparent in the steel and the metal did not develop the "hot-shortness" that every one heretofore has attributed to sulphur. Above a sulphur content of 0.13% the metal began to show signs of brittleness and was clearly injured.

With steels as ordinarily made at present the sulphur should not exceed 0.10% for any use, but for tool making or other uses where the metal has to be repeatedly heated and cooled this should not be over 0.03%, and preferably as much lower as possible. Steel as now made would be much better for nearly all kinds of work if the sulphur could be reduced to a trace.

OXYGEN, HYDROGEN, AND NITROGEN

Of all the elements that enter into the composition of the earth's crust, oxygen forms nearly one-half, or, to be more explicit, 47.29%. It comprises eight-ninths of water and about one-fifth of the air. It occurs also in combination with carbon and hydrogen, and with carbon, hydrogen, and nitrogen. Besides this it forms a part of most manufactured chemical products. The iron ores that are chiefly used for making iron are combinations of ferrite and oxygen. At the higher temperatures it has a greater or lesser affinity for and unites with every other elemental substance known, except fluorine, helium, neon, argon, krypton, and xenon, and it acts readily upon a large number of compounds. At the ordinary temperatures oxygen does not act readily upon most things. Its simple compounds are called oxides, and these usually form with the production of heat. One of the elements that combine with it at low temperatures is iron, and this is coated with an oxide when heated to about 400° F., or at nearly any temperature in the presence of moisture.

Hydrogen is the lightest substance known, and like oxygen is a gas that is colorless, tasteless, and odorless. It has a high chemical affinity for oxygen, and is a good reducing agent. It forms with carbon something like 200 combinations, known as hydrocarbons. At a red heat it penetrates iron readily, probably forming a compound with it.

Nitrogen, owing to its inactivity, acts principally as a dilutent of oxygen.

These three gases readily dissolve in iron or steel when it is molten, but as it solidifies comes out of the state of solution, and then much the larger part passes away. A portion, however, is usually entrapped, and this portion if segregated in large bodies causes blow-holes, gas bubbles, etc. Carbon monoxide gas (CO), which may be generated during the solidification period by a reaction of the oxide of iron with the carbon when carburizing, is also a cause of blow-holes. These blow-holes are usually removed by the use of the deoxidizers, such as manganese, silicon, aluminum, etc. Another portion of these gases, however, is liable to remain in the steel in the form of occluded gases and oxides that are just beginning to be recognized as among the most harmful things in steel; oxygen probably being the most weakening element that can be left in steel, with hydrogen and nitrogen closely following.

As evidence of this, Bessemer steel, which is purified by blowing air through it, is the poorest and weakest of steels; while open-hearth steel, which is purified without this blast of air, but is not protected from the air striking the surface of the bath, comes next; and crucible steel being protected from air by the melting process taking place in a closed pot, is the strongest and finest grained of all the steels, except those made in the electric furnace, and this is also protected from the air. Another proof is the added static and dynamic strength, wearing qualities, etc., given to steels, by such elements as vanadium, titanium, etc., when they are used to cleanse the metal of these gases.

Oxide occurs in very small black specks throughout the metal and can only be seen when the surface has been perfectly polished and magnified at least one thousand times. These are invariably found in steels that produce blisters when pickling, and this leads to the conclusion that the blisters were formed by the reduction of oxide by the nascent hydrogen evolved during the pickling process. High-carbon steel rods that contain the same impurity occasionally fracture in the pickling bath and doubtless the same pressure that blows a blister in mild steel will cause a rupture in hard steel.

Owing to the gaseous nature of oxygen, and the fact that the drillings must be very fine, it is difficult to analyze steel for the oxygen content. A series of tests, however, was carried out by E. F. Law, of London, by cutting a piece from each of eleven bars of acid and basic Bessemer steel that contained from 0.10 to 0.18% of carbon, and only a trace of silicon. Each piece was then rolled into 24 sheets which were pickled and annealed by the usual process. An adjacent piece of the bar was analyzed, examined with a microscope, and the oxygen determined. The result of these tests was as follows: (See table on page 85.)

An examination of the table will show that as the oxygen content increased the number of blistered sheets increased, while the percentage of sulphur seemed to have no effect on the blistering; the set containing 19 blistered sheets only showing 0.071% of sulphur, while the set of sheets that did not blister at all contained 0.076, 0.069, and 0.061% of sulphur, respectively. By way of comparison a piece of basic Bessemer steel was analyzed just before the ferro-manganese was added, and this showed 0.062% of oxygen. The results shown here seem to forcibly confirm the oxide theory.

