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SOLID STATE PHYSICS PROGRAM

ANNUAL PROGRESS REPORT

U. S. ATOMIC ENERGY COMMISSION
CONTRACT NO. AT 11-1-623

NOVEMBER, 1973

MASTER

CASE WESTERN RESERVE UNIVERSITY

UNIVERSITY CIRCLE

CLEVELAND, OHIO 44106

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ABSTRACT

The present status of seven problems in thin film and surface physics, six in cohesive and dielectric properties, and two in solid state theory is described. One result of special significance from each area is as follows: the magnetoresistance of a metal having a spherical Fermi surface, but cubic symmetry for the electron scattering, has been calculated by the magnetic-scattering eigenfunction approach. The low frequency dielectric constant of vitreous silica and several orientations of anisotropic crystals has been measured to high accuracy.

Mössbauer measurements of amorphous cobalt films show a slightly smaller internal field and significant line broadening as compared to the crystalline phase at the same temperature.

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INTRODUCTION

This report describes the research of those faculty and students directly involved in the Solid State Physics Program supported by the Atomic Energy Commission at Case Western Reserve University during the period between November, 1972 and October, 1973.

Professor Taylor was on leave at the University of Washington during the Spring, 1973 term. Mr. P. Cardon accompanied him in order to carry out his research using the Washington computer. Both returned to Case Western Reserve University during the summer.

Professor Schuele was named Acting Dean of Case Institute of Technology in January, 1973 and Dean in September, 1973. In addition to his duties as Dean of the undergraduate college, he will still continue his research and lighter teaching responsibilities in the Department of Physics.

Professor Hoffman continues his second term as a Director of the American Vacuum Society. He has also been active in recruiting undergraduate students. The fourth volume of "Critical Reviews in Solid State Sciences" edited by Professors Schuele and Hoffman is now in production.

Appendix I lists the personnel active in the program. No graduate students have joined our research effort, but two have received degrees. All those who completed their research are presently employed, although one is in a non-permanent postdoctoral position. Two undergraduate physics majors also contributed to our research.

Two technical reports are in press, and represent completed problems. These are listed in Appendix II. In addition, papers from preprint through

reprint stages are detailed in Appendix III. Research that is in progress will be emphasized in the body of this report. Appendix IV lists the major equipment purchases.

Three research areas are identified: (A) thin film physics, directed by Professor Hoffman; (B) cohesive and dielectric properties of solids, with Professor Schuele and Dr. Andeen; and (C) the solid state theory efforts of Professor Taylor.

All the faculty associated with this project have spent approximately 50% of their effort during the academic year on the research described and 100% of their effort for the two summer months with Professor Taylor being on leave during the Spring term.

Mr. Reynolds of the Chicago Operations Office, has informed us that the patent for the capacitance high pressure gauge will be issued. This patent is in the names of Drs. Schuele, Andeen, and Fontanella and is based on the AEC-supported effort of this contract over the past several years.

A. Thin Film Physics

1. Torque Magnetometer Measurements - R. E. Chase and R. W. Hoffman.

The torque data remains elusive although significant progress has been made. During the last year, problems were encountered in the servo-system and in the signal conditioning for measurement of torque and magnetic field. The signal conditioning was completely redesigned and rewired to remove serious noise pickup and reduce drift effects. The servosystem exhibited occasional instability, leading to damage of the potentiometer used for measuring the torque. The potentiometer was replaced (rather than repaired) with a higher resolution potentiometer. The servosystem was re-examined and the design reworked to remove instabilities. The new design was implemented with the necessary electronics. Stability of the servo-system is now predictable and controllable. Electronics for both the servo-system and the signal conditioning were panel mounted in their finished form. A circuit for blowing the six position shutter system fuses in timed sequence was constructed to overcome the inaccuracies for small thickness changes in the earlier approach of using the quartz crystal monitor to control shutter openings and closings. The computer program previously used for calculating the magnetization from the torque versus magnetic field data was reviewed and a significant simplification made in the method of solving the central transcendental equation, a simplification which avoids an iterative technique that often would not converge. ~~No~~ data have been taken.

