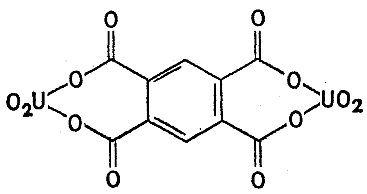
was then measured by visual observation of the signals from the detectors on an oscilloscope.

Uranyl acetate. A dilute solution ($10^{-4}M$) of uranyl acetate was sprayed onto a clean carbon film and allowed to dry. Single bright spots were observed with visibility varying between 1.3 and 1.7. The fact that these were due to material of high Z was verified by taking micrographs with the use of only inelastic electrons. The spots were then invisible, although we observed similar spots which remained bright under these conditions. These may have been due to local concentrations of carbon.

The carbon substrate background noise was not entirely removed by taking the ratio N_e/N_i. This is presumably because the inelastic scattering process is not so highly localized as the elastic process.

Uranium pairs. At the suggestion of M. Beer, uranyl acetate was reacted with 1, 2, 4,5-benzenetetracarboxylic acid. In this case we expect to produce a molecule



where the two uranium atoms are expected to be separated by about 13 Å.

According to Roberts and Caserio (*3*), carboxylic acids are usually found as dimers in the liquid phase. Because the tetracarboxylic acid is symmetrical, we might expect this particular form to polymerize. In this case, we would expect the spacing of the uranium atoms to be approximately $[13 + (n - 1)10]$ Å, where $n = 2$ for a dimer, and so on.

A dilute solution of the reaction product was sprayed onto clean carbon, and pairs of bright spots were seen (Figs. 1 and 2). These spots have a visibility which varies between 1.4 and 1.7, and the spots disappeared when only the inelastic signal was used. The variation in the spacing is consistent with the idea of polymerization. Spacings attributable to one, two, and three molecules were observed.

Thorium chains. Thorium nitrate was reacted with the same carboxylic acid. Thorium is tetravalent and one can therefore make chains of thorium atoms separated by the same organic structure as in the case of uranium. This specimen was made by M. Beer. A dilute solution was sprayed onto clean carbon, and long chains were observed (Figs. 3 and 4). Once again the visibility varied between 1.4 and 1.8, and the spots disappeared when only inelastic electrons were used. Again the average spacing of the spots was somewhat larger than 13 Å, indicating polymerization.

It appears that the bright spots which we have observed are probably due to single atoms. The evidence for this conclusion rests on several facts. (i) The visibility factor is close to the calculated one and is within reasonable error limits. (ii) The spots disappear when we use only inelastic electrons to form an image. (iii) The geometrical arrangement of the bright spots corresponds to the expected one.

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Jupiter's Convection and Its Red Spot

Abstract. *Physical properties of the liquid hydrogen-helium layer of Jupiter are calculated and used in evaluating convection and in interpreting the approximately constant rate of longitudinal motion of the Red Spot on the basis of the Hide-Streett model.*

The Red Spot of Jupiter, known for some 300 years, presents a fascinating object of planetary physics. No satisfactory explanation has been found of its nature and of its huge, remarkably constant rate of longitudinal eastward and westward motion, with an absence of any significant latitudinal motion. Hide's recent proposal (*1*) that what is visible is the top of a Taylor column generated in Jupiter's atmosphere by a surface irregularity has stirred new interest in this problem (*2*). The present report describes an attempt to explain the rate of motion of the spot (about 25 deg/year or 10^2 cm $\sec^{-1}$) in terms of cellular convection in the liquid region of the planet. The model (*3*) of Jupiter used in these studies is a modification of earlier models and is based on a theoretical analysis of the hydrogen-helium system. It suggests that besides a liquid metallic hydrogen-helium core (which in analogy to Earth probably is the source of the huge magnetic field of the planet) there is a solid metallic hydrogen mantle surrounded by a solid molecular hydrogen-helium mantle and a supercritical atmosphere. The latter, made chiefly of hydrogen, may contain much helium in its lower strata.

