or even out according to the direction of net flow. The size of stable irregularities would be determined by a balance between the rate of build-up due to drift and of disappearance due to surface tension effects. The following experimental observations on tantalum support the above hypothesis: 1. dc heating produces "etching" on one side only of suitably oriented crystal grains in a 0.001-in. Ta strip. (Drift direction is reversed relative to crystallographic axes on opposite sides of the grain.) 2. 211 surfaces appear facing the positive end; 100, 310, and 110 planes develop facing the negative. 3. A thermal gradient produces effects similar to an electric field, with higher temperature equivalent to positive polarity. 4. Size and spacing of ridges developed by etching are consistent with reasonable values of D_s and surface energy.

* U. S Atomic Energy Commission Liason Officer.

FA7. The Activation Energy for the Recovery of Reactor Irradiated Copper Crystals. J. K. REDMAN, R. R. COLTMAN, AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—Five single crystals of high purity copper were irradiated in an Oak Ridge reactor to an integrated flux of 6×10^{18} neutrons per square centimeter. One of each of these crystals was isothermally annealed in a salt bath at each of the following temperatures: 305°C, 325°C, 345°C, 365°C, and 385°C. In no case was recrystallization observed despite the fact that the irradiation raised the initial shear stress for plastic flow from 0.2 kg/mm² to 3.5 kg/mm². The critical shear stress was determined as a function of annealing time at each of the above temperatures. The relaxation time varied from about 400 hours at 305°C to 11 minutes at 385°C. Using the data collected in this manner an activation energy of 2.2 electron volts was determined from the slope of the line relating the natural logarithms of the relaxation time to the reciprocal of the temperature. Although the isothermal recovery curves are indicative of a higher order, there is evidence that the recovery is that of a first-order reaction. The fact that the above-determined activation energy is apparently equal to that for self-diffusion is believed to be significant, and will be discussed.

FA8. The Effect of Strong Electrostatic Fields on the Resistance of Tungsten Wires. W. J. DESHOTELS AND A. H. WEBER, *Saint Louis University.*—The effect of a radial electrostatic field upon the resistance of tungsten in high vacua was reinvestigated employing lower pressures and better vacuum technique than in the original experiments.[1–3] Wires of 0.004-in. and 0.00045-in. diameter were subjected to negative and positive fields up to 9.0×10^6 and 1.4×10^6 volts/cm, respectively. The resistance abruptly decreased upon application of the electric field, increased slightly with time while the field was constant, and increased abruptly upon removal of the field. The abrupt increase was usually somewhat less than the abrupt decrease. The abrupt resistance changes satisfied the equation $\Delta R=\alpha E^{\frac{1}{2}}$, where ΔR=resistance change, E=applied field in volts/cm$\times10^6$, and $\alpha=0.46$. A large part of the small resistance change with constant field was due to an observed filament temperature increase resulting from bombardment by the electronic portion of the observed ion-, photo-, and field emission current. It was found that the photo and ion currents were much larger than the field emission currents. No observable electrostatic effect was found which could account for the abrupt resistance changes.

[1] A. G. Worthing, Phys. Rev. **17**, 418 (1921).
[2] G. B. Estabrook, Phys. Rev. **63**, 352 (1943).
[3] P. L. Vissat, Phys. Rev. **64**, 119 (1944).

FA9. The Stress-Strain Curves of Copper Single Crystal at 4.2°K. T. H. BLEWITT, R. R. COLTMAN, R. E. JAMISON, AND J. K. REDMAN, *Oak Ridge National Laboratory.*—Pairs of single crystals were grown by the Bridgman technique from high purity copper and annealed in high vacuum at 1030°C for three hours. The crystals were grown in the shape of $\frac{1}{8}$-in. tensile bars. One of each pair was deformed at 4.2°K and the other at a higher temperature. The stress-strain relationship shows a dependence of temperature which is consistent with the earlier conceptions[1] based on deformation at 78°K and at 300°K. The critical shear stress at 4.2°C shows little if any increase over that at 300°K and the stress-strain curve is linear so long as the deformation occurs by slip. The high and low temperature curves are coincident over the linear portion of the high temperature curve. After a stress of approximately 15 kg/mm² is reached, which is greater than that obtainable at 78°K, the crystal deforms by twinning. After considerable strain by twinning the crystal fractured by cleavage. This latter phenomenon has not been observed at 78°K or higher temperatures.