X 2. Mössbauer Measurements - M. Kwan and R. W. Hoffman..

Amorphous cobalt films have been condensed on glass substrates held at 20 K, and the Mössbauer spectra determined below and above the amorphous-crystalline transition occurring at about 50 K. The experimental phase of this research is now complete and has been accepted for presentation at the International Vacuum Congress in Kyoto, Japan next March. The abstract follows:

Pure amorphous cobalt films ($<100 \text{ Å}$) have been prepared by condensation onto liquid helium cooled glass substrates. Evaporation was accomplished with the electron bombarded pendant drop technique in pressures of 10^{-10} Torr. In situ measurements were made of the electrical resistivity and Mössbauer spectra of the films during annealing to room temperature. The films underwent an abrupt and irreversible drop in resistivity, characteristic of metallic films at the amorphous to crystalline transition.¹ This three to fourfold drop occurred at about 55°K for the purest films, the transition temperature increasing with increasing impurity content. The Mössbauer spectra, obtained at various temperatures before and after the transition, all exhibited six lines with hyperfine fields near those of crystalline cobalt and intensities corresponding to in plane magnetization. The parameters obtained from the analysis of the Mössbauer data will be presented and examined with respect to their variation with structural disorder.

The details of the instrumentation and ultra high vacuum system and cryostat are being written up for publication.

¹M. R. Bennett and J. G. W. Wright, Phys. Stat. Sol. (a) 13 135 (1972).

3. Intrinsic Stress in Metal Films - F. A. Doljack, W. Bowser, R. W. Springer, and R. W. Hoffman

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The theoretical model for the origin of intrinsic stress in condensed metal films has been written up for publication. The paper, entitled Grain Boundary Relocation Stress in Nickel Films, has the following abstract:

A quantitative model which explains the origin of intrinsic stress in polycrystalline metal films is described and compared with data measured for evaporated nickel films. The stress originates by the constrained relaxation produced by the interatomic forces at grain boundaries during film growth. Consequently, the magnitude of the resultant stress can be predicted from a knowledge of the cohesive properties of the metal and its microstructure.

The stress in nickel films evaporated at substrate temperatures between -40°C and 225°C was measured by an optical interference method. The observed average grain size for each sample was used in the model to calculate the stress. The measured stresses were roughly 30% lower than the calculated values and the temperature dependences correlated well.

In addition, the likelihood was demonstrated that impurity grain boundary diffusion could account for compressive stresses observed in this experiment at the elevated substrate temperatures.

In order to check the effect of impurity diffusion from the substrate as suggested earlier, the stress in nickel films condensed on cantilevered silicon substrates has been measured by an undergraduate physics major, W. Bowser. Although the raw data are in hand, reduction

to stress values as a function of deposition temperature and thickness remain to be done. Qualitatively, the same compressioned features for films less than 1000 Å thick were seen.

The measurement of the stress in nickel films condensed on nickel substrates reported last year has been published in the Journal of Vacuum Science and Technology.

4. UHV Intrinsic Stress Measurements - P. Martin Alexander and R. W. Hoffman.

The apparatus for measuring intrinsic stress in ultra high vacuum and in the presence of controlled gas impurities is nearly completed.

The technique suggested last year for measuring the end displacement of a cantilevered beam substrate has been found to be acceptable. A laser housing, a laser and photocell support attachable to the UHV system, and a modified laser power supply which regulates laser intensity via a feedback photocell have been completed.

The substrate clamp, which was mounted on bearings, has been linked to a linear motion feedthrough, so that the substrate edge, which acts as one side of a slit, may be positioned relative to the knife edge, which is the other edge of the slit. Before each run, the single slit diffraction signal to a photocell will be recorded as a function of the feedthrough reading. Through an added system of gears, accurate readings corresponding to small displacements of the substrate's free end are possible.

