radiation in metals are[1] (1) the production of interstitials and vacancies and (2) the production of thermal spikes. The indentation hardness increases which have been observed as a result of such irradiations may be a consequence of (1) or (2) or both. It appears that thermal spike effects are negligible when the irradiation consists of 1-Mev electrons since no disordering was observed upon irradiating ordered Cu_3Au.[2] This result suggests the attractive possibility of using electron irradiation to isolate the effects of (1) from (2). A moderate electron bombardment (5×10^{18} electrons/cm^2) of annealed copper was carried out at about −20°C. Tukon hardness measurements made at room temperature showed a change in D.P.H. number from 44.3 to 47.7 kg/mm^2 between the non-irradiated and irradiated portions of the specimen, respectively. About half of this increase annealed out in 8 hours at 170°C. It is believed this indicates that either interstitials or vacancies can contribute to hardness changes.

* This report is based on studies conducted for the U. S. Atomic Energy Commission.
[1] F. Seitz, Phys. Today **5**, 6 (June, 1952).
[2] Dixon, Meechan, and Brinkman (to be published in Phil. Mag.).

T11. Displacement Energy for Radiation Damage in Copper. D. T. Eggen and M. J. Laubenstein, *North American Aviation.*—M. Mills[1] has proposed the measurement of the lattice displacement energy in crystals by electron bombardment. Following this theory, Klontz has measured the displacement energy in Ge to be about 30 ev[2] and Denney has measured that in a Cu-Fe alloy to be about 26.5 for the iron.[3] A target box was constructed so as to be an extension of the acceleration tube of the NAA statitron. Thin Cu specimens were mounted on a heavy copper plate which was immersed in liquid air during the irradiation and measurements. Electrical resistance measurements were made at various times during the irradiation. The rate of change of the resistance of the damaged sample was plotted for electron energies ranging from 0.45 to 1.0 Mev. These slopes were then plotted against the electron energy. The zero damage intercept occurs at an electron energy between 0.45 and 0.50 Mev (0.49±0.02 Mev). This corresponds to a displacement energy in copper of about 25.0±1.0 ev.

[1] M. M. Mills (personal communication).
[2] E. E. Klontz, Ph.D. thesis, Purdue University, June, 1952.
[3] J. Denney, Bull. Am. Phys. Soc. **27**, No. 6, 9 (1952).

T12. Low Temperature Fast Neutron Bombardment of Copper-Beryllium Alloy. J. W. Cleland, D. S. Billington, and J. H. Crawford, Jr., *Oak Ridge National Laboratory.*—Taylor and Murray[1] have investigated the behavior of electrical resistivity and hardness of a solution-quenched copper-beryllium alloy containing 2 percent Be under pile irradiation at ~300°K. They attribute the appreciable increase in hardness and resistivity to the formation of precipitate nuclei made possible by enhanced microdiffusion associated with radiation disordering. Such an enhancement has been demonstrated by Blewitt and Coltman[2] for the in-pile ordering of Cu_3Au. In order to check this proposed mechanism for copper-beryllium, solution-quenched samples have been irradiated consecutively at ~120°K and ~300°K. The increase in resistivity at 120°K for a given exposure in the graphite reactor is smaller by about a factor of four than that observed at 300°K. If a sample, bombarded for some period at ~120°K, is subsequently irradiated for a short period at or somewhat above 300°K, the total change in resistivity is approximately that which would be expected if the total irradiation were carried out at ~300°K. These results indicate that the greater portion of radiation induced resistance increase depends on a process, presumably microdiffusion, which involves thermal activation.

[1] W. E. Taylor and G. T. Murray, Oak Ridge National Laboratory Report No. ORNL 1323 (to be published in Acta Metallurgica).
[2] T. H. Blewitt and R. R. Coltman, Phys. Rev. **85**, 384 (1952).

