the χ *vs* T curves being $\sim 2.5\times 10^{-11}$ cgs units/deg in the high-temperature range. The curve of the high-resistivity material (curve 5) shows concave downward curvature which is characteristic of both *n*- and *p*-type high-resistivity germanium. The curves for low-resistivity material are markedly concave upward, this being more pronounced for the *n*-type specimens. This difference in curvature is presumably due to the sum of the impurity and carrier contributions (χ_I and χ_e) which would be negligible in the case of curve 5. Thus, it appears that the Landau orbital dimagnetism of the free carriers exceeds the paramagnetism of the free carriers and impurities with unpaired electrons in both electron and hold conductors. From considerations similar to those of Busch and Mooser for the case of $\alpha-$Sn it can be shown that for germanium the ratio of the free electronic mass to the carrier effective mass is ~ 4 for holes and ~ 6 for electrons.

A more detailed report of this work based on more extensive data will be submitted for publication in the near future.

One of the authors (D. K. Stevens) is indebted to Professor H. D. Crockford for his aid in the capacity as advisor from the University of North Carolina.

* Part of a dissertation submitted by D. K. Stevens to the University of North Carolina in partial fulfillment of the requirements for the Ph.D. degree.
† Formerly a predoctoral fellow of the Oak Ridge Institute of Nuclear Studies from the University of North Carolina. Present address: Oak Ridge National Laboratory, Oak Ridge, Tennessee.
[1] The authors are indebted to Miss Louise Roth of Purdue University for preparing samples.

[2] T. S. Hutchison and J. Reekie, J. Sci. Instr. **23**, 209 (1946).
[3] T. R. McGuire and C. T. Lane, Rev. Sci. Instr. **20**, 489 (1949).

[4] Thanks are due to J. C. Pigg of this laboratory for the design of the field control equipment, details of which are being submitted for publication.

[5] P. W. Selwood, *Magnetochemistry* (Interscience Publishers, Inc., New York, 1943), p. 29.

[6] We are indebted to J. W. Cleland of this laboratory for the Hall coefficient measurements.

[7] G. Busch and E. Mooser, Z. Physik. Chem. **198**, 23 (1951).

The Contribution of Solar x-Rays to *E*-Layer Ionization

E. T. Byram, T. A. Chubb, and H. Friedman
United States Naval Research Laboratory, Washington, D. C.
(Received September 24, 1953)

Attempts to attribute *E*-layer ionization to absorption of solar ultraviolet radiation lead to serious difficulties. The most recent rocket measurements[1] of the intensity of the solar continuum in the neighborhood of 1200A indicated an upper limit of about 0.01 ergs cm^{-2} sec^{-1} per 100A corresponding to a black body temperature of 4500°K. The extrapolated intensity at 1000A would be less than 0.0004 ergs cm^{-2} sec^{-1} per 100A, and the intensity of radiation capable of ionizing the atmospheric constituents ($800<\lambda<1000$A) would be entirely inadequate to account for *E*-layer ionization. On the other hand, it has been known for some time that the soft x-ray spectrum between 10A and 100A furnishes a source of ionizing radiation with absorption coefficients appropriate for layer formation between 100 km and 120 km. The x-ray possibility was first indicated by Hulburt[2] and by Vegard[3] in 1938. Since Edlén,[4] in 1940, identified the lines of the visible coronal spectrum with highly ionized atoms such as Fe xv and Ca xiii, it has been recognized that the solar corona may be a source of x-rays of sufficient intensity to make an important contribution to *E*-layer ionization. More recently, Hoyle and Bates[5] treated the x-ray absorption process in detail and concluded that conditions for *E*-layer formation were satisfied by an x-ray spectrum with a maximum either near 38A or near 9.5A.

Rocket experiments performed since 1948 have provided positive evidence for soft x-rays in the ionosphere. Detection was accomplished with photographic films,[6] thermoluminescent materials,[7] and photon counters.[8] In the latter type of experiment, intensity data were telemetered to a ground station continuously throughout the flight. The first photon-counter experiment[8] was performed in V-2 No. 49, September 1949, using counters with beryllium windows capable of transmitting an appreciable percentage of the x-ray flux up to a wavelength of about 10A. X-rays were detected only above 87 kilometers, from which it was concluded that the spectrum had a short-wavelength limit at about 7A. Between this limit and the spectral cutoff of the photon counters at 10A, the x-ray flux incident on the earth's atmosphere amounted to between 10^{-4} and 10^{-3} ergs cm^{-2} sec^{-1}.