It might appear at first sight that the quantities present are extremely small, but in making comparisons we should not consider alone the amount of the elements present, but also the combinations of these elements that influence the quality of the steel. Thus, we speak of 0.05% of sulphur, when in reality it is 0.13% of manganese sulphide that affects the quality of the steel. Oxygen has only half the atomic weight of sulphur, and is capable of forming larger quantities of compounds, therefore it exerts a greater influence. Thus, where 0.05% of sulphur corresponds to 0.13% of manganese sulphide, 0.05% of oxygen corresponds to 0.22% of ferrous oxide.

TABLE SHOWING EFFECT OF OXYGEN ON BLISTERING

Kind of Bessemer Steel	Analysis			Microscopical Appearance	Sheets in 24 that Blistered	Percentages of Oxygen
	S	P	Mn			
Acid..........	.061	.049	.340	Very good	0	.021
Basic..........	.069	.034	.385	Good	0	.021
Acid..........	.076	.070	.350	Good	0	.022
Basic..........	.101	.126	.475	Fair	4	.025
Basic..........	.080	.066	.430	Moderate	6	.026
Acid..........	.106	.188	.320	Bad	7	.026
Basic..........	.079	.098	.440	Bad	7	.027
Basic..........	.045	.075	.473	Bad	8	.034
Acid..........	.061	.081	.350	Bad	9	.032
Basic..........	.080	.068	.450	Bad	12	.030
Basic..........	.071	.090	480	Very bad	19	.046

Another fact brought out in these tests is that the amount of oxide visible under the microscope was much less than would be expected from the amount actually found by chemical analysis, and this might be accounted for on the theory that a considerable quantity of oxide was in solution in the steel surrounding the black oxide spots. The oxide showing on the surface of a polished piece was also reduced by the aid of hydrogen and an electric current, and the pits thus formed occupied a much larger area than the spots of oxide seen by the microscope.

Steels containing oxides also apparently rust much quicker than those free from them, and with two pieces placed side by side the oxide steel will show rusting long before the other, while in dilute acid solutions steels containing oxides corrode more easily and much faster than those free from oxides. The same is true regarding the other impurities in steel and this has led to the production of a metal called "Ingot iron," in which the total impurities, except carbon, have been reduced to from 0.05 to 0.08% and the carbon content to 0.02%. A typical analysis showed carbon 0.02%; manganese, 0.01%; sulphur, 0.02%; oxygen, 0.03%, and phosphorus and silicon a trace.

In the making of this metal the theory that ferro-manganese was needed to produce a workable metal in the hot condition was doubted, and the usual ferro-manganese decarburizer was omitted. Open-hearth furnaces are worked entirely on cold pig iron low in silicon and sulphur, and with the phosphorus limited to the content for Bessemer working. An active basic slag is maintained that is composed of limestone and fluorspur, with a comparatively large amount of the latter flux to prevent the phosphorus from returning to the metal at the high temperature of 3000° to 3100° F., that is maintained toward the end of the process. A fairly large proportion of scrap is charged in the form of open-hearth mill scrap and low-carbon steel turnings, the larger part being of the latter. When sufficient mill scale can be obtained it is substituted for ore in the charge.

The removal of oxygen, probably in the metal in the form of oxides, is most important, and instead of manganese, ferro-silicon, or an equivalent material, is added to the bath to remove the oxides, while the other gases are removed by adding below 0.10% of granular aluminum in the ladle. The time consumed for each charge is about 10 hours, and the boiling is carried to a high temperature to thoroughly oxidize the impurities. This brings the temperature very high in the final stages, owing to the higher melting point of the purer materials. If there is too much oxygen in the steel it is liable to cause it to crack on the edges when rolling, owing to its creating a red-shortness.

COPPER

Copper is a widely distributed element of the earth's crust, and occurs in large quantities; sometimes in the uncombined condition, such as the native copper of the Lake Superior regions. It is very malleable and tenacious. In most of the copper ores used, sulphur and iron occurs, and in some of the iron ores used for making steel, copper occurs. A few contain as high as 1% of copper, and some of the Bessemer and open-hearth steels contain from 0.30 to 0.50% of this metal. That copper alloys perfectly with all steels and does not segregate until above 4% has been added is a well-established fact.

Copper can be alloyed in all proportions, with iron containing 0.15% of carbon, and with 0.09% of sulphur added to this no segregation will occur until 7.70% of copper has been added. With the sulphur low and the carbon at 0.20% no pronounced segregation appears until a copper content of 40% is reached, while with 0.40% of carbon it occurs with a copper content of about 30%; with carbon 0.60%, at 20% copper; with carbon 0.80%, at 12% copper; and with the carbon at 1%, copper segregation is liable to occur when the copper is 8%. This, however, is only a general rule, and it may be varied greatly by the various other ingredients and methods of making the steel. As the best results seem to be obtained when copper is kept below 5%, segregation will not be much of a factor in copper steel.