The feedthrough readings have been calibrated in terms of the actual motion of the substrate. A rod was attached to the rotating substrate

clamp, and the motion of the end of the rod was measured with a traveling microscope. The distance from the end of the rod to the axis of rotation was measured so that the beam motion could be found. The angular motion of the clamp and substrate was found to be reasonably linear with feed-through reading.

Also, the following have been completed:

- (1) Supports for the thermocouple wires. The substrate and clamp temperatures have been monitored during evaporation.
- (2) A substrate heater.
- (3) A shutter system, including circuits for outgassing and melting fuse wires.
- (4) A quartz crystal evaporation monitor has been installed.

Several preliminary runs have been made, and the evaporation of large enough nickel charges at desired rates is a problem. Tungsten filaments with nickel charges, now commercially available, will be tried.

Installation of a residual gas analyzer in the UHV system is in progress.

X 5. Adhesion and Thin Films - C. W. Hagerling and R. W. Hoffman.

Progress in the construction of the ultracentrifuge has been steady. Most of the non-electronic parts of the ultracentrifuge have been constructed in final form. The original wooden frame has been replaced with a rigid aluminum structure. A functionally flexible but mechanically rigid optical system for sensing the rotor height has been machined. It consists basically of a tungsten light source, focusing lens, anti-glare rings, a stop, spatial filter and photodetector.

The magnetic field used to accelerate the rotor will be produced by a four pole magnet driven by a high frequency sine wave. These poles could have an air core but performance would be substantially improved by using ferrite cores. A suitable high frequency ferrite was located, cut and fitted to produce the desired pole configuration. These poles were then mounted in a rigid aluminum holder.

In addition to this mechanical work, three highly regulated power supplies needed to run the electronics were implemented in final form.

6. Determination of Surface and Depth Impurity Concentration Profiles -

X C. R. Anderson and R. W. Hoffman.

Impurity concentration analyses ^{in films} as a function of distance from the substrate must be made to quantitatively compare the intrinsic stress calculation with experimental data. An ESCA analysis, in collaboration with Dr. G. Mateescu, of the Ni/Si and Ni/Ni samples on which stress data already exists is being made to chemically identify what the impurities are, though they may be as few as 10^{12} atoms/cm² when expressed as a surface impurity. The technique requires bombardment of the sample with X-rays of up to 10 keV energies and observation of the electrons given off. These electrons escape the sample from depths no greater than about 20 Å, so the surface must be kept free from atmospheric contaminants. For this reason and to make the depth analysis of impurity concentration, surface layers of about 20 Å thickness must be sputtered from the sample. The sputtering power is sufficiently great that a new probe and sample holder with a cooling system to dissipate about 10 W. of power with a temperature

rise of no more than about 30°C at the sample was constructed. One must prevent significant thermal diffusion of impurities through the sample's grain boundaries.

Calculations are being made by Dr. W. Lindstrom on the feasibility of using (p, α) charged particle reactions to establish depth and concentration of O and N through proton reactions with O^{18} and N^{15} . This effort, in collaboration with both he and Professor A. H. Heuer, on the Van de Graaff accelerator located in the Department of Physics and on existing equipment, awaits further knowledge of the specific impurities found by ESCA before further calculations can be profitably made.

X 7. Appearance Potential Spectroscopy - M. Matthews, C. R. Anderson, and R. W. Hoffman.

In anticipation of the next Mössbauer study of atoms on surfaces, an undergraduate summer student, M. Matthews, has investigated the feasibility of soft X-ray appearance potential spectroscopy for the geometry of our samples which may be insulators. The APS technique bombards the sample with electrons of accurately known energy, which in turn emits a sudden increase of soft X-rays at the ionization potentials of the electron shells. A lock-in amplifier picks this sudden increase of signal from the photoelectron signal caused primarily by white radiation. The technique seems appropriate for our conditions, and work is started on a prototype.