[1] Blewitt, Redman, and Sherrill, Bull. Am. Phys. Soc. **28**, No. 2, 38 (1953).

FA10. Small Angle Scattering of X-Rays from Cold Worked Crystals. D. L. DEXTER, *University of Rochester.*—The small angle scattering of x-rays or thermal neutrons ($\lambda\sim1$A) from cold-worked crystals is calculated on the basis of a model which takes into account the density variations around edge-type dislocations, which neglects the effects of screw-type components (since the density variations are small), which neglects end effects at the termination of an edge-type segment, and which neglects coherence in the scattering from the regions surrounding different dislocations. The angular variation in the density change around an edge-type dislocation results in a complete modification of the usual small angle scattering formulas. The highly characteristic scattering curve shows a parabolic increase from zero at zero scattering angle, a maximum, and finally a monotonic decrease with increasing scattering angle. Multiple scattering will be negligible even in thick samples. There is large anisotropy in the scattering from an ordered array of dislocation. Scattering from dislocations does not explain the measured[1] scattering from cold-worked Cu, but may be observable under suitable conditions

[1] J. Blin and A. Guinier, Compt. rend. **233**, 1288 (1951).

FA11. An Anomaly in the Heat Content of a Metal in the Fatigued State. B. WELBER AND R. WEBELER, *National Advisory Committee for Aeronautics.*—Three copper specimens were fatigued almost to fracture. To determine their heat content calorimetric measurements carried up to 450°C were made in the same way used previously to determine the energy stored in cold work.[1] In the following, a sample once heated up to 450°C during a measurement is designated as annealed. It was found that 0.36 ± 0.05 more cal/g were required to bring a fatigued sample from 250°C to 350°C than an "annealed" one. Thus, it appears that, quite unexpectedly, the fatigued state is one of *lower* heat content than the "annealed" state, while the cold worked state is one of *higher* heat content than the annealed state. Moreover, in fairly severely cold worked copper about 0.3 cal/g is released between 150°C and 250°C,[1] a temperature range within which the fatigued sample neither releases nor absorbs energy in amounts exceeding the experimental error of 0.03 cal/g. This is of interest since fatigue is supposed to be caused by localized strain hardening.

[1] B. Welber, J. Appl. Phys. **23**, 876 (1952).

FA12. Work Hardening in Substitutional Alloys. J. S. KOEHLER, *University of Illinois.**—It is shown that the mechanical properties of single crystals of the face-centered cubic alloys can be understood by supposing that source hardening and impurity hardening are important whereas interaction hardening is not. Source hardening arises because the Frank Read generators which can act at low stresses lock after giving a finite amount of glide. The internal stresses produced by impurities impede the motion of dislocations particularly at small strains. Interaction hardening arises because the motion of dislocations past one another becomes more difficult as the density of dislocations rises. Observations on slip bands and stress strain data imply that the production of a new slip band is accompanied by a reduction of the impurity stresses nearby. It is suggested that vacancies and interstitials produced during the slip process diffuse away from the original slip band and settle down so as to annul the internal impurity stresses. This implies that the "purification" range should be reduced at low temperatures. T. H. Blewitt[1] has found that the width of a cluster of slip bands in alpha-brass after a given strain decreases as one goes to low temperatures. This agrees with the above theoretical suggestion.

* Supported by the U. S. Office of Naval Research.
[1] T. H. Blewitt, Bull. Am. Phys. Soc. **28**, No. 2, 39 (1953).

