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W.E. Henry Symposium Compendium

Lawrence Berkeley National Laboratory
September 19, 1997

Hattie Carwell, Editor
Directorate
Work Force Diversity Office

September 1997

The graph on the cover shows experimental work performed by Dr. Henry in 1952 at the Naval Research Laboratory. It appears in the Haliday and Resnick, Physics Textbook in the section on paramagnetism.

The graph displays the ratio M/Mmax (ratio of magnetic moment to maximum magnetic moment) for a paramagnetic salt (chromium potassium alum) in magnetic fields as high as 50,000 gauss and at temperatures as low as 1.3°K. These high precision data verify Curie's law, and compare well with a theoretical curve calculated from modern quantum physics. Henry's work on paramagnetism has been a standard in Physics textbooks (introductory, solid state and quantum physics) for many years.

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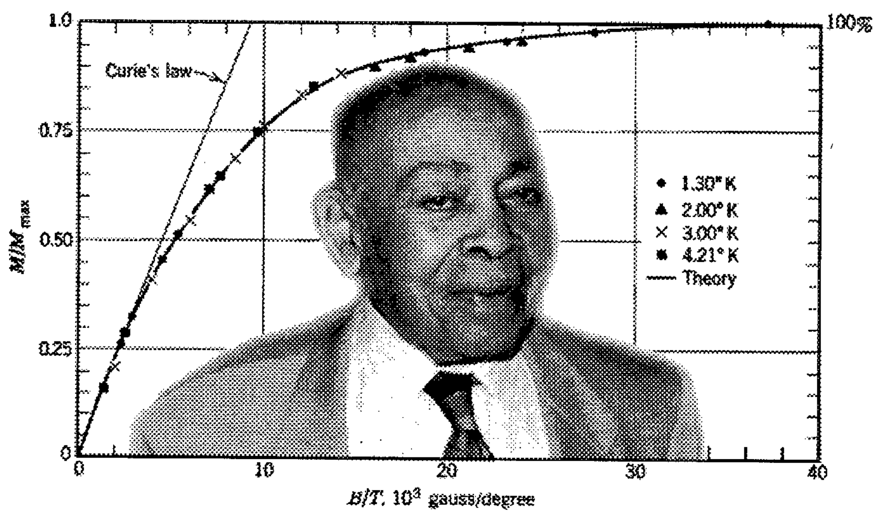
W. E. HENRY SYMPOSIUM

THE IMPORTANCE OF MAGNETISM
IN PHYSICS AND MATERIAL SCIENCE

SEPTEMBER 19, 1997



COMPENDIUM

MASTER

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FOREWORD

We here at Berkeley Lab are proud to host this symposium and to share Dr. Henry's rich scientific legacy in magnetism and solid state physics. Dr. Henry's achievements have greatly benefited the scientific community, and he has inspired many students to pursue careers in science. This event is part of an ongoing commitment by our Laboratory to encourage a diverse science and engineering workforce for our community, and to promote our nation's goals in science and education.

To you, Dr. Henry, I extend my personal congratulations on a remarkable lifetime of achievements. As a scientist and as an African American, you have established a truly remarkable standard for future generations to emulate.

Charles Shank

Director

PREFACE

This compendium contains papers presented at the W. E. Henry Symposium, *The Importance of Magnetism in Physics and Material Science.* The one-day symposium was conducted to recognize the achievements of Dr. Warren Elliot Henry as educator, scientist, and inventor in a career spanning almost 70 years. Dr. Henry, who is 88 years old, attended the symposium. Nobel Laureate, Dr. Glenn Seaborg, a friend and colleague for over 40 years, attended the event and shared his personal reminiscences. Dr. Seaborg is Associate Director-At-Large at the Lawrence Berkeley National Laboratory.

The Compendium begins with three papers which demonstrate the ongoing importance of magnetism in physics and material science. Other contributions cover the highlights of Dr. Henry's career as a researcher, educator, and inventor. Colleagues and former students share insights on the impact of Dr. Henry's research in the field of magnetism, low temperature physics, and solid state physics; his influence on students as an educator; and his character, intellect and ingenuity, and passion for learning and teaching. They share a glimpse of the environment and times that molded him as a man, and the circumstances under which he made his great achievements despite the many challenges he faced.

Appreciation is expressed to the Diversity Office of the Lawrence Berkeley National Laboratory (LBNL) for funding the symposium. The organizing committee, which included Robert Bragg, University of California at Berkeley, Hattie Carwell of the Department of Energy, Keith Jackson, LBNL, Harry Morrison, University of California at Berkeley, and Harry Reed, LBNL, are to be congratulated on their foresight, time, and efforts expended for this noteworthy event.

Particular gratitude is expressed to the invited speakers, friends, and relatives of Professor Henry who attended the symposium, and to those who sent recollections and congratulatory remarks. Special thanks go to the cities of Berkeley, Oakland, Palo Alto, and San Francisco for Proclamations which proclaimed September 19 as Warren E. Henry Day, and to Congressman Dellums for the Statement in the U.S. Congressional Record on September 17 recognizing Dr. Henry's achievements.

The assistance of Dr. Bragg, Mr. Issac Moore, and the LBNL staff in preparation of this document is acknowledged with appreciation.

Hattie Carwell

SEPTEMBER 19, 1997

Mistress of Ceremonies
Hattie Carwell
DOE Berkeley Site Office

9:00-9:30 am	Welcome/Opening Remarks
	Pier Oddone, Ph.D. *Deputy Director, LBNL*
	James Turner, Ph.D. *Manager, DOE Oakland Operations Office*
	Harry Reed *Head of Workforce Diversity*
	Glenn Seaborg, Ph.D. *Associate Director At-Large, LBNL*
9:30-10:15 am	James Gates, Ph.D. *University of Maryland* Topic: Gauge Invariance: An Aspect of Real Magnetism and Beyond
10:15-10:30 am	Break
10:30-11:10 am	Vladimir Kresin, Ph.D. *Lawrence Berkeley National Laboratory* Topic: Oxides: Unusual Superconductivity
11:10-11:45 am	Matthew Ware, Ph.D. *Grambling University* Topic: High Field Magnetic Properties of Dimeric Copper(II) Complexes of Biodentate Salicylaldimine
11:45-1:00 pm	Box Lunch
	Topic: Proceedings of Symposium
1:00-1:35 pm	Arthur Thorpe, Ph.D. Topic: Dr. Warren Henry and His Impact on the Field of Magnetism

1:35-2:10 pm	William Holton Topic: Dr. Warren Henry and America's African-American Air Force of World War II
2:10-2:40 pm	Eleanor Franklin, Ph.D. Topic: Reflections on Dr. Warren Henry: Physics Professor At Morehouse College and Spelman College
2:40-3:00 pm	Break
3:00-3:30 pm	George Ferguson, Ph.D. Topic: Dr. Warren Henry/Naval Research Laboratory, 1948-60 Recollections
3:30-3:40 pm	Emory Curtis Topic: Dr. Warren Henry: The Scientist and the Man: The Lockheed Years (1960-69)
3:40-5:00 pm	Panel Moderator Harry Morrison, Ph.D. *UC Berkeley* Topic: Highlights of Warren Henry's Career - "Trouble the Waters"
Panelists:	Emory Curtis George Ferguson, Ph.D Zolili Ndlela, Ph.D. Eleanor Franklin, Ph.D. William Holton Arthur Thorpe, Ph.D.
Dinner Program	Masters of Ceremonies Keith Jackson, Ph.D. *Lawrence Berkeley National Laboratory*
6:30 -7:00 pm	Reception
7:00 -8:00 pm	Dinner
8:00 -8:30 pm	Speaker Ronald Mickens, Ph.D. *Clark Atlanta University*
8:30 -9:00 pm	Recollections and Presentations Acknowledgments, Plaudits, Close

A Look at Fundamental Problems and Magnetism
A contribution to the Warren E. Henry Symposium
LBNL, Sept. 19, 1997

S. James Gates, Jr., Ph.D.

Department of Physics, University of Maryland at College Park

OPENING REMARKS

Foremost, I wish to extend my thanks to the organization committee for this symposium held to honor Professor Warren E. Henry. As some of you may know, Professor Henry and I were colleagues together during my tenure as the chairman of Howard University's Physics Department from 1991 - 1993. Although Professor Henry held emeritus status during my time at Howard, I regularly encountered him in Thirkeld Hall. He was actively involved in encouraging young African-American students to continue their studies in our field of physics. He provided counsel that was actively sought by many. Thus it is a great honor for me to be able to dedicate this talk to Dr. Warren Henry in recognition of his accomplishments as a scientist, teacher, and mentor.

His was truly a remarkable career. I admire him greatly, not just for his scientific accomplishments in the areas of magnetism and low-temperature physics, but also for his testimony to the power of determination. Even though Edward Bouchet (the first African-American physicist) obtained his physics Ph.D. in 1874, this nation was still not hospitable to the very concept of an African-American physicist by the time Warren Henry decided that this would be his path. He, Herman Branson, and other such pioneers, in spite of their circumstances and environments, were able to find a path to demonstrate their intellectual prowess in a field that is the common birthright of all people with the head and heart to do its work. Mostly their achievements were overlooked and unrecognized. However, for those of us who find the literature of physics journals accessible, these records have not been lost. These writings stand as eloquent proof of discoveries and milestones achieved. My presence on this occasion is meant to celebrate his career as well as congratulate and commend him for his efforts.

My work, as someone who investigates the purely theoretical application of the concept of 'supersymmetry' to the field of elementary particle physics, is far removed from the realms in which Dr. Henry spent his research career. It is thus doubly an honor for me to be asked to make this presentation. As such I will endeavor to show how concepts closely related to magnetism play out an important role in today's fundamental physics.

THE ELECTROMAGNETIC UNIFICATION

Maxwells Equations and Constituency Relations

The basic laws of electromagnetic phenomena are governed by these celebrated four equations,

$$\vec{\nabla}\cdot\vec{D} = 4\pi\rho \quad , \quad \vec{\nabla}\cdot\vec{B} = 0 \quad ,$$

$$\vec{\nabla}\times\vec{H} - \frac{1}{c}\frac{\partial\vec{D}}{\partial t} = \frac{4\pi}{c}\vec{J} \quad , \quad \vec{\nabla}\times\vec{E} + \frac{1}{c}\frac{\partial\vec{B}}{\partial t} = 0 \quad .$$

In the presence of matter there exist, in general, nonlinear relations between the fields,

$$\vec{D} = \vec{f}_1(\vec{E},\vec{B}) \quad , \quad \vec{H} = \vec{f}_2(\vec{E},\vec{B}) \quad .$$

CONSERVATION LAW

The charge density ρ and current density $\vec{J}$ as a consequence of Maxwell's Equations satisfy a conservation law,

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot \vec{J} = 0 \quad .$$

ELECTROMAGNETIC POTENTIALS

The electromagnetic potentials $\Phi(\vec{r},t)$ and $\vec{A}(\vec{r},t)$ are solutions to the source-free Maxwell Equations

$$\vec{B} = \vec{\nabla} \times \vec{A} \quad , \quad \vec{E} = -\vec{\nabla}\Phi - \frac{1}{c}\frac{\partial \vec{A}}{\partial t} \quad ,$$

and the substitution of these into the remaining equations yield,

$$\nabla^2 \Phi + \frac{1}{c}\frac{\partial}{\partial t}(\vec{\nabla} \cdot \vec{A}) = -4\pi\rho \quad ,$$

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\vec{A} - \vec{\nabla}(\vec{\nabla} \cdot \vec{A} + \frac{1}{c}\frac{\partial}{\partial t}\Phi) = -\frac{4\pi}{c}\vec{J} \quad .$$

LORENTZ FORCE LAW

The basic interaction of a fundamental charge with electromagnetic fields is governed by the Lorentz force law,

$$\vec{F} = Q\left[\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right] \quad ,$$

for a charge Q moving with velocity $\vec{v}$.