If the Taylor column of the Red Spot were associated with an irregularity floating on a liquid surface, then its motion could be the result of convection within the liquid layer. An analysis of this motion is difficult because of the absence of a sufficiently general theory of equatorial convection in a rapidly rotating spherical shell. For instance, the problem of convection (governed by the Rayleigh number $R = g\,\alpha\,\rho^2\,C_p d^4\,\lambda^{-1}\,\eta^{-1}$ grad T, where g is gravitational acceleration; λ, thermal conductivity; η, viscosity; d, thickness of the convecting layer; ρ, density; α, thermal expansion; C_p, specific heat; and grad T, the average vertical temperature gradient) has been solved numerically by Durney (*4*), but only for low Rayleigh numbers (about 1500) and low angular velocities not applicable in our case. Certain conclusions can also be drawn from studies of rotating fluid spheres (*5, 6*) rather than shells, but here again the analogies cannot be pushed very far. Finally, much theoretical effort has been directed at analyzing the effect of rotation on convection in the experimentally accessible case when the angular velocity is parallel to the gravitational acceleration. These results are, unfortunately, of little use for the motion of the Red Spot which is so close to the planet's equator. One is forced, therefore, to make assumptions, in particular with respect to the stabilizing effect of rotation on convection. It is well known (*5, 6*) that for low angular velocity the critical Rayleigh number R_c, at which convection sets in, is constant but it increases as $Ta^{2/3}$ for Ta

greater than 10^2 to 10^3, where $Ta = 4\,\Omega^2\,\rho^2\,d^4\,\eta^{-2}$ is the Taylor number; Ω, the angular velocity. For terrestrial and jovian solid mantles this effect is unimportant because the respective Taylor numbers are smaller than 10^{-20}. This is, however, not the case either for Earth's oceans or, as shown below, for Jupiter's liquid layer where Ta can reach values of the order of 10^{21} to 10^{23}. It thus seems natural to assume that Rayleigh numbers (larger than R_c), which are characteristic of various convective patterns, depend on Ta in the same manner as R_c. This basic assumption, which underlies the calculations presented here, permits the use of Turcotte and Oxburgh's (7) analysis of terrestrial convection valid for Rayleigh numbers of the order 10^6. Clearly, this indirect procedure can give, at best, a rough insight into these phenomena and is far from being a solution of a very difficult problem of fluid dynamics.

A supercritical pure hydrogen atmosphere of Jupiter would preclude the existence of a liquid surface. On the other hand, the expected (3) considerable helium content in the lower liquid regions of the atmosphere makes it likely that there is a boundary at which a steep gradient of density occurs and which behaves in many ways like a liquid surface. This conclusion is analogous to that made recently by Streett (8), which is discussed further later on. In order to evaluate the various formulas, the densities and temperatures in the jovian atmosphere given by Peebles (9) are assumed valid, and the various parameters and transport coefficients are calculated with the use of recently developed theories of dense fluids. In particular, Dymond and Alder (10) have shown that $\lambda/\lambda_0 = G_0^{-1} + 4.8f + 12.08\,G_0f^2$ and $\eta/\eta_0 = G_0^{-1} + 3.2f + 12.176\,G_0f^2$, where λ_0 and η^0 are the thermal conductivity and kinematic viscosity for a dilute gas; G_0, the value of the radial distribution function G at contact; and f, the packing fraction or the ratio of the hard-sphere volume of an atom to volume per atom at a particular pressure (p) and temperature (T). The appropriate values of f (and of the related G_0) can be obtained from the Percus-Yevick hard-sphere equation of state (11)

$$(pV)/(NkT) = (1 + f + f^2)\,(1 - f)^{-3} \qquad (1)$$

(V is volume; N, the Avogadro number; and k, Boltzmann constant) in which, according to Dymond and Alder (10) the temperature-dependent, hard-sphere radius can be deduced from the known Lennard-Jones potential. One can also use the Ascarelli and Paskin (12) formulation, in which the right side of Eq. 1 is replaced by

$$(1 + f + f^2)\,(1 - f)^{-3} - 10\,(T_m\,V_m)\,(TV)^{-1} \qquad (2)$$

where T_m and V_m are the melting temperature and melting volume at a particular point. Both Eq. 1 and Eq. 2 turn out to reproduce various properties of dense liquids extremely well. The necessary thermal expansion coefficient and the specific heat can be deduced directly from the equation of state by differentiation of volume and of energy content with respect to temperature.