Hard and soft steels with a percentage of copper as one of the ingredients have been used for many purposes with the usual number of failures, but these failures have always been traced to other ingredients and none to the copper contents. Crank-shafts for the United States' battleships and gun tubes for 6-inch guns, have been made out of steel containing 0.57% copper, and they stood successfully all of the tests required by the Government.

Commercially steels containing over 4% of copper cannot be rolled and forged unless the percentage of carbon is very low, owing to its hardening effect and the consequent brittleness it gives to the metal. With percentages up to 4, the copper all goes into solution in the iron, but above that, saturation begins to occur. The point at which saturation begins appears to be between 4 and 8%; it being lowered as the carbon content is increased. When the copper content is increased to above 8% free copper occurs; in a fibrous form in the soft or semi-soft steels, and in nodules in the higher carbon steel.

When there is enough sulphur in the steel, it will form with the copper a copper sulphide, according to the formula (Cu_2S), but if there is an excess of copper it will combine with the iron. Steels containing copper and copper sulphide have an irregular structure, as regards the size and joining together of the ferrite crystals, as these imbricate with one another with curved junctions. This gives the metal a higher strength than that of steel without copper.

Copper and copper-sulphide principally distribute themselves between the crystals of ferrite, which they envelop. They also cause the quantity of pearlite to increase and the grains of this to assume a finer structure and permeate the metal more and more with each increase in copper. In fact, the structure so closely approaches the martensitic form that it has been mistaken for this in some instances, and in a 7% copper steel threads of cementite and of pearlite appeared. In this way they intensify the iron carbide and give to the metal a greater hardness as well as enable it to be hardened more easily when heating and quenching. Copper also lowers the recalescent point from 100 to 150° F. below that of ordinary steels, but it never brings this below 800° F. In this it about equals high-carbon steel. The 1 to 5% copper steels that are liable to become commercially successful should be quenched in water from about 1325° F. or in oil.

It is possible to find traces of copper sulphide in metal that contains only 7% of iron and 0.025% of sulphur. As a small amount of iron in solution in copper makes copper harder, this might suggest the idea of strengthening copper or copper alloys with iron.

Copper increases the hardness of steel, as the copper content increases.

When the carbon content is low it has a greater effect than when it is high; in some cases almost doubling the Brinnell hardness, and it reached its maximum increase in one series of tests at from 10 to 15% copper. It does not give any color to steel until 8% has been passed.

With the carbon content high, copper steel is difficult to work mechanically, but it can be easily cast into the shapes desired. If, however, the carbon is kept below 0.50%, steels containing as high as 4% of copper can be easily and successfully rolled and forged, and the heat treatment made a less delicate operation. Such steels seem to have a future as they have a greater tensile strength and elastic limit than the same steel without copper; a better elongation and contraction; more resiliency; a greater resistance to shock and torsional strains; a greater hardness without loss of ductility and a finer grain. The copper steels closely resemble nickel or chromium steel, and follow the same laws as to their increases of strength for each increase of percentage, but they are said to possess a higher elastic limit and maximum strength than nickel steel, as well as greater dynamic strengths. Copper has a more active influence on steel than nickel or manganese, and nearly approximating chromium, molybdenum, and vanadium, and it is a cheaper alloying material than these.

Copper steels as rolled show greater tensile strength with each increase of copper, and this is more manifest with the lower carbon percentages, but it is not dependable in this state. Annealing corrects this to a large extent, but does not leave the metal much if any stronger than the ordinary steel. Hardening and tempering after this, however, more than doubles the tensile strength and elastic limit, and brings the latter up close to the former with a good percentage of contraction. This would seem to indicate that if copper steels were well made they would be able to withstand shock, torsional, alternating, or vibrational strains, as well as the high-grade steels of the present day, and, owing to the comparative cheapness of copper, they could be produced cheaper.

Some corrosion tests were carried on that showed that corrosion was lower by something like 100% in copper steel than in steels that contained no copper. The electrical resistance is also increased in steels containing copper, and reaches its maximum in a 0.15% carbon steel at 2% of copper; in a 0.7% carbon steel at 0.5% copper, and in a 1.7% carbon steel at 0.35% copper.