MAXWELL'S EQUATIONS AND EINSTEIN'S REVOLUTION

Maxwell's Equations have successfully survived two revolutions in our understanding of fundamental physics. One of these is the revolution created by A. Einstein's theory of special relativity. This is most efficiently described by expressing Maxwell's Equations in terms of quantities of geometrical significance in Minkowski space

$$F_{\mu\nu} \equiv \begin{bmatrix} 0 & E_x & E_y & E_z \\ -E_x & 0 & -B_z & B_y \\ -E_y & -B_z & 0 & B_x \\ -E_z & -B_y & -B_x & 0 \end{bmatrix} \quad , \quad \eta_{\mu\nu} \equiv \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad .$$

$$\partial_\mu \equiv \begin{bmatrix} \frac{1}{c}\frac{\partial}{\partial t} \\ \vec{\nabla} \end{bmatrix} \quad , \quad A_\mu \equiv \begin{bmatrix} \Phi \\ -\vec{A} \end{bmatrix} \quad , \quad J_\mu \equiv \begin{bmatrix} cp \\ -\vec{J} \end{bmatrix} \quad , \quad x^\mu \equiv \begin{bmatrix} ct \\ \vec{x} \end{bmatrix} \quad .$$

$$F_{\mu\nu} \equiv \partial_\mu A_\nu - \partial_\nu A_\mu .$$

In terms of these quantities, Maxwell's Equations become

$$\eta^{\mu\nu}\partial_\mu F_{\nu\rho} = \frac{4\pi}{c} J_\rho \quad , \quad \partial_\mu F_{\nu\rho} + \partial_\nu F_{\rho\mu} + \partial_\rho F_{\mu\nu} = 0 \quad ,$$

while the Lorentz force takes its relativistic form as

$$F^\mu = \eta_{\nu\rho} \frac{Q}{c} F^{\mu\nu} \frac{dx^\rho}{dr} \quad .$$

THE POINT CHARGE SOLUTION AND CURRENTS

Motionless Point Charge

Among the simplest solutions to Maxwell's Equations is the one that describes the electromagnetic fields

$$\vec{E} = \frac{Q}{r^2}\hat{r} \quad , \quad \vec{B} = 0 \quad ,$$

produced by a point charge Q located at the origin and created by the sources,

$$\rho(\vec{r},t) = Q\delta^{(3)}(\vec{r}) \quad , \quad \vec{J}(\vec{r},t) = 0 \quad .$$

Moving Point Charge

If the location of the point charge is not fixed, and if the velocity of the particle is small compared to the speed of light, we may use a Newtonian description of the motion of the charge. If its position is described by the vector function $\vec{\ell}(t)$, there is induced both a charge density and a current density,

$$\rho(\vec{r},t) = Q\delta^{(3)}\left[\vec{r} - \vec{\ell}(t)\right] \quad , \quad \vec{J}(\vec{r},t) = Q\left(\frac{d\vec{\ell}}{dt}\right)\delta^{(3)}\left[\vec{r} - \vec{\ell}(t)\right] \quad ,$$

Currents must produce $\vec{B}$-field lines that curl around their paths. The $\vec{B}$-field can be calculated from the law of Biot-Savart,

$$\vec{B}(\vec{r},t) = \frac{1}{c}\int \frac{Id\vec{\xi} \times (\vec{r} - \vec{\xi})}{\left|\vec{r} - \vec{\xi}\right|^3} \quad ,$$

if we replace the single moving charge by a current and replace the path of the single charge by the path of the current of magnitude *I* whose path is described by $\vec{\xi}(t)$. Since classically electrons "whirl" around the nucleus, magnetic fields, like electrical fields, are an intrinsic property of matter.

ON THE POSSIBILITY OF MAGNETIC MONOPOLES

Dirac Monopole

As is well known, Maxwell's Equations possess a noticeable asymmetry. The first equation allows for the existence of point charges, but the second equation rules out the existence of their magnetic analogs called "magnetic monopoles." This is an experimental fact. Cutting a bar magnet never leads to only an isolated north (or south) pole, a nomopole.

Dirac is credited with the first serious contemplation of magnetic monopoles. We may follow his approach by considering the potential field configurations given by

$$\vec{A}(\vec{r}) = g\left[\frac{\hat{n}\times\hat{r}}{r(1+\hat{n}\cdot\hat{r})}\right] \quad , \quad \Phi(\vec{r}) = 0 \quad ,$$

where $\hat{n}$ is a fixed unit vector pointed in an arbitrary direction. A calculation of the $\vec{E}$ and $\vec{B}$ fields associated with these yields

$$\vec{E} = 0 \quad , \quad \vec{B} = \frac{g}{r^2}\hat{r} \quad .$$

It is remarkable that the unit vector $\hat{n}$ does not appear anywhere in the field variables. These satisfy Maxwell's Equations *in vacuo* except at the origin, where there is a singularity. Also, a careful study shows that if $r+\hat{n}\cdot\vec{r}=0$, then the field is ill-defined along this line. This is called the Dirac string.

Yang Monopole

The Dirac treatment of the magnetic monopole suggests that its source must necessarily be an extended object. However, a treatment due to Yang shows this can be avoided. Yang's treatment eliminates the Dirac string. In the use of Schroedinger's Equation of Quantum Theory even for quite simple systems, it is common to use piece-wise defined expressions for the wavefunction $\Psi(\vec{r},t)$. This can also be done for the vector potential of Maxwell's Equations by considering the vector potential field configuration given by

$$\vec{A}_{+}(\vec{r}) = g\left[\frac{\hat{n}\times\hat{r}}{r(1+\hat{n}\cdot\hat{r})}\right] \quad , \quad if \quad \hat{n}\cdot\hat{r} > 0 \quad ,$$

which leads to the same expression for the $\vec{B}$-field throughout all of space.

It is well known that the potential fields are ambiguous. For a given configuration of $\vec{E}$ and $\vec{B}$ fields, there exist an infinite number of Φ and $\vec{A}$ fields all related to each other by local or "gauge" transformations.

$$\vec{A} = \vec{A} - \vec{\nabla}\Lambda \quad , \quad \Phi' = \Phi + \frac{1}{c}\frac{\partial}{\partial t}\Lambda \quad , \quad \rightarrow \quad A_{\mu}' = A_{\mu} + \partial_{\mu}\Lambda \quad .$$

In fact, in the overlap region (i.e. $\hat{n}\cdot\hat{r} = 0$), one can show that there exists a function Λ such that $\vec{A}_{+} = \vec{A}_{-} + \vec{\nabla}\Lambda$. We will return to more general issues of gauge invariance shortly. Also, there is the matter of the Dirac quantization of electrical charge to be discussed later.

A Non-abelian Monopole

Since the 1970s, another type of monopole solution has been proposed. But this requires "non-abelian symmetry." Among the simplest such model is that of Georgi and Glashow. The idea is that we may hypothetically consider a theory of three photons $A^{+}{}_{\mu}, A^{0}{}_{\mu}$ and $A^{-}{}_{\mu} = \overline{A^{+}{}_{\mu}}$ unified into a matrix in "isotopic charge space,"

$$A_{\mu} \equiv \frac{1}{\sqrt{2}} A^{-}{}_{\mu} \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} + \frac{1}{\sqrt{2}} A^{+}{}_{\mu} \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} + \frac{1}{2} A^{0}{}_{\mu} \begin{pmatrix} 1 & 1 \\ 0 & -1 \end{pmatrix} .$$

The analog of $F_{\mu\nu}$ is given by

$$F_{\mu\nu} = \partial_{\mu} A_{\nu} - \partial_{\nu} A_{\mu} + ie\{A_{\mu}, A_{\nu}] .$$

We also require a set of spin-0 fields ("Higgs bosons")

$$\phi \equiv \frac{1}{\sqrt{2}} \varphi^{-} \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} + \frac{1}{\sqrt{2}} \varphi^{+} \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} + \frac{1}{2} \varphi^{0} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} .$$

These are not related to the scalar potential Φ. We replace the usual Maxwell's Equations by the Yang-Mills Equations

$$Tr[\eta^{\mu\nu} D_{\mu} F_{\nu\rho} - i\tfrac{4\pi}{c}[\phi, D_{\rho}\phi]] = \tfrac{4\pi}{c} J_{\rho} \quad , \quad D_{\mu} F_{\nu\rho} + D_{\rho} F_{\mu\nu} = 0 \quad ,$$

where Tr indicates the trace over the matrices and

$$D_{\mu} F_{\nu\rho} \equiv \partial_{\mu} F_{\nu\rho} + ie[A_{\mu}, F_{\nu\rho}] \quad , \quad D_{\mu}\phi \equiv \partial_{\mu}\phi + ie[A_{\mu}, \phi] .$$

It turns out that this system of equations also leads to monopole configurations for the $\vec{E}$ and $\vec{B}$ fields. However, these solutions also require ϕ to be non-vanishing. The key point to note in these models is that a vector in ordinary space may be defined by

$$\vec{\phi} \equiv \frac{1}{\sqrt{2}}[\varphi^{+} + \varphi^{-}]\hat{x} - i\frac{1}{\sqrt{2}}[\varphi^{+} - \varphi^{-}]\hat{y} + \varphi^{0}\hat{z} .$$

This only makes sense if the rotations in isotopic charge space are "locked" to rotations in ordinary space. To solve the Yang-Mills equations we may look for solutions of the form

$$\frac{1}{\sqrt{2}}[\varphi^{+} + \varphi^{-}] = \phi_0 f(r) \sin\alpha \cos\beta \quad , \quad \varphi^{0} = \phi_0 f(r) \cos\alpha \quad ,$$

$$-i\tfrac{1}{\sqrt{2}}[\varphi^{+} - \varphi^{-}] = \phi_0 f(r) \sin\alpha \cos\beta \quad , \quad \vec{A} = \tfrac{\hat{\phi}\times\hat{r}}{er} g(r) \quad ,$$

where we use α and β to denote the usual angles of a spherical coordinate system. After substitution of these into the Yang-Mills equations, a set of coupled differential equations for f(r) and g(r) can be found. From the solution to these, it can be shown that as $r \to \infty$,

$$\vec{B} \to \frac{1}{er^2}\hat{r} .$$

So the Georgi-Glashow model does possess monopole solution if we identify the coupling constant that appears in the Yang-Mills Equations as the reciprocal of the monopole charge g. This is an example of the charge conjugation implied by monopoles, although the non-abelian condition differs by a factor of two from that of the Dirac monopole.

Quantum Theory and Gauge Invariance

Wavefunction and Magnetism

The world of the electron is governed not by Newtonian mechanics but instead by quantum mechanics. So a more accurate description uses

$$\rho(\vec{x},t) = -e_0 \Psi^\dagger(\vec{x},t)\ \Psi(\vec{x},t)$$

$$\vec{J}(\vec{x},t) = i\left(\frac{e_0 \hbar}{2m_e}\right)\left[\Psi^\dagger \vec{\nabla}\Psi - \Psi\vec{\nabla}\Psi^\dagger\right]$$

(But even this misses spin, relativistic effects, etc. However, such a more complete description takes us into the realm of the Dirac Equation and relativistic quantum field theory.) As we have already noted, Maxwell's Equations are invariant under gauge transformations. This is a gauge or local symmetry since $\Lambda = \Lambda(\vec{r},t)$ is arbitrary. This symmetry is of profound importance, so much so that its realization modifies Schroedinger's Equation,

$$i\hbar c\, D_0 \Psi = -\frac{\hbar^2}{2m} D^2\, \Psi + W(\vec{r})\Psi \quad ,$$

$$D_0 \equiv \frac{1}{c}\frac{\partial}{\partial t} - i\frac{e_0}{\hbar c}\Phi \quad , \quad \vec{D} \equiv \vec{\nabla} + i\frac{e_0}{\hbar c}\vec{A} \quad ,$$

to insure that this symmetry is present. In order to reach this goal the wavefunction must also transform,

$$\Psi(\vec{r},t)' = \exp[i\frac{e_0}{\hbar c}\Lambda]\ \Psi(\vec{r},t) \quad .$$

So both Maxwell's Equations and Schroedinger's Equation possess gauge invariance.

One of the curious features of the gauge covariant form of Schroedinger's Equation is that it allows a nonlocal redefinition of the wavefunction so that the new wavefunction satisfies Schroedinger's Equation without electromagnetic potentials,

$$\Psi_{(old)}(\vec{x},t) = \exp[i\frac{e_0}{\hbar c}\int_{x_0}^{x} dx'^{\mu}\ A_\mu(x')\,]\ \Psi_{(new)}(\vec{x},t) \quad .$$

This is nonlocal because the integral factor above depends on the value of $A_\mu(x)$ all along an entire path, not at a single point.

