Chapter I

INTRODUCTION (VIEWPOINT AND SCOPE).

THE story of alloy steel may have its beginning before the dawn of history when primitive man fashioned implements from nickel-bearing meteorites, — "iron from Heaven". It seems certain, however, that the last thirty or forty years have encompassed more progress in the alloying of special steels and putting them to work effectively than the millenniums preceding. Fascinating as an account of this recent rapid development might be, it must nevertheless be omitted from these discussions for want of time. Furthermore, a chronological survey of alloy steels and their development would, almost certainly, not constitute the most effective means of becoming acquainted with them. It will rather be the objective in these lectures to develop a simple philosophy of the alloy steels, for which we shall have need to utilize as many of the fundamental scientific observations as possible, although curiously enough they are none too plentiful, despite the technically advanced state of the utilization of alloy steels. We shall try to build up a concept of the actual function of the various common elements incorporated in alloy steels and to discover how the atoms of these auxiliary elements distribute themselves in the steel, just what they accomplish by their presence and how it may be that they contrive to alter the properties of the ordinary carbon steels so profoundly.

One observes that already in the first few sentences it has been necessary to bring in a basis of comparison when, even in the most general way, the effects of the alloying elements are called to mind. It is then a most natural thing in considering alloying effects to use as a basis of reference, comparison and evaluation, those steels which depend mainly upon iron and carbon for their properties and contain little or no intentional addition of other elements to modify their properties. The mode of approach to the subject shall involve a realization, first, that the plain carbon steels, with their moderate content of manganese and silicon, possess a considerable range of valuable properties which, however, are subject to limitations even though elaborate treatments are employed to bring out their potential properties and, second, that these limitations may be extended by the presence of certain other elements, mostly metallic ones. Interest immediately attaches to the question of which properties may be improved, and by which elements, — but still more fundamental is the question of *how* these other elements enhance the valuable properties of ordinary carbon steel.

In contemplating the property *enhancements* contributed by alloying elements it is important that measures be employed which are in nature really quantitative. In general the effects of alloying elements are strong when a substantial amount is present and it will be unnecessary to draw fine distinctions which require hair-splitting accuracy of measurement. Nevertheless, the viewpoint must remain quantitative; otherwise the risk is run of ending up with opinions, conjectures or, at the worst, some wishful thinking, all reflections of a departure from objectivity which can be maintained only when quantitative data are at hand. It is thus essential that the basis of references, i.e. steels free from or low in special elements, be well understood and it might conceivably be profitable to devote fully half of these discussions to the characteristics of plain carbon steels. For those to whom these discussions are addressed, a much shorter review of carbon steel will be adequate and doubtless much more acceptable. The series of lectures[1] corresponding to the current

[1]"The Principles of Heat Treatment", by M. A. Grossmann, 1935, American Society for Metals, Cleveland, Ohio. A series of five educational lectures on the principles of the heat treatment of steels presented to the members of the American Society for Metals during the Seventeenth National Metals Congress and Exposition, Chicago, Ill., Sept. 30 to Oct. 4, 1935.

ones, presented by Dr. M. A. Grossmann in 1935, constitute an excellent viewpoint of the physical metallurgy of steel treating from which to consider in detail the effects of alloy elements in steel.

While an enquiry into the alloying elements in steel implies a discussion of alloy steels, it is not regarded as at all necessary for the present purpose to set forth a finely-drawn definition of "alloy steel". The objective is a knowledge of, and if possible, a subsequent classification of, the common alloying elements as to their basic functions in steel, — functions which result in property contributions. We may reason about these functions with the firm conviction that the effects of the several elements will remain quite the same regardless of which name is applied to any steel bearing any of them. As to the carbon steels used as bases of comparison it may suffice to say that they will contain less, generally, than one per cent total of any elements other than iron and carbon, and little enough of any to insure a relatively unimportant modification of properties. In the case of manganese, it will be realized that its normal occurrence may already be of detectable significance.

It will not be possible to cover this subject at all thoroughly; neither the writer nor the time allotted is adequate to such a task, and accordingly it will be necessary to concentrate attention upon certain ranges of composition, and certain categories of properties. Special attention will be directed toward enhancement of mechanical properties and to those alloy steels of considerable tonnage which are generally hardened and tempered; that is, such as show a substantial response to heat-treatment. This means the steels which carry sufficient carbon, and not too much of alloying element, to permit the characteristic control of transformation of medium- and high-carbon steel. Generally speaking, this group of steels contains upwards of about 0.35 per cent carbon and not more than, say, 5 per cent of alloying element. Relatively less attention will be devoted to low-carbon steels and to those containing such large amounts of alloying element as to preclude the allotropic inversions in the ordinary sense, such as Hadfield's manganese steel, some of the stainless steels, Invar, and so forth.

The author has been forced to conclude that it is unproductive to attempt to correlate systematically ultimate mechanical properties directly with the presence of the several common alloying elements without considering the proportion of the element, the carbon content, and above all, the heat-treatment employed and the final structure. Thus, it would seem almost misleading to say, without qualification, that any certain element contributes, for example, hardness and toughness to steels without stating in what composition and after which treatment. It is now established that an element does not, merely by its auspicious presence alone, contribute a property, as sugar lends sweetness, without regard for the *structure* favored by the element under specific circumstances.

Accordingly it seems that a more potent attack would be brought to the problem by a consideration of the individual effects upon structure and thus in turn upon properties. The data are not complete and many gaps must remain unfilled, but if the viewpoint is fortunately chosen, the data, as they are accumulated, should be found to fit in harmoniously with the plan of enquiry. Most of the discussions will have to do with solubilities, rates of reaction, effective rates of diffusion and thus of microscopic structures and their persistence. In turn the relation of structure to useful properties will of necessity be enquired into repeatedly.

While it will be possible to consider in detail only those influences of alloying elements mentioned above, it is interesting to observe how extensive the list of properties may be which are altered by alloying elements and, under suitable handling, improved for engineering applications. Some of the characteristics of steels influenced by alloying elements are as follows:

A. Enhancement of Mechanical Properties.

1. Increase in strength of steel as manufactured.
2. Increase in toughness or plasticity in steel at any minimum hardness or strength.
3. Increase of allowable maximum section which may be quench-hardened to desired properties.
4. Decrease in quench-hardening capacity.
5. Increase in rate of hardening with cold work.
6. Decrease in plasticity at given hardness in the interest of machinability.
7. Increase in abrasion resistance or cutting capacity.
8. Decrease in warping and cracking in development of desired hardness.
9. Improvement of physical properties at either high or low temperatures.

B. Enhancement of Magnetic Properties.

1. Increase in initial permeability and maximum induction.
2. Decrease in coercive force, hysteresis and watt loss (magnetically "soft" iron).
3. Increase in coercive force and remanence (permanent magnets).
4. Decrease of all magnetic responses.

C. Enhancement of Chemical Inertness.

1. Decrease of rusting in moist environment.
2. Decrease of attack at elevated temperature.
3. Decrease of attack by chemical reagents.