B. COHESIVE AND DIELECTRIC PROPERTIES

1. The Low-Frequency Dielectric Constant of Vitreous Silica -

Preliminary measurements of the dielectric constant for many different types of fused silica and fused quartz were reported in Technical Report #78. A good correlation has since been found between the hydroxyl ion concentration (as determined by IR absorption at 2.73 μm), dielectric loss, and the observed low-frequency dielectric constant. This work is now complete and has been submitted for publication in the Journal of Applied Physics. The abstract follows:

The 1000 Hz, 300°K dielectric constant, ϵ_s , of twenty-four kinds of commercially available vitreous silica has been measured to an accuracy of 0.01% and a precision of about 1 part in 300,000 by the method of substitution (two-fluid technique). The observed dielectric constant ranges from 3.8073 to 3.8304. These results are correlated with hydroxyl ion content and other imperfections. It is found that $\epsilon_s = 3.8073 + 2.72 \times 10^{-22}N$ where N is the hydroxyl concentration in ions/cm³, and observed deviations from this rule are attributed to metallic impurities and inclusions. From the results, it appears that 3.8073 closely approximates the low frequency dielectric constant of pure vitreous silica.

2. The Low-Frequency Dielectric Constant of Anisotropic Crystals. The

low-frequency dielectric constants for several orientations of crystalline quartz (obtained from the P. R. Hoffman Co.) were reported in Technical Report #78. Our colleague, Dr. J. Fontanella of the U. S. Naval Academy has recently obtained samples of crystalline quartz from the Valpey Corp.

with orientations ranging from 0° (Z-cut) to 90° (X-cut and Y-cut) relative to the optic axis, in steps of 15° . He has also obtained several orientations of synthetic Al_2O_3 from the Linde Co. and MgF_2 from the Harshaw Chemical Co.

The low-frequency dielectric constant of these anisotropic crystals has since been measured by Dr. J. Fontanella at the U. S. Naval Academy in collaboration with Dr. C. Andeen, using the dielectric constant substitution cell and its associated capacitance bridge which are on loan from this laboratory. These measurements are now complete and have been submitted for publication in the Physical Review. The abstract follows:

The 1000 Hz, $300^\circ K$ dielectric constants were measured for crystalline α -quartz, sapphire, MgF_2 , and MgO , and polycrystalline sapphire (Lucalox), magnesium fluoride (IRTRAN 1), and magnesium oxide (IRTRAN 5). The measurements were performed using the method of substitution (two-fluid method). The results are: single crystal α -quartz, $\epsilon_{s\parallel} = 4.6368 \pm 0.001$, $\epsilon_{s\perp} = 4.5208 \pm 0.001$; single crystal sapphire, $\epsilon_{s\parallel} = 11.589 \pm 0.005$, $\epsilon_{s\perp} = 9.395 \pm 0.005$; polycrystalline sapphire (Lucalox), $\epsilon_s = 10.154 \pm 0.007$; single crystal MgF_2 , $\epsilon_{s\parallel} = 4.826 \pm 0.01$, $\epsilon_{s\perp} = 5.501 \pm 0.01$; polycrystalline MgF_2 (IRTRAN 1), $\epsilon_s = 5.289 \pm 0.001$; single crystal MgO , $\epsilon_s = 9.830 \pm 0.001$; and polycrystalline MgO (IRTRAN 5), $\epsilon_s = 9.833 \pm 0.001$, where $\epsilon_{s\parallel}$ and $\epsilon_{s\perp}$ are the dielectric constants parallel and perpendicular, respectively, to the c-axis.

✓ 3. Accurate Determination of Orientation of Single Crystals from Laue Photographs - C. Andeen. For a material having a dielectric anisotropy of 20% a change in orientation of $.03^\circ$ at 45° results in a change in the observed dielectric constant of .01%. Since the method of substitution is capable of 0.01% accuracy and even better precision it is necessary to determine the

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orientation of highly anisotropic crystals to better than $.03^\circ$ to retain this high accuracy. To achieve this orientation capability a method has been developed which utilizes ordinary Laue back-reflection photographs, analyzed in such a way that intrinsic errors are minimized. With this method it is possible to determine the orientation of single crystals to better than $.01^\circ$.

