when the two plates are close together the temperature profile is linear, given by:

$$T = \frac{T_1 + T_2}{2} - \frac{1}{2}(T_1 - T_2)\frac{y}{L}, \quad -L \leq y \leq +L \quad [1]$$

Furthermore, under these conditions the fluid velocity is dominated by the vertical velocity component, u_z . The following approximate expression has been derived for the velocity profile:⁸

$$u_z = \frac{\mu}{12\rho L} \text{Gr} \left[\left(\frac{y}{L} \right)^3 - \frac{y}{L} \right] \quad [2]$$

where μ is the viscosity, ρ is the density, and Gr the Grashoff number is defined as:

$$\text{Gr} = \frac{\rho^2 \beta g L^3 \Delta T}{\mu^2} \quad [3]$$

where β is the coefficient of thermal expansion and $\Delta T = T_1 - T_2$. Rearrangement of Eq. [2] yields:

$$u_z = \frac{\Delta T}{L} \left(\frac{\beta g L^3}{12\mu} \right) \left[\left(\frac{y}{L} \right)^3 - \frac{y}{L} \right] \quad [4]$$

Inspection of Eq. [4] readily shows that the convective velocity may be drastically increased by increasing the value of L , while the temperature gradient $\Delta T/L$ is kept constant.

While the geometry used by the authors would have resulted in a great deal more complex flow field, the general argument still holds in a qualitative sense, that the scale of the system must play an important role in determining the absolute values of the fluid velocity.

This fact, well known to students of natural convection, may explain practical observations about the persistence of convective flow in large solidifying ingots even at very low levels of superheat. As a corollary it may be postulated that natural convection transients are unlikely to be important in melts enclosed between closely spaced dendrite arms, even if there exist steep temperature gradients within such regions.

A great deal of information has become available on natural convection in confined systems which need not be reproduced by metallurgists; it is the adaptation of these results to solidification problems that provide the real challenge.

Authors' Reply

L. MacAULAY AND F. WEINBERG

We think that Dr. Szekely has misinterpreted the purpose of this investigation. We are not trying to demonstrate qualitatively that fluid flow results from density differences in the liquid associated with temperature gradients. This is well established, as he points out, and we are aware of the extensive body of theoretical and experimental information available related to fluid dynamics.

What we are measuring directly is the *quantitative* flow rate of liquid metal in a system in which the length to height ratio is very large. In our case the liquid length is 25 cm, the height 0.6 cm. This configuration has been used extensively in solidification studies for many years since it allows one to assume

an essentially linear heat flow and one dimensional solidification. The transition gradient at which significant fluid flow occurs is particularly of interest since below this transition solute is transported in the liquid exclusively by diffusion, and this can be quantitatively defined. To the best of our knowledge, there is no means of applying existing fluid dynamics theory or experimental results, to predict quantitatively the onset of significant fluid flow associated with temperature or solute gradients in our configuration for a liquid metal. We consider this knowledge, as well as the flow pattern taken up in actual experimental configuration where small lateral temperature gradients can be important, is an essential step in the full understanding of the solidification process.

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8. *ibid.*, p. 297

The Gamma-to-Alpha Transformation in Iron

GLENN D. BODA AND DAVID J. MACK

A recent paper¹ calls attention to a massive transformation in an Fe-5 pct Ni alloy. There is no reason why any allotropic pure metal will not show both a massive and a martensite transformation.² This communication describes such transformations in pure iron.

The irons used were Ferrovac E from the Crucible Steel Co. of America and a zone refined iron from the American Iron and Steel Institute via the Battelle Memorial Institute.

The specimens of size $\frac{1}{8}$ by $\frac{3}{16}$ by $\frac{7}{16}$ in., were subjected to a "stepped quench", i.e., samples were quickly heated in a salt bath to 1020°C, quenched into another salt bath held at subtransformation temperature for varying lengths of time from 10 sec followed by a quench into ice water. The stepped quench thus consists of an isothermal hold before completion of the quench.

Prior to polishing for optical and electron metallography, $\frac{3}{16}$ in. was cut from the edge of each specimen. Hardness readings were taken on most specimens.

Three distinct structures were obtained, depending on the combination of austenitizing time at 1020°C and the temperature of the stepped quench.

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