T13. Nature of Radiation Damage in Diamond.* G. J. Dienes and D. A. Kleinman, *Brookhaven National Laboratory.*—Debye temperature measurements[1] on irradiated silicon indicate strongly that the damage in this crystal cannot be explained by the presence of vacancies and interstitials. A model of radiation damage, applicable to silicon and diamond, has been constructed to explain the above observation and stored energy and lattice parameter changes. The model is based on the known tendency of carbon and silicon to form structures with single and double bonds. Energetic recoil atoms rupture the covalent single bonds which then reform into a system of double and single bonds. Calculations on diamond, which successfully correlate stored energy and lattice expansion with radiation dosage indicate that: (a) each fast neutron collision produces an isolated disordered region, (b) these regions are about 45A in diameter and contain about 10^4 atoms, (c) these regions are mechanically weak due to the rupture of bonds and may be considered as holes in the diamond. The predicted decrease in the elastic constants of diamond is of the same order of magnitude as found experimentally for silicon. In this model 10–100 times more atoms are involved than in the vacancy-interstitial picture.

* Under contract with the U. S. Atomic Energy Commission.
[1] Keesom, Lark-Horovitz, and Pearlman, Science **116**, 630 (1952).

T14. Irradiation Induced Photoconductivity in Magnesium Oxide.* Harold R. Day,† *University of Missouri.*—Photoconductivity in single crystals of magnesium oxide was measured by a dc method. The spectral distribution of photoconductivity is characterized by peaks at 1.2, 2.1, 3.7, and 4.8 ev. Irradiation of the crystals by ultraviolet light causes an enhancement of the photoconductivity subsequently measured in the 1.2- and 2.1-ev bands. The enhancement effect reaches a saturation level which is independent of the intensity of the ultraviolet light and which is a measure of the density of imperfections in the crystal lattice. The ultraviolet activated region can be displaced by an electric field in such a direction as to indicate that the charge carriers are holes in the valence band. Neutron irradiation of the crystals gives rise to a thermally unstable enhancement of photoconductivity throughout the spectrum and also causes an increase in the level of saturation of the ultraviolet activation. The latter increase is stable at room temperature and indicates that the neutron irradiation produces new lattice defects. This effect saturates with increasing neutron flux. The density of lattice defects can be estimated from the photoconductivity. An energy level model is proposed.

* Work supported in part by the U. S. Office of Naval Research and a grant from R. C. A.
† Now at General Electric Research Laboratory, Schenectady, New York.

Saturday Morning at 11:00

Library, Assembly Room

TA. Business Session of the Southeastern Section

Saturday Morning at 10:00

Business Administration

(F. Seitz presiding)

Invited Papers in Solid-State Physics

U1. Studies of the Tensile Strengths and the Adhesion of Metals by Means of High Centrifugal Fields. J. W. Beams, *University of Virginia.* (30 min.)
U2. Theoretical and Experimental Studies of Electronic Phenomena in Graphite. W. P. Eatherly, *North American Aviation.* (40 min.)
U3. The Minimum in Electrical Resistance of Metals at Low Temperatures. E. Mendoza, *Carnegie Institute of Technology.* (30 min.)

Business Meeting of the Division of Solid-State Physics

Saturday Afternoon at 2:00

Business Administration

(J. W. Beams presiding)

Invited Papers in Solid-State Physics

V1. Possibilities of X-Ray Small-Angle Scattering for Study of Crystal Imperfections. A. Guinier, *Universite de Paris.* (30 min.)
V2. Theory of Conduction-Electron Spin Resonance. Charles Kittel, *University of California.* (30 min.)
V3. Thermodynamics of Irreversible Processes. H. B. Callen, *University of Pennsylvania.* (35 min.)
V4. The 1952 NRC Conference on the Nature and Properties of Surfaces of Solids. Harvey Brooks, *Harvard University.* (25 min.)

