Difference of Temperature between Pole and Equator of the Sun

BOTH Emden's[1] old hydrodynamic solar theory and the more modern thermo-hydrodynamical solar theory due to Bjerknes[2] lead to a higher temperature at the poles than at the equator of the sun. Bjerknes's theory is, however, more definite as regards the order of temperature difference to be expected. Bjerknes regards the sun as a baroclinic cosmic vortex in which there is a stratified circulation directed from the poles to the equator in the upper photospheric layer and a reverse circulation in the layer immediately below. According to him, sunspots, which he considers also to be vortices, originate in the sub-photospheric stratum; and the depth of a sunspot vortex is connected with the actual difference of temperature between the pole and the equator of the sun. This difference of temperature thus acquires a special importance in solar physics, and therefore an observational determination of this quantity is greatly to be desired. To our knowledge, no measurement of this quantity is so far available. The reason for this lacuna is perhaps to be found in the difficulty of measuring the temperature of the sun with the required degree of accuracy; for the usual methods of measuring the effective temperature of the sun cannot be trusted to give an accuracy greater than ± 400° or 500°. But the temperature difference between the poles and the equator might be of the order of 100° or even less, so that some procedure capable of a higher precision is evidently required.

Some twenty years ago, Woolley[3] evolved such a procedure, which he called the method of "calcium ionization temperature" and which could give an accuracy of ± 50° or better. Recently, during a period of conspicuous solar inactivity and under perfect observing conditions, we were able to apply this method to the determination of the temperature difference between the pole and the equator. Our measurements were aimed at the evaluation of the equivalent widths of the λ 4227 line due to the neutral Ca atom and the λ 3933 line due to the ionized Ca^+ atom at the pole and at the equator from nearly two hundred solar spectra secured under high dispersion. All these spectra yielded concordant values for the equivalent breadths. Our final evaluation of the pole–equator difference of temperature, which was done in accordance with Woolley's theory, led to the conclusion that the temperature at the pole is measurably higher than at the equator. In the calculations we used two alternative theoretical values for the ratio of the coefficients of continuous absorption at λ 3933 (k_1) and at λ 4227 (k_0) derived by Pannekoek[4] and by Chandrasekhar[5]. Pannekoek's value of $k_1/k_0 = 1{\cdot}35$ gave a temperature difference of 96° ± 18°, while Chandrasekhar's more recent value $k_1/k_0 = 0{\cdot}925$ gave 86° ± 16°.

One can derive the depth of a sunspot umbral column from Bjerknes's theory by using the observed difference of temperature between the pole and the equator. From the above values the depth of a sunspot vortex works out as 125 km. and 140 km. respectively. It is perhaps significant that these depths are of the same order as those deduced by Milne[6], Petrie[7] and Unsöld[8] from entirely different theoretical considerations. It is therefore not improbable that the umbral temperature of sunspots may yet turn out to be one of the solar constants as imagined by Milne many years ago.

Full details of our observational procedure and of our method of calculation are given in a paper which will form part of "Vistas in Astronomy", a book (now in the press) dedicated to Prof. F. J. M. Stratton, of Cambridge, on his seventieth birthday.

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