ARSENIC AND THE ANALOGOUS ELEMENTS ANTIMONY AND BISMUTH

Phosphorus, arsenic, antimony, and bismuth all belong to the same chemical group, and in general form compounds of the same character and of similar composition. Like nitrogen they unite with metals to form binary compounds, called phosphides, arsenides, and antimonides. They all form two oxides, which contain 2 atoms of the above-named elements to 3 atoms and 5 atoms of oxygen. Of these elements phosphorus occurs most abundantly in nature; arsenic and antimony next, and bismuth last. The last three occur sometimes in the uncombined state, but phosphorus always occurs in combination with other elements.

Many steels contain an appreciable percentage of arsenic, as it combines with iron in forms that are similar to the sulphide which it frequently accompanies. The arsenides, which are its compounds with metals, occur very widely distributed, and often accompany the sulphides to which they are similar. The most common compound of this kind has the composition $FeAsS$, and may, therefore, be regarded as iron pyrites (FeS_2), in which one atom of arsenic has been substituted for one atom of sulphur. Simple compounds of pyrite and arsenic occur that are analogous to the sulphide FeS_2, and combinations of sulphur and arsenic form into sulphides.

When steel contains an appreciable percentage of arsenic it will give off an odor similar to garlic when heated to a red heat, and this odor may become very intense at a welding or forging heat. As an element it is not poisonous, but when oxidized it may become extremely so and it is easily oxidized.

If the arsenic in commercial steel does not exceed 0.20% it does not have any material effect upon the mechanical properties, as the elongation and reduction of area are not changed and the tenacity is but slightly increased. This leaves the bending properties unchanged at ordinary temperature. Above 0.20% the strength of steel is increased and the toughness decreased with each increase in the percentage of arsenic until 4% is reached, when the elongation and reduction of area become nil and the steel becomes very brittle. Even with 4%, however, it does not affect the hot working of the metal, and it can be alloyed with iron in proportions as high as 56% under certain conditions of mixing. These conditions, however, are difficult to fulfil.

By ordinary methods attempts have been made to produce alloys in various proportions up to 10% of arsenic, but when analyzed the sample showed that the maximum of arsenic taken up and retained by the iron was about 4%, this appearing to be about the largest amount that could be commercially added to steel. While steels with the higher percentage of arsenic are brittle, no special difficulty is met with in machining them with any percentage of arsenic.

Owing to the fact that arsenic, when present in acid pickling solutions, causes a marked reduction in the rate of attack by the acid, it was thought that if the arsenic was added to the iron it might resist the attacks of corrosion and become more durable. Numerous tests that were made, however, show no appreciable difference in the non-corrosive qualities of iron and steel that contained arsenic and those of the ordinary brand.

Any benefits derived from alloys of arsenic with iron or steel will probably be in connection with their magnetic properties, as some very interesting results have been obtained along this line. It alloys with iron practically in proportions of the solid mixtures, up to an arsenic content of 4%. With each increase of arsenic in steel up to 5%, the magnetic qualities of iron are made better and the arsenic alloys are on an equality with the best electrolytic material known in respect to magnetic permeability. When the metal is heated to 1250° F. and slowly cooled, so as to allow the grain to become normal and the forging or rolling strains to be removed, the metal shows a decided improvement. A second heating to 1800° F., with slow cooling, improves the quality in the lower ranges of the magnetic forces, but there is a falling off in the upper ranges of the curve. Quenching from 1650° F. shows no hardening and but slight changes in the magnetization curves. Arsenic added to iron imparts to the alloy magnetic qualities excelling those of the purest iron, and at least equaling those of the best material from which data is obtainable.

Antimony may be added to iron in quite large percentages, but above a content of 1% the metal is not forgeable, and only then with difficulty. It renders the metal brittle so that it is practically worthless, and it is of a lower grade magnetically than the ordinary electrolytic iron. Thus while antimony is in the same chemical group as arsenic, it makes iron products that are difficult to work and have no apparent value as a magnetic material. Antimony is useful in the non-ferrous alloys for the hardening effect it gives, and that it expands when solidifying makes it valuable for such uses as type casting. These same properties make it detrimental to iron and steel products, and luckily it does not appear in the crude materials used for making these.

Bismuth, like antimony, does not occur in combination with iron or in the products used for producing the iron ore when refining it into steel, consequently it does not have to be removed as an impurity. To a greater degree than antimony it has the property of expansion when passing from the liquid to the solid state, and therefore it is useful in non-ferrous alloys.

When 2% of bismuth, the most diamagnetic element known, was added to iron, it improved the already high magnetic quality of the pure iron. The density values reached exceed those obtained from any of several hundred other different alloys that have been tested. How much bismuth remained in the metal after adding the 2%, however, was not known. With bismuth alloys there is but little increase in electrical resistance. Arsenic and antimony, however, give a decided increase in resistance to iron, and in some cases this was from 62 to 67%.

