motion of the superfluid then is represented by adiabatic changes in this ground state under the influence of changing boundary conditions.

The significant difference between He^3 and He^4 stands out at this point. In He^4 there is a single ground state, while in He^3 there are 2^N states very close together just above the lowest one. Hence superfluidity is not to be expected in He^3, except possibly at extremely low temperatures and extremely low velocities.

In He^4, excitation above the ground state can take two forms. There is first the excitation associated with a redistribution of the nuclei among the individual particle states of the low-lying band. Such excitation will involve significant amounts of energy, since it will lead to the equivalent of ionic states. The other form involves excitation of one or more nuclei to the band of excited particle levels. The energy involved in such an excitation may well correspond to as much as the 8°K assumed by London in his model of He^4.

This point of view as to the nature of He^4 appears to embody some of the aspects of the treatments of both Landau and London-Tisza.[3] The liquid is treated as a whole and attention is given to the states of excitation of the whole system. On the other hand, the treatment is based on individual particle states separated by an energy gap. The symmetry properties of the wave functions must be taken into account, and the difference between He^3 and He^4 is correlated to the ways in which these individual-particle states can be occupied.

Further calculations are now in progress to clarify the energy relations among these various kinds of excited states.

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Hypothesis for the Origin of the Magnetic Fields and Angular Rotations of Stars and Planets

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From theoretical considerations it is to be expected that gravitational contraction of ionized material across a magnetic field will produce an enhancement of the magnetic field and a rotational angular momentum of the mass. This process may be associated with the magnetic fields and rotations of galaxies, stars, and planets, and may possibly play a role in expanding universe.

IF it can be assumed that originally a general, weak magnetic field occupied space in which matter was originally diffusely distributed in an ionized state, the action of gravitational force would be such as first to draw the material together *along* the lines of magnetic force to produce the disklike or lenticular-shaped structures resembling our galaxy (the axis of the disk being parallel to the magnetic field). The contraction of the material under gravitational forces *across* the magnetic lines of force is a process slower by ν_e^2/ω_e^2, where ν_e and ω_e are respectively the collison and gyrofrequencies for electrons. As this latter process occurs, one would expect that the total magnetic flux enclosed by the matter would remain the same. This conservation of flux is accomplished by an adiabatic compression of the enclosed magnetic field; the field is enhanced by currents induced in the contracting ionized matter.

This quiescent, collision-permitted process of gravitational contraction across the magnetic field occurs as long as the *e*-folding time constant, τ, for Kruskal-Schwarzschild[1] instability is long compared with the times involved. The value of τ is given by $(\lambda/2\pi g)^{\frac{1}{2}}$, where λ is the wavelength of a perturbation (λ must be much greater than the gyro-radius of positive ions) and g is the gravitational acceleration. During the initial stages of the contractional process, g will presumably be so small and λ so large that instabilities have no opportunity to develop. However, eventually the concentration of matter and magnetic field will reduce the minimum value of λ and increase g to the point where instabilities will develop, and the matter may be expected to jet inward at various locations, producing enhanced inward motion and fluctuations in ion density. (The fluctuations in ion density produced by this general type of instability have been observed in the laboratory.[2,3]) These local regions of higher ion density can now become local centers for gravitational attraction across the magnetic field. Local enhancement of magnetic fields may be expected to occur around these local centers, and further instabilities will eventually permit the matter to contract into stars and planets in the various localities. Each star and planet then presumably has trapped within it its own dipole magnetic field which is the concentration of flux which was swept up over a large area.

For such a dipole field the relaxation time τ (L/R

[1] M. Kruskal and M. Schwarzschild, Proc. Roy. Soc. (London) A223, 348–360 (1954).
[2] W. H. Bostick and M. A. Levine, Phys. Rev. **97**, 13 (1955).
[3] W. H. Bostick and M. A. Levine, Phys. Rev. **87**, 671 (1950).