Several anomalous details can be observed in any back-reflection Laue photograph, but when accurate results are desired the most basic limitation is that the distance from the center of the film to a spot is not well defined. This becomes obvious if one looks at the line of spots resulting from diffraction by planes of a zone. The spots would ideally be ellipses whose centers lie on a hyperbola, but what is observed is a blurring of the ellipses toward the side of the hyperbola away from the center. This effect (which is particularly significant for materials like Al_2O_3 and SiO_2 which consist of elements having a low atomic number and hence a low mass absorption coefficient) is due to the finite penetration of the sample by the X-ray beam with an apparent increase in the sample-to-film distance, which results in the spot being displaced outward from its ideal position as well as being blurred along the major axis of the ellipse.

Another effect which can be significant is the excess blackening of a spot which occurs if the diffracted wavelength almost coincides with a characteristic wavelength of the X-ray tube target material. In this case the spot can be displaced either inward or outward.

Since distances on Laue photographs can be misleading the present method ignores the measurement of distances entirely and relies instead on the measurement of angles only. If one determines the directions to the three vertices of a spherical triangle from a point on the sphere lying within the triangle, the position of the included point is uniquely determined. Also, the angles

included by the vertices of the spherical triangle are the same as the angles included by the vertices of the plane triangle formed when the spherical triangle is projected from a source at the center of the sphere on to a plane tangent to the sphere at the included point. Thus the angle measurements to any three indexed spots (which include the center of the film) on a Laue photograph can be related directly to the spherical triangle formed by the three spots.

The angles are determined on an R, θ measuring table with the spots in the plane of the film being imaged onto a plane containing two perpendicular sets of dual cross-hairs which box in the desired spot. To determine the orientation of the crystal relative to its surface plane it is necessary to take two Laue photographs with the sample being rotated 180° for the second photograph. By this means angular misalignment and translational error of the collimator axis relative to the center of the film are cancelled by a large factor. These two measurements not only accurately determine the orientation of the crystal surface, but also result in a determination of the collimator error which can be used as an internal check of the data if the collimator is not moved between photographs. For the dielectric constant samples it is necessary to determine the orientation of both surfaces of a disc to measure the non-parallelism of these surfaces.

Although the solution of the spherical triangle problem is non-trivial, it has been possible to determine the orientation consistently to $\sim .01^\circ$ by measuring the angles to different sets of spots.

X 4. Capacitive Pressure Gauge. The capacitive pressure gauge continues to receive considerable effort. Over the past year T. Adams of the Los Alamos Scientific Laboratory has put together a capacitive pressure gauge with calibrated CaF_2 sensors which we have loaned him, and is quite close to becoming operational. R. Miller, III of Redstone Arsenal, is attempting to put together a prototype capacitive pressure gauge which would be optimized for the pressure range up to 10,000 psi.

Our interaction with the National Bureau of Standards continues at a high level and we have been invited back to recalibrate the CaF_2 sensors which were originally calibrated during the summer of 1970. The extension of the pressure range awaits their putting into operation the ultra high pressure dead weight gauge. We continue to exchange information concerning sensing material with CaF_2 still in the forefront.

We have designed on paper a bridge which will give direct readout in pressure with no loss of sensitivity.

X 5. 200,000 PSI Pressure System. During the past year we have obtained the major components for a 200,000 psi pressure system to be used for the investigation of dielectric properties at high pressures. The system consists of a pressure vessel having a 1.25 in. diameter x 4.00 in. long sample chamber with 6 electrical feedthroughs, a 200,000 psi pressure intensifier, and the necessary plumbing for either gas or liquid operation.

The ultimate goal of this 200,000 psi system is the development of the capacitive high pressure gauge for use at pressures where present measuring devices are inadequate, as well as to extend the meaningful range of our dielectric constant measurements.