BORON

In nature boron chiefly occurs in the form of boric acid, or as salts of this acid, such as borax, a sodium salt, or two calcium salts. It belongs to the same chemical family as aluminum, and is very similar to it in the composition of its compounds, but its oxide is acidic, while the oxide of aluminum is usually basic. In some respects it resembles the members of the family to which nitrogen and phosphorus belong. It has a strong affinity for nitrogen, especially at the higher temperatures, and also combines readily with sulphur and chlorine. Some boron crystals contain carbon and aluminum, which seem to be in combination with the boron.

Ferro-boron can be prepared from borate of lime, in the electric furnace, without any special difficulty, and the above data would suggest that boron might have some qualities that would be beneficial to steel, but very little in the way of investigation has so far been done. What little has been done would indicate that boron acts like carbon in many respects, especially in adding hardness to the metal.

In some recent tests which were made on steel containing 0.20% of carbon and 0.20, 0.50, 0.80, 1, and 2% of boron, the Brinell hardness of the samples tested and quenched at 1460° F. was three times that of the annealed pieces, and equal to that of high-carbon steel similarly treated. Notwithstanding this the hardened samples could be easily filed, sawed, or machined, while 0.87% carbon steel, similarly treated, could not be scratched except with an emery wheel.

This is adding evidence to the statement that has been made several times, but disputed by some, namely: that hardness is not the same thing as the ease or difficulty with which steel can be machined with cutting tools. The tests also show that boron confers upon steel the property of tempering; but a tempering that is very different from that conferred upon the metal by carbon, in that it increases the tensile strength and elastic limit, without materially increasing the toughness or hardness to machine. On the other hand, the ability to withstand shock tests was doubled by quenching, and the elastic limit was brought up close to the tensile strength.

In heating boron steels they show a definite emission of heat at 2100° F., which resembles the recalescent point in high-carbon steel. Slightly marked critical points appear at 1900°, 1525°, 1350°, and 1225° F. The three latter are about the temperature of the points Ar3, Ar2, and Ar1 of mild steel. The point at 1240° F. is definitely shown in carbon steel, but when boron is added and the steel heated, this point almost entirely disappears, and is replaced by the point at 2100° F.

Boron may be said to give steel a hardness that increases its strength, up to a content of 2% of boron, providing the carbon is kept below 0.2%, but beyond a content of 2% boron or 0.2% carbon, the metal becomes so brittle that it is weakened and easily powdered under a hammer. Other elements might be found, with further investigations, that would overcome this brittleness and make boron more useful for special alloys of steel.

Microscopical examinations show intense black spots in boron steels that are polished and etched, first with picric acid and then with picrate of sodium. These increase in quantity with each increase in the percentage of boron. These spots may be a combination of boron-iron; a solid solution of boron-iron containing a very low percentage of boron; a borocarbide of iron, or a boride of carbon. In specimens thus treated the ferrite appears white, the pearlite grayish, and the special constituent very black.

On annealing, the volume of pearlite increases and the special constituent disappears by forming a eutectic with the ferrite that at times is strongly marked. By annealing in the presence of oxide of iron, so as to decarburize the metal, the pearlite is first caused to disappear and then the special constituent.

In carbonizing the special constituent is not increased by case-hardening, although at the edges a layer of pearlite is found and this is thinner if the metal does not contain boron. This would indicate that the penetration of carbon is delayed by boron, and that the amount of the special constituent depends upon the percentage of boron, and is independent of the carbon content.

In the quenched steels, the special constituent was hardly discernible when the percentage of boron was below 0.50, but large quantities appeared in the steels with the higher percentages of boron. This was not altered even when the quenching was carried to 2200° F. The percentage of carbon increases the solubility of the special constituent, and the higher the percentage of boron the less easily does it dissolve.

The above data probably indicates that the black spots were a borocarbide of iron, and its percentage of carbon very low; otherwise a phenomena would occur similar to that brought out in the investigations of the vanadium steels, *i.e.*, as the boron increased the pearlite would diminish; but in these steels the special constituent continues to increase.

Boron steels are very weak and brittle in the normal state, and, if heated to a very high temperature, crumble when forged or rolled. But if heated to a dull red they can easily be forged, rolled, or otherwise mechanically worked, as they act much like soft steel. This will make them useless in the raw state, but after quenching they possess a high tensile strength, a very high elastic limit, and are not any more brittle than the special steels that are in actual use at present.