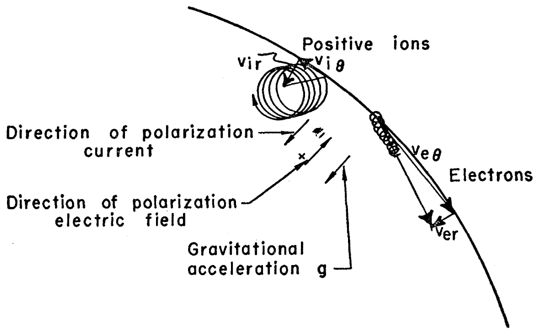

FIG. 1. Drift velocity relationships and polarization involved in the gravitational contraction of ionized matter across a magnetic field. H up out of plane of paper.

time-constant, where L is inductance in henries and R is resistance in ohms) is given[4] approximately by $\tau = 4r^2/10^9\pi\rho$ sec, where r is the radius of the celestial body in cm and ρ is the resistivity in ohm cm. For the sun, ρ is low enough and r high enough to give a value of τ which is long enough for practically all the originally concentrated field to be present. For the earth $r \cong 7\times 10^8$ cm, and if the value of ρ taken is that for iron ($\cong 10\times 10^{-6}$ ohm cm), then $\tau \cong 2\times 10^6$ years, which is about 500 times shorter than the age of the earth. However, if the resistivity under conditions of temperature and pressure encountered in the interior of the earth is substantially less than that of solid iron, the value of τ will be larger. Furthermore, it is quite possible that the earth, during a large fraction of its history, possessed a highly conducting extensive atmosphere, which would effectively increase r and reduce ρ during this period, and hence increase the value of τ. The possibility that even the earth's magnetic field is the residue of a primeval field generated by the contractional enhancement of a general, weak field should, therefore, in spite of Schuster's[4] statement to the contrary, be seriously considered, especially if it can be assumed that some generating process exists which continues to supply enough energy to this field to take care of the relaxation losses.

It can even be reasoned that the rotations of the earth and the sun and astronomical bodies in general have been induced by the gravitational contraction across the magnetic field. The diagram of Fig. 1 illustrates the process whereby the field-enhancing currents are carried primarily by the θ-drift velocity of the electrons, $v_{e\theta} = -(\omega_e/\nu_e)v_r$, but the θ momentum is carried primarily by the positive ions[2] whose θ velocity is $v_{i\theta} = (\omega_i/\nu_i)v_r$. Ambipolar conditions prescribe that the steady-state radial velocities of electrons and positive ions are equal, i.e., $v_{er} = v_{ir} \equiv v_r$. In the approximation that $\omega_e/\nu_e \gg \omega_i/\nu_i$, we can write that $v_r = gm_i\nu_e/m_e\omega_e^2$, where g is the effective inward gravitational acceleration at the point in question, and m_i and m_e refer to the masses of positive ion and electron, respectively. This general rotation may be expected to be imparted to the galaxy as a whole and individual rotations will be imparted to the various stars and planets as they are formed. In general the rotations and magnetic fields should line up. The torque for the production of this angular momentum is produced by the inward polarization current, carried by the positive ions, crossed with the magnetic field (see Fig. 1). The magnetic field must be assumed to be anchored in conducting matter elsewhere so that angular momentum as a whole can be conserved.

It is noteworthy that the alignment of magnetic field and rotation outlined in Fig. 1 is consistent with that found in the sun, and the alignment and sign agree with those for the earth.

A more detailed analysis of the gravitational contraction across a magnetic field is being prepared.

It should be kept in mind that this contractional process represents a conversion of gravitational potential energy to magnetic energy and to kinetic energy of rotation of the mass. In the later phases of contraction into stars where instabilities and recombination may be expected to play a large role, the gravitational energy, of course, is converted largely into heat. This conversion of gravitational energy to magnetic energy in the formation of a galaxy produces varying magnetic fields at large distances from that galaxy. These varying magnetic fields will have a repelling effect on any conducting matter at these large distances, and should therefore have a tendency to expand galaxies away from each other. This mechanism of expansion is essentially the operation of Lenz' law in which the model is that of a group of coils (free to move) in which changing currents are being excited. These coils will move away from each other, the ones on the periphery receding with the highest speed. This effect should be assessed numerically on an intergalactic scale to ascertain whether it is strong enough to produce the observed expansion of the universe.

[4] S. Chapman and J. Bartels, *Geomagnetism* (Oxford University Press, London), p. 704.