The use of Eq. 2 requires the insertion of T_m and V_m known from observation. For hydrogen, such values are obtainable only in the region where quantum effects play an important role and thus, at high temperatures, might lead to erroneous conclusions. It was, therefore, decided to use the rather well-established criterion (12) that, at the melting point, $f = 0.45$. When Peebles' data (9) is used, melting occurs at $T = 1700°K$ and $p = 10^{11}$ dyne cm^{-2} at 0.94 of the radius of Jupiter or a depth of the atmosphere of 4000 km. It appears that the quantitative conclusions thus obtained from Eq. 1 and Eq. 2 are in agreement with each other within the limits of the various uncertainties. One obtains in the lowest layer, 100 km deep, the following average values: $\eta = 2 \times 10^{-2}$, $\lambda = 3 \times 10^6$, and $\alpha = 1.5 \times 10^{-4}$, in centimeter-gram-second units, which give $R \sim 10^{26}$ and $Ta \sim 10^{21}$.

The above values were obtained if we assume that pure hydrogen is present. In order to see how they will differ if there is, say, 20 percent helium, the calculations were repeated for pure helium and the suitable interpolation methods (13) for mixtures was applied. It turns out, somewhat surprisingly, that none of the various parameters and coefficients are altered by more than 20 to 50 percent and that the corrections to R and Ta are less than an order of magnitude. Another aspect of the presence of helium, which had to be checked, has to do with the fact that solutes inhibit the onset of convection in solvents. With the use of Veronis's formulas (14), the necessary correction was calculated and again found to be negligible as compared to other uncertainties.

The calculated Rayleigh number can now be adjusted according to the $Ta^{2/3}$ law and inserted into the formula for the rate of convective flow (7):

$$u = 0.142\,\lambda R^{2/3}\,d^{-1}\,\rho^{-1}\,C_p{}^{-1} \qquad (3)$$

which has been derived under certain assumptions, the most important one being the validity of the Boussinesq approximation, requiring that except for density all other parameters are constant. This condition implies that, as assumed above, the depth d is relatively small. The result (15) is a velocity of $10^{1\pm1}$ cm sec^{-1}. Most of the uncertainty in this value is caused by the assumed validity of the dependence of the effective Rayleigh number on Ta. Nevertheless, a comparison with the observed rate of 10^2 cm sec^{-1} indicates that convection in the liquid layer is a reasonable mechanism for the motion of the Red Spot, although, admittedly, it is far from being firmly established. In particular, a detailed consideration of the prevailing convective patterns near the equator should be made. A sequence of alternating eastward and westward convective cells would account for the abrupt change of direction of the Red Spot and for its almost constant velocity. Various theoretical studies (4, 5) mentioned earlier indicate longitudinal motion in the equatorial area, but, in view of their limitations, a definite conclusion does not seem possible at the present time. It should be mentioned also that recent studies (16) of the Red Spot show that it has a small, almost periodic, oscillation superimposed upon the constant eastward or westward motion. A probable explanation of this phenomenon is an oscillation in the upper atmosphere around the Taylor column rather than an oscillatory motion of the base of the column itself.

The question remains: If the Red Spot is the result of an irregularity floating on the liquid "surface," what is this irregularity? Among the various possibilities discussed in this connection, the most likely is that it is nearly pure, solid, molecular hydrogen floating on a helium-rich liquid hydrogen. This model has recently gained strong support in Streett's analysis (8) of the probable structure of the hydrogen-helium system at high pressures. The objection that such a solid raft would be torn apart into smaller pieces by differential accelerations can be avoided by assuming that the surface tension of the liquid (or even a magnetic anomaly) would hold the pieces together. It would be presumptuous, in the present lack of knowledge of the hydrogen-helium system, to calculate this tension. Nevertheless, the general model of the Red Spot and of its motion appears to have many attractive features.

