Whitney, Charles A. and Richard N. Thomas.
Comment on the progressive wave in Cepheid atmospheres.

The "standing-"¹ and "running-wave"² models of Cepheid variables discussed in the literature are based on three implicit assumptions, i.e., the reversing layer and photosphere are (a) geometrically thin while (b) optically thick, and (c) the time average of the observed expansion velocity is zero. Only the character of the phase relation between density and velocity in a compression wave has been utilized in the "running-wave" model. There has been no attempt at a self-consistent picture from a gas-dynamic standpoint.

Thomas has earlier suggested that a consideration of the propagation of the wave, and its energy transfer to the atmosphere, in atmospheres of varying gravity and effective temperature may well illuminate such observed Cepheid features as the hump on the light curve and the anomalous extent of the atmosphere.³

While a detailed investigation, under way at the Harvard Observatory, is necessary, some physical insight results from considering a third extreme model. We assume that the Cepheid disturbance is a compression wave which is geometrically thin relative to the atmosphere. The disturbance is represented by a hump on the normal temperature-optical depth curve. The variation of luminosity arises from a combination of the disturbed region's movement into less optically deep layers and a change of disturbance amplitude.

The extent and character of the atmosphere determine whether the wave develops into a shock front, its change in thickness, and whether a second peak develops, corresponding to the well-known *N*-wave character of a mature shock. Evidently the model permits a qualitative reproduction of the observed character of the Cepheid variation, of the occurrence of emission lines, and the phase lag features. On this model the hydrogen emission lines are the first spectral lines to be observed during the new pulsation phase, not the absorption lines.

Color observations should provide some of the characteristics of the model applied to a particular star. Such color observations on Cepheids have shown the variation of apparent color temperature to be greater than compatible with variations of effective temperature inferred from conventional integrations of the velocity curve.⁴

In an analysis of Stebbins' six-color observations of δ Cephei, Canavaggia and Pecker have

utilized monochromatic fluxes computed by Pecker for classical yellow-giant atmospheres.⁵ With an assumed temperature at one phase they have derived the effective temperature for δ Cephei as a function of phase. From these temperatures, the monochromatic light curves, freed from changes of radius, were drawn and compared with the observed curves to obtain the changes of radius. A comparison with the change of radius computed from the radial velocity curve in the conventional manner, using an absolute magnitude on the revised scale, led Canavaggia and Pecker to suggest the need for a reconsideration of the pulsation hypothesis. Eggen had earlier reached a similar conclusion from different considerations.⁴

Using the phase of zero expansion velocity as parameter, we find that by choosing this phase to agree with the phase 0.60 of maximum radius as required by the observations, we obtain excellent agreement between the variation of radius computed from color and computed from radial velocity. The phase change requires a change in systemic velocity of +10 km/sec. This new integration of the velocity curve also eliminates the observed phase lag of red vs. violet light curves.⁶

This interpretation of the velocity curve implies that the disturbance suffers a net displacement outwards during the time of observation. This suggests that the disturbance is geometrically thin relative to the atmosphere.

The fact that the light variations can be explained in terms of fluxes computed for a single normal atmosphere indicates that the out-running wave is optically thick. The picture of an optically thick disturbance is in accord with the absence of observed hydrogen emission lines in the spectrum of δ Cephei.

Multi-color observations on Cepheids which do show hydrogen emission lines would be invaluable in further examining this model.

1. Rosseland, *Pulsation Theory of Variable Stars*, 1949.
2. Schwarzschild, *Circ. Harv. Coll. Obs.* Nos. 429, 431, 1928.
3. *A. J.* 52, 158, 1947.
4. O. J. Eggen, *Ap. J.* 113, 367, 1951.
5. *Comptes Rendus* 234, 1739, 1952.
6. J. Stebbins, *Ap. J.* 101, 47, 1945.

Harvard College Observatory,
Cambridge, Mass.

Wilson, O. C. and L. H. Aller. Monochromatic isophotic contours of planetary nebulae.

Slitless spectrograms of a number of bright planetary nebulae including NGC 1535, 2392,