and the frozen solution always appeared dark blue when first formed. The rings of frozen solution were tested for persistent currents by removing them from the magnetic field and bringing them up quickly to a compass needle immersed in liquid nitrogen. The compass needle was enclosed in a brass case with a glass top which was tight enough to prevent liquid nitrogen from entering. The sensitivity of 0.02 oersted was found to be unaffected by immersion in the liquid nitrogen. The solution into which the cells were dipped was kept free of moisture with a stream of precooled nitrogen, and its concentration was kept approximately at one molar by adding fresh liquid ammonia from time to time as the volume of solution decreased by evaporation. Twenty-four trials were made with fields ranging from a few oersteds to 1000; in no case was there any indication of a persistent current.

* Publication assisted by the Ernest Kempton Adams Fund of Physical Research of Columbia University.

[1] R. A. Ogg, Jr., Phys. Rev. **69**, 243 (1946).

Superconductivity in Solid Metal-Ammonia Solutions

RICHARD A. OGG, JR.
Department of Chemistry, Stanford University, California
July 1, 1946

THROUGH the courtesy of Drs. Boorse *et al.*, their concurrently appearing communication was submitted to the author before publication. The implications of such a report make it advisable to publish at this time the experimental details which lack of space caused to be omitted from the previous communication.[1]

The conductivity cell was U-shaped, constructed of Pyrex capillary tubing some 10 cm in length and 0.2 mm in bore, with flanged ends sealed to relatively large reservoir vessels, the latter containing strip platinum electrodes. The sodium-ammonia solutions were prepared directly in the cell, while the latter was immersed in a bath of liquid ammonia. Resistances were measured with a direct current bridge. After calibration, estimates of concentration could be made from the measured resistance at $-33°C$.

In typical experiments, measured resistances at $-33°C$ were of the order of 10,000 ohms. On *slow* cooling to temperatures slightly above the melting point (some $-80°C$) the resistance *increased* by a factor of some three to five. Behavior on rapid immersion of the cell in liquid oxygen was distinctly erratic, but the typical result consisted of a rapid resistance decrease to some few hundred ohms, followed by a sudden breaking of the circuit, as shrinkage caused fracture of the column. On then immersing the cell in a pre-cooled pentane bath at some $-95°C$, expansion usually caused reclosing of the circuit, with a fairly constant resistance of the order of 10 to 50 ohms. Further slow temperature rise caused practically no change until the melting point was reached, when the resistance suddenly rose to values of the order of 30,000–50,000 ohms. In a few cases the systems remained conducting at liquid oxygen temperature, with practically no change in the (relatively small) resistance between $-180°C$ and the melting point. Such behavior, the variability of the lowest obtainable resistances, and the obvious difficulties with mechanical breakage strongly suggest that even the small residual resistances found were largely caused by poor contacts. Such large resistance changes were observed only with solutions in the concentration range characterized by liquid-liquid phase separation. It must be observed that the phenomenon is of the nature of a *discontinuity* at the melting point of the rapidly frozen solid solution, and is not to be confused with the exponential temperature dependence of the resistance of a solid semiconductor.

Cells for study of persistent currents were constructed (afresh for each trial) of thin circular microscope cover glasses, separated by a small center spacer of extremely thin mica, fastened with vaseline. Each cell was attached to a glass rod handle. The cell was dipped into a sodium-ammonia solution (in the concentration range characterized by liquid-liquid phase separation) at $-33°C$, and allowed to fill by surface tension. It was then plunged rapidly into a Dewar vessel containing liquid oxygen, situated in a magnetic field of strength up to 1500 gauss. The cell was quickly transferred to another liquid oxygen bath containing a fixed search coil attached to a semi-ballistic galvanometer. Any residual magnetic moment was detected by "flipping" of the ring sample in the vicinity of the coil. Fields of the order of 0.05 gauss were detectable. Nearly two hundred trials, with differing concentrations and field strengths, yielded negative results. However, in seven cases unmistakable galvanometer deflections were observed, indicating rather rapidly decaying fields of the order of one or two gauss at the first measurement, but remaining of measurable magnitude for periods of one or two minutes. Since the decay constant of a current in a closed circuit is the ratio of the resistance to the self-inductance (the latter estimated from the cell geometry), it is apparent that this degree of persistence indicates a resistance of the order of 10^{-13} ohm or smaller. In view of the fact that the liquid samples possessed resistances of the order of a thousand ohms, the solids in question may fairly be said to be superconducting.

The very large proportion of negative results seems to be in accord with expectations from the obvious contact difficulties encountered in the resistance studies. The solids probably crack into a micro mosaic pattern, and it would appear to be a very rare accident that the residual contact resistances are sufficiently small to allow an appreciably persistent current.

[1] R. A. Ogg, Jr., Phys. Rev. **69**, 243 (1946). See also April 1 and 15, 1946 issue, for erratum.

Note on the Problem of Uniform Rotation

NATHAN ROSEN
University of North Carolina, Chapel Hill, North Carolina
June 18, 1946

RECENTLY, in an article with the above title,[1] E. L. Hill considered the problem of determining the velocity as a function of position for a fluid rotating with constant angular velocity, according to relativity theory. However, his method of calculation appears questionable since it makes use of a Lorentz transformation in going over to an accelerated frame of reference. It therefore seems desirable to try a different method.

