SOLUBILITY LIMIT

For many alloy systems and at some specific temperature, there is a maximum concentration of solute atoms that may dissolve in the solvent to form a solid solution; this is called a ***solubility limit***. The addition of solute in excess of this solubility limit results in the formation of another solid solution or compound that has a distinctly different composition. To illustrate this concept, consider the sugar– water ($C_{12}H_{22}O_{11}$–H_2O) system. Initially, as sugar is added to water, a sugar–water solution or syrup forms. As more sugar is introduced, the solution becomes more concentrated, until the solubility limit is reached, or the solution becomes saturated with sugar. At this time the solution is not capable of dissolving any more sugar, and further additions simply settle to the bottom of the container. Thus, the system now consists of two separate substances: a sugar-water syrup liquid solution and solid crystals of undissolved sugar.

This solubility limit of sugar in water depends on the temperature of the water and may be represented in graphical form on a plot of temperature along the ordinate and composition (in weight percent sugar) along the abscissa, as shown in Figure 2. Along the composition axis, increasing sugar concentration is from left to right, and percentage of water is read from right to left. Since only two components are involved (sugar and water), the sum of the concentrations at any composition will equal 100 wt%.The solubility limit is represented as the nearly vertical line in the figure. For compositions and temperatures to the left of the solubility line, only the syrup liquid solution exists; to the right of the line, syrup and solid sugar coexist. The solubility limit at some temperature is the composition that corresponds to the intersection of the given temperature coordinate and the solubility limit line. For example, at 20°C the maximum solubility of sugar in water is 65 wt%. As Figure 2 indicates, the solubility limit increases slightly with rising temperature.

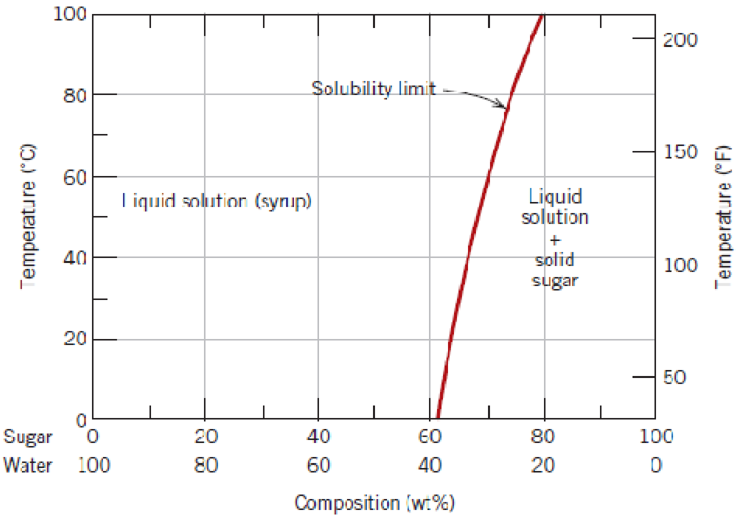

Figure 2: The solubility of sugar ($C_{12}H_{22}O_{11}$) in a sugar-water syrup.

PHASES

- **Phase: -** *a homogeneous aggregation of mater. Every one notes that H_2O can exit as a gas, a liquid and a solid. These are three different phases.*
- **Phase: -** is a region of material that has uniform physical and chemical properties

Also critical to the understanding of phase diagrams is the concept of a ***phase.*** A phase may be defined as a homogeneous portion of a system that has uniform physical and chemical characteristics. Every pure material is considered to be a phase; so also is every solid, liquid, and gaseous solution. For example, the sugar–water syrup solution just discussed is one phase, and solid sugar is another. Each has different physical properties (one is a liquid, the other is a solid); furthermore, each is different chemically (i.e., has a different chemical composition); one is virtually pure sugar, the other is a solution of $H_2O$and $C_{12}H_{22}O_{11}$. If more than one phase is present in a given system, each will have its own distinct properties, and a boundary separating the phases will exist across which there will be a discontinuous and abrupt change in physical and/or chemical characteristics.When two phases are present in a system, it is not necessary that there be a difference in both physical and chemical properties; a disparity in one or the other set of properties is sufficient. When water and ice are present in a container, two separate phases exist; they are physically dissimilar (one is a solid, the other is a liquid) but identical in chemical makeup. Also, when a substance can exist in two or more polymorphic forms (e.g., having both FCC and BCC structures), each of these structures is a separate phase because their respective physical characteristics differ. Sometimes, a single-phase system is termed “homogeneous.” Systems composed of two or more phases are termed “mixtures” or “heterogeneous systems.” Most metallic alloys and, for that matter, ceramic, polymeric, and composite systems are heterogeneous. Ordinarily, the phases interact in such a way that the property combination of the multiphase system is different from, and more attractive than, either of the individual phases.