Possible Electroweak Magnetism

A recent triumph of particle physics is the creation and verification of the Glashow-Salam-Weinberg Model. Within the neutral current sector of this model, there occurs a massive vector boson (the Z^0-particle). These actually couple to the electron, and a Schroedinger Equation approximating the correct G-S-W model can actually be constructed by replacing

$$A_\mu \quad \rightarrow \quad A_\mu + \tan\theta_w \, Z_\mu \quad ,$$

everywhere in D_0 and $\bar{D}$. The parameter θ_w is known as the "Weak Mixing Angle" and has been experimentally measured. This changes Schroedinger's Equation. Normally, one does not expect there to be a dramatic effect owing to the large mass of the Z^0. Still, it is barely conceivable that in some unique conditions, or under special conditions, such an effect might be detectable. So on this fanciful note, let me hope that this crazy idea will one day be realized within the regime of the study of magnetism.

Electromagnetic Duality

A Symmetry Lost and Found?

As is easily seen, Maxwell's equations *in vacuo* possess a symmetrical appearance

$$\vec{\nabla}\cdot\vec{D}=0 \quad , \quad \vec{\nabla}\cdot\vec{B}=0 \quad ,$$

$$\vec{\nabla}\times\vec{H} - \frac{1}{c}\frac{\partial\vec{D}}{\partial t} = 0 \quad , \quad \vec{\nabla}\times\vec{E} + \frac{1}{c}\frac{\partial\vec{B}}{\partial t} = 0 \quad .$$

These are so symmetrical that a symmetry appears here. We can'rotate' the electric and magnetic field into each other via

$$\vec{E}' = \vec{E}\cos\Theta \quad + \quad \vec{B}\sin\Theta \quad ,$$
$$\vec{B} = -\,\vec{E}\sin\Theta \quad + \quad \vec{B}\cos\Theta \quad ,$$

with the result that the form of the equation is unchanged when expressed in terms of the new variables.

$$\vec{\nabla}\cdot\vec{E}' = 0 \quad , \quad \vec{\nabla}\cdot\vec{B}' = 0 \quad ,$$

$$\vec{\nabla}\times\vec{B}' - \frac{1}{c}\frac{\partial E'}{\partial t} = 0 \quad , \quad \vec{\nabla}\times\vec{E}' + \frac{1}{c}\frac{\partial\vec{B}'}{\partial t} = 0 \quad .$$

This type of symmetry is called "electromagnetic duality." It is a realization of a concept that occurs in the mathematics of differential forms where it is called the "star" product. If magnetic monopoles are ever discovered, we will be forced to modify Maxwell's Equations to a more symmetrical form.

This is actually simplest to see using the relativistic formulation where we may define

$$*F_{\mu\nu} = \equiv \frac{1}{2}\,\varepsilon_{\mu\nu\rho\sigma}\,\eta^{\rho\kappa}\,\eta^{\sigma\lambda}\,F_{\kappa\lambda}$$

and it is easy to show that the two relativistic Maxwell's Equations *in vacuo* are satisfied still under the re-definition

$$F_{\mu\nu}{}' \quad = \quad \mathrm{Re}\Big[\, e^{i\Theta}\,(F_{\mu\nu} - i * F_{\mu\nu})\,\Big] \quad .$$

Under the action of the "star operation" the Bianchi identities (i.e., the two equations of Maxwell without sources) are mapped into the "equations of motion" (i.e., the equations of Maxwell with sources).

This type of mapping often occurs in relativistic quantum field theories. We can refer to it as "Poincaré duality" in this more general context.

If a monopole is ever discovered, we will change Maxwell's Equations to read:

$$\vec{\nabla}\cdot\vec{D} = 4\pi\rho \quad , \quad \vec{\nabla}\cdot\vec{B} = -4\pi\rho_m \quad ,$$

$$\vec{\nabla}\times\vec{H} - \frac{1}{c}\frac{\partial\vec{D}}{\partial t} = \frac{4\pi}{c}\vec{J} \quad , \quad \vec{\nabla}\times\vec{E} + \frac{1}{c}\frac{\partial\vec{B}}{\partial t} = \frac{4\pi}{c}\vec{J}_m \quad .$$

The discovery of magnetic monopoles would force us to add a magnetic charge density ρm, as well as magnetic current density Jm. The relativistic form of Maxwell's Equations would become hauntingly symmetrical,

$$\eta^{\mu\nu}\partial_\mu F_{\nu\rho} = \frac{4\pi}{c}J_\rho \quad , \quad \partial_\mu F_{\nu\rho} + \partial_\nu F_{\rho\mu} + \partial_\rho F_{\mu\nu} = \frac{4\pi}{c}\varepsilon_{\mu\nu\rho\lambda}J^\lambda_m \quad .$$

The concept of duality is one of the areas that is most actively being investigated in the field of theoretical particle physics right now. There has been a suggestion by Seiberg and Witten that duality may hold the key to understanding nonperturbative behavior of some relativistic quantum systems! Throughout my career, I have often found myself looking at some aspect of duality. One of my most recent works has led to a new class of purely hypothetical supersymmetrical models for the sub-nuclear physics of pions. In order to carry out this construction, it was necessary that I precisely make use of Poincaré duality. As part of my discovery, I have been able to show that should aspects of what I call "supersymmetrical pion physics" actually be found in the laboratory, this will necessarily lead to a new constant of Nature (that I have named qs "gamma-ess" and which is very similar to hw), as well as to the possibility that parity violation is an intrinsic property of matter, not the forces acting on fundamental particles.

CLOSING REMARKS

We have touched on the career of our honoree from my very first transparency. His works in superconductivity and low-temperature physics represent real-world studies useful to understanding the nature of the relation between Ju and D. His works in defense science to utilize effects of Maxwell's Equations in areas such as radar, navigational and guidance system design attest to his striving to put our science of physics to the defense of this nation's much heralded democratic values. An alternate expression of this also can be found in his teaching of physics to an often forgotten group of Americans who fought battles in the air (as well as elsewhere) during World War II, the "Tuskegee Airmen."

It is not possible for me to do justice to such a career, especially in my allotted time. So, I have chosen to discuss topics that fascinate me as a theoretical particle physicist and which touch on the topic of magnetism. It is my hope that our honoree has enjoyed this look into the possible future of an area in which a good part of his career was spent.

OXIDES: UNUSUAL SUPERCONDUCTIVITY AND MAGNETISM

Vladimir Z. Kresin, Ph.D.

Chemical Sciences Division, Lawrence Berkeley National Laboratory

I will describe an interesting family of materials: the layered oxides. They provide an unusual bridge between superconductivity and magnetism.

In 1986 we entered a new era of superconductivity which began with the paper by George Bednorz and Alex Müller [1]. They discovered a new class of high-temperature superconducting materials, copper oxides. This discovery gave rise to a period of uniquely intense research. The number of papers published in the last ten years is counted in the thousands. The family of the oxides has grown, and the critical temperature has reached values on the order of 150K.

In describing the properties of the high Tc oxides, one encounters a parameter which has not played any significant role in conventional materials.

This parameter is the carrier concentration n. The cuprates are doped materials, with Tc strongly depending on the carrier concentration. This dependence Tc(n) has a rather sharp maximum at n=nopt. In the so-called overdoped region (n>nopt.) one observes a sharp decrease in Tc. For example, in the overdoped Tl2Ba2CuO6+x, compound Tc drops from 90K to 14K [2]. We have arrived at the conclusion that this decrease is mainly caused by the pair-breaking effect of magnetic impurities. The interaction between localized magnetic moments and the Cooper pairs destroys pair correlation and is accompanied by spin-flip scattering (this scattering provides conservation of the total spin).

The appearance of a peak in the dependence Tc(n) is due to a peculiar interplay of two factors. First of all, doping increases n, and consequently Tc. However, if Tc is increased by the usual means of additional doping, then the addition of oxygen is accompanied by the generation of new local magnetic moments whose presence depresses Tc. The observed maximum thus corresponds to a crossover of these two trends. If we want to increase the value of Tc further, we need to employ a different type of doping, e.g., pressure-induced doping, the photoinduced channel. For example, external pressure would decrease the c lattice parameter, leading to additional charge transfer and thereby raising Tc, without introducing additional magnetic moments.

Our recent work has led to the conclusion that there exists an upper limit to the critical temperature in copper oxides [3]. This upper limit lies in the region of 160-170K. Let me briefly describe our arguments.

We began with a study of the unusual temperature dependence of the critical field. A dependence of Hc2 on T drastically different from the conventional picture was recently observed in overdoped high Tc oxides [2]. Conventional bulk superconductors display a linear temperature dependence of Hc2 near Tc, a quadratic behavior for T—>0, and a negative curvature over the entire temperature region. Contrary to this picture, the layered cuprates exhibit a linear dependence near T=0K and a positive curvature for all temperatures. Furthermore, Hc2(0) greatly exceeds the value which follows from conventional theory.

We have shown [3] that one can observe a new phenomenon which can be called "strengthening of superconductivity." Let me describe here the qualitative picture. Spin-flip scattering leads to a depression of the superconducting state, as reflected by the relatively small values of Tc and Hc2. The magnetic impurities can be treated as independent , and the impurity spin-flip scattering provides conservation of the total spin. However, at low temperatures (in the region near T=1K), because of the correlation of the magnetic moments, the ordering trend of the moments becomes important, and this frustrates the spin-flip scattering. Pairing is now less depressed, which leads to a large increase in Hc2 and, consequently, to a positive curvature in Hc2 vs. T.

An analysis of the overdoped state, and of the dependence Hc2(T) in particular, has allowed us to introduce an important new parameter, the so-called "intrinsic" Tc; that is, the value of the critical temperature in the absence of magnetic impurities.

We have calculated the value of Tc;int for various cuprates. It is remarkable that it turns out to be approximately the same for all high Tc oxides and lies in the region Tc;int =160-170K. We believe that this is not a coincidence. The fact of the matter is that even though there are many high temperature oxides, all of them share one common feature: Namely, all cuprates contain a key structural unit, the CuO plane. The intrinsic Tc is an upper limit of Tc for this class of materials.

This conclusion about the upper limit of Tc may be upsetting, but it really is not so surprising. Indeed, the amount of effort spent in the field of superconductivity in the last ten years has greatly exceeded that of the previous 70 years. As a consequence, it is not unexpected that we should have arrived almost to the saturation point for the critical temperature.

One may wonder about future developments. What about our dream of producing a room-temperature superconductor? I do not think that there is any reason to be pessimistic. The road to high Tc continues, but it should follow the main lesson given to us by Bednorz and Müller. Indeed, for a long time Nb played a special role in the field. Eventually, people came to the conclusion that any new superconductor with a higher Tc must be based on Nb. Bednorz and Müller's breakthrough came in an entirely different direction: the cuprates do not contain Nb. At present, I think that it is time to start looking for other classes of materials. This will continue the remarkable road to high Tc. Of course, nobody knows the exact trajectory, and each opinion is subjective. My personal view is that the future room-temperature superconductor will be an organic compound.

Let us discuss properties of the magnetic oxides, so called manganates, e.g., (LaCa)MnO3. As we know, the transition to the ferromagnetic state (at T=Tc) has been described by the double exchange picture. The substitution of Ca for La leads to the formation of the complex Mn3+OMn4+, and the extra electron hopping allows ferromagnetic ordering to occur. The ferromagnetic transition is also accompanied by a drastic increase in conductivity. Another remarkable feature of this compound is that oxygen isotope substitution (O16 AE O18) leads to a large effect on Tc, so that the isotope coefficient (Tc u M-a) is equal to 0.85 for La0.8Ca0.2MnO3+y and 0.70 for La0.9Ca0.1MnO3+y [4]. This is the largest isotope shift observed for any phase transition. Giant magnetoresistance is another remarkable property of the oxides.

A detailed study of the dynamic Jahn-Teller (JT) effect for oxygen allows us to evaluate the value of Tc and the large isotope effect. The JT splitting of the Mn ions, along with the manganese d-oxygen p hybridization leads to the JT behavior of the Mn-O-Mn unit. The JT effect is manifested in the oxygen dynamics being characterized by two close minima in proximity to the crossing of two electronic terms.

In order to address these problems, it is very convenient to employ the method based on the diabatic representation (see e.g. [5]).

Qualitatively, the charge transfer for the extra-electron can be visualized as a multistep process; first, the electron makes a transition from the Mn4+ site to the oxygen, then the oxygen transfers to another electronic term, and this is finally followed by the transition of the electron to the other Mn ion. Therefore, the charge transfer contains an important additional step, namely, the oxygen transition between two terms. This additional step caused by the JT effect, and described by the FC factor, leads to a drastic increase in the characteristic time for the jump between two Mn ions, and thus to a decrease in the strength of the ferromagnetic coupling, and, consequently, Tc. The charge transfer is accompanied by transfer to another electronic term; this process is similar to Landau-Zener effect (see e.g., [6]).