FA13. Tensile Strength and Adhesion of Thin Films of Silver.* H. S. MORTON, JR., AND J. W. BEAMS, *University of Virginia.*—Studies of the tensile strengths and adhesion of thin metal films by subjecting them to high centrifugal fields have been continued.[1] The silver films were electrodeposited without "striking" on small cylindrical steel rotors and the rotational speeds required to throw them off were measured. The rotors were magnetically suspended and spun in a high vacuum. The tensile strength, in agreement with the previous results, showed an abrupt increase at a thickness of roughly 2×10^{-5} in. Also the adhesion starts increasing rapidly at a thickness of about 1.6×10^{-5} in. Prolonged annealing at a temperature of 300°C increased the adhesion. Rapid cooling and heating between limits of 90°C and −70°C greatly reduced the adhesion and facilitated tensile strength measurements with small film thicknesses. The adhesion, of course, depended upon the method of electrodeposition.

* Supported by Navy Bureau of Ordnance.
[1] Beams, Walker, and Morton, Phys. Rev. **87**, 524 (1952).

FA14. The Structure and Aging of Thin Metal Films. I.* ROBERT J. RAUDEBAUGH AND RICHARD B. BELSER, *Georgia Institute of Technology.*—Electron diffraction studies of thin metal films have shown that such films, whether deposited by vacuum evaporation, sputtering or electroplating, are composed generally of small crystallites of the metal. Because these films are deposited atom by atom, or little by little, on a normally foreign surface and intermingled with foreign atoms during their growth, they are subjected to a certain amount of disorder and strain not so predominant in a metal cooling in bulk from a molten condition. After deposition, with time alone or with a temperature increase and time, a rearrangement of the atoms of a thin metal film to a state of greater order usually occurs. This transition may be detected by measurement of changes in electric resistance, in optical properties, and in x-ray and electron diffraction patterns of the film. This susceptibility to change, designated as "aging," appears to be inherent in the nature of the growth of the film. This aging is accelerated by heating the film, and there appears to be a certain temperature unique to each metal and its thickness at which an optimum condition of the film is attained.

* Supported by the U. S. Army Signal Corps.

FA15. The Structure and Aging of Thin Metal Films. II.* RICHARD B. BELSER AND ROBERT J. RAUDEBAUGH, *Georgia Institute of Technology.*—Examination of thin films of silver, gold, copper, platinum, and other metals, deposited by evaporation and sputtering on glass substrates, has shown that these films undergo a change in structure with time, either at room temperature or at elevated temperatures. Electron micrographs of films 50–250 angstroms thick may or may not show an initially visible particle size. By heating these films a growth of particle size is produced. This growth is accompanied by better definition of the lines of x-ray and electron diffraction patterns and some evidence of orientation. The resistivities of these films and thicker films generally undergo a reduction concurrently with the structural change. If a film be heated to a temperature above one specific to the metal and its thickness, defined as the "preferred" aging temperature, aggregation of the film will commence and its resistivity usually increases. At a somewhat higher temperature complete aggregation usually occurs. For 1000 angstrom evaporated films "preferred" aging temperatures have been found as follows: Copper and silver, 175–225°C; gold, 250–300°C; platinum, nickel, aluminum, and iron, 400–500°C. These temperatures appear to be related to the recrystallization temperatures of respective metals. Sputtered films may require somewhat higher temperatures for proper aging.

* Supported by the U. S. Army Signal Corps.

FA16. Precipitation Effects in Copper-Iron Alloys. THOMAS S. HUTCHISON, *Royal Military College of Canada.*—Alloys of copper with up to 1.5 percent iron have been investigated by electrical, magnetic, and x-ray diffraction methods. The particular form in which the iron exists in the different alloys can be deduced from a coordinated study of the results from the three sets of investigations. With the particular heat treatment applied to all the alloys (long vacuum anneal at 850°C followed by furnace cooling) lattice parameter measurements show that the iron can be maintained in supersaturated solid solution up to 0.26 percent. A peak in the value of electrical resistance also occurs at this iron content. Beyond this point it is believed that the iron begins to form a coherent precipitate, until, at an iron content of 0.5 percent, incoherent precipitate in the α-phase begins to form. This is accompanied by a marked rise in magnetic susceptibility of the alloys, and at the same time the body-centered cubic lines of α-iron are observable in the x-ray diffraction pictures.