In May 1952, counters flown in two Aerobee rockets again gave indication of x-rays above 90 km. These tubes also used beryllium windows, but the apertures were larger than those of V-2 No. 49 and the sensitivity at 7A was about ten times greater. The results emphasized again the fact that the x-ray spectrum of a quiet sun had a well defined short-wavelength limit at about 7A. No information however was obtained regarding the x-ray flux beyond 10A.

An experiment to determine the x-ray intensity out to 100A was attempted in a Viking rocket (No. IX) in December, 1952. A number of tubes were prepared with windows of graded x-ray spectral transmission characteristics, utilizing thin films of beryllium, aluminum, soft glass, and nitrocellulose. Tube dimensions and gas fillings were selected in combination with the above window materials to produce bands of spectral response peaking in different parts of the spectrum. Although the rocket attained an altitude of 218 km, it developed an excessively high roll rate and faulty telemetering, which left only a small portion of the experimental data suitable for interpretation. Sufficient information was obtained from three tubes, however, to indicate a large flux of x-rays above 10A within the *E*-region. A photon counter with an aluminum window, 0.00025 inch thick, sensitive to radiation between 8 and 20A, measured a flux of about 0.6 erg cm^{-2} sec^{-1}. The variation with altitude is shown in Fig. 1. Two tubes with nitrocellulose windows, sensitive to wavelengths as long as 60A, detected about 1.0 erg cm^{-2} sec^{-1} at the top of the atmosphere.

Although none of the attempts to measure the full x-ray spec-

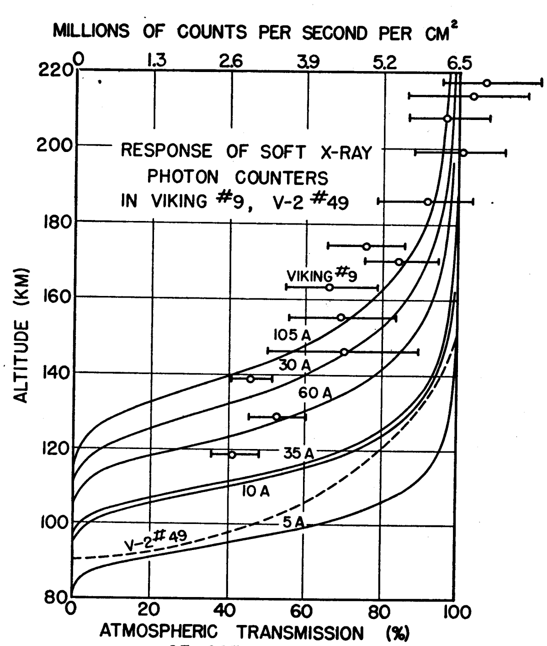

Fig. 1. Variation with altitude of the atmospheric transmission of soft x-rays. The solid lines are computed from absorption coefficients published by A. H. Compton and S. K. Allison [*X-Rays in Theory and Experiment* (MacMillan and Company, New York, 1935)]. The dashed curve is the averaged experimental data of two beryllium window photon counters in V-2, 49. Each open circle is the average of approximately 15 exposures of an aluminum window photon counter flown i Viking IX. The length of the bar through the circle represents the rms deviation of the data. The rocket was stable to 118 km with the photon counter looking away from the sun. Above 118 km the rocket rolled very rapidly and the tube received about 200 exposures to the sun.

trum have thus far been entirely successful, the partial results described above do show that the solar x-ray spectrum supplies of the order of one or two ergs cm^{-2} sec^{-1}, which is adequate to account for all of *E*-layer ionization. If the effective rate of electron production q is computed from the simple recombination law

$$q=\alpha N_\epsilon^2,$$

where α, the effective recombination coefficient,[9–13] is taken as 2×10^{-8} cm^3 sec^{-1}, and N_ϵ, the electron density, is about 10^5 cm^{-3}, then q must be about 400 electrons cm^{-3} sec^{-1}. The production of this rate of ionization would require only about 10^{-1} erg cm^{-2} sec^{-1}. The excess energy observed in the Viking IX experiment may therefore be indicative of a relatively high ratio of negative ions to electrons[13–16] in the *E*-layer, or a higher value for the effective recombination coefficient than has been deduced from radio reflection measurements.