One way of solving the problem is first to generalize the definition of angular velocity in relativity theory and then to use that definition to get the motion of the fluid directly in an inertial coordinate system. In classical mechanics the angular velocity of a fluid is given by

$$\boldsymbol{\omega}=\tfrac{1}{2}\nabla\times\mathbf{v},$$

where $\mathbf{v}$ is the velocity vector. In general relativity theory, the obvious generalization is to define angular velocity as an antisymmetric tensor

$$\omega_{ik}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x^k}-\frac{\partial u_k}{\partial x^i}\right),\quad (i,\ k=1,\ 2,\ 3,\ 4),$$

where u_i is the covariant velocity vector, the contravariant vector for a moving point being given by

$$u^i=dx^i/d\tau,$$

with $d\tau$ the proper-time element.

Consider a Galilean coordinate system with coordinates $x^1=x$, $x^2=y$, $x^3=z$, $x^4=ct$, so that the metric is taken as -1, -1, -1, $+1$, and $d\tau=(1-\beta^2)^{\frac{1}{2}}dt$ $(\beta=v/c)$. For small velocities one finds that ω_{23}, ω_{31}, ω_{12} reduce to the classical expressions for the x, y, z components of $\boldsymbol{\omega}$, while ω_{41}, ω_{42}, ω_{43} are proportional to the components of acceleration. If we take $v=v(R)$, with $R^2=x^2+y^2$, and

$$v=-vy/R,\quad v_y=vx/R,\quad v_z=0,$$

calculate ω_{ik} and set

$$\omega_{12}=\omega=\text{const.},$$

we find

$$v(R)=\frac{\omega R}{(1+\omega^2R^2/c^2)^{\frac{1}{2}}}.$$

This velocity v is in general different from that obtained by Hill, although it has nearly the same behavior for small and large values of R.

This question will be treated more fully in a forthcoming paper.

[1] E. L. Hill, Phys. Rev. 69, 488 (1946).

Solar and Lunar Effects on Cosmic Rays

M. Kidnapillai
Department of Mathematics, Ceylon Technical College, Colombo, Ceylon, India

AND

A. W. Mailvaganam
Department of Physics, University of Ceylon, Colombo, Ceylon, India

April 25, 1946

DUPERIER[1] has from a harmonic analysis of the hourly records made in London, reported a semi-diurnal variation of cosmic-ray intensity of amplitude 0.18 percent and nearly in opposite phase to the semidiurnal oscillation of the barometer. He explains this variation in terms of the finite lifetime of mesons and the up-and-down motion of the meson-producing layer in the atmosphere, caused by the semidiurnal solar atmospheric tides; and using certain calculations of atmospheric oscillations[2] he showed that one could entirely account in this manner for the observed semidiurnal variation of cosmic-ray intensity.

Independently of Duperier, one of us[3] has applied the theory of forced oscillations, magnified by resonance, of the earth's atmosphere with a period of 12 hours as worked out by Pekeris[2] to the oscillation of the meson-producing layer in the atmosphere and obtained, taking into account the finite lifetime of mesons, for the amplitude of the semidiurnal variation of the meson intensity 0.14 percent. This is in fair agreement with the value deduced by Duperier from his harmonic analysis of the London records.

We have continued our calculations with a view to seeing to what extent the tide-producing properties of the moon affect the meson intensity as observed at the earth's surface. For this purpose we have used with slight modifications, the theory of atmospheric tides developed by Pekeris.[2] We also use the stratification of the atmosphere employed by him. It is, of course, to be expected that the lunar effect will be smaller than the solar effect, in view of the fact that the atmosphere has free periods of oscillation, *viz.* 10.5 and 12 hr., neither of which is sufficiently close to 12 hr. 25 min. which is the semiperiod of the motion of the moon round the earth.

It can be shown that, when the period of forced oscillation of the atmosphere is 12 hr. 25 min. (mean solar time), the atmosphere oscillates like an ocean of depth of 7.04 km. Assuming that the moon moves in the equatorial plane, the semidiurnal component of the tidal potential Ω at a place on the equator is

$$-2.63\times10^4\cos(\sigma t+2\varphi+\epsilon)$$

where $2\pi/\sigma$ and φ are the period of oscillation and the longitude of the place, respectively, and ϵ is a constant. The amplitude of the lunar semidiurnal pressure variation at the equator is taken to be 72 microbars. Substituting these values of Ω and p in Eq. (47) of Pekeris,[2] the constant B/A is calculated. In the case of forced oscillations the vertical velocity in the region (0–1) of the atmosphere is given by the equation

$$w=-\frac{\gamma H}{2(n+1)x^n}\left\{A\left[J_n(x)-\frac{\gamma x}{0.8n-2}J_{n+1}(x)\right]+B\left[Y_n(x)-\frac{\gamma x}{0.8n-2}Y_{n+1}(x)\right]\right\}-\frac{i\sigma\Omega}{g}.$$

Since B/A is known, we obtain the values of A and B by means of this equation. In the region (1–2) χ satisfies the differential equation,

$$\frac{d^2\chi}{dy^2}+\frac{1}{h_1}\frac{d\chi}{dy}+\frac{\gamma-1}{\gamma}\frac{\chi}{h_1H}=0.$$

The solution of this equation is

$$\chi=C\exp(-y/2h_1)\cos\frac{Vy}{2h_1}+D\exp(-y/2h_1)\sin\frac{Vy}{2h_1},$$

where

$$V=\left|\left(1-\frac{8h_1}{7H}\right)^{\frac{1}{2}}\right|.$$