THURSDAY AFTERNOON AT 2:00

Wardman Park, Continental Room

(C. O. MUEHLHAUSE presiding)

Neutron Physics, II.

G1. Measurement of Resonant Neutron Scattering Cross Sections.* C. SHEER, J. MOORE, AND C. HEINDL, *Columbia University.*—The thick target method[1] for measuring the ratio of scattering to total cross section has been used to study a number of neutron resonances. Methods have been worked out for analyzing experimental scattering data for level parameters in cases where the levels are resolved. Completely resolved spectra are obtained for capture levels below about 10 ev and nearly resolved curves for levels lying between 10 and about 30 ev. When the experimental curve is resolved,

the value of Γ_N/Γ for the resonance is obtained directly. The level strength ($\sigma_0\Gamma^2$) is then obtained from an area measurement under the scattering curve. Nuclear radii are determined by fitting the data in the neighborhood of the scattering minimum. For cases where the experimental curve is not quite resolved, Γ_N/Γ is obtained by curve fitting, taking the resolution width of the apparatus into consideration. The 5.13 ev resonance in Ag 109, the 16.6 ev resonance in Ag 107, and the 2.36 ev resonance in Te^{123} have been analyzed. These results together with preliminary results for the cobalt 126 ev, manganese 345 ev levels will be presented.

* Supported by the U. S. Atomic Energy Commission.
[1] Jay Tittman and Charles Sheer, Phys. Rev. **83**, 746 (1951).

G2. Neutron Resonances in Silver. W. Y. Kato, Marilyn J. Stafne, J. S. Levin, and D. J. Hughes, *Brookhaven National Laboratory.**—The total cross section of normal silver has been measured in the energy region 5–500 ev with the Brookhaven fast chopper. The present time resolution is limited to ½ percent by the flight path in the counter at low energy, and to 3 μsec by the counter collection time at high energy. At this resolution it is felt that practically all resonances have been resolved up to 100 ev; the observed level spacing below 100 ev agrees with that obtained from 1 Mev capture cross sections.[1] For most of the nine resonances found below 100 ev, only the quantity $\sigma_0\Gamma^2$ can be measured because all samples used are thick relative to the actual resonance peak σ_0. The values of $\sigma_0\Gamma^2$ are corrected for Doppler broadening, which is about five times the true width Γ at 100 ev. If Γ_γ is assumed to be 0.1 ev, the Γ_n's for eight of the levels lie between 1.3 and 5.6 mv (converted to the value at 1 ev to remove the velocity factor), in agreement with the value expected, on the usual statistical model, from the observed level spacing. A level at 46 ev, however, has a Γ_n of only 0.2 mv.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] Garth, Hughes, and Levine, Phys. Rev. **87**, 222 (1952).

G3. Low Energy Neutron Resonance Scattering.* H. L. Foote, Jr.,† *Brookhaven National Laboratory.*—A new crystal spectrometer has been developed at Brookhaven National Laboratory for the observation of low energy neutron resonance scattering. A beryllium single crystal is used as a monochromator and a lithium iodide tin activated scintillation crystal as a detector. The salient features of the instrument will be described. Preliminary results on the 1.458 ev resonance of indium[1,2] and the 2.37 ev resonance of tellurium[3] have been observed, and a scattering peak has been obtained in each case at approximately the resonant energy. The analysis of the tellurium resonance will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† Doctorial candidate from the University of Utah.
[1] B. N. Brockhouse, Can. J. Phys. (to be published).
[2] L. B. Borst, Bull. Am. Phys. Soc. **28**, No. 1, 25 (1953), Phys. Rev. (to be published).
[3] C. Heindl and I. W. Ruderman, Phys. Rev. **83**, 660 (1951), and C. Heindl, private communication.