Borax is a sodium salt from which amorphous boron, in almost pure form, can be obtained by heating with magnesium powder. It has been used by many misinformed people as part of a mixture for carbonizing steel, or in a special compound for hardening it, but they have never given any good reason for its use or shown any results that were obtained thereby. It, like boron, retards the penetration of carbon, but when used in a quenching bath may aid in producing a greater hardness, or preventing the metal from cracking or checking. Common table salt (NaCl), however, gives much better results, and is easier obtained and cheaper. Therefore borax is not useful here; its chief value is as a flux in welding.

TANTALUM

Tantalum is one of the rare elements. It is never found free in nature, but occurs in combination in the minerals columbite and tantalite, accompanied by niobium. In chemistry it is grouped with vanadium, niobium, and didymium, all of which are rare. Its rareness, and consequent cost, has prohibited it from being experimented with to any extent, but one series of tests that was conducted appeared to prove that it had a hardening effect upon steel, similar to that exerted by tungsten and molybdenum, and to a certain extent gave promise of being beneficial for high-speed steel tools.

In all of the eight tests made, the tantalum which varied from 0.42 to 1.69% increased the tensile strength, elastic limit, elongation, and reduction of area over that of the same steel without tantalum, but when nickel or chromium was added in place of the tantalum, the same strengths were obtained and in one case 1.10% of chromium gave about 10% greater strength than 0.43% of tantalum. The greatest increases in strength were obtained with the smallest percentages of tantalum.

Under the microscope a dark constituent appeared that was greater in quantity as the percentage of tantalum increased, and this occurred in a finely granular matrix that in the hardened specimens seemed to be martensitic and more or less homogeneous.

From the results obtained and its similarity to vanadium the suggestion occurs that it acts on steel as a scavenger similar to this, and the best results would be obtained in the quaternary steels, but no evidence has been submitted to prove that it is any better, or even as good as the alloying materials already in use, and which are much cheaper. It is also very difficult to separate it from niobium, with which it is always combined, and this element is liable to cause erratic results in steel.

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The above data probably indicates that the black spots were a borocarbide of iron, and its percentage of carbon very low; otherwise a phenomena would occur similar to that brought out in the investigations of the vanadium steels, *i.e.*, as the boron increased the pearlite would diminish; but in these steels the special constituent continues to increase.

Boron steels are very weak and brittle in the normal state, and, if heated to a very high temperature, crumble when forged or rolled. But if heated to a dull red they can easily be forged, rolled, or otherwise mechanically worked, as they act much like soft steel. This will make them useless in the raw state, but after quenching they possess a high tensile strength, a very high elastic limit, and are not any more brittle than the special steels that are in actual use at present.

Borax is a sodium salt from which amorphous boron, in almost pure form, can be obtained by heating with magnesium powder. It has been used by many misinformed people as part of a mixture for carbonizing steel, or in a special compound for hardening it, but they have never given any good reason for its use or shown any results that were obtained thereby. It, like boron, retards the penetration of carbon, but when used in a quenching bath may aid in producing a greater hardness, or preventing the metal from cracking or checking. Common table salt (NaCl), however, gives much better results, and is easier obtained and cheaper. Therefore borax is not useful here; its chief value is as a flux in welding.

TANTALUM

Tantalum is one of the rare elements. It is never found free in nature, but occurs in combination in the minerals columbite and tantalite, accompanied by niobium. In chemistry it is grouped with vanadium, niobium, and didymium, all of which are rare. Its rareness, and consequent cost, has prohibited it from being experimented with to any extent, but one series of tests that was conducted appeared to prove that it had a hardening effect upon steel, similar to that exerted by tungsten and molybdenum, and to a certain extent gave promise of being beneficial for high-speed steel tools.

In all of the eight tests made, the tantalum which varied from 0.42 to 1.69% increased the tensile strength, elastic limit, elongation, and reduction of area over that of the same steel without tantalum, but when nickel or chromium was added in place of the tantalum, the same strengths were obtained and in one case 1.10% of chromium gave about 10% greater strength than 0.43% of tantalum. The greatest increases in strength were obtained with the smallest percentages of tantalum.

Under the microscope a dark constituent appeared that was greater in quantity as the percentage of tantalum increased, and this occurred in a finely granular matrix that in the hardened specimens seemed to be martensitic and more or less homogeneous.

From the results obtained and its similarity to vanadium the suggestion occurs that it acts on steel as a scavenger similar to this, and the best results would be obtained in the quaternary steels, but no evidence has been submitted to prove that it is any better, or even as good as the alloying materials already in use, and which are much cheaper. It is also very difficult to separate it from niobium, with which it is always combined, and this element is liable to cause erratic results in steel.

PLATINUM

Platinum occurs in nature associated with five other elements, more rare than itself. They are divided into two chemical sub-groups commonly called the platinum metals. These nearly always occur in an alloy in which the platinum is from 50 to 80%, while the other five compose the balance.

