## THE MINIMUM TEMPERATURE AT THE BASE OF THE STRATOSPHERE.

By W. J. HUMPHREYS.

One of the surprises that has come from sounding-balloon data is the evidence of a minimum temperature in the lower portion of the stratosphere. It has been thought that this recorded minimum is not real—not indeed in the air—but merely the effect of an instrumental error due to the gradual insolational warming of the thermograph under insufficient ventilation. Some records undoubtedly have been seriously affected in this manner, and it may well be conceded that none obtained in full sunshine is wholly free from temperature errors. Nevertheless, such errors are not sufficient to account in full, nor even in large part, for the decided temperature minima often recorded at and next above the base of the stratosphere.

If, however, it be affirmed that the vertical temperature distribution in this region is substantially as shown, which the accumulated records, including night records, require, then the obligation is thereby assumed of explaining how it is possible for a layer of air to be, so much of the time, colder than the atmosphere either above it or below. Such a layer certainly could neither be established nor maintained in a medium so nearly homogeneous in composition as the atmosphere by any known process of radiation or absorption. The explanation, therefore, of this minimum temperature, must be sought in some dynamical process. Nor, indeed, is it far to seek, for its nature appears to be indicated by the fact that the minimum temperature in question is essentially a phenomenon of the anticyclone, as is clearly shown in figures 2 and 3 of the article in this REVIEW, pages 159 and 160, on "Temperatures, pressures, and densities of the atmosphere at different levels in the region of northeastern France."

Now, whatever the origin of the anticyclone, one of its essential features is an extensive movement of air from higher latitudes toward lower. This air, therefore, because of the rotation of the earth, loses more or less of such eastward component of its velocity as it may have had. Hence it lags in its west-to-east flow and thereby acts as a partial barrier to the westerlies. These latter, in rising over this barrier, attain unwonted heights and consequently the topmost layers cool dynamically to temperatures below that which would put them in thermal equilibrium with the outgoing radiation; that is, below the normal temperature of the stratosphere. As such air runs forward it must produce at least three effects: (*a*) It must load that portion of the atmosphere over which it flows, and thus produce high pressure, with descending and dynamically warmed air below; (*b*) it must, in some measure, lift and, thus, through the consequent pressure readjustment, dynamically cool the stratosphere; and (*c*) it must establish, and in part itself constitute, a layer of minimum temperature at the bottom of the stratosphere. An exactly similar effect may also be produced, in some cases, by air on the forward side of a cyclone, as a result of its increased eastward velocity induced by its travel to higher latitudes.

This abnormally cold layer obviously is soon warmed to some extent by radiation, but as the intervals between anticyclones generally are only a few days, it follows that the lower portion of the stratosphere usually is colder than is the atmosphere either next above or below—colder because of endless repetitions at short intervals of dynamic expansions that always chill the topmost overflow beyond the limits of thermal equilibrium.

## WHY THERE ARE NO CLOUDS IN THE STRATOSPHERE.

By W. J. HUMPHREYS.

The very frequent occurrence of cirrus clouds at and immediately below the base of the stratosphere makes it certain that during much of the time the atmosphere at this level is fully saturated. One might, therefore, suppose that the stratosphere, even if wholly devoid of vertical convection, would eventually also become saturated through long-continued diffusion. But the temperature of at least the lower portion of this region often drops 10° C., or more, with no evidence whatever of the formation in it of even a slight haze. Hence it would seem (*a*) that the stratosphere is so nearly devoid of condensation nuclei that it can become two to three fold supersaturated without appreciable condensation; or (*b*) that the difference between the amounts of water vapor that would produce saturation at the temperatures before and after cooling, −55° C. and −65° C., respectively, say, is not sufficient to produce a noticeable haze; or (*c*) that the assumption that the stratosphere is even approximately saturated is in error.

It will be convenient to consider these alternatives in the order given.

The idea that the absence of clouds in the stratosphere may be owing to the lack of condensation nuclei appears to be rendered untenable by the fact that in addition to the cosmic, or meteoric, dust always present, it occasionally contains also vast quantities of volcanic dust, and that even at such times it develops no clouds.

To test the second of the above alternatives—that is, whether or not the supposed condensation would produce a perceptible cloud—it is necessary to consider the effect of the possible amount of condensed water vapor on visibility. Let the initial temperature of the stratosphere be −55° C. and let it be temporarily cooled to −65° C., a supposition in approximate accord with actual occurrences. At −55° C. saturation pressure (expressed in terms of the height of a balancing column of mercury) is 0.0153 millimeter. At −65° C. it is 0.0038 millimeter, and the corresponding amounts of water vapor per cubic meter 0.02028 gram and 0.00528 gram, respectively. Hence on cooling from the higher to the lower of these temperatures there should appear (allowing for temperature contraction of volume) 0.01525 gram of ice crystals per cubic meter. Now it has been found [1] that, roughly, 0.3 gram of fog particles per cubic meter limits vision to about 90 meters. If, then, the ice crystals were the same size as the fog particles referred to the above computed quantity should limit vision to less than 2 kilometers. But it is also known that ice crystals formed at such low temperatures generally are much smaller than the average fog droplet, and therefore a decidedly more restricted vision should be anticipated. At any rate, it appears quite certain that if the strato-

[1] Wagner, Sitz. der K. Akad. der Wis. Wien, 117, p. 1290, 1908.