Saturday Afternoon at 2:00

Bingham Hall

(A. E. Ruark presiding)

X-Rays; Scattering; Theoretical Physics

W1. Determination of an X-Ray Spectrum from Absorption Measurements by Laplace Transformation.* Judith Cassidy Gursky and P. K. S. Wang, *Vanderbilt University.*—The attenuation of the beam from a 50-kv beryllium-window x-ray tube has been measured in aluminum and carbon. This information is used to determine the spectrum of the beam. The transmitted intensity I_x as a function of the absorber thickness x is given by[1]

$$\frac{I_x}{I_0}=\int_{\lambda_0}^{\infty}e^{-\mu(\lambda)x}f(\lambda)d\lambda,$$

where $f(\lambda)$ is the fractional intensity of the primary beam. $\mu(\lambda)$ being given, $f(\lambda)$ may be obtained by a simple change of variable if I_x/I_0 is known. The inverse Laplace transform of $(I_x/I_0)e^{\mu_0 x}$ leads directly to $f(\lambda)$ where μ_0 is the attenuation coefficient of the shortest wavelength λ_0. The practical problem lies in fitting an analytic expression to the experimental curve I_x/I_0 *vs* x. The spectra obtained from different fits and their comparison with the theory[2] will be presented.

* This work was supported, in part, by the U. S. Atomic Energy Commission.
[1] J. A. Greening, Proc. Phys. Soc. (London) **A63**, 1231 (1950).
[2] H. A. Kramers, Phil. Mag. **46**, 836 (1923).

W2. Second-Order Scattering Correction in Neutron and X-Ray Diffraction.* George H. Vineyard,† *Brookhaven National Laboratory.*—A calculation has been made to estimate the multiple scattering correction needed in x-ray and neutron diffraction structure determinations. The sample is assumed to be a plane slab and to consist of small elements scattering with random phases. The intensity of n-fold scattered radiation may be expressed in terms of iterated integrals. Second-order scattering has been explicitly evaluated, with the aid of an approximation valid when the single scattering from each element is distributed nearly equally in a number of direc-

tions, as is usually the case with liquids and crystalline powders. Universal curves have been computed for several experimental arrangements. Some features which emerge are: (a) In all cases the ratio of 2nd-order to 1st-order scattering is proportional to the ratio scattering cross section/scattering plus absorption cross sections. For this reason multiple scattering is generally more important with neutrons than with x-rays. (b) In transmission arrangements the 2nd-order scattering is nearly isotropic for all scattering angles appreciably lower than 180°. (c) So long as 2nd-order scattering is small compared to 1st-order, 2nd-order is sufficiently representative of all multiple scattering.

* Under contract with the U. S. Atomic Energy Commission.
† On leave from the University of Missouri.

W3. Spin-Relativistic Effects in the Multiple Scattering of Electrons.* L. V. SPENCER AND C. H. BLANCHARD, *National Bureau of Standards*.—The slowly convergent Legendre polynomial series representing the angular distribution of electrons which have undergone multiple elastic scattering in traveling a given distance in a material has previously[1] been evaluated assuming a Rutherford single-scattering cross section with a correction for screening at small angles; and, usually, using a small angle approximation. A new method[2] for summing Legendre polynomials permits evaluation taking account of the spin-relativistic corrections[3] to the Rutherford cross section and without small angle approximation. The results show that the spin-relativistic correction greatly improves the agreement of the theory (particularly at larger angles) with the experiment of Hanson *et al.*[4] for a thin gold foil at 15.7 Mev. The various effects other than elastic scattering (especially inelastic scattering and energy loss), and also the error involved in identifying foil thickness with pathlength will be discussed.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Moliere, Z. Naturforsch. **3A**, 78 (1948). Snyder and Scott, Phys. Rev. **76**, 220 (1949).
[2] Spencer, Phys. Rev. (to be published).
[3] Feshbach, Phys. Rev. **88**, 295 (1952).
[4] Phys. Rev. **84**, 634 (1951).