These materials present us with many unanswered questions. We do not know the mechanism of high temperature superconductivity. It is unknown why the ferromagnetic transition is accompanied by a drastic increase in conductivity. And finally, the oxides are the best superconductors, the most interesting magnetic systems, as well as the best ferroelectric materials. What makes the oxides so special?

I hope we will be able to answer these questions during the next Prof. W.E. Henry Symposium.

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HIGH-FIELD MAGNETIC PROPERTIES OF DIMERIC COPPER(II) COMPLEXES OF BIDENTATE SALICYLALDIMINE

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INTRODUCTION

Measurements of the high-field dc magnetization of powdered Cu(II) complexes of bidentate salicylaldimine parallel-planar dimers are reported. The measured samples include Cu(II) *N*-methylosalicylaldimine, Cu(II) *N*-methylo 3-ethoxysalicylaldimine, and Cu(II) *N*-methylonaphthasalicylaldimine(1,2). These measurements were conducted using a vibrating sample magnetometer over the magnetic field range of $0 \leq H \leq 10.8$ T and temperature range of $1.8 \text{ K} \leq T \leq 4.2$ K. The magnetic field was produced by a superconducting solenoid. The temperature was determined by the vapor pressure over pumped liquid helium. The magnetic properties of Cu(II) bidentate salicylaldimine dimers are characterized by weak interplanar spin-exchange mediated by a Cu-O-Cu bond. The reported measurements are explained by a spin-exchange Hamiltonian of the form: $\mathcal{H} = -2\mathbf{S}_1 \cdot \mathbf{J} \cdot \mathbf{S}_2$, where $\mathbf{J}$ is the tensor form of the spin-exchange integral, and $\mathbf{S}_1$ and $\mathbf{S}_2$ are the spins of the copper ions in each plane, respectively. These measurements were performed in a regime where the spin-exchange coupling and the Zeeman splitting were of the order of the thermal energy. A significant fraction of the spins were aligned. All the elements of the spin-exchange tensor were determined. The magnetization of Cu(II) complexes of bidentate salicylaldimine shows evidence of long-range order, which is treated as a lattice field that reduces the applied magnetic field. All elements of the spin-exchange tensor are resolved. The strength of the lattice field is also determined.

SPIN-EXCHANGE

Spin-exchange is important to the understanding of the magnetic properties of ferromagnetic materials, of interest to the recording industry as well as to the understanding of antiferromagnetic materials such as the precursors to high-temperature superconductors. In the absence of an external magnetic field, the magnetic properties of a ferromagnet or antiferromagnet is determined by the following Hamiltonian:

$$\mathcal{H} = -\sum_{ij} J_{ij} S_i S_j \tag{1}$$

where S_i and S_j are the spins of the i-th and j-th atoms, and J_{ij} is the spin-exchange integral for the spin-pair. Ferromagnets are described by the case of $J_{ij} > 0$. Antiferromagnets are described by the case of $J_{ij} < 0$.

The Heisenberg model and the Ising model are popular models that have been proposed to explain the magnetic properties of ferromagnetic and antiferromagnetic materials. The Heisenberg model treats spin-exchange among all atoms in the sample giving of the order of N^2 pairs, where N is the number of spins in the model. The Ising model considers the coupling of the spins only of nearest neighbors, giving of the order of N pairs. Each model is the subject of considerable interest to computational physics. These computational studies deal with the stochastic behavior of a large number of spins. As N is of the order of 10^{23}, the number of spin pairs precludes the study of the spin-exchange mechanism in ferromagnetic and antiferromagnetic materials at the level of individual pairs.

Unlike the global interactions of ferromagnetic and antiferromagnetic materials, the spins of dimers interact in isolated pairs. The finite number of states permit the magnetization of dimers to be calculated in closed form. In 1952, Bleaney and Bowers (3) first successfully employed a dimer model of spin-exchange to explain the anomalous low-field magnetic susceptibility of cupric acetate. The magnetic properties of cupric acetate are determined by the single unpaired electron of Cu^{2+}. The spin of Cu^{2+} is given by $S = \frac{1}{2}$, giving Cu^{2+} dimers just four spin states.

The Bleaney and Bowers formalism gives the states of a dimer using the following Hamiltonian:

$$\mathcal{H} = -2\,J\mathbf{S}_1 \cdot \mathbf{S}_2 - g\beta\mathbf{S} \cdot \mathbf{H} \tag{2}$$

where $\mathbf{S}_1$ and $\mathbf{S}_2$ are the respective spins of the dimer and J is the scalar form of the spin-exchange integral, g is the Landé g-factor, β is the Bohr magneton, $\mathbf{S} = \mathbf{S}_1 + \mathbf{S}_2$, and $\mathbf{H}$ is the magnetic field. Cu^{2+} dimers form a singlet if $\mathbf{S}_1$ and $\mathbf{S}_2$ are antiparallel or a triplet if $\mathbf{S}_1$ and $\mathbf{S}_2$ are parallel. The four possible energy states are given by the eigenvalues of the Hamiltonian in Equation 2:

$$E_{0,0} = 2J \qquad \text{singlet} \tag{3}$$

$$\left.\begin{aligned} E_{1,-1} &= +g\beta H \\ E_{1,0} &= 0 \\ E_{1,+1} &= -g\beta H \end{aligned}\right\} \quad \text{triplet}$$

The magnetization can be determined using Boltzmann statistics giving the following expression:

$$M(H,T) = Ng\beta\frac{2\sinh\frac{g\beta H}{kT}}{2\cosh\frac{g\beta H}{kT} + 1 + e^{-\frac{2J}{kT}}} \tag{4}$$

where k is Boltzmann's constant. In the case of anisotropic spin-exchange, Erdos (4) and Moriya and Dzialoshinski (5) generalized the Bleaney and Bowers formalism to give the following Hamiltonian:

$$\mathcal{H} = -2\,\mathbf{S}_1 \cdot \mathbf{J} \cdot \mathbf{S}_2 - g\beta\mathbf{S} \cdot \mathbf{H} \tag{5}$$

The Hamiltonian may be written with the symmetric and antisymmetric elements of the spin-exchange tensor separated:

$$\mathcal{H} = -2\,(J_x S_{1x} S_{2x} + J_y S_{1y} S_{2y} + J_z S_{1z} S_{2z}) + \mathbf{D} \cdot \mathbf{S}_1 \times \mathbf{S}_2 - g\beta\mathbf{S} \cdot \mathbf{H} \tag{6}$$

where J_x, J_y, and J_z are the respective symmetric elements of the spin-exchange tensor; and $\mathbf{D}$ is given by the antisymmetric elements of the spin-exchange tensor. The energy states for tensor spin-exchange are given by the eigenvalues of the following matrix:

$$\mathcal{H} = \begin{pmatrix} g\beta H_z & \frac{1}{\sqrt{2}} g\beta\left[H_x + iH_y\right] & -\frac{1}{2}\left[J_x - J_y\right] & \frac{1}{2\sqrt{2}}\left[-iD_x + D_y\right] \\ \frac{1}{\sqrt{2}} g\beta\left[H_x - iH_y\right] & -\frac{1}{2}\left[J_x + J_y\right] + J_z & \frac{1}{\sqrt{2}} g\beta\left[H_x + iH_y\right] & \frac{1}{2} iD_z \\ -\frac{1}{2}\left[J_x - J_y\right] & \frac{1}{\sqrt{2}} g\beta\left[H_x - iH_y\right] & -g\beta H_z & \frac{1}{2\sqrt{2}}\left[iD_x + D_y\right] \\ \frac{1}{2\sqrt{2}}\left[iD_x + D_y\right] & -\frac{1}{2} iD_z & \frac{1}{2\sqrt{2}}\left[-iD_x + D_y\right] & \frac{1}{2}\left[J_x + J_y\right] + J_z \end{pmatrix} \tag{7}$$

The magnetic moment is determined by the partial derivative of the Hamiltonian with respect to the magnetic field strength:

$$\mu = -\frac{\partial \mathcal{H}}{\partial H} = \begin{pmatrix} -g\beta e_z & -\frac{1}{\sqrt{2}} g\beta\left[e_x + ie_y\right] & 0 & 0 \\ -\frac{1}{\sqrt{2}} g\beta\left[e_x - ie_y\right] & 0 & -\frac{1}{\sqrt{2}} g\beta\left[e_x + ie_y\right] & 0 \\ 0 & -\frac{1}{\sqrt{2}} g\beta\left[e_x - ie_y\right] & g\beta e_z & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{8}$$

where e_x, e_y, and e_z are the direction cosines between **H** and the respective coordinate axes of the dimer. Quantum statistics gives the thermodynamic average of magnetic moment of each dimer as:

$$\bar{\mu} = \frac{\mathrm{Tr}[\mu e^{-\mathcal{H}/kT}]}{\mathrm{Tr} e^{-\mathcal{H}/kT}} \tag{9}$$

for a single value of **H**. As the measurements reported here were made on powered samples, the value of $\bar{\mu}$ must be averaged over all possible directions:

$$\langle\mu\rangle = \frac{1}{4\pi}\oint\!\!\oint \bar{\mu}\, d^2\Omega \tag{10}$$

The magnetization of the anisotropic dimeric sample is given by:

$$M(H,T) = N\langle\mu\rangle \tag{11}$$

where N is the number of dimers per unit mass. In general, Equation (11) cannot be expressed as a closed-form function. It must be evaluated by numerical means.

SAMPLES

The measurements reported here extend the work of Bleaney and Bowers to the high magnetic field, low temperature regime. The magnetic properties of Cu(II) complexes of bidentate salicylaldimine are determined by Cu^{2+}. The dimeric form of Cu(II) complexes of bidentate salicylaldimine are characterized by two parallel planes connected by Cu-O bonds (Figure 1a). The magnetic properties of these dimers are determined by weak interplanar spin-exchange coupling ($|J| < 10$ K) via the Cu-O-Cu bond. The strength of the exchange is determined by the Cu-O-Cu bond angles and the Cu-O bond length. The bond angles and lengths are determined by group substitution of R_1, R_2, and R_3 (Figure 1b).

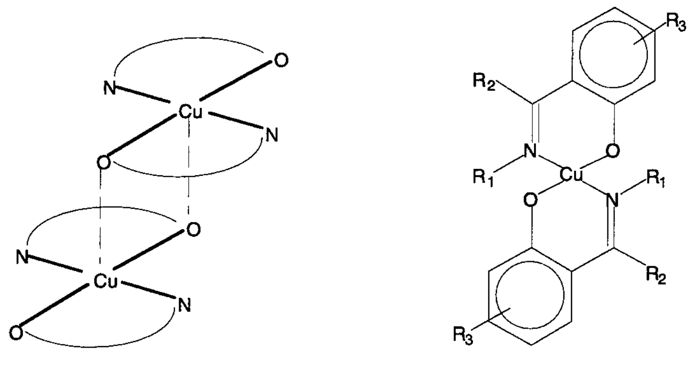
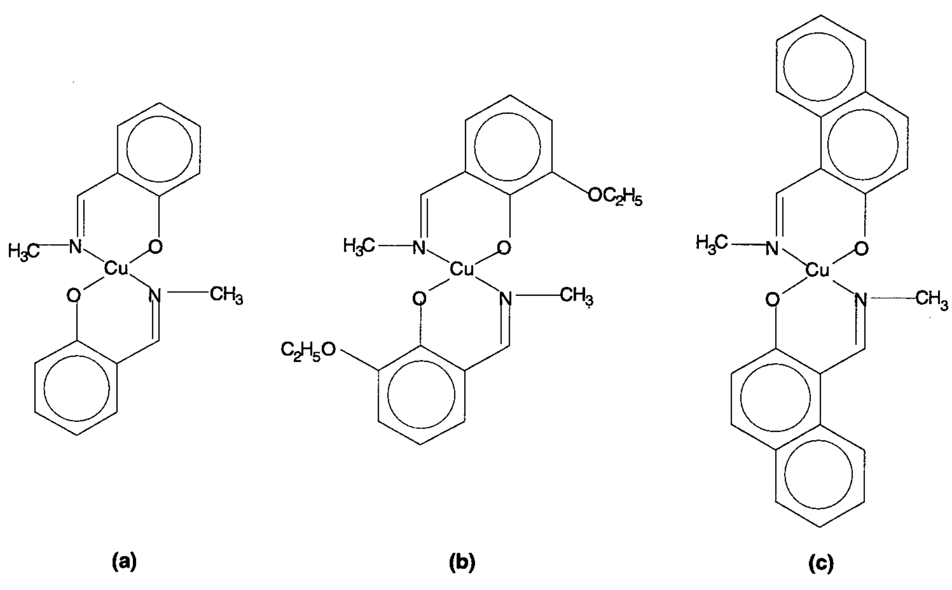


Figure 1. Dimeric form of Cu(II) complexes of bidentate salicylaidimine

For each of the samples reported here, $R_1 = CH_3$, a methyl group, and $R_2 = H$, a hydrogen ion. In the case of Cu(II) *N*-methylosalicylaldimine, $R_3 = H$ (Figure 2a). This is the basic structure of the other two dimers of interest to the work reported here. In the case of Cu(II) *N*-methylo 3-ethoxysalicylaldimine, $R_3 = C_2H_5O$, an ethoxy group (Figure 2b). In the case of Cu(II) *N*-methylonaphthasalicylaldimine, an aromatic ring is substituted for R_3 (Figure 2c).