G4. Occurrence of Neutron Resonances in the Rare Earths.* V. L. Sailor, H. H. Landon, and H. L. Foote, Jr., *Brookhaven National Laboratory.*—A survey of the slow neutron cross sections of the rare earth elements[1] has been completed with the exception of Nd, Pm, and Tb. Measurements were made over the energy range from 0.1 to 30 ev with the Brookhaven National Laboratory crystal spectrometer. The rare earth elements in the vicinity of the closed neutron shell ($N=82$), i.e., La, Ce, and Pr apparently exhibit complete absence of resonances up to 30 ev. On the other hand, the elements from $Z=62$ to 71 are characterized by a copious abundance of resonances. A crude estimate of the average level density can be obtained from the spacing of the resonances. The level density varies between the limits, 8 ev to 40 ev for the average isotope of the elements $Z=62$ to 71, the spacing in the isotopes of odd mass being consistently smaller than those of even mass. A comparison will be made between the elements in the rare earth region and the elements in neighboring regions.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] This work was made possible by the generosity of Dr. F. H. Spedding of the Ames Laboratory, U. S. Atomic Energy Commission, in making available exceptionally pure specimens of most of the rare earths.

G5. Doppler Effect on Neutron Resonance Levels.* E. Melkonian, W. W. Havens, Jr., and L. J. Rainwater, *Columbia University.*—In applying the area method of analysis of neutron resonance transmission dips,[1] Doppler broadening has usually been neglected. With improvements in both the methods of analysis and in the data, it is now necessary to take the Doppler effect into account, and extensive calculations have been performed in a way which is generally applicable. The area above a transmission dip is given by

$$[A_E]_D=\Gamma/2\int_{-\infty}^{\infty}[1-e^{-n\sigma_0\psi(x,\,\Gamma/\Delta)}]dx,$$

where $\psi(x, \Gamma/\Delta)$ is the Breit-Wigner cross-section formula with the Doppler broadening applied, Δ=Doppler width and $x=2(E-E_0)/\Gamma$. The quantity $[A_E]_D/A_E$ (where A_E is the corresponding area with $\Delta=0$) is the factor by which the Doppler effect increases the area above a transmission dip. This ratio has been calculated for a wide range of values of Γ/Δ and $n\sigma_0$. ($\Delta/\Gamma=0.3,\ 0.5,\ 2,\ 5,\ 50,\ \infty$; $0.1\leq n\sigma_0\leq 100$.) Plots of the calculations will be shown and application to the area method discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] W. W. Havens, Jr., and L. J. Rainwater, Phys. Rev. **83**, 1123 (1951).

G6. Neutron Transmission Measurements of Cadmium, Gadolinium, and Mercury Using the Argonne Fast Chopper. R. Ronald Palmer* and Lowell M. Bollinger, *Argonne National Laboratory.*—Neutron transmission measurements of cadmium, gadolinium, and mercury and the separated isotopes of cadmium and mercury, with flight paths of 10, 20, and 40 meters, will be reported. Resolution, which improves with distance, is about 0.13 μsec/m (full width at half-maximum) at 40 meters. Gadmium shows resonance transmission dips at neutron energies of 18.0, 27.2, 66.6, 88.2, 122, 163, 234, 400, and 840 ev, with the 27.2- and 88.2-volt dips most prominent. The 27.2-volt dip is assigned to the Cd^{111} isotope; the 82.2-volt dip, tentatively to Cd^{110}. Transmission dips for gadolinium occur at 1.93, 2.58, 2.85, 6.26, 7.74, 11.6, 14.4, 16.6, 20.6, 22.1, 29.8, 33.2, 49, 81, 109, 355, and 740 ev, with the 2.58, 2.85, 20.6, and 22.2-volt dips most prominent. Mercury shows transmission dips at 23.1, 33.3, 42.8, 71, 91, 127, 175, 200, 311, 437, and 1230 ev, with the 23.1, 33.3, 175, and 311-volt dips most prominent. The 33.3 and 175-volt dips are assigned tentatively to Hg^{201}.

* On leave from Beloit College, Beloit, Wisconsin.