W4. Energy Spectrum Resulting From Electron Slowing-Down.* U. FANO AND L. V. SPENCER, *National Bureau of Standards*.—Given a uniformly distributed source of electrons of energy E_0, we wish to calculate the flux $y(E_0, E)dE$ of electrons of energy E traversing a small unit spherical probe. The distribution of energy losses ϵ is very skew, with an ϵ^{-2} tail further extended by bremsstrahlung. This precludes a continuous-slowing-down model (according to which y is the reciprocal stopping power) as well as the direct integration which works for x-rays.[1] An analytical Landau-type treatment, valid at all E_0, yields

$$y(E_0, E) = (mv^2/2\pi NZe^4)\int_0^\infty du \exp(-u)\tan^{-1} \times\{\pi/\log[1.5262(E_0-E)/Q_{\min}u]\},$$

where the symbols have their standard meaning and $Q_{\min}$ is the effective minimum permissible recoil energy. The integral is essentially an average reciprocal stopping number with slowly varying value$\sim$0.1. The analytical treatment breaks down as E decreases, when departures from the assumptions of a constant $Q_{\min}$ and of an ϵ^{-2} tail can no longer be disregarded. Here one can switch to a numerical procedure, akin to that for x-rays, which takes into account analytically the singularity of the cross section for $\epsilon\sim 0$.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] P. R. Karr and J. C. Lamkin, Phys. Rev. **76**, 1843 (1949).

W5. Methods for Calculating Approximate Cross Sections for Electron-Scattering. WILLIAM J. BYATT, *University of Alabama* (introduced by Arthur E. Ruark).—In computing differential cross sections for electron scattering, either by the Born approximation or the much-improved method of Montroll, Hart, and Greenberg, it is very helpful to start with a simple closed formula for the potential of the scattering atom. The scattering of electrons by He, Ne, A, and Hg is discussed. The Hartree fields of these elements are represented analytically; and the differential cross section is considered for electron energies from 100 ev to 1 Mev. Extension of the method to intermediate atomic numbers is simple in principle, but actual application in this domain must await computation of a few Hartree potentials in the region Z equals 30 to 70.

W6. Nyquist and Einstein Relations Derived from a Scattering Model. STEFAN MACHLUP, *Bell Telephone Laboratories*.—The Nyquist relation between electrical conductivity and thermal (Johnson) noise spectral density, and the Einstein (-Nernst-Townsend) relation between mobility and diffusion coefficient are classically derived by thermodynamic reasoning (equipartition). Therefore any microscopic model of a conductor which permits calculation of these quantities must also lead to the proper relations between them. It was thought that verifying the relations for a particular model (scattering of electrons in a crystal) may help in gaining insight into the model. The model must, of course, be statistical: scattering (e.g., by lattice vibrations, impurities) is a random process. If interactions between electrons are neglected, a model is completely determined by specification of both (1) electron distribution function f and (2) transition proabilities. From the latter one obtains a relaxation time τ for each electron state. One finds that the electron mobility, the thermal noise spectrum, and the electron diffusion coefficient are all proportional to the same functional of f and τ, making their ratios obey the classical relations.

W7. Energy Exchange in Molecular Collisions. B. WIDOM* AND S. H. BAUER, *Cornell University*.—It is shown that the semiclassical theory[1] of inelastic molecular collisions is an adequate approximation to the quantum-mechanical theory[2] when the relative translational energy of the colliding molecules is much greater than the change in internal energy. The semiclassical theory, however, fails in the neighborhood of the threshold. The average cross section for de-excitation collisions between carbon-dioxide and water is known[3] to have a maximum at about 350°K; its falling at higher temperatures has hitherto been considered an anomaly. When applied to this system, the semiclassical theory yields an effective collision diameter which is indeed a monotonically decreasing function of the temperature, this behavior being a direct consequence of the mutual reactivity of these molecules. When corrected for the low energy failure of the theory, the calculated collision diameter must also fall at low temperatures. The results are then in qualitative accord with the experimental facts over the whole temperature range.