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Quartz: Preferred Orientation in Rocks Produced by Dauphiné Twinning

Abstract. *X-ray analyses of quartz aggregates deformed in the laboratory and in nature show a striking difference in the preferred orientation of the positive and negative trigonal forms. These observations may be accounted for by mechanically induced Dauphiné twinning. This orienting mechanism is unusual in that it requires no permanent strain.*

It has long been known that naturally deformed and recrystallized quartz aggregates develop preferred orientations of their *c* axes (*1*). Only recently has it become possible for one to derive the preferred orientations of all planes and directions within deformed quartz aggregates, using spherical harmonic analysis of x-ray pole figures (*2*). A natural quartz mylonite revealed a pronounced difference in the preferred orientation of the positive and negative trigonal forms (*3*). Similar differences in orientation, most marked for the positive ($r = 10\bar{1}1$) and negative ($z = 01\bar{1}1$) unit rhombohedra, were also found in flints subjected to syntectonic recrystallization (*4*) at constant strain rate in a piston-cylinder apparatus with a solid confining medium (*5*). A satisfactory explanation for this asymmetry in the preferred orientation has not hitherto been found.

Recent x-ray analyses of experimentally deformed quartzites have shown that a difference in the preferred orientations of *r* and *z* also develops in the plastically deformed original grains, even in the absence of recrystallization. A typical inverse pole figure for a sample deformed in the alpha quartz field, where quartz has trigonal symmetry 32 (diffraction symmetry $\bar{3}\ 2/m$), is shown in Fig. 1a; the concentration of the poles to *r* parallel to the maximum compressive stress (σ_1) is more than 1.5 times that of a uniform distribution, whereas the concentration of the poles to *z* parallel to σ_1 is less than 0.5.

Despite the similarity of this inverse pole figure to some of those found by Green *et al.* (*4*) for recrystallized flints, the processes occurring in the two cases were apparently quite different. Thus attempts were made to explain this feature of the preferred orientation in terms of the slip processes known to have operated in the quartzites and thought to have been responsible for orienting the *c* axes (*6*).

Measurements on the universal stage of deformation lamellae in these deformed quartzites reveal that slip occurs primarily on basal (0001) and, to a lesser extent, on prismatic ($10\bar{1}0$) planes. Slip directions have been determined from tests on single crystals (*7*). If the critical resolved shear stress for slip on the prism parallel to *c* were significantly higher for one sense of shear than for the other, then a difference in the preferred orientation of *r* and *z* could develop. Two single-crystal experiments were performed to test this possibility. One cylindrical sample was cored with its length normal to *r* and the other with its length normal to *z*. A prism plane is very nearly in the orientation of maximum resolved shear stress for both orientations, but the sense of shear on it is crystallographically reversed. Both samples were subjected to axial compression at a temperature and strain rate (900°C and 10^{-5} sec^{-1} at a confining pressure of 14 kb) such that deformation was primarily by prismatic slip (*8*). Both crystals showed exactly the same strength (25 kb at the yield point) and essentially identical patterns of deformation lamellae and kinks as seen in thin section.

Further evidence in opposition to the theory that slip processes cause the difference in preferred orientation of positive and negative forms was obtained from analyses of quartzites plastically deformed in the beta quartz field, where quartz has true hexagonal 6/*mmm* symmetry. Inverse pole figures for such samples are indistinguishable from those for quartzites deformed in the alpha quartz field. Since differences between positive and negative forms, such as those displayed in Fig. 1a, are not allowed by the symmetry of the beta quartz field, the differentiation must have occurred during the brief interval in which the samples were under nonhydrostatic stress in the alpha quartz field at the termination of the experiments. Essentially no plastic deformation occurred during this interval; consequently, slip processes could not be responsible for the asymmetrical part of the preferred orientation.

The similarity in the inverse pole figures for quartzites plastically deformed in the alpha and beta fields and for flints recrystallized in the alpha field demands some previously unrecognized mechanism to account for the preferential orientation of the pole of *r* parallel to σ_1. The mechanism apparently involves neither slip nor recrystallization processes and must occur rapidly. Mechanical Dauphiné twinning, first reported in 1933 (*9*) and studied extensively 20 to 25 years ago (*10–12*) in a context unrelated to preferred orientation in rocks, satisfies these conditions.

Dauphiné twins are related to each other by a rotation of 180° about the *c* axis; the hand of the crystal is un-