X 6. Elastic Properties. Single crystals of Li^6 and Li^7 have been grown and samples have been prepared by Professor Trivisonno of John Carroll University. The measurement of the elastic constants as a function of temperature are being measured in his laboratory.

Our gas high pressure system has been modified in order to accept these materials. We expect to begin elastic constant measurements as a function of pressure around the first of the year.

X Articles. Several other papers have been prepared for publication: "Some Comments on Manganin Wire Pressure Gauges" and "The Low Frequency Dielectric Constant of Vitreous Arsenic Trisulfide." Preprints of these articles are enclosed, the abstracts follow:

A standard manganin wire pressure gauge is examined by comparing it with a recently developed 0.01% CaF_2 capacitive pressure gauge. The effects of the Bridgman "water kick" and intrinsic time constant are clearly shown and the results punctuate the usual assertion that manganin wire gauges are extremely difficult to use approaching the 0.1% level. (Accepted for publication in the International Journal of High Pressure and High Temperature Physics.)

The 1000 Hz, 300°K dielectric constant of two samples of Servofrax arsenic trisulfide glass was measured to an accuracy of about 0.01% by the method of substitution (two-fluid technique). The values were determined to be 7.9093 and 7.9097. These results are discussed in the light of recent refractive index and reflectivity measurements. (Submitted for publication - Journal of Physics and Chemistry of Solids.)

C. SOLID STATE THEORY

1. Properties of Disordered Systems - P. L. Taylor and K. C.

Acharya.

A calculation of the spin-wave spectrum of an amorphous Heisenberg ferromagnet has now been completed. In this approximate treatment a transformation due to Taylor and Wu [Phys. Rev. B2 1752 (1970)] was applied to a perturbation expansion for the Green function of an amorphous array of interacting spins. An arbitrary mean-field model was chosen as the unperturbed system, and the difference between the exact and unperturbed system was applied as a perturbation. As this work represents the first realistic calculation to be performed on such a system, it is interesting to note that physically reasonable results were obtained when the perturbation series was truncated at the lowest non-trivial set of diagrams. At low frequencies the spin-wave spectrum that we calculated tended to the correct continuum limit, and the total number of modes contained in the spectrum retained its correct value. The upper limit of the spectrum in the amorphous material was in every case reduced below that of its crystalline analog, while internal van Hove singularities of the crystalline spectrum were absent in the amorphous system. The temperature dependence of the magnetization was also found to be affected by the disorder. At the lowest temperatures the deviation of the magnetization from its saturation value exhibited the usual Bloch $T^{3/2}$ behavior, with a coefficient identical to that of the crystalline analog. At higher temperatures, however, the depletion of the

high-frequency end of the spectrum caused the magnetization for the amorphous system to fall below that of the crystal, with a corresponding reduction in the Curie temperature. This work has been submitted to the Physical Review.

Exact calculations of the spectra of disordered systems have been confined for the most part to one-dimensional assemblies. Within this framework we have attempted to resolve a number of qualitative questions concerning the electron spectrum of disordered alloys. We have, for instance, studied the effects of correlations in the occupancies of neighboring sites in a binary alloy, and have found a very strong influence of short-range order on the spectrum. This work was published in Solid State Communications [12 309 (1973)]. The form of the spectrum near the so-called special energies at which the density of states vanishes has also been studied, and the results published in the Journal of Physics [C6 1889 (1973)].

2. Transport Properties of Metals - P. L. Taylor, P. Cardon and F. Szmulowicz.

Considerable progress has been achieved during the past year in our attempts to reduce the exact solution of the Boltzmann equation for Bloch electrons in magnetic fields to a form suitable for detailed computations. The extreme delicacy of the problem rests on the fact that the high-field magnetoresistance is determined by the very small difference between several large quantities appearing in the calculation, and this requires more precision in one's results than most computational programs permit.