* Now at University of North Carolina.
[1] C. Zener, Phys. Rev. **38**, 277 (1931).
[2] C. Zener, Phys. Rev. **37**, 556 (1931).
[3] A. Eucken and L. Küchler, Physiks Z. **39**, 831 (1938).

W8. On the Energy-Momentum Tensor of the Electromagnetic Field Inside Matter. N. L. BALAZS, *Dublin Institute for Advanced Studies** (introduced by Eric Rodgers).—Two different energy-momentum tensors have been proposed to describe the electromagnetic field inside matter. Abraham suggested a symmetric tensor while Minkowski's tensor is nonsymmetric. With the aid of a thought-experiment it is shown here that only the symmetric tensor satisfies the momentum conservation and center-of-mass theorems simultaneously.

* Now at University of Alabama.

W9. Nuclear Shell Structure as a Many-Body Phenomenon.* INGRAM BLOCH AND YÜ-CHANG HSIEH, *Vanderbilt University*.—A nuclear Hamiltonian containing pairwise

Hooke's law interactions between the nucleons[1] provides a first approximation to many-body nuclear theory. The normal-mode oscillators obey a more restrictive exclusion principle than that which applies to individual nucleons. The ground-state energy of one set of oscillators depends on the number of neutrons present, while that of another set depends on the number of protons present. The magic numbers have not emerged from the simple Hamiltonian described, but may be derivable from a refined Hamiltonian.

* Assisted by the U. S. Army Office of Ordnance Research and by the Carnegie Foundation for the Advancement of Teaching.
[1] W. V. Houston, Phys. Rev. **47**, 942 (1935); **49**, 206 (1936). For other references, see H. Margenau and K. G. Carroll, Phys. Rev. **54**, 705 (1938).

W10. Magic Numbers and the Statistical Model of the Nucleus.* H. W. NEWSON, *Duke University*, AND E. MERZBACHER, *University of North Carolina*.—While the Fermi gas model of the nucleus is well known to predict the general features of energy level densities in fairly excited nuclei, particularly their dependence on excitation energy and particle number, it fails, of course, to describe such details as the observed increase in the average level spacing in compound nuclei near neutron magic numbers. In an attempt to incorporate some effects of shell structure into the scheme of individual particle energy levels, which the nucleons of the gas can occupy, a "semiconductor" model for the nucleus was considered. The following sequence of individual particle energy levels was assumed: A low-lying n-fold degenerate level, separated by an adjustable gap from the set of energy levels of a free particle confined to the nuclear volume, where, however, the levels immediately above the gap are as dense as those near the Fermi energy in the conventional model. Calculations for low temperatures were made, and the entropy *versus* excitation energy was plotted for various sizes of the gap. Several ways of correlating the variables in the model with characteristic nuclear quantities will be discussed in the light of the empirical evidence. about level spacings.

* Under contract with the U. S. Atomic Energy Commission.

W11. On the Statistical Theory of Nuclear Reactions. BERNARD L. COHEN, *Oak Ridge National Laboratory*.—If Weisskopf's expression for the energy distribution, $N(E)$, of particles emitted from nuclear reactions which proceed via a compound nucleus is generalized by dropping his assumption that the sticking probability, η, for the inverse reaction is independent of energy, one obtains $1/\Sigma(E, E_0) = -\partial\log\eta/\partial E + 1/T(E_0-E)$ where $\Sigma = \{-\partial/\partial E(\log N(E)/E)\}^{-1}$, the slope of the energy spectrum as usually plotted. The following evidence is cited to show that the $-\partial\log\eta/\partial E$ term (hereafter (A)) is not negligible: (a) all observed neutron and proton ($E \gg$ Coulomb barrier) energy spectra curve away from the axis whereas assuming (A)$\equiv 0$ demands curvature toward the axis; (b) comparing these observed spectra shows that Σ is definitely not a function of (E_0-E) alone; (c) the values of (A) required to remove the large discrepancies between observed and calculated (n, p) and (n, α) cross sections are roughly consistent with those obtained from the experimental energy spectra. Assuming (A) not ignorable means that selection rules operate to make transitions to low-lying levels excessively probable. It also demands that if excited nuclei could be bombarded, sticking probabilities would not be unity as they are when ground-state nuclei are bombarded.