G7. The Absorption Cross Section of Gold and Boron for Thermal and Cold Neutrons. R. S. Carter, H. Palevsky, and V. W. Myers,* *Brookhaven National Laboratory.*†—The absorption cross sections of gold and boron have been measured with the Brookhaven slow chopper over the wavelength region from 1.8 to 11A. These cross sections are important because they constitute comparison standards for much slow neutron work. For gold, beyond the Bragg cutoff (4.7A) the total cross section consists of capture and inelastic scattering only, the latter being very small (0.3 b). The cross section between 4.8 and 11A follows a 1/v law and the slope of the curve is 54.3 barns/A. If gold followed a 1/v law to thermal (2200 m/s), this slope would give an absorption cross section of 97.5±0.3 b. As the measured total cross section at thermal is 104 b, either an unusually low scattering cross section or a slight departure from 1/v is indicated. The boron measurement was made with two samples of boron of normal isotopic content, B_2O_3 in glass prepared and analyzed by Corning for Columbia University, and the Argonne standard B_2O_3 dissolved in D_2O. The value obtained at 2200 m/s for normal boron is 753±3 barns. Enriched boron (96 percent B^{10}) is being measured as a check on the isotopic constitution of normal (source-California) boron.

* On leave from Pennsylvania State College.
† Work carried out under contract with the U. S. Atomic Energy Commission.

G8. Total Neutron Cross Sections of Heavy Water and Glass at Long Wavelengths. V. W. Myers,* R. S. Carter, and H. Palevsky, *Brookhaven National Laboratory.*†—The cross sections of D_2O and boron-free glass at room temperature have been measured from 4 to 15A with the Brookhaven slow chopper. In the wavelength region covered, the capture cross sections of these materials is small compared to the scattering. The coherent scattering due to liquid structure is observed in both materials but essentially disappears at 10A. As the wavelength is increased beyond 10A, the measured cross sections rise monotonically and approach a 1/v law. From the work at Brookhaven on the inelastic scattering of neutrons in solids, it is known that the inelastic scattering approaches 1/v at long wavelengths; hence the residual scattering in D_2O and glass is interpreted to be inelastic scattering plus a constant contribution due to incoherent scattering. For D_2O the inelastic cross section at 10A is 15 barns per molecule and in glass at the same wavelength it is of the order of 5 barns per SiO_2 molecule.

* On leave from Pennsylvania State College.
† Work carried out under contract with U. S. Atomic Energy Commission.

G9. Coherent Cross Sections of Iron and Nickel. M. D. Goldberg and J. A. Harvey, *Brookhaven National Laboratory.**—Coherent scattering cross sections (σ_{coh}) can be obtained from free atom (σ_{fa}) and incoherent scattering ($\sigma_{in\ coh}$) cross sections. σ_{fa}'s of iron and nickel have been determined from total cross-section measurements using broad energy distributions of pile neutrons. This method is applicable when the total cross section is nearly constant with energy. Different energy distributions can be selected by proper combinations of B^{10} filters and differences, and the median energy for each distribution can be calculated. Two beams were used and the cross section measured both absolutely and relative to bismuth, which has a σ_{fa} of 9.28±0.02 b. A correction for capture was applied and other small corrections considered. The σ_{fa}'s of iron and nickel were determined as 11.39±0.04 b and 17.43±0.05 b, respectively. These agree with the indium resonance neutron measurements of Rayburn and Wollan.[1] The $\sigma_{in\ coh}$ for iron, calculated from the isotopic contributions and measured by a slow chopper, is 0.43±0.03 b, which, when subtracted from the bound atom cross section, yields a σ_{coh} of 11.37±0.05 b. A calculation of $\sigma_{in\ coh}$ of nickel yields 5.0±0.3 b; a more accurate chopper measurement is in progress. Direct determinations of σ_{coh} by mirror techniques will be described.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] L. A. Rayburn and E. O. Wollan, Oak Ridge National Laboratory, 1164, 34 (1951).