ONE-COMPONENT (OR UNARY) PHASE DIAGRAMS

Much of the information about the control of the phase structure of a particular system is conveniently and concisely displayed in what is called a ***phase diagram,*** also often termed an ***equilibrium diagram***. Now, there are three externally controllable parameters that will affect phase structure-viz. temperature, pressure, and composition- and phase diagrams are constructed when various combinations of these parameters are plotted against one another. Perhaps the simplest and easiest type of phase diagram to understand is that for a one-component system, in which composition is held constant (i.e., the phase diagram is for a pure substance); this means that pressure and temperature are the variables. This one-component phase diagram (or *unary phase diagram*) [sometimes also called a *pressure–temperature* (or *P–T*) *diagram*] is represented as a two-dimensional plot of pressure (ordinate, or vertical axis) versus temperature (abscissa, or horizontal axis). Most often, the pressure axis is scaled logarithmically.

We illustrate this type of phase diagram and demonstrate its interpretation using as an example the one for H_2O which is shown in Figure 3. Here it may be noted that regions for three different phases-solid, liquid, and vapor-are delineated on the plot. Each of the phases will exist under equilibrium conditions over the temperature-pressure ranges of its corresponding area. Furthermore, the three curves shown on the plot (labeled *aO*, *bO*, and *cO*) are phase boundaries; at any point on one of these curves, the two phases on either side of the curve are in equilibrium (or coexist) with one another. That is, equilibrium between solid and vapor phases is along curve *aO*-likewise for the solid-liquid, curve *bO*, and the liquid vapor, curve *cO*. Also, upon crossing a boundary (as temperature and/or pressure is altered), one phase transforms to another. For example, at one atmosphere pressure, during heating the solid phase transforms to the liquid phase (i.e., melting occurs) at the point labeled 2 on Figure 3 (i.e., the intersection of the dashed horizontal line with the solid-liquid phase boundary); this point corresponds to a temperature of 0ºC. Of course, the reverse transformation (liquid-to-solid or solidification) takes place at the same point upon cooling. Similarly, at the intersection of the dashed line with the liquid-vapor phase boundary [point 3 (Figure 3), at 100ºC] the liquid transforms to the vapor phase (or vaporizes) upon heating; condensation occurs for cooling. And, finally, solid ice sublimes or vaporizes upon crossing the curve labeled *aO*.

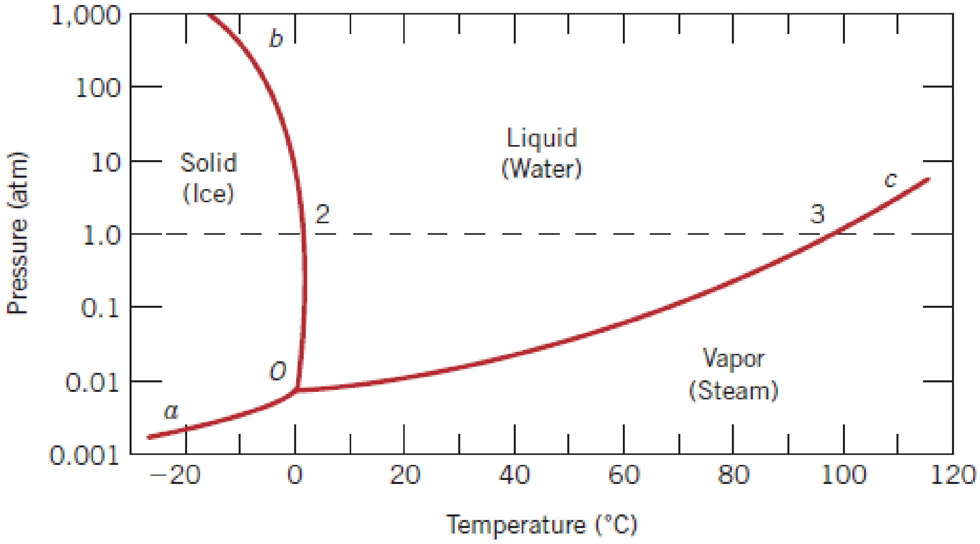

Figure 3: Pressure–temperature phase diagram for H_2O Intersection of the dashed horizontal line at 1 atm pressure with the solid-liquid phase boundary (point 2) corresponds to the melting point at this pressure (*T* = 0ºC). Similarly, point 3, the intersection with the liquid-vapor boundary, represents the boiling point (*T* = 100ºC).

As may also be noted from Figure 3, all three of the phase boundary curves intersect at a common point, which is labeled *O* (and for thisH_2O system, at a temperature of 273.16 K and a pressure of 6.04×10^{-3} atm). This means that at this point only, all of the solid, liquid, and vapor phases are simultaneously in equilibrium with one another. Appropriately, this, and any other point on a *P*–*T* phase diagram where three phases are in equilibrium, is called a *triple point;* sometimes it is also termed an *invariant point* inasmuch as its position is distinct, or fixed by definite values of pressure and temperature. Any deviation from this point by a change of temperature and/or pressure will cause at least one of the phases to disappear. Pressure-temperature phase diagrams for a number of substances have been determined experimentally, which also have solid, liquid, and vapor phase regions. In those instances when multiple solid phases (i.e., allotropes) exist, there will appear a region on the diagram for each solid phase, and also other triple points.