The planes of the dimers of interest to this work: (a) Cu(II) *N*-methylosalicylaldimine; (b) Cu(II) *N*-methylo 3-ethoxysalicylaldimine; (3) Cu(II) *N*-methylonaphthasalicylaldimine.

Figure 2

APPARATUS

All measurements reported here were conducted using a PARC Model 155 vibrating sample magnetometer (VSM) (Figure 3). The sample rod of the VSM was extended to hold the sample at the center of an American Magnetics NbTi superconducting solenoid. The sample was vibrated coaxial with the solenoid and a pair of Helmholtz pick-up coils placed at the center of the solenoid core. The superconducting solenoid and pick-up coils were placed inside a metallic helium cryostat with a liquid nitrogen jacket. Temperatures below 4.2 K were achieved by lowering the vapor pressure over the liquid helium with a large capacity roughing pump. The temperature was set using a controlled leak in the vacuum line.

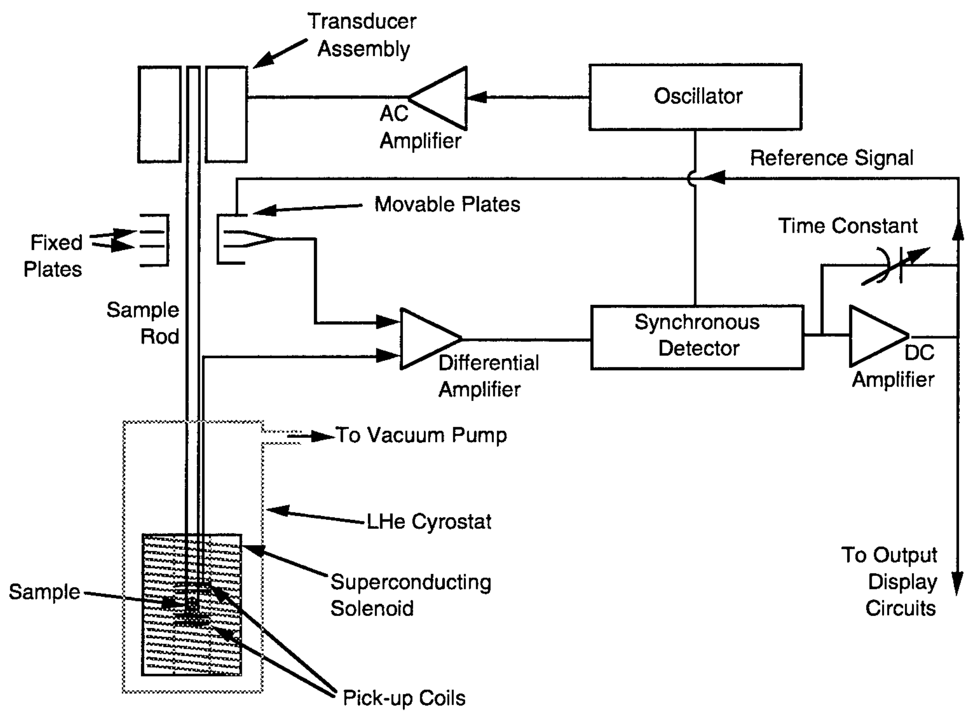


Figure 3. Diagram of vibrating sample magnetometer

RESULTS AND ANALYSIS

The magnetization of Cu(II) *N*-methylosalicylaldimine is plotted in Figure 4. The data were measured at three temperatures: 4.2 K, 2.8 K and 1.8 K. These measurements show the strongest spin-exchange coupling of the three samples measured. The data plotted in Figure 4 were fitted to the expression in Equation (11). The parameters determined from the fit are listed in the Empirical Parameters table. The strength of the spin-exchange coupling at the higher temperatures of interest to Bleaney and Bowers is determined by J_z, the symmetric spin-exchange integral along the *z*-axis. For this dimer, J_z is the largest element of the spin-exchange tensor; J_x is the smallest. The antisymmetric elements are significant. D_x and D_y are comparable to J_z., and D_z is an order of magnitude less than J_z. These data show evidence of long range antiferromagnetic order. The long range order is treated as a lattice field that reduces the external magnetic field, giving an effective external magnetic field of $H_{eff} = H - \lambda M$. This sample exhibits the weakest long-range order of the samples reported here. The value of $Ng\beta$ determines the saturation magnetization of the dimers in the sample. The difference between this value and the maximum value of the magnetization plotted in Figure 4 is due to the small monomer contribution to the magnetization.

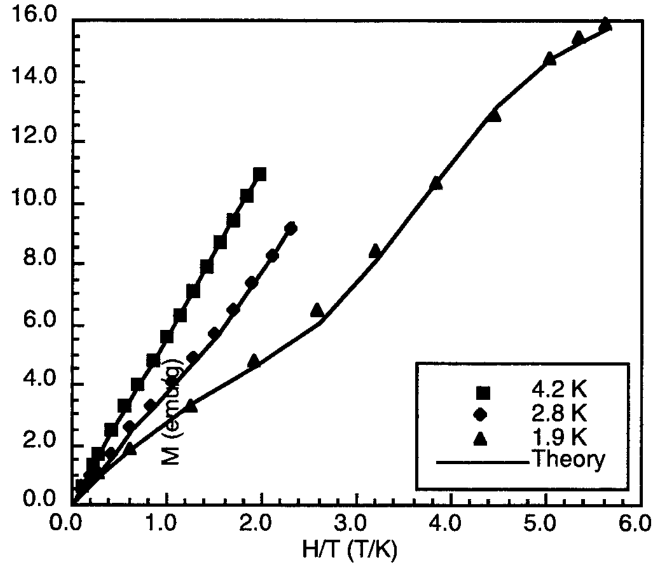


Figure 4. Cu(II N-methylosalicylaidimine

The magnetization of Cu(II) *N*-methylo 3-ethoxysalicylaldimine is plotted in Figure 5. The magnetization was measured at two temperatures, 4.2 K and 1.8 K. These measurements show the most anisotropic spin-exchange of the three samples reported here. J_z is an order of magnitude less than that of the base material reported above. J_x is comparable to J_z. However, J_y is the largest spin-exchange element of any sample measured. D_x is the largest of the antisymmetric elements of any sample measured. However, D_y and D_z are both determined to be zero. With λ an order of magnitude larger than that of the base material, this sample exhibits the strongest long range order of the three samples reported here.

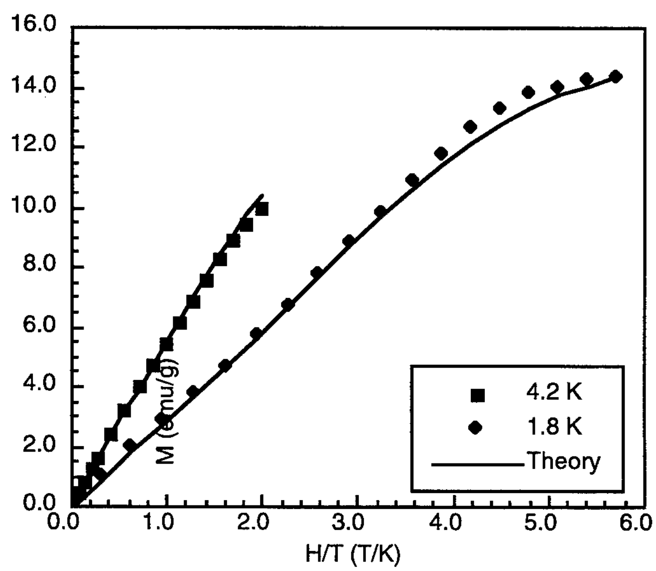


Figure 5. Cu(II N-methylo 3-ethoxysalicylaldimine

The magnetization of Cu(II) *N*-methylonaphthasalicylaldimine is plotted in Figure 6. The magnetization was measured at two temperatures, 4.2 K and 1.8 K. The measurements show the weakest spin-exchange of the three samples reported here. J_z is the largest symmetric element of the exchange tensor. All symmetric elements are of the same order of magnitude as J_z. The antisymmetric element, D_y is comparable to J_z, but is an order of magnitude larger than D_x. D_z is nearly negligible. This sample exhibits significant long range order.

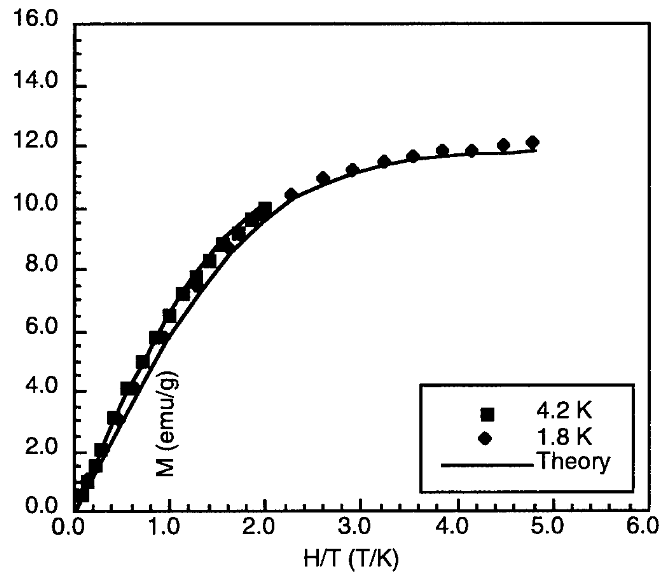


Figure 8. Cu(II N-methylonaphthasalicylaidimine

Empirical Parameters

	Cu(II) *N*-methylosalicy-laldimine	Cu(II) *N*-methylo 3-ethoxysalicylaldimine	Cu(II) *N*-methylo-naph-thasalicylaldimine
$Ng\beta$ (emu/g)	12.724 ± 0.023	13.814 ± 0.831	11.844 ± 0.015
J_x (K)	-2.185 ± 0.008	-0.597 ± 0.031	-0.226 ± 0.002
J_y (K)	-5.774 ± 0.019	-8.328 ± 0.329	-0.551 ± 0.004
J_z (K)	-6.719 ± 0.019	-0.649 ± 0.022	-0.905 ± 0.010
D_x (K)	3.252 ± 0.011	5.722 ± 0.111	-0.035 ± 0.001
D_y (K)	2.178 ± 0.005	0.0	0.276 ± 0.004
D_z (K)	0.238 ± 0.001	0.0	0.000 ± 0.001
λ (g/cm^3)	66.590 ± 0.244	964.328 ± 46.684	321.623 ± 1.086

In many respects, the magnetic properties of these materials are quite curious. These measurements suggest that Cu(II) bidentate salicylaldimine dimers have unique *x*, *y*, and *z* coordinate axes. However, measurements on powdered samples cannot correlate the magnetic coordinates to the lattice structure. Measurements of the magnetization of single crystals are required.

CONCLUSIONS

Measurements of the magnetization of the dimeric forms of Cu(II) *N*-methylosalicylaldimine, Cu(II) *N*-methylo 3-ethoxysalicylaldimine, and Cu(II) *N*-methylonaphthasalicylaldimine have been performed. These measurements were performed at high magnetic fields ($0 \leq H \leq 10.8$ T) and low temperatures ($1.8 \text{ K} \leq T \leq 4.2$ K). This work shows that the magnetic properties in this regime cannot be described by the Bleaney and Bowers scalar formalism for spin-exchange coupling. The magnetization are explained by the tensor formalism of spin-exchange. This work found evidence of weak long-range ordering of the magnetic moments of dimeric Cu(II) complexes of bidentate salicylaldimine. The long range order can be treated as an antiferromagnetic lattice field. All the symmetric and antisymmetric elements of the spin-exchange integral were determined. The strength of the lattice field was determined. For future study, measurements of single crystal Cu(II) complexes of bidentate salicylaldimine will be performed to relate the magnet coordinates to the crystal structure. Measurements of the magnetic properties of weakly coupled dimers based on other metallic ions such as Ni^{2+}, Fe^{2+}, and Fe^{3+} will be conducted.