G10. Neutron Time-of-Flight Spectrometer with Betatron Source. M. L. Yeater and E. R. Gaerttner, *Knolls Atomic Power Laboratory,** and G. C. Baldwin, *General Electric Research Laboratory.*—The 100-Mev betatron at Schenectady is being used as a neutron source for the measurement of neutron cross sections by the time-of-flight method. Approximately 10^{10} neutrons per second are produced in a thick natural uranium target mounted inside the betatron doughnut in pulses having a full width at half maximum intensity of 0.35 microsecond. A moderator is also placed inside the betatron doughnut, partly surrounding the uranium. Shielding consists of water tanks in front of the betatron. Tanks packed with sodium metaborate and boron carbide make up the collimating sections between the shield and the detector. With a BF_3 ionization chamber detector, the background is approximately 1 percent of the open-beam intensity. (Scintillation counter detecting equipment is described in an accompanying paper). Timing equipment consists of a delay and 64-channel analyzer. The "zero time" signal is the output of a photomultiplier energized by x-rays from the uranium target. The resolution with a 7-meter flight path is approximately 0.1 μsec/m at 1000 ev. Measurements will be described.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

G11. Measurement of Neutron Capture Resonances using an (n, γ) Scintillation Detector. R. D. Albert and E. R. Gaerttner, *Knolls Atomic Power Laboratory.**—Neutron capture gamma-rays are detected by a pair of toluene-terphenyl liquid scintillators connected in coincidence. The scintillators are in the form of cylindrical volumes as defined by thin-walled aluminum containers. Each container is a cylindrical vessel six inches in length and eight inches in diameter with a four-inch diameter axial opening for the neutron beam which passes first through one, then the sample foil position, then the other all centered on a common axis. Each of the chambers has four RCA 5819 photomultipliers viewing its interior. The foil sample is located midway between the two chambers in a plane transverse to the beam and is seen with a solid angle of 40 percent of the total by each detector. Under actual operating conditions the counting efficiency of each counter is about 5 percent at a coincidence resolving time of 10^{-8} second. The counting efficiency is determined from the ratio of coincidence to single counting rate for Co^{60} gamma-rays. The background counting rate is less than one-tenth the total counting rate at exact resonance for the 4.9 electron-volt gold resonance when operated with the betatron velocity selector. Its use as a high resolution detector with the velocity selector and some of the results obtained will be discussed.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

G12. Neutron Detectors for the Brookhaven Fast Chopper.* H. Palevsky, N. G. Sjöstrand,† and D. J. Hughes, *Brookhaven National Laboratory.*—Investigations have been made of various possible neutron detectors for use with the Brookhaven fast neutron chopper. This machine is a time-of-flight neutron spectrometer that covers the energy range from about 10 volts to 5 kev. It is now operating with a burst time of 1 μsec (full width at half maximum) and shortly should give ½ μsec bursts of neutrons. The detector must have high efficiency, low gamma-ray sensitivity, and a time uncertainty of less than ½ μsec. This time uncertainty implies that the detector must be fast and small enough so that the neutron flight time in the counter is short. A pulse counting $B^{10}F_3$ ion chamber has been constructed and tested; a multiple $B^{10}F_3$ proportional counter array is now being constructed. For both, the size limitation decreases the attainable efficiency. Preliminary tests have been made with several possible types of scintillation counters, for which the use of neutron sensitive solids offers the possibility of high detection efficiency and small size. However, the gamma-ray sensitivity sets the limit for these detectors. Arrangements for which the boron disintegration alphas and the U^{235} fission neutrons are detected have been tried.

* Work carried out under contract with the U. S. Atomic Energy Commission.
† Guest physicist from AB Atomenergi, Stockholm, Sweden.

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LANCASTER PRESS, INC., LANCASTER, PA.

THE PHYSICAL REVIEW

VOLUME 91 *Second Series* NUMBER 2

JULY 15, 1953

Published for the

AMERICAN PHYSICAL SOCIETY

by the

AMERICAN INSTITUTE OF PHYSICS
Incorporated

LANCASTER, PA., AND NEW YORK, N. Y.

THE PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

Published by the American Institute of Physics for the

AMERICAN PHYSICAL SOCIETY

Manuscripts for publication should be submitted to S. A. GOUDSMIT, Brookhaven National Laboratory, Upton, Long Island, New York. The authors' institutions are requested to pay a publication charge of $15 per page which, if honored, entitles them to 100 free reprints. Instructions will be sent with galley proofs.

Proof and all correspondence concerning papers in the process of publication should be addressed to the Publication Manager, American Institute of Physics, 57 East 55 Street, New York 22, New York.