It forms two oxides and two sulphides. It is very ductile and is a grayish-white metal that looks like steel. It can be welded at a white heat. An alloy of platinum and silicon can be formed by bringing it in contact with red-hot charcoal and silicon dioxide. Nitric, hydrochloric, or sulphuric acid will not dissolve it. Platinum, when finely divided, has an extraordinary power of condensing gases upon its surface; for instance, it absorbs 200 times its own volume of oxygen, also other gases similarly. The oxygen is then in the active condition, and oxidizable materials are easily oxidized when brought into contact with it. Thus when sulphur dioxide and oxygen flow together over spongy platinum, or even the compact metal, they form sulphur trioxide by a unity of the two gases, or when hydrogen flows against the spongy platinum it takes fire.

Iridium belongs to the same chemical group and, when this is alloyed with platinum in the proportions of 1 to 9 respectively, it reduces the malleability of platinum, which can be easily drawn into very fine wire; makes the alloy harder; more difficult to fuse; as elastic as steel; unchangeable in the air, and capable of taking a high polish.

While platinum is but little cheaper than gold, the above properties have led to its being investigated as an alloying material for iron, but as yet the experiments have been very few, and limited in their scope. Platinum has no transformation points, and it consequently reduces those of iron when mixed with it. Up to 10% of platinum, two transformation or recalescent points occur, while with the platinum from 10 to 40% but one point is produced. The melting-point diagram shows considerable analogy to that of the nickel-iron alloys, but this is stronger when the alloys are rich in iron than when they are rich in nickel or platinum.

The hardness of the platinum alloys decreases from 0 to 5% of platinum, and then gradually increases from there to a platinum content of 40%, after which it remains fairly constant until 90% of platinum is reached, after which it declines again. At 50% of platinum the greatest brittleness occurs.

From 0 to 90% of platinum all the alloys are magnetic, and this diminishes in the same ratio as the iron in percentages of from 80 to 20 of that metal. Alloys with the platinum from 10 to 50% lose their magnetic power when heated to from 1475° to 1200° F., and it returns at a much lower temperature when cooling. Alloys with the platinum from 60 to 90% regain their magnetic power at a temperature even lower than this.

NICKEL

The chemical sub-group in which nickel belongs is composed of iron, cobalt, and nickel, and in many respects they are very similar. It occurs native in meteorites, and the iron meteorites always contain nickel. The principal minerals that contain it are nickeliferous pyrites and garnierite. Large deposits of minerals containing both nickel and copper have been found. The metals are reduced together and put on the market under the name of monel metal.

Nickel, however, is separated in the pure form for many uses, and one of the most important of these is as an alloying material in the manufacture of special steels. It is a white metal with a slight yellow cast, and is very hard and capable of being highly polished. It is very brittle in its ordinary condition, but when deoxidized by magnesium becomes very malleable.

Nickel reduces the size of the crystalline structure and increases the toughness of steel. It brings the elastic limit closer to the tensile strength, and microscopic cracks, that are liable to develop into larger cracks and produce rupture, do not appear as quickly in steels containing nickel as those without it. In certain proportions it also makes steel more resilient or springy, increases the hardness, raises the tensile strength, and segregates only slightly.

Nickel was first added to steel for the purpose of overcoming the property of "sudden rupture," which is inherent in all carbon steels. This it does to a large extent, making steel better able to withstand severe shock and torsional stresses, as well as compressive stresses. This is not due to hardening, as soft steel cannot be made hard by the addition of nickel, except in large quantities, and it is considered that 17.55% of nickel is the equivalent of only 1% of carbon.

The properties of nickel steel depend as much upon the carbon content as on the nickel. The fact that a 2 or 3.5% nickel steel is used means nothing unless the carbon content is right for the use to which the steel is to be put. To illustrate, a steel containing 2% nickel and 0.12% carbon has a good tensile strength with a great elongation, and is useful for some purposes, while a steel that is equally useful for another purpose may contain 2% nickel and 0.9% carbon, and this would give it a high tensile strength with very little elongation. With a high carbon content nickel steel is difficult to harden, especially locally, as fissures and cracks tend to develop in quenching. It also has more tendency to warp in quenching than other steels and may be decarbonized by heating. These tendencies may be overcome to a great extent if the metal is thoroughly annealed before it is machined to size, in order to relieve all of the internal strains. Then, when quenched, the piece should be immersed in the bath so that the liquid can cover the greatest possible surface at the instant it strikes the bath, and it should be agitated while cooling.

