and the grating-loss. The two telescope-losses may be responsible for $O^m_{-15}$ each, and the remaining five for $O^m_{-10}$ each, so that the grating-loss would be $1^m_{-6} + O^m_{-8} = O^m_{-8}$; this is one- or two-tenths of a magnitude more than expected, but again reasonably close, and the discrepancy is in the opposite direction from the Lick one. We may thus regard (1) as a reasonable guide; the zero-point of $-3^m_{-0}$ cannot be far wrong for this sky, emulsion, and exposure time, and it can be adjusted for others without difficulty.

I am, Gentlemen,
Yours faithfully,
R. D'E. Atkinson.

Royal Greenwich Observatory.
1964 August 11.

Reference


Convection and the Differential Rotation of the Sun

Gentlemen,—

Criteria for estimating the superadiabatic temperature gradient required to produce a given convective energy flux in a rotating system have been discussed elsewhere. An attempt is made here to apply these criteria to the solar convective zone. It appears that, although the effect of rotation is negligible in the photosphere, it may double the superadiabatic gradient in the deep convective zone. Consequently, if convective heat transport is the same at the poles as at the equator of the Sun, the polar regions should be cooler by an amount of order 20°K. As Plaskett has pointed out, the associated meridional pressure gradient might explain the differential rotation of the Sun.

The Effects of Rotation on the Solar Convective Zone

It is generally assumed that convection within the Sun has a characteristic length scale equal to the local density scale height. This is much less than the radius of the Sun and it is therefore adequate to describe the convection at a co-latitude $\theta$ in terms of a plane system rotating with an angular velocity $\Omega$ about an axis inclined at an angle $\theta$ to the vertical. If the convection is confined to rolls elongated in the vertical plane containing the axis of rotation, then only the vertical component $\Omega \cos \theta$ of the rotation vector enters into the equations.

On the equator of the convective zone, the necessary superadiabatic temperature gradient

$$\beta \sim 1.5 \times 10^{-9} \, ^\circ \text{K cm}^{-1}$$

The arguments advanced elsewhere indicate that rotation will affect heat transport provided that

$$\Omega^2 \lesssim g\beta/4\Theta$$

where $g$ is the gravitational acceleration and $\Theta$ the temperature. When typical values for the convective zone are inserted, the two sides of this inequality are approximately equal. Under these conditions the effect of
rotation on convection cannot be precisely estimated, but \( \beta \) might be increased by a factor of order unity. Thus the superadiabatic temperature gradient at the poles could be greater by a factor of 2 or 3 than that at the equator. In the photosphere and the shallower regions of the convective zone, on the other hand, the effects of rotation will be negligible.

If the convected energy flux is the same at all latitudes, then this increased temperature gradient will cause the polar regions to be cooler than the equator by about 20 °K at the top of the convective zone.

**Differential Rotation of the Sun**

The variation with co-latitude of the Sun's angular velocity is of the form

\[
\Omega = \Omega_0 (1 + \epsilon \sin^2 \theta)
\]

The motions of deep-seated fields indicate that the equatorial acceleration is not just confined to the photosphere and it is of interest to establish whether this differential rotation could drive the solar magnetic cycle or whether it might be driven by a magnetic couple itself. Mestel has shown that a magnetic field distribution can cause differential rotation. However, the Sun's rotation does not vary with the solar cycle, and the magnetic energy is much less than the kinetic energy in the equatorial acceleration. These facts favour the assumption that the differential rotation is a hydrodynamic rather than a hydromagnetic phenomenon. Kippenhahn has ascribed it to the effects of an anisotropic turbulent viscosity, and Plaskett has pointed out that a meridional pressure gradient could be balanced by the Coriolis force acting on a heliostrophic wind. He suggested that such a pressure gradient might be produced in the photosphere by polar cooling, caused by the mechanism discussed above.

Now the differential rotation requires a pressure excess at the equator on an isopotential surface which could be produced either by an excess equatorial density

\[
\delta \rho = \epsilon \, Q^a \, \rho^2 \, R^2 / 2P
\]

or by an excess temperature

\[
\delta \Theta = \epsilon \, Q^a \, R^2 / 2 \mathcal{R}
\]

where \( \mathcal{R} \) is the gas constant per unit mass. This excess temperature is independent of the local state of the gas. For the observed differential rotation it has a value of 30 °K at the top of the convective zone (and twice that amount in the un-ionized layers above).

This has the same magnitude and sign as the temperature difference already estimated in the first section. It therefore appears that polar cooling, owing to the effects of rotation on convection in the deep convective zone, could produce an equatorial acceleration in that zone. The photosphere would then be dragged round with the underlying matter by friction, since the meridional temperature gradient would, in itself, be insufficient. In the absence of dissipation, the differential rotation would be stable but mechanisms for establishing it and maintaining it against friction have still to be explained.

Observations might permit one to determine whether there is a density or a temperature excess at the equator on an equipotential surface. Preliminary results reported by Plaskett indicate a density excess, i.e., that the differential rotation in the photosphere is produced by a couple. However, such
measurements are difficult to interpret, and it is to be hoped that further observations will enable the point to be settled.

Acknowledgements

I am very grateful to Professor H. H. Plaskett for discussing his results with me. This work was carried out at the Research Laboratory of Electronics of the Massachusetts Institute of Technology and was supported in part by the United States Army Signal Corps, the Air Force Office of Scientific Research and the Office of Naval Research.

I am, Gentlemen,

Yours faithfully,

N. O. Weiss,

U.K.A.E.A.,
Culham Laboratory,
Abingdon, Berks.

References


The Law of Interstellar Extinction

Gentlemen,—

The criticism by Miss Underhill\(^1\) of the work by Johnson and Borgman\(^8\) on the law of interstellar extinction has attracted my attention after its publication. The issue is the conclusion by Johnson and Borgman that there is no unique wavelength dependence of interstellar extinction, confirming earlier and independent investigations\(^3, \, 4, \, 5\). The variations of the law of interstellar extinction lead to values of \(R = A_V/E_{B-V}\) which range from 3 (in most regions) to 7 (in the Orion Nebula region) with intermediate values in young clusters.

The technique which is used to test the uniqueness of the extinction law and to evaluate the variations is very simple and straightforward\(^3\). If in a colour-colour diagram of \(e.g.*\) a large number of \(O\) stars the scatter increases with reddening, then this effect is interpreted as being caused by a variable colour excess ratio (of course after allowance, if necessary, has been made for the expected portion of the effect due to increasing observational errors for fainter stars). This conclusion seems almost unavoidable if the deviations from the mean reddening path are in accord for members of a particular cluster or if they are correlated with galactic longitude. In our paper we have demonstrated such behaviour of the deviations. The scatter, due to the presence of spectroscopic binaries in the sample or due to dissimilarities of