[1] Byram, Chubb, Friedman, and Gailar, Phys. Rev. **91**, 1278 (1953).
[2] E. O. Hulburt, Phys. Rev. **53**, 344 (1938).
[3] L. Vegard, Geofys. Publikasjoner **12**, No. 5 (1938).
[4] B. Edlén, Z. Astrophys. **22**, 30 (1942) and Monthly Notices Roy. Astron. Soc. **105**, 323 (1945).
[5] D. R. Bates and F. Hoyle, Terr. Mag. Atmos. Elec. **53**, 51 (1948).
[6] T. R. Burnight, Phys. Rev. **76**, 165 (1949).
[7] Tousey, Watanabe, and Purcell, Phys. Rev. **83**, 792 (1951).
[8] Friedman, Lichtman, and Byram, Phys. Rev. **83**, 1025 (1951).
[9] E. O. Hulburt, Phys. Rev. **55**, 639 (1939).
[10] J. N. Bhar, Indian J. Phys. **13**, 253 (1939).
[11] A. J. Higgs, Monthly Notices Roy. Astron. Soc. **102**, 24 (1942).
[12] T. R. Gilliland, Nat. Geograph. Soc., Solar Eclipse Series No. 2, 88 (1942).
[13] C. W. McLeish, Can. J. Research **A26**, 137 (1948).
[14] E. O. Hulburt, Phys. Rev. **46**, 822 (1934).
[15] Bates, Buckingham, Massey, and Unwin, Proc. Roy. Soc. (London) **A170**, 322 (1939).
[16] H. S. W. Massey, Proc. Roy. Soc. (London) **A163**, 542 (1937).

Nonsymmetric Unified Field Theories

W. B. BONNOR
University of Liverpool, Liverpool, England
(Received April 6, 1953; revised manuscript received October 5, 1953)

KURŞUNOĞLU[1] has recently proposed an interesting modification of Einstein's nonsymmetric unified field theory. In the modified form the doubts about the compatibility of the field equations do not arise because the latter can be derived from a variational principle; and it is claimed that the new field equations imply the Lorentz equations of motion for an electric charge. To derive the equations of motion, Kurşunoğlu uses the assumption that mass is entirely electromagnetic in origin. It appears, however, from a study of the static, spherically symmetric solutions of the field equations, that this assumption is not justified by the theory. I have not succeeded in obtaining the exact solutions of Kurşunoğlu's equations, but it is not difficult to obtain an approximation which gives an insight into their probable nature.

The proposed field equations are

$$R_{\underline{\alpha\beta}}=-p^2(a_{\alpha\beta}-b_{\alpha\beta}), \tag{1}$$

$$R_{\underset{\vee}{\alpha\beta},\gamma}+R_{\underset{\vee}{\beta\gamma},\alpha}+R_{\underset{\vee}{\gamma\alpha},\beta}=-p^2I_{\alpha\beta\gamma}, \tag{2}$$

$$\mathfrak{g}^{\underset{\vee}{\alpha\beta}}{}_{,\beta}=0, \tag{3}$$

in which p^2 is a fundamental constant and all the other quantities have the same meanings as in Einstein's theory except

$$a_{\alpha\beta}=g_{\underline{\alpha\beta}},$$
$$b^{\alpha\beta}=\mathfrak{g}^{\underline{\alpha\beta}}/(-\det\mathfrak{g}^{\underline{\alpha\beta}})^{\frac{1}{2}}.$$