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DR. WARREN E. HENRY AND HIS IMPACT ON THE FIELD OF MAGNETISM

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INTRODUCTION

The scientific genius of Warren Henry and how he applied his ability to a particular magnetic problem will be discussed. (The magnetic problem is the paramagnetism of non-interacting (free) ions in materials.) A brief history of the status of the theoretical and experimental work in paramagnetism up to the 1940s will also be presented.

Dr. Henry's early background, education, research training, and teaching was very important in preparing him to work on magnetic problems. In spite of the segregation laws and practices which existed at the time when he began his work, he was extremely lucky to be in the right places at the right times to accomplish this work. His demonstration of the proof of non-interacting paramagnetic ions is a remarkable contribution and is contained in many new textbooks today.

STATUS OF THEORETICAL AND EXPERIMENTAL STUDIES OF PARAMAGNETISM IN THE LATE NINETEEN-FORTIES

Curie[1], in an 1895 paper describing magnetic susceptibility on the magnetism of materials, showed that a certain class of materials exhibited a field-independent and a temperature-independent susceptibility given by:

$$X=C/T = M/H \qquad (1)$$

where X is the magnetic susceptibility, M is the magnetization, H is the magnetic field intensity, T is the absolute temperature, and C is called the Curie constant, which is unique for each material. An example of this behavior is shown in Fig. 1. Materials that obey Curie's law within certain limits are called normal paramagnetics, and now we know that this type of susceptibility occurs in materials that contain permanent magnetic dipoles. These magnetic dipoles are associated with the ions in the materials, and for strict obeyance of the Curie law there must be no interaction between the ions. Later experiments showed that if there is interaction between the ions, the susceptibility obeyed a modified Curie law developed by Weiss:

$$X = \frac{C}{T+\Theta} \qquad (2)$$

where θ is a constant. This is called the Curie Weiss law[2]. An example of Curie Weiss behavior is shown in Fig. 2.

It is to be noted that Curie made his measurements at weak magnetic fields <10,000 Oe and relatively high temperatures (above 77)K. However, if one assumes that paramagentism is a function of the permanent magnetic dipoles, then if the temperature is low enough and the field is very large, it is possible to align all of the dipoles with the field, and the Curie law would not be obeyed. Langevin[3] in 1905, using classical principles where all orientations of the dipole moment become possible when a field is applied, derived the following equation for the paramagnetism of free ions:

$$M = N \mu L(a) \qquad (3)$$

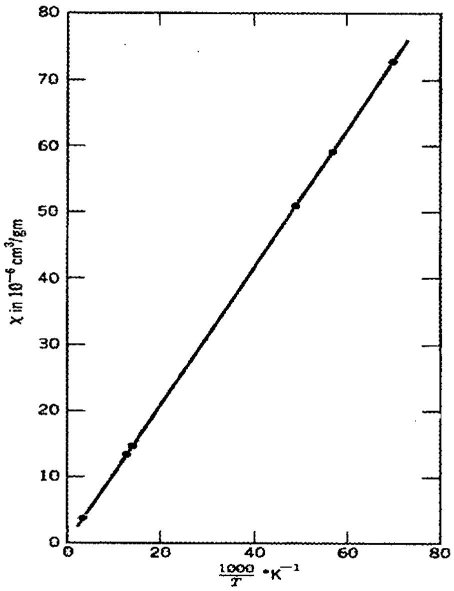


Figure 1 - Susceptibility per gm versus reciprocal temperature for powdered $CuSO_4 \bullet 6H_2O$

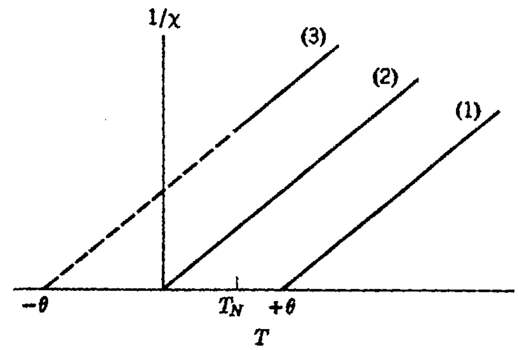


Figure 2 - Plot of $1/\chi$ versus temperature. Curve 1, $\chi = C/(T - \theta)$ (Curie-Weiss law); curve 2, $\chi = C/T$ (Curie's law), and curve 3, $\chi = C/(T + \theta)$

where μ is the strength of the magnetic dipoles, N is the number of dipoles, and the Langevin function, $L(a) = \coth(a)-(1/a)$, with $a = \mu H/K_BT$. For small H and large T this expression reduces to the Curie law.

In 1927 Brillouin[3] using a quantum mechanical approach which utilizes the space-quantized model of the free paramagnetic ions derived a similar equation:

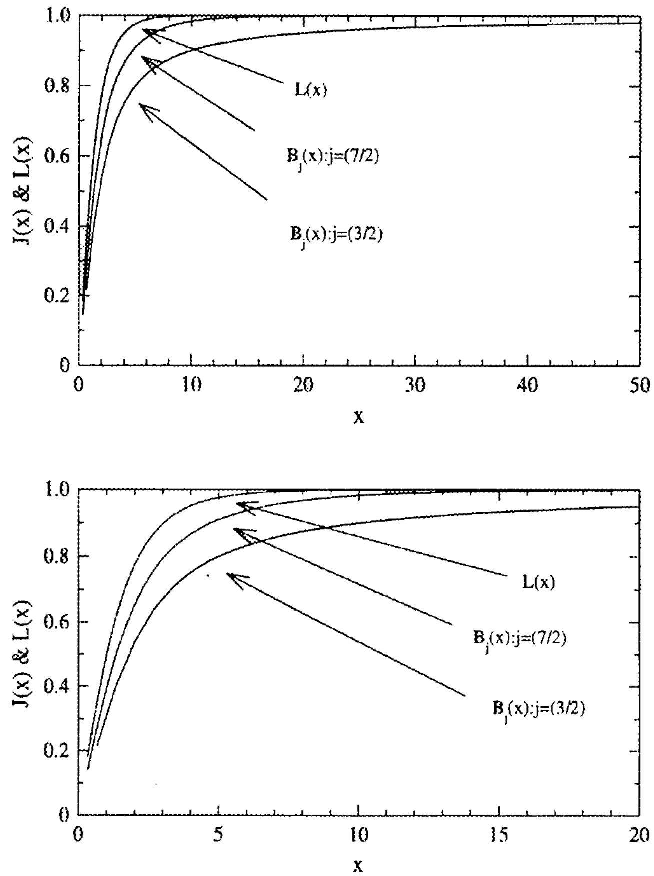
$$M = Ng\mu_B J B_J(a) \quad (4)$$

where N is the same as before, μ_B is the bohr magneton, g is the g factor, J the total angular momentum quantum number and $B_J(a)$, the Brillouin function is:

with $a=\mu H/K_BT$.

$$B_J(a) = \frac{2J+1}{2J}\coth\left(\frac{(2J+1)a}{2J}\right) - \frac{1}{2J}\coth\left(\frac{a}{2J}\right)$$

For large J the Brillouin function reduces to the Langevin function as is shown in fig. 3. Figure 3 compares the brillouin and Langevin functions. Experimentally the approach to saturation had been first observed in 1923[4] for $Gd_2(SO_4)_3 \bullet 8H_2O$. In this case J is large (7/2) and the measurements were not that good. However, the measurements did appear to favor the Brillouin function.



Tabulations of the Brillouin and Langevin Functions

Figure 3

WARREN HENRY—TRAINING AND EARLY WORK

Dr. Henry was fortunate in that both his mother and father finished Tuskegee and knew Dr. George Washington Carver, studying and working under him. When he was a young boy, Dr. Henry spent time with Dr. Carver when Carver came to visit the Henry farm. Also, he interacted with the famous scientist when he was an undergraduate at Tuskegee where Carver was a professor. At Tuskegee Dr. Henry majored in math and minored in physics and chemistry, which prepared him for a research career. He earned his Master's degree in chemistry while teaching physics at Spelman and then taught at Tuskegee, which aided him in being accepted for graduate studies in physical chemistry at the University of Chicago.

Dr. Henry was an excellent Ph.D. student. At the time he took the qualifying exam, he was the only one of the five individuals taking the exam to successfully pass. His physical chemistry Ph.D. thesis on resistance thermometry compelled him to develop techniques and skills which would be useful for later research. Upon completing his Ph.D. in 1941, he returned to Tuskegee for two years. However, in the summer of 1943 before going to Spelman to teach he visited MIT, and was offered a position in the radiation laboratory. After the first semester at Spelman, he moved to MIT where he worked with the radar group for one year. While there he met and became friends with Dr. Bitter, the inventor of the high field Bitter magnet. He did post-doctoral research at Chicago, and in 1947 joined the faculty of Morehouse College for one year. In 1948 after much effort, he obtained a job with the low temperature group at the Naval Research Laboratory (NRL) in Washington, D.C. At that time the laboratory was segregated, and

Negroes could not use many of the facilities at NRL. Dr. Henry was allowed to build equipment and carry out experiments that would make him famous. There were no other Negro Ph.D's at NRL, and Dr. Henry was started at the GS-9 level. This was below the normal GS-11 starting level for a Ph.D., but it was a very high position for a Negro. By working very hard and very late, sometimes all night and weekends, Dr. Henry was able to overcome and accomplish almost impossible tasks. To make very accurate measurements of paramagnetic moments, he needed temperatures of 4.2 K and below, stable high magnetic fields, and a sensitive system for measuring the induced magnetism in the sample.

The Classic Experiment

To obtain the low temperatures in an experimental configuration in the magnetic field, a metal dewar was needed. Previously only glass dewars were used for these experiments, but they were not suitable for use in the Bitter magnet which was being constructed at NRL. Within a year Dr. Henry had completed the design and construction of the first metal dewar suitable for this work. A short note on this work was published in conjunction with his boss in early 1950[5]. The next year, Dr. Henry was allowed to publish the theory of this dewar as a single author[6]. The Bitter magnet at NRL was not stable enough for accurate measurements at the high fields needed to saturate paramagnetic moments. Dr. Henry solved this problem by gold plating the contacts in the Bitter magnet. The one remaining task was designing a measuring system. A special lift was built which moved the sample between two bucking coils. The current pulse induced in the coils by the magnetization of the sample was measured by a ballistic galvanometer. A schematic diagram of the measuring assembly is shown in Fig 4.