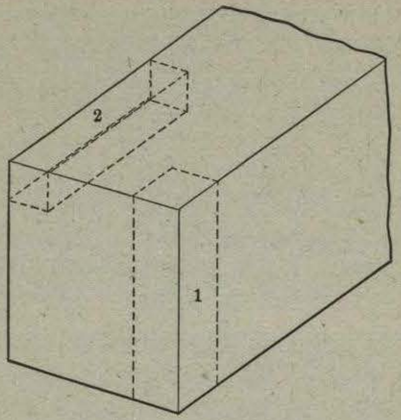

FIG. 47. — Cutting test bars.

Nickel also gives steel a tendency to show laminations, and makes it weaker at right angles to, than in line with, the direction in which it is rolled. The higher the nickel content the greater will be the contrast between the strength in these two directions. This is best shown by tests which were made on test bars 1 and 2, cut from a piece of 3.5% nickel steel as indicated in Fig. 47. Test bar 1 showed an elongation of 12% and a reduction of area of 17%. Test bar 2 gave an elongation of 25% and a reduction of area of 65%. The good qualities which nickel gives to steel offset these bad qualities to such an extent that it makes a much better steel for gears, crank-shafts and pieces which have similar work to perform than the ordinary carbon steel.

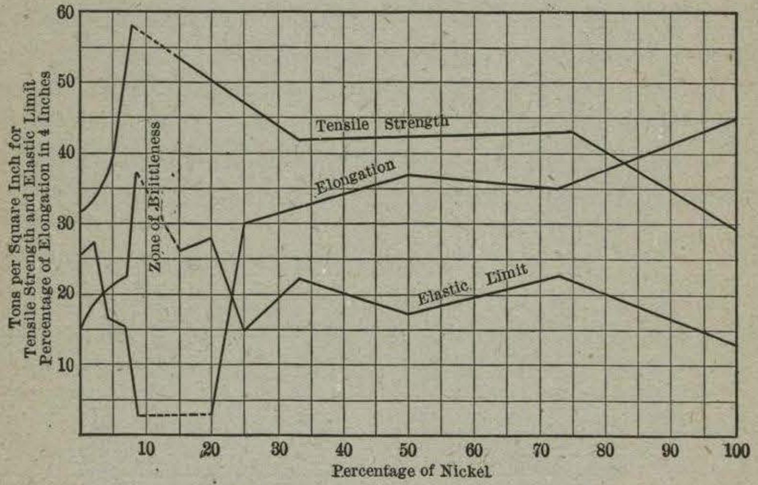

FIG. 48. — Effect of nickel in different percentages.

Nickel greatly reduces the tendency of steel to be damaged by overheating, and also increases the effect of hardening in raising the strength of the metal. One series of tests which were made showed a tensile strength of 88,000 pounds per square inch, an elastic limit of 60,000 pounds per square inch, an elongation of 28% and a reduction of area of 58% when in the annealed state. These figures were changed by hardening to a tensile strength of 225,000 pounds, an elastic limit of 224,500 pounds, an elongation of 8%, and a reduction of area of 19%. A good quality of carbon steel might give the same results in the annealed state, but they could not be increased to nearly the same extent by means of the ordinary hardening.

Nickel has one peculiarity in its influence on steel which is best shown by Fig. 48. It increases tensile strength and elastic limit, but steels containing 8 to 15% of nickel are so brittle that they can be powdered under a hand-hammer; at 15% of nickel the toughness begins to be restored; from 20 to 25% the elongation rapidly increases, and from there on to 50% a gradual increase is shown.

Steel with percentages of nickel from 30 to 35 gives good results for valves on internal-combustion engines, as the nickel makes the steel wear better and it is not as good a conductor of heat as other metals. Nickel steel can be purchased in the open market in nearly all percentages of nickel from 1 up to 35%, and with varying percentages of carbon.

In Fig. 49 is shown the actual results that were obtained from a series of twenty tests, in which the nickel varied from 0 to 20%, and the other ingredients remained fairly constant. Ten of the tests were with forged steel and ten with cast steel. They give a good idea of the strengths that can be expected in nickel steels, although, as has been said many times, nickel steel in the annealed or natural state is but little better than carbon steel, but if properly heat-treated it will greatly exceed carbon steel for static and dynamic strengths, wearing qualities, etc.

COBALT

The principal minerals containing cobalt are smaltite and cobaltite, and in each of these iron and nickel take the place of a part of the cobalt. It, like nickel, forms compounds that are analogous to ferrous compounds, and also a few that are analogous to ferric compounds. In the latter case, its power is greater than that of nickel. Cobalt is harder than iron, melts at a slightly lower temperature, and has a silver-white color with a tinge of red.