

Again, a steel may be dangerously high in phosphorus and sulphur and yet pass the ordinary physical tests. Cases of failure have been recently studied by polished cross-sections which showed numerous micro-flaws around the normal crystals of the steel—these being invariably accompanied by extra high phosphorus or sulphur. In the testing machine these steels might be manipulated so as to pass muster, but when in position vibration gradually enlarges these flaws until under some sudden strain for which the factor of safety was supposed to provide, fracture occurs, mysterious breaking of rails, shafts, axles, are often examples of this. Nothing seems to be proven clearer by long experience than that carbon is the only hardener to be tolerated in steel for general use, and that everything else must be reduced to the lowest possible limit, especially phosphorus.*

Bessemer inaugurated the reign of the age of steel in 1856 by announcing his process. He early experienced the deleterious effect of phosphorus which the operation in the converter would not

properties of the metal; this hypothesis being deduced from the fact that when all other foreign elements are present in the same proportion in each, there still remains a decided difference in properties depending upon the mode of manufacture.

The Bessemer converter affords steel the best chance to take up these gases, as they are all three forced through the molten metal in large quantities; in the Open Hearth the metal is more or less protected from the gases passing through the furnace, and we would expect to find less present in the finished metal, while in the crucible where the steel is entirely isolated from such contamination, the least quantity of these gases should be found in the metal.

The determination of nitrogen, oxygen and hydrogen in the laboratory is accompanied by peculiar difficulties which have never been satisfactorily surmounted, however, careful examination by the best known methods has shown the foregoing hypothesis to be relatively correct, and that variation in physical properties follows variation in content of oxygen, hydrogen and nitrogen, just as the effect of manganese, sulphur and phosphorus manifests itself.

* Prof. Roberts-Austen has pointed out the marked relation which exists between the atomic volumes of those elements, which when present in very small quantities in metallic gold increases or decreases, the tenacity and extensibility of the metal, i.e., the elements which increase this property of gold have the same or a lower atomic volume, while the elements which have the opposite effect, have invariably a larger atomic volume.

Similarly in steel the foreign elements can be classified distinctly into two groups, according to their atomic volume:

I.		II.	
C (as diamond)....	3.6	W.....	9.6
Mn	6.7	Si	11.2
Ni	6.9	As.....	13.2
Cu	7.1	P	13.5
Cr	7.7	S	15.7
Fe	7.2	O	17.0
		Al.....	10.7
		Sn.....	16.1
		Sb.....	18.2
		Bi.....	21.1