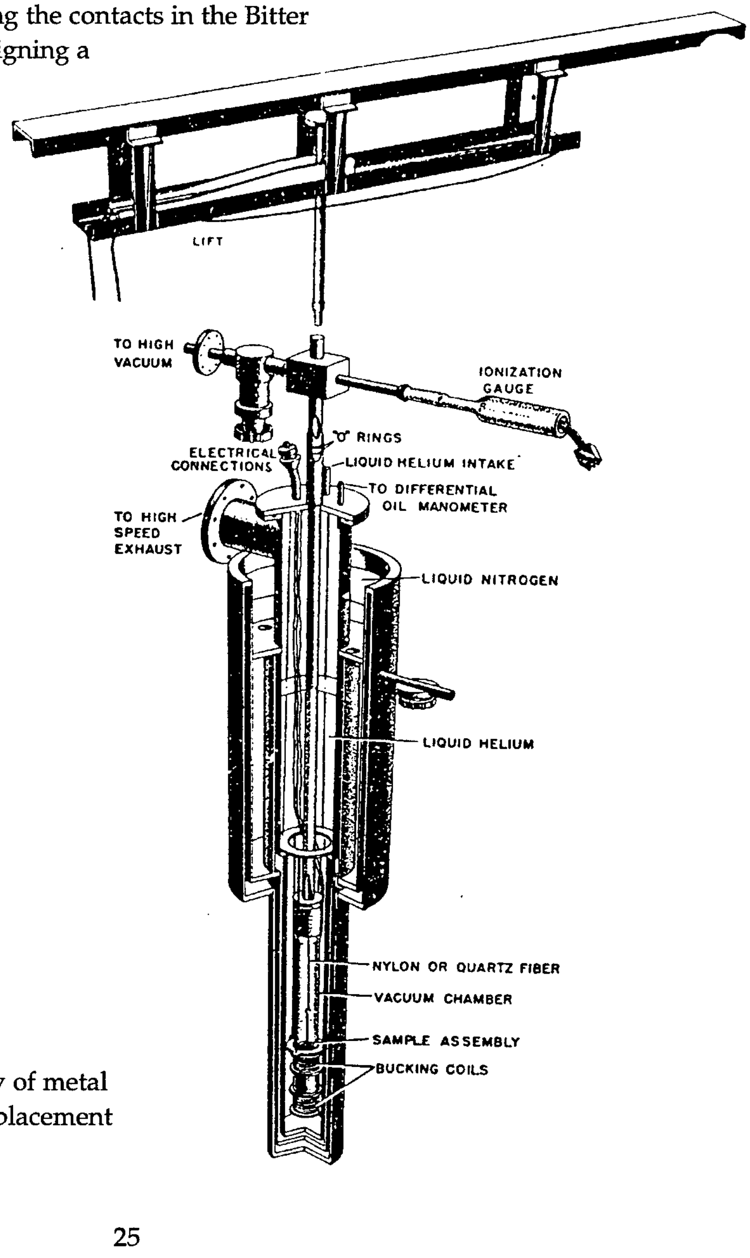


Figure 4 - Schematic diagram of assembly of metal Dewar for liquid helium and sample; displacement lift is shown at top.

The Bitter magnet, dewar, and measuring system worked very well, and a sample was selected. The sample chromium potassium alum has a J of 3/2, which is small enough to easily differentiate between the Brillouin and Langevin function behavior if careful measurements are made. As the Bitter magnet used so much power, and a tremendous number of measurements were needed, most of the experiments were performed at night. There was no doubt that the data obtained fitted the Brillouin function. A report was submitted by Dr. Henry to *Physical Review Letters* in early December 1951 and published in early 1952[7]. A full paper with data for J=3/2, 5/2, and 7/2 was published in *Physical Review* in November 1952[8].

Because of the accuracy, the number of data points, and the precision of fit to the Brillouin function, these results demonstrated beyond a shadow of doubt a positive proof of spatial quantization of the free paramagnetic ions. All of these measurements were made by W.E. Henry personally. These results shown in figures 5 and 6 were picked up by text and reference book writers and have been used in elementary as well as advanced text and reference books when the quantum nature of the paramagnetic ion is discussed. It has been included in all editions of *Introduction to Solid State Physics* (by Kittel) since 1953, and in the famous general physics textbooks by Halliday and Resnick. Dr. Henry published many more papers on high field magnetization at low temperature while at NRL, but the first papers are the classics and will be used by scientists and writers for many years to come as a demonstration of special quantization.

When Dr. Henry left NRL in 1960 many years after producing this classic work and other famous studies, he was only a GS-13. He was not considered for promotion to GS-14, whereas colleagues in charge of groups similar to his, held this rank.

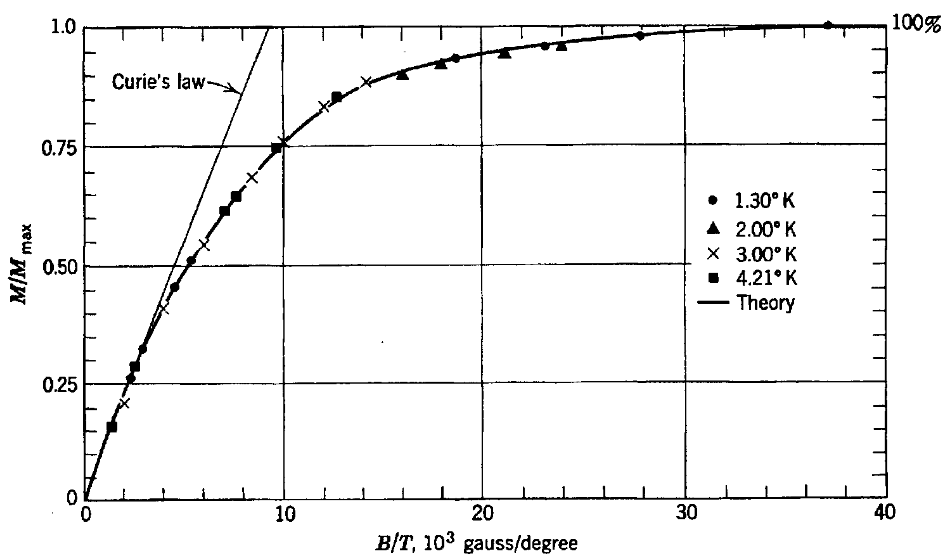


Figure 5 - The ratio M/M_{max} for a paramagnetic salt (chromium potassium alum) at various magnetic field and at various temperatures. The curve through the experimental points is a theoretical curve calculated from modern quantum physics.

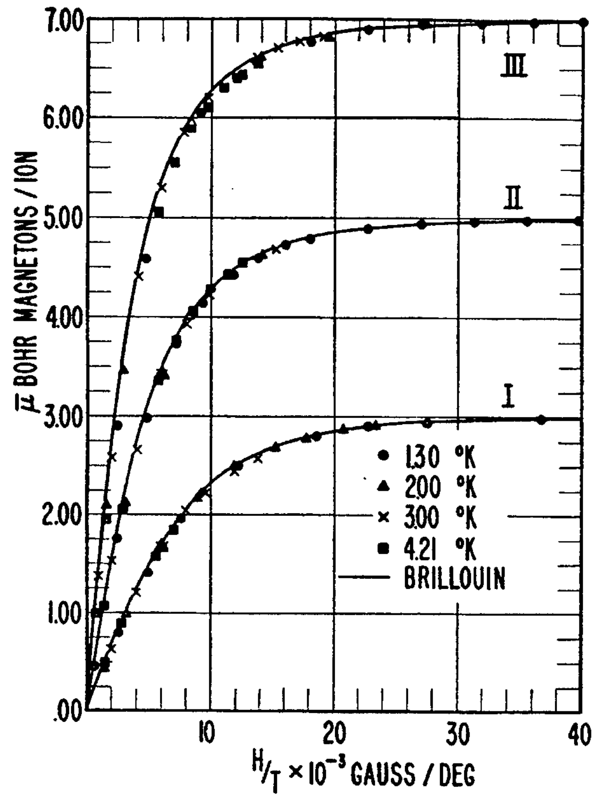


Figure 6 - Plot of magnetic moment versus H/T for spherical samples of (I) potassium chromium alum, (II) ferric ammonium alum, and (III) gadolinium sulfate octahydrate. Over 99.5% magnetic saturation is achieved at 1.3°K and about 50,000 gauss.

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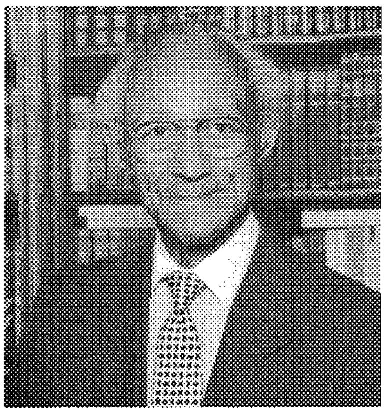
WARREN E. HENRY AND AMERICA'S BLACK AIR FORCE OF WORLD WAR II



William F. Holton

National Historian, Tuskegee Airmen, Inc.

ABSTRACT

In the fall of 1941, Dr. Warren Elliott Henry returned to Tuskegee Institute, his alma mater, with a recently conferred Doctor of Philosophy degree from the University of Chicago to assume a two-year teaching position which was to last through the summer of 1943. It was during this period that Dr. Henry began his association with the "Tuskegee Airmen," the men who were destined to become America's Black Air Force of World War II. Dr. Henry greatly admired the brilliance and competence of these young men and was eager to participate in the early phase of their training program as Instructor of Physics. He believed that lessons well learned in the classroom, along with strong individual will and determination, would dispel forever the stereotypical myth of black inferiority and supplant it with indisputable proof that, given equal training and the opportunity to succeed, the Tuskegee Airmen would be second to no other unit in the Air Corps. And indeed, their distinguished combat record compiled in the skies during the Mediterranean and European campaigns in World War II amply supported that assertion.

While Warren Henry was pursuing his 11th grade high school studies at a church school in Greenville, Alabama, some 40 miles from his home, the U.S. Army War College in Washington Barracks, District of Columbia, was completing a study titled "The Use of Negro Man Power In War," dated 30 October, 1925. This study concluded that Negro men believed themselves inferior to the white man, were by nature subservient, lacked initiative and resourcefulness, did not possess cranial capacity for learning or the ability to operate highly technical equipment and, not only lacked the mental capacity to command, but the courage as well. Worst of all, according to the report, the Negro lacked confidence in his colored officers because, after all, the colored officer was still a Negro with all the faults and weaknesses of character inherent in the Negro race, exaggerated by the fact that he wore an officer's uniform. Their interest was seen as not in fighting for their country, but solely in advancing their racial interests. The report continued by saying that the American Negro fell far behind the white man and possibly behind all other races. Therefore (the study asserted), racial separation was dictated by inferiority and made the close association of whites and blacks in military organizations inimical to harmony and efficiency (1). This War College study, though directed specifically at black military personnel, clearly reflected the current attitude of the country and was perceived as official policy. This not only adversely affected all operational aspects of black military service through the first few years of World War II, but was equally applied to the civil society as well. It would present Warren Henry and the men of America's Black Air Force with challenges that would last for a considerable part of their professional careers.

Two years after the War College issued its conclusions, Warren Elliott Henry followed in the footsteps of his parents by matriculating at Tuskegee Institute in the fall of 1927. Over the next four years, he successfully completed credits sufficient for three majors in math, English and French, and for three minors in chemistry, physics, and German. He was awarded the Bachelor of Arts in 1931. Not surprisingly, he was valedictorian of his graduating class.

Shortly after graduation, Warren was recruited by the white Superintendent of Negro Education in Alabama for a teaching position. When he was asked what subjects he thought he could teach, Warren answered that he could teach English, math, and French. To this, the Superintendent replied that there would be no occasion for him to teach French in Black schools since Blacks did not have the mental capacity for learning the French language. Warren's reply was to challenge the superintendent to a French language duel. The red-faced superintendent refused to answer the challenge, but Warren got the job.

As Warren was preparing to travel to the location of his first teaching position, he received a telegram from the same superintendent, offering him a principal's position at a normal school in Atmore, Alabama. Warren accepted the offer.

Black public schools were traditionally overcrowded and understaffed, and Warren's school was no exception. On one occasion, he went to the superintendent to ask for an additional teacher and was told he could not have one. The superintendent assumed that his answer ended the conversation, but Warren persisted by asking whom he should see to get another teacher. The superintendent replied that the only people above him were members of the Board of Education. "When do they meet?" Warren requested. The greatly agitated superintendent told Warren that if he was crazy enough to come to a Board meeting, he would tell him the meeting date and time.

Warren went to the Board and was not surprised to be greeted with "Boy, what are you doing here." Undeterred by this lack of courtesy, Warren continued to argue his case before the Board. When he finished, the Board told him that they would get back to him at a later time. In reply, Warren reminded the Board that schools had already opened and teachers were hard to find at this point. He continued to tell the Board that he had found a person who was willing to work in his school, and that he had promised to send her a telegram following this meeting. By this time a very angry Board, referring to Warren as a "crazy boy," told him to go ahead and tell her to come.

On another occasion Warren clashed with his superintendent when he was told to stop emphasizing the teaching of physics in his school. The reason for the order was that one of his students, who was quite advanced in physics, had a mother who worked for a prominent white family in town who also had a daughter studying physics in the white schools. The problem was that this girl was not as advanced as Warren's student. Warren Henry however, did not honor the superintendent's demand.

Warren, in good humor, attributes his actions in these cases to not having "good sense" in those days. I view his courageous actions as expressions of an individual's will to maintain moral and intellectual integrity at all cost, at a time and in a place where such courageous acts were often fatal.

Warren left his principal's position before his term expired after persuading his Superintendent to permit his brother, who was also a graduate of Tuskegee Institute, to take his place as principal. For the next few years Warren simultaneously pursued his academic interests while working in teaching positions at Tuskegee Institute, Spelman College, and Atlanta University, where he also earned the Master of Science degree. The pinnacle of his academic attainment was reached in the spring of 1941, when he was the only Black person, and the only one of five candidates in his class, to be awarded the Doctor of Philosophy degree from the University of Chicago.