The approach to the problem is similar to that in the case of the static, spherically symmetric solutions in Einstein's theory.[2,3] Using spherical polar coordinates and considering the purely electric case (magnetic field zero), we may take as the only nonzero $g_{\alpha\beta}$:

$$g_{11}=-\alpha,\quad g_{22}=-\beta,\quad g_{33}=-\beta\sin^2\theta,\quad g_{44}=\gamma,\quad g_{23}=-g_{32}=f\sin\theta,$$

where α, β, γ, and f are functions of r only. Equations (1) and (2) reduce to

$$\begin{aligned}R_{11}&=p^2\alpha[1-(1+f^2/\beta^2)^{-\frac{1}{2}}],\\ R_{22}&=p^2\beta[1-(1+f^2/\beta^2)^{\frac{1}{2}}],\\ R_{44}&=-p^2\gamma[1-(1+f^2/\beta^2)^{-\frac{1}{2}}],\\ R_{\underset{\vee}{23}}&=-p^2f+c,\end{aligned}\tag{4}$$

where c is a constant of integration, and the $R_{\alpha\beta}$ have the values calculated previously[3] (with $w=0$). Equation (3) is empty in the purely electric case. We assume that the tensor $a_{\alpha\beta}$ determines the metric of the space (though the same conclusions follow if $b_{\alpha\beta}$ is taken for this purpose), and that for large values of the radial coordinate r, this metric shall tend to that of the Schwarzschild solution for a point mass m. We suppose also that the electric field for large r shall be that of a point charge e, so that, as we are using spherical polar coordinates, g_{23} must have at large r the form $ie\sin\theta$. These suppositions are met if we assume a solution of the form

$$\begin{aligned}&\alpha=1+2m/r+\sum_{n=2}^{\infty}h_n/r^n,\quad \beta=r^2,\\ &\gamma=1-2m/r+\sum_{n=2}^{\infty}k_n/r^n,\quad f=ie+i\sum_{n=1}^{\infty}e_n/r^n,\end{aligned}\tag{5}$$

h_n, k_n, e_n being constants. These expansions in powers of $1/r$ will give no information about the fields in the neighborhood of the origin, but will be of interest for distant regions.

Substituting (5) into (4), and supposing that $p^2\neq0$, it is found, after a long but straightforward calculation, that the solutions are

$$\begin{aligned}\alpha&=[1-2m/r+\tfrac{1}{2}e^2p^2/r^2+O(r^{-4})]^{-1},\\ \gamma&=1-2m/r+\tfrac{1}{2}e^2p^2/r^2+O(r^{-4}),\\ f&=i[e-4me/p^2r^3+O(r^{-4})].\end{aligned}\tag{6}$$

The constants m and e are arbitrary, and it becomes clear during the course of the calculation that no further arbitrary constants will arise.

It thus appears that the static, spherically symmetric solution has two distinct arbitrary constants, corresponding to mass and charge. If this solution is taken as referring to the electron and if mass is electromagnetic in origin, a relation between the constants would be expected. If m is taken as zero so that the solution contains only the arbitrary constant e, the terms in $1/r$ in the metric tensor vanish and the form of the gravitational field for large r does not allow any concentration of mass near the origin. It is noteworthy that since for large r the gravitational field is determined by the terms in $1/r$ in α and γ, and the electric field by the numerical term in f, the constant p does not affect the fields at large distances.

The electromagnetic origin of mass would be attractive in a nonsymmetric unified field theory because the charge density, which is defined, would presumably determine the mass density, which is not explicitly defined. If, as appears from the above, the hypothesis cannot be sustained, one has to consider how masses are to be represented. In Kurşunoğlu's theory it seems at first sight possible that part of the component $\mathfrak{T}_4{}^4$ of the pseudo stress-energy-momentum tensor density might represent mass density. However, if, as is suggested by the above solution, the masses and charges of particles may be assigned separately, the theory ought to give an account of the gravitational fields of uncharged masses; but if one abolishes the electromagnetic field by putting $g_{\underset{\vee}{\mu\nu}}=0$ the field equations reduce to those of general relativity for empty space, and $\mathfrak{T}_4{}^4$ reduces simply to the term $\mathfrak{t}_4{}^4$ of the pseudo tensor density $\mathfrak{t}_\nu{}^\mu$, which certainly does not represent mass density. Thus $\mathfrak{T}_4{}^4$ cannot in general contain a term representing mass density, and matter must presumably be represented by singularities in the field quantities. It is then necessary to suppose, since the charge is spread out over space (the charge density in (6) is proportional to df/dr), that charge can exist not associated