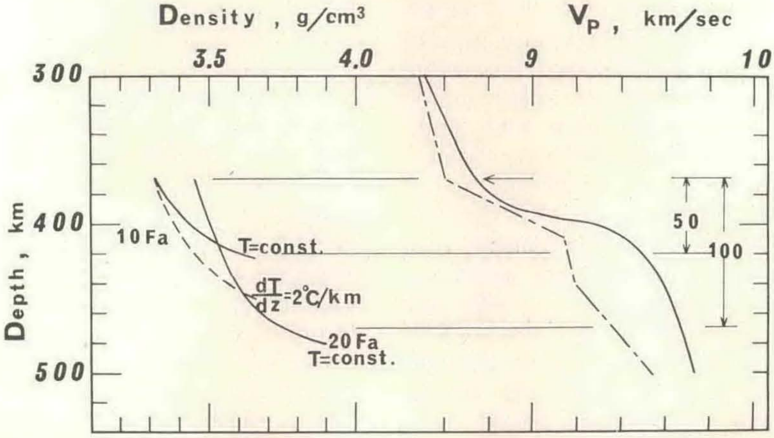

Fig. 6. The zero-pressure density increase with increasing amount of spinel in the two-phase region is compared with the anomalous velocity gradient zone.

1967*b*] and *Birch's* [1960, 1961] velocity-density relation, *Anderson* [1967*c*] pointed out that the observed velocity increases associated with each transition are slightly less than predicted for the appropriate phase change and that the whole density increase associated with the olivine-spinel transition and the spinel-oxides decomposition is fairly less than the total density increase across the transition layer of the mantle. He suggested that increasing the content of Fe_2SiO_4 from 20% in the upper mantle to 40% through the transition layer is satisfactorily consistent with the CIT 204 model, provided that the earth's mantle is composed mainly of olivine. This interpretation seems disagreeable, however, from the preceding discussion of the density and the petrological evidences.

An alternative for lessening the velocity increase through olivine-spinel transition region is to add more pyroxene to the mantle materials. Coexistence of an adequate amount of pyroxene will reduce the change of bulk properties in this region. Another solution to the problem of this velocity increase in the olivine-spinel transition in the homogeneous-composition model is to consider that the transition region determined by the seismological observation would correspond to some part of the transition, not the entire transition region, as mentioned above. These would not clear away Anderson's suggestion of the difficulties in the homogeneous-composition model. In the present stage of investigation, however, the existence of such difficulties may be the problem to solve, and the accurate knowledge of elastic properties of denser phases is an essential factor in further discussions.

TEMPERATURE AT TOP OF TRANSITION LAYER

From the discussions above it appears likely that the region of the anomalous velocity gradient around the depth of 400 km in the present velocity models would approximately correspond to the two-phase region of olivine-spinel transition in ferromagnesian olivine within the mantle. Consequently, the stability conditions for the two-phase region must be satisfied within this depth interval. As for the interior of the earth, pressures had been determined at each depth with sufficient accuracy, and the only adjustable parameter to satisfy the stability conditions is the temperature at the depth considered. This can be seen in Figure 5.

Before estimating the temperature, we will consider the accuracy of the measurement of pressures and temperatures in the olivine-spinel equilibrium experiment of *Akimoto and Fujisawa* [1967]. (The data from their work are used in this discussion.) The amount of error in the estimated pressure values for the fixed calibration points up to 100 kb would not exceed a few per cent, and the reproducibility of pressure calibration is quite good. For ordinary calibration runs, however, the construction of samples is different from construction for the phase equilibrium runs; that is, the samples for the latter runs are heated in a graphite-tube furnace. It has been found that the presence of a graphite-tube furnace in a pressure medium makes the pressure transmission inefficient by nearly 10% to a tube-less assemblage for the pressure calibration at the room temperature and in the pressure range up to the Ba I-II transition. This inefficiency would hold true in higher pressure region. On the other hand, it is believed that at temperature higher than 1000°C the pressure medium would soften and pressure would be transmitted more efficiently [*Boyd and England,* 1963]. Thus, the working pressures would be increased several per cent higher than the values estimated from the calibrations at room temperature. In the phase diagrams presented by *Akimoto and Fujisawa* [1967] (see Figures 1 and 5 (except olivine solvus 5)), these effects are not considered. Putting all accounts together, it could be said that there is a possibility of decreasing the transition pressure shown in Figures 1 and 5 by a few per cent.

There are two sources of error in the temperature estimation. First, the simple error coming from stability of furnace temperature; this error does not exceed ±20°C in the experiment. Second, the pressure effect on the emf of thermocouples must be considered. Accurate estimation of this effect is very difficult, because there are no quantitative results available for the range of pressures and temperatures considered here. Direct measurement of this effect has made only up to 100°C under relatively lower pressure [*Bridgman,* 1918; *Bundy,* 1961]. *Hanneman and Strong* [1965, 1966] estimated indirectly the pressure effect up to 50 kb and to 1300°C with Pt|Pt-10Rh, C|A, and Pt|Pt-13Rh thermocouples. If their results are true in higher-pressure range, the temperatures indicated in the phase diagrams of Figures 1 and 5 (except olivine solvus 5), which were determined with the Pt|Pt-13Rh thermocouple, must be corrected by nearly +100°C, since in the experiment no correction was made for this kind of error. This indirect method of determining the pressure effect has not yet been justified by any other evidence. We tentatively adopt the value of +100°C as the maximum amount of correction needed.

Now we will try to estimate the temperature at the top of the transition layer in two limiting cases. From the preceding discussions, we will use in this attempt the assumed parameters: (1) the Fe/Mg ratio in mantle minerals is 1 : 9, and (2) the depth at which olivine-spinel transition begins is at about 370 km ($\simeq$125 kb).

Lower limit of the temperature at 370-km depth. We will assume that (1) the pressure transmission is not affected by the existence of a graphite-tube furnace, and (2) the pressure effect on the emf of thermocouple can be considered negligible. In this case the phase relations indicated in Figure 5 can be used without corrections, and the temperature at the depth of 370 km is estimated to be 1150°C from olivine solvus 1 in this figure.

Upper limit of the temperature at 370-km depth. We will assume that (1) the existence of a graphite-tube furnace results in a 10% reduction of the pressures previously estimated, and (2) the pressure-induced correction for the emf of thermocouple reaches nearly 100°C. In this case the phase relation shown in Figure 5 must be modified as shown in the curve for olivine solvus 5, and the estimated temperature at the 370-km depth reaches about 1530°C.

Thus the temperature at the depth of about 370 km would be limited in the range

$$1150°\text{C} \leq T_{370\,\text{km}} \leq 1530°\text{C}$$

as long as the model of Kanamori or Johnson is considered. The temperature distributions given by *Rikitake* [1952] and *Verhoogen* [1954] fall in this range of temperatures. Extrapolated value from *Ringwood*'s [1966*b*] geotherm would exceed even the highest limit of the present estimation at the 370-km depth, and *Gilvarry*'s [1957] distribution gives lower temperature values than are given by the present estimation at that depth.

The temperature at that point will be lowered (to 800°C at the 320-km depth, in the lowest case, with CIT 11CS3) if other recent models referred to in the former section are taken into account, since in all these models the rapid rise of velocity around the 350-km depth always begins at a shallower depth than in the model of Kanamori or Johnson.

The temperature distribution in the olivine-spinel transition region cannot be determined strictly, since the correlation between the observed thickness of the transition region and the width of the two-phase region in the olivine-spinel transition has not yet been established