Subscription Price

United States and Canada.....$30.00
Elsewhere.....$32.00

Back Numbers[1]

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Changes of address in the case of members of the American Physical Society should be addressed to the Treasurer; in the case of other subscribers to the American Institute of Physics.

[1] For Series I inquire of Physics Department, Cornell University, Ithaca, New York.

The Physical Review is published semi-monthly at Prince and Lemon Streets, Lancaster, Pennsylvania.

Entered as second-class matter March 6, 1947, at the Post Office at Lancaster, Pennsylvania, under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in paragraph (d-2), section 34.40, P. L. & R. of 1948, authorized January 27, 1933.

THE PHYSICAL REVIEW

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SECOND SERIES, VOL. 91, NO. 2 JULY 15, 1953

Low Temperature Diamagnetism of Electrons in a Cylinder*

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(Received January 19, 1953)

The exact eigenfunctions are found for an electron in a cylindrical container in the presence of a uniform axial magnetic field. The eigenvalue spectrum, while superficially similar to that in free space, is so essentially different that the statistical properties of an electron assembly in the cylinder are entirely different from those derived in previous work. It is therefore of interest to use an integration approximation in computing the energy of the assembly at 0°K. It turns out to have a very strong size-dependent paramagnetic term, and the reasons for this are carefully explained. The work lends support to the view that the observed diamagnetism of electrons in the superconducting state cannot be understood in terms of any free-electron approximation, and that interactions with the lattice potential play an essential role.

INTRODUCTION

PREVIOUS work on the quantum-mechanical properties of electrons in a magnetic field has been characterized by a wide variety of conflicting results. Recently in two important papers Osborne and Steele[1] have shown how very carefully one has to handle the statistics in order to avoid some of these conflicts. However their work, and apparently much previous work, has treated the boundary value problem of fitting the eigenfunctions to the walls of the container by the WKB method, and the concept of localized reflected electron orbits is basic to the work.†

The present paper derives from the idea that this concept of reflected localized orbits may be inapplicable to the low temperatures pertaining in superconductivity work. The fuzziness of the Fermi surface in wave-number space, representing the possible uncertainty in the momentum of any particular electron, is too sharp to provide localized wave groups in ordinary space for the conducting electrons: the uncertainty in position is necessarily at least of the order 10^{-5} cm. Especially for small cylinders it would therefore be quite unsafe to picture an electron as a particle capable of being reflected in a definite orbit.

In itself, this is not a serious objection to the WKB approximation. At least for one-dimensional problems, the WKB approximation necessarily becomes equivalent to an exact solution for large quantum numbers, and does not depend on the particle being localized in (one-dimensional) space. In three dimensions the situation is somewhat different. One first separates the variables and then applies the WKB method to each variable separately if the equation does not solve exactly. For a cylindrical box one knows the angular-momentum quantum-number spectrum exactly, and the axial or longitudinal quantum numbers are usually obtained by using periodic boundary conditions at the ends. The WKB method is used only on the radial equation. The radial equation does not have the proper boundary conditions for a rigorous application of the WKB method and one always has to add a fictitious potential $1/4r^2$ to modify the singularity at the center of the cylinder, before a proper path can be set up over which the wave number can be integrated between $r=0$ and $r=a$. The order of magnitude of this fictitious term must be small compared with any significant term except over a small circle round the origin whose radius is negligible compared with that of the cylinder. The method works well for the H atom problem in spherical coordinates because the fictitious term does no more than modify the centrifugal term, effectively changing the angular-momentum quantum number from an integer to half an odd integer. Because this quantum number does not occur in any other term, this modi-

* This paper constitutes a technical report of work done under contract with the U. S. Office of Naval Research.

[1] M. F. M. Osborne, Phys. Rev. **88**, 438 (1952); M. C. Steele, Phys. Rev. **88**, 451 (1952).

† *Note added in proof:*—R. B. Dingle, Proc. Roy. Soc. (London) **A216**, 118 (1953), used the WKB method and obtained different results again from Osborne and Steele.