W12. The Energy-Momentum Tensor in General Stream Electrodynamics. M. AVRAMY MELVIN, *Florida State University*.—Unnecessary use of the canonical formalism may hinder insight into the structure of a theory. This is exhibited in recent discussions of the energy-momentum tensor in the "new classical electrodynamics," where the final symmetrized tensor turns out to be the same for both the first and second theories of Dirac. It is also the same for the more general stream theory discussed by the author. The simple reason for this sameness is that the form of the energy-momentum tensor does not depend at all upon the gauge conditions which characterize the different theories; this tensor is a consequence only of applying to a fine-grained stream of corpuscles of mass μ, charge ϵ, *specific* concentration N (i.e., number of corpuscles contained *in a unit comoving volume*), and continuous differentiable 4-velocity field $u^\alpha = dy^\alpha/ds$ (1) the Lorentz force law (L) for the individual corpuscles, and (2) the Maxwell equations: (M_1) expressing the vanishing of the cyclical divergence $\{A_{\alpha\beta,\gamma}+\text{cycl.}\}$ of the electromagnetic field $A_{\alpha\beta}$, and (M_2) equating the divergence $A^{\alpha\beta}{}_{,\beta}$ to the current density $N\epsilon u^\alpha$. The law of conservation of specific charge is as usual an identical consequence of (M_2). Assuming also $d\epsilon/ds = 0$, we have also (M_2') the vanishing of $(Nu^\alpha)_{,\alpha}$. The total specific force density is obtained upon multiplying (L) by N. Integrating this by parts and using (M_2') gives: $(N\mu u_\alpha u^\beta)_{,\beta} = (A_{\alpha\beta}A^{\beta\gamma})_{,\gamma} - A^{\beta\gamma}A_{\alpha\beta,\gamma}$.

SATURDAY AFTERNOON AT 2:00

Venable Hall

(E. K. PLYLER presiding)

Ultraviolet Spectra; Theory of Molecular Structure; Mass Spectroscopy

X1. The Near Ultraviolet Absorption Spectrum of *p*-Difluorobenzene Vapor. C. DEWEY COOPER, *University of Georgia*.—The vapor absorption spectrum of *p*-difluorobenzene has been investigated in the 2900–2400A region with a Bausch and Lomb Littrow quartz spectrograph. Most of the bands are double with a separation of only 3 or 4 cm^{-1}. The 0,0 band is located at 36 843 cm^{-1}. Prominent bands on the violet side of this band are found to involve the excited state frequencies of 163, 409, 819, and 1250 cm^{-1}. Both the 819 and 1250 frequencies are found in progressions. Weak, temperature dependent bands on the red side of the 0,0 band are found to involve the ground-state frequencies of 247, 452, 860, and 1260 cm^{-1}. In the *p*-difluorobenzene spectrum the 0,0 band is shifted 1246 cm^{-1} toward the red relative to the calculated 0,0 band of benzene. This shift will be compared with similar shifts for other mono- and di-substituted benzenes.

X2. A Correlation of the Infrared and Ultraviolet Spectra of Associated Alcohols.* GLADYS A. ANSLOW AND IRENE S. WHITE, *Smith College*.—To aid the interpretation of the ultraviolet absorption in alcohols, ascribed to OH$^+\cdots$O and OH$\cdots$O association,[1] freshly distilled specimens, showing no impurities in the infrared, have been investigated in the 3μ region with a Perkin-Elmer double-beam spectrometer and in the ultraviolet with a Beckman spectrophotometer; recording spectra at numerous concentrations in carbon tetrachloride and isooctane, respectively. Changes in the ratio of polymer to dimer components in the infrared were paralleled by corre-

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