The zone-melting technique has been used for determining eutectic compositions in complex metal systems. The application of this technique is demonstrated in a ternary system, Mg-Al-Zn, in which the literature is uncertain as to the composition of the ternary eutectic; in a quaternary system, Al-Mg-Zn-Si, in which the eutectic composition is unknown, and in a complex system, Al-Mg-Zn-Cu-Sn-Pb, in which the eutectic composition cannot possibly be determined using the conventional method. The advantages and disadvantages of the unique approach for the determination of the eutectic composition are discussed.

SOLIDIFICATION ANALYSIS OF A HYPOTHETICAL TERNARY PHASE DIAGRAM

Consider the directional solidification by zone-melting of an alloy in a hypothetical phase diagram of a ternary system ABC, as shown in Fig. 1. Components A, B, and C are completely soluble in each other in the liquid state. Components A and B form a compound D; A and C form a compound F; B and C form a simple eutectic having a limited solid solubility optimum strengths.

The purpose of this investigation is to apply the zone-melting technique to determine eutectic compositions in the Mg-Al-Zn system in which the literature is not certain as to the composition of the ternary eutectic; in the Al-Mg-Zn-Si system in which a quaternary eutectic composition is unknown; and in a complex system, Al-Mg-Zn-Cu-Sn-Pb, in which the eutectic composition cannot possibly be determined using the conventional technique.

Fig. 1—Hypothetical ternary phase diagram.
of C in B; D has a maximum melting point, i.e., it forms a eutectic with A and B; F is formed by the peritectic reaction at 500°C, i.e., melt M reacts with α solid solution to form compound F. Curves $E_1P_1, MP_1, E_2P_2, P_2P_3, P_3P_4, E_3T,$ and $E_4T$ are the space curves which are similar to valleys between hills. A liquid at any point of any space curve is doubly saturated with two solid phases. The heavy dashed curves of $\Delta ABC$ are the projections of all space curves from the space diagram.

To demonstrate the zone-melting process in this ternary system, we consider the solidification of a liquid mixture, $l$, as indicated at the left-hand corner of Fig. 1. The first solid freezing out of the liquid is the α solid solution. Upon further solidification, the liquid is depleted in α solid solution and moves toward the space curve $MP_1$ along which the liquid is in equilibrium with α solid solution and F. Then, the liquid moves continuously down along the space curve $MP_1$ until it reaches the space-curve junction $P_1$. At $P_1$, a four-phase invariant reaction occurs, i.e., melt $P_1 + α \rightarrow F + D$. The melt $P_1$ then moves down to $P_2$ along the path $P_1P_2$. At $P_2$ another four-phase reaction occurs, i.e., melt $P_2 + F \rightarrow C + D$. From $P_2$ to $T$, the only ternary eutectic point of the hypothetical space diagram $ABC$, the melt is in equilibrium with pure C and compound D, and finally freezes completely at $T$, the ternary eutectic point at the ternary eutectic temperature. Below this temperature, the ternary alloy consists of three solid phases, namely, pure C, solid solution $\beta$, and intermetallic compound, D. After passing a molten zone through alloy $l$ many times unidirectionally, the last portion of the frozen liquid, in principle, should yield the ternary eutectic composition $T$.

The vertical section $AX$ perpendicular to the hypothetical space diagram, Fig. 1, is given in Fig. 2, which shows the phase relationship at various temperatures throughout the entire section. From Fig. 2, it can be seen that the liquidus has one cusp, because the vertical section $AX$ cuts the space curves $E_1P_1$ at position 2. To segregate efficiently the eutectic composition toward the end of a rod during zone-melting, it is evident that a mixture of composition 2 should be selected, because it is close to the ternary eutectic point $T$.

**EXPERIMENTAL PROCEDURE**

A Lepel 10 kw low frequency induction furnace was used for the zone-melting operation. In brief, a single-loop coil was set up on a portable carrier which runs on tracks to control the freezing rate. The ternary, quaternary, and sexinary alloy rods, $\frac{1}{2}$ in. in diameter and 12 in. long, were zone-melted under a dried argon atmosphere. The average zone length was 1 in. At the end of the experimental run, the solidified rods were cut along their longitudinal and transverse sections for metallographic examination. Only the last 3 in. of the zone-melted rod were analyzed chemically using the standard procedures for magnesium alloys.

**RESULTS AND DISCUSSION**

The Mg-Zn-Al System. According to Mikheeva, the ternary eutectic temperature of the ternary eutectic alloy, Mg-52.2 Zn-1 Al, is 338°C, 2 deg less than a value reported by Koster and Dullenkopf, who mistakenly placed the ternary eutectic composition at 51 pct Zn and 49 pct Mg. These conflicting data have led Yue and Clark to re-determine the ternary eutectic composition in the magnesium-rich region of the Mg-Zn-Al system using the zone-melting techniques. Their result is represented by the hollow circle in Fig. 3. Since a Globar resistance furnace was used to introduce a molten zone in the solid, practically no stirring effect was detected in the liquid during the zone-melting process. Under this condition the transport of solute build-up at the solid-liquid interface was done by liquid diffusion. Consequently, a question was raised as to the accuracy of the determined eutectic composition. To answer this question, it was decided to re-determine eutectic composition using a