In the meantime, the clouds of war had engulfed Europe and the Far East, and the American military, sensing the inevitability of their entrance into the war, had accelerated its military preparedness program. Nonetheless however, it continued to exclude black servicemen, believing them unsuited for duty. But in the face of this exclusion, a number of Black organizations and individuals were campaigning relentlessly for the acceptance of Blacks in all branches of the military, including the Air Corps. By 1941, in spite of strong resistance from the military establishment and most officials from the War Department, Congress, feeling the pressure from politicians eager to garner the black vote for the coming presidential election, and added pressure from threatened lawsuits from enterprising Blacks, decided to establish one pursuit squadron at Tuskegee Institute for the Air Corps. On July 19, 1941, the first class of black pilot trainees began their Aviation Cadet Training at Tuskegee Army Flying School in Alabama. This flight training program was considered by the military leadership to be an "experiment"; an experiment to see if black men could fly high tech aircraft and if they could fight in combat in accordance with standards required by the Air Corps. The military leadership predicted this experiment would fail.

Warren Henry entered this "experimental" fray in the fall of 1941 as Instructor of Physics in the pre-flight phase of the flying program. He was aware of its prediction of failure and knew instinctively that the lot of blacks in the current and post-war military would be largely determined by the combat performance of these men of America's Black Air Force. He also believed that victory in the air could not be successfully achieved if one's mind was focused on the vagaries of segregation and discrimination. Therefore, he would not permit his classroom to be a forum for commiseration on issues of race. His classroom would be a place where only flight-related, war-borne technical developments would be transferred to the flying cadets–not only so they could successfully complete the course, but also so they would be able to compete successfully in aerial combat, which was their primary mission.

For the cadets coming into the flying program in 1941, the minimum requirement was a college degree. They also had to be single. Young men of high moral integrity, these cadets were ambitious. They deported themselves well, and possessed the will and determination to prove to the country and to the world that they were equal to any other unit in the Air Corps. In short, the cadets were, as was Warren Henry, the cream of the crop from the Black community and they had a great deal of mutual respect for each other.

Warren instructed the Tuskegee Airmen in all the principles of physics, emphasizing always their special application to flight. He taught them about Newton's Law, the law of gravity, the principles of aerodynamics, thermodynamics, and meteorology. He taught them about the solar system and the stars and constellations and how to use them as navigational aides. He taught them about the earth's rotations and how they relate to conditions of atmosphere, weather, temperature, humidity. He also explained the effects these elements have on the ability to control a plane. He taught his Tuskegee students about the law of gravity and its effect on the body during periods of high acceleration, as for example, when a plane is in a high speed dive. He taught about heat engines and the fuels that power them, the effect of high altitude flights on the human body. He educated the cadets about electronics and the application of that technology in the development of communications, radar detection systems, and much more.

Warren's approach to teaching the cadets was to treat the subjects not as something complicated or difficult, but rather as something interesting and new with real-world application to their current war-time mission. He considered many of the cadets to be brilliant, and all of them to be competent and capable. He gloried in their ability to quickly assimilate and apply the physical principles discussed in his classroom. One of the cadets who took the course in the spring of 1942 remembered 55 years later that "his instructor was no older than many of the cadets he taught, and was not at all strict in the classroom. He would lean on the desk or sit at one of the student's desks with legs outstretched in a relaxed manner. He never used a single note or anything as he taught us to understand the most complicated physical principles. We all thought he was brilliant. We were all enthusiastic about the course and got a lot out of it" (2). Warren Henry was popular with his students and he chuckles when he recalls that they frequently wanted to have their pictures taken with him.

Warren Henry's interest and admiration for the Tuskegee Airmen did not end when he left his teaching position in the summer of 1943. He continued to follow their exploits throughout the remainder of the war as they simultaneously won their victories against America's enemy in Europe–and against bigotry on the home front.

In spite of this compounded burden, the Tuskegee Airmen went on to establish an enviable combat record during World War II. Their exceptional performance and outstanding combat record was reflected in the destruction or damaging of over 400 German aircraft and over a thousand ground and sea targets. Their most renowned accomplishments, however, were the sinking of a destroyer using only machine gun fire, and the fact that they had a perfect bombing escort record—not one bomber, while under their escort in over 200 missions, was ever lost to enemy aircraft.

These accomplishments were not gained without losses. The Tuskegee Airmen lost 66 pilots killed in combat. Thirty-two more were shot down and became prisoners of war. On the home front, they refused to obey unlawful orders that would degrade them as officers, which resulted in the successful integration of the Officer's Club at Freeman Field Army Air Base. These double victories were crucial factors in the integration of the American military services and were the capstone of the subsequent Civil Rights Movement in this country.

To Warren Henry, the Tuskegee Airmen were the personification of what a people can achieve with meticulous academic preparation and training, steadfast courage of one's convictions, faith in one's own ability, and the will not to surrender to the inevitabilities of life one's intellectual honesty and quest for academic excellence. He was proud of the Airmen because they made history in a great way and brought honor to their race and to their nation (3). Ironically, all these qualities have an all too familiar ring—for they are the same qualities that have made Dr. Warren Elliott Henry the renowned and beloved scholar whom we have come to know and for whom we have come to this place, on this day, to honor.

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Reflections on Warren E. Henry: Professor of Physics

Eleanor I. Franklin, Ph.D.

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Let me, first, add my congratulations to Warren Henry on this occasion which is being given in his honor. I also wish to express my deep appreciation to the Berkeley Laboratory and to the Symposium Organizing Committee for inviting me to share in this event. I believe this is my first opportunity to say, publicly, a long overdue "Thank You!" to Warren Henry for his contribution to my overall professional development and career.

As is the unfortunate predicament of the student, a full understanding of what comprises the life and mind of the teacher is seldom realized. Virtually a lifetime of interaction is necessary to learn who they really are, and even then, that knowledge is superficial. This was certainly the case when I was enrolled in General Physics (a two-semester course with laboratory) in 1946-1947. It was my third year at Spelman College. At that time, the small liberal arts colleges of the Atlanta University Center functioned as a true consortium economizing in faculty appointments. For example, General Physics was offered by Morehouse College, but the course was open to all students in the Center. In that year, World War II had just ended, and the inevitable occurred. The classroom of nearly 200 students was filled to capacity with men from Morehouse and Clark Colleges and only four women were seated.

As we waited for the teacher and for class to begin, there was considerable boisterousness, for many of the students were veterans who were resuming their studies after their tour of duty. They all seemed very sophisticated and self-confident ... characteristics not enjoyed by yours truly. I must admit that I was somewhat intimidated. Physics was a required course for biology majors and, prior to that course, I had not been exposed to it as a discipline.

Shortly, on that first day, a small, mild, shy-looking grey-eyed man entered the room and was virtually unnoticed until he cleared his throat and requested the class to settle down. As he began announcing the usual details for the course (e.g., required texts, schedule of examinations, student performance expectations, etc.), the students recognized that this was to be our physics instructor. He was entirely unknown to this group, who fully expected to see Dr. Halson V. Eagleson (whom Dr. Henry had replaced as the head of physics at Morehouse). The "Hoss," as Dr. Eagleson was affectionately called, had joined the faculty at Howard University, and had taken with him his commanding visage, voice, and size. As we would soon learn during the year, Dr. Warren Henry was neither shy nor self-effacing nor obsequious. He would smile while he patiently explained some principle for the third time, always associated with a little hesitation stutter, all the more to emphasize the simplicity of what he was trying to impart (or perhaps he was amused at the innocence of our questions).

The course would prove to be challenging to me, and I recall many anxious moments feeling that I did not fully understand. It is interesting that even now, 50 years later, I can recall a problem which Dr. Henry assigned to the class that no one succeeded in solving, and that I cannot solve today. Although the problem was one more exemplary for civil engineering, it is intriguing that the principles to be applied in solving it remain clear to me today. It is this laudable aspect of Dr. Henry's ability to teach the "unprepared" such that they achieve an understanding of the laws and principles which, in my case, were critical to my future success as a physiologist.

In the 1940s, the essentials of electronics were only then being defined by such minds as that of Warren Elliott Henry, and applied largely to the war effort. He introduced to the students in that class the potential applications that would later be required for advances in medical research. In the next year, when I took the national Graduate Record Examination, I was astounded when I learned that I had scored at the 98th percentile in physics. I attribute that entirely to the level of my understanding of the principles of the physics of fluids, electricity, magnetism, materials behavior, and other fundamentals which Dr. Henry's instruction had brought to me. The level of my scoring in that subject was to be my peak performance and exceeded that for my major field of biology.

And so, I safely negotiated General Physics in 1946-1947.

In the previous year, I was similarly challenged in the General Chemistry course taught by Henry Cecil McBay. And similarly, I had not previously had courses in chemistry in high school. I was later to learn that Drs. Henry and McBay were very close friends, that they each enjoyed a rich research experience, and shared a common bond in their graduate studies as students, and, most of all, because their scientific interests were so similar, they shared ideas and the excitement in solving problems.

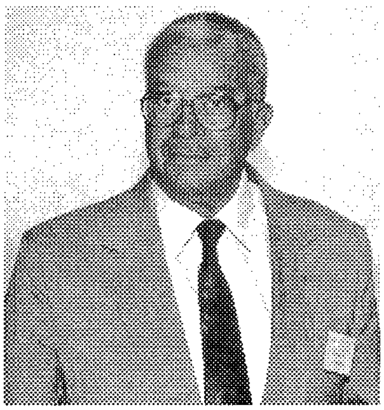
The two friends (for each remained a part of my life over the years) were also fun-loving and perhaps should be described as "mischievous pranksters." For those who have known Warren Henry, you would agree that it is almost impossible to refer to the behavior of one without including the other. And it has been my observation that whatever mischief they managed to get into, Dr. Henry was most likely the instigator of it all, with embellishments to the prank added by the imagination of Dr. McBay. In the past year, Dr. McBay passed away; thus was the separation of a deep friendship.

Dr. Henry is well known around the campus of Howard University. He participates in all of its activities including commencement, adorned in his academic regalia. His influence and esteem continues among the undergraduate students, the graduate students, and faculty colleagues in his capacity as Professor Emeritus. He is always seen walking about the campus, and enjoys eating lunch in one of the campus dining rooms. He is never far from the academic life which he has created and enjoys.

In April of this year, I attended a ceremony sponsored jointly by the Faculty Senate and the University Library System at which Dr. Henry was presented the "Excellence at Howard Award," which was accompanied by several warm tributes from colleagues and friends. I consider it to have been most deserving and timely.

In today's present company, I can admit that I am grateful that my good fortune continues, for I have sat on the same Howard University Faculty with my physics teacher during more than 30 years. I am privileged to share in this tribute to him at this symposium. Among his many achievements and contributions to the field of physics and to his country, a most admirable one is his talent for teaching to high standards, such that his students learn in spite of themselves.

WARREN E. HENRY/NAVAL RESEARCH LABORATORY, 1948/1960 RECOLLECTIONS



George A. Ferguson, Ph.D.

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WHY DID HE DO THAT? I will briefly tell you of my interaction with Dr. Warren Henry and give you my answer to the question "WHY DID HE DO THAT." While my interaction with Warren Henry has continued over a period of more than forty-five years, I will limit my remarks to the twelve-year period between 1948 and 1960 during his employment at the U.S. Naval Research Laboratory.

The Naval Research Laboratory is located in Washington, D.C. and was established in 1923 on the recommendation of Thomas A. Edison. The purpose of the Laboratory is to conduct research of interest to the U.S. Navy.

The twelve-year period between 1948 and 1960 followed the end of World War II, and the country was still revelling in its wartime victories.

The year I will start with is 1954. At that time, I had attempted to continue my collegiate education after a painful disruption caused by the war but was forced to suffer another postponement due to the lack of finances and mounting family responsibilities. I desperately needed a full-time job. I returned to Washington D.C., my hometown, to begin my job search. After several promising employment opportunities vanished, a friend suggested that I apply at the Naval Research Laboratory. Knowing the biased attitudes of the Navy at that time, I felt that my application would be "put on file." To my complete astonishment, I was offered a position after a painless interview.

When I joined NRL in 1954 as a research scientist, I found a relaxed collegiate atmosphere that was very stimulating to my research. The facilities were first-class. For example, the Laboratory boasted such facilities as:

a cyclotