the piece, i.e., that all parts are heated at the same rate, and also that all parts are heated to the same temperature. These conditions are facilitated by slow heating, especially in case the treated piece is large. A uniform heat, as slow in temperature as will give the required hardness, produces the best product. Lack of uniformity in heating causes irregular grain, internal strains and may even produce surface cracks. Any temperature above the "critical point" of a steel tends to open its grain—to make it coarse and to diminish its strength, though such a temperature may not be sufficient to lessen appreciably its hardness.

Critical Temperatures.—The temperatures at which take place the previously mentioned internal changes of structure of a steel, are frequently spoken of as the "critical points." These are different in steels of different carbon contents. The higher the percentage of carbon present, the lower the temperature required to produce the internal change. In other words, the critical points of a "high" carbon steel are lower than those of a "low" carbon steel. In steel of the commonly used carbon contents there are two of these "critical temperatures," called the "decalescent point" and "recalescent point" respectively.

The decalescent point of any steel marks the correct hardening temperature of that particular steel. It occurs while the temperature of the steel is rising. The piece is ready to be removed from the source of heat directly after it has been heated uniformly to this temperature, for then the structural change, necessary to produce hardness, has been completed. Heating the piece slightly higher may be desirable for either or both of the two following reasons: (1) In case the piece has been heated too quickly, and not uniformly, this excess temperature will assure the structural change being complete throughout the piece; (2) any slight loss of heat which may take place in transferring the piece from the furnace to the quenching bath may thus be allowed for, leaving the piece at the proper temperature when quenched.

If a piece of steel, which has been heated above its decalescent point be allowed to cool slowly, it will pass through a structural change, reverse to that which takes place on a rising temperature. The point at which this takes place is the "recalescent point" and is lower than the rising critical temperature by some 30° to 100° C. (86° to 212° F.). The location of these points is made evident by the fact that while passing through them the temperature of the steel remains stationary for an appreciable length of time. It is well to observe that the lower of these points does not manifest itself unless the higher one has been first fully passed.

It is for the reason that these critical points are different for different steels, that they cannot be definitely known, for any particular steel, without an actual determination.

Heating a piece of steel to its correct hardening temperature thus produces a change in its structure, which makes possible an increase in its hardness, but this condition is only temporary unless the piece is "quenched."

Quenching.—This treatment consists in plunging the heated steel into a bath, cooling it quickly.

By this operation the structural change seems to be trapped and permanently set. Were it possible to make this cooling instantaneous and uniform throughout the piece, it would be perfectly and symmetrically hardened. This condition can not, however, be realized, as the rate of cooling is affected both by the size and shape of the treated piece; the bulkier the piece, the larger the amount of heat that must be transferred to the surface and there dissipated through the cooling bath; the smaller the exposed surface in comparison with the bulk, the longer will be the time required for cooling. Remembering that the cooling should be as quickly accomplished as possible, the bath should be amply large to dissipate the heat rapidly and uniformly. Too small a quenching bath will cause much loss, due to the resulting irregular and slow cooling. To insure uniformly quenched products the temperature of the bath should be kept constant so that successive pieces immersed in it will be acted upon by the same quenching temperature. Running water is a satisfactory means of producing this condition.

The composition of the quenching bath may vary for different purposes; water, oil or brine being used. Greater hardness is obtained from quenching, at the same temperature, in salt brine and less in oil than is obtained by quenching in water. This is due to a difference in heat-dissipating power possessed by these substances. Quenching thin and complicated pieces in salt brine is unsafe as there is danger of the piece cracking, due to the extreme suddenness of cooling thus produced.

In the actual round of shop work the steel to be hardened is generally of a variety of sizes, shapes and even compositions. To obtain uniformity both of heating and of cooling, as well as the correct limiting temperature, the peculiarities of each piece must be given consideration in accordance with the above outlined points. In other words, to harden all pieces in a manner best adapted to but one, would result in inferior quality and possible loss of all except this one. Each different piece must be treated individually in a way calculated to bring out the best results from it.

Theory.—The presence of these critical points in the heating and cooling of a piece of steel is a phenomenon. The most reasonable theory advanced to explain this is as follows:—

While heating, the steel uniformly takes on heat. Up to the decalescent point all of the energy of this heat is exerted in raising the temperature of the piece. At this point, the heat taken on by the steel is expended, not in raising the temperature of the piece but in work, which produces the internal changes here taking place between the carbon and the iron. Hence, while the heat added is being taken up in this manner, the temperature of the piece, having nothing to increase it, remains stationary or, due to surface radiation, may even fall slightly. After the change is complete the added heat is again expended in raising the temperature of the piece, which increases proportionally.

When the piece has been heated above the decalescent point and allowed to cool slowly, the process is reversed. Heat is then radiated from the piece. Until the decalescent point is reached, the temperature falls uniformly. Here the internal relation of the carbon and the iron is transformed to its original condition, the work required to do this being converted into heat. This heat, set free in the steel, supplies for the moment the equivalent of that being radiated from the surface. While this condition holds, the temperature of the piece ceases falling and remains stationary. Should the rate of evolution of heat from the internal changes be greater than that of surface radiation, the resulting temperature of the piece will not only cease falling, but will obviously rise slightly at this point. In either event the condition exists only momentarily, for when the carbon and iron