An alternative approach to the high-field conductivity tensor has now been developed, and this is providing us with some useful upper bounds to the magnitudes of the quantities involved. This in turn is allowing us to estimate the range of validity of the more general results obtained from the magnetic-scattering-eigenfunction approach of Fair and Taylor [Phys. Rev. B2 4844 (1970)].

The principal result we have obtained relates to the magnetoresistance of a metal having a spherical Fermi surface, but in which the electron scattering has cubic symmetry. We find that the magnetoresistance rapidly saturates at modest magnetic fields, but that very small misalignments can yield an apparently linear and non-saturating magnetoresistance very similar to that observed experimentally.

APPENDIX I

Personnel Associated with the Contract

Professional Staff

Richard W. Hoffman, Professor of Physics
Donald E. Schuele, Associate Professor of Physics
Philip L. Taylor, Associate Professor of Physics
Carl G. Andeen, Research Associate

Research Assistants and Thesis Students

V. C. Acharya
P. M. Alexander
C. R. Anderson
P. M. Cardon de Lichtbuer
R. E. Chase
C. W. Hagerling
M. Kwan

Undergraduate Students

W. Bowser
M. Matthews

Machinist

J. Jaroscak

Secretaries

Z. M. Clifford
M. E. Young

Technical Reports

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APPENDIX III

Publications

The following papers were cited in reports of previous years or this current year. Reprints are now being sent under separate cover.

Origins of Stress in Thin Nickel Films. F. A. Doljack and R. W. Hoffman.
Thin Solid Films, 12 71 (1972). C00-623-186

Seebeck Coefficient at the Curie Temperature. P. L. Taylor, Phys. Rev.
B7 1197 (1973). C00-623-187

Growth Effects on Stress in Nickel Films, R. W. Springer and R. W.
Hoffman. J. Vac. Sci. Tech., 10 238, (1973). C00-623-188

Spin Waves in an Amorphous Heisenberg Ferromagnet, J. E. Gubernatis
and P. L. Taylor. Proceedings of Conference on Amorphous Magnetism.
Plenum Press, N.Y. (1973). C00-623-189

Effect of Short-range Order on the Band-edge Behavior of the Electronic
Spectrum of Disordered Alloys. J. E. Gubernatis and P. L. Taylor,
Solid State Communications 12 309 (1973). C00-623-192

Some Details of the Density of States of a Disordered Alloy. J. E.
Gubernatis and P. L. Taylor, J. Phys. C6 1889 (1973). C00-623-193

The following papers have been published or submitted for publication but no reprints are available. Preprints are being sent under separate cover or are available at Case Western Reserve University.

Spin-wave Spectrum of an Amorphous Ferromagnet. J. E. Gubernatis and P. L. Taylor. Submitted to Phys. Rev. COO-623-194

Some Comments on Manganin Wire Pressure Gauges, C. G. Andeen, D. E. Schuele, and J. J. Fontanella. Accepted for publication by the International Journal for High Temperatures and High Pressures. COO-623-195

The Low Frequency Dielectric Constant of Vitreous Arsenic Trisulphide, J. J. Fontanella, C. G. Andeen, and D. E. Schuele. Submitted to J. Phys. Chem. Solids. COO-623-196

The Effect of OH^- on the Low Frequency Dielectric Constant of Vitreous Silica, C. G. Andeen, D. E. Schuele, J. J. Fontanella. Submitted to J. App. Phys. COO-623-197

The Low Frequency Dielectric Constants of α -quartz, Sapphire, MgF_2 , and MgO , J. J. Fontanella, C. G. Andeen, and D. E. Schuele. Submitted to Phys. Rev. COO-623-198

APPENDIX IV

EQUIPMENT REPORT

AEC Contract AT(11-1)-623

Case Western Reserve University

for the period 1 February 1972 through 30 September 1973

PURCHASED TO DATE: (30 September, 1973)

<u>ITEM</u>	<u>DATE PURCHASED</u>	<u>COST</u>
Ratio Transformer	May 1973	\$782.00
UHV Thickness Sensor	May 1973	497.00
Digital Multimeter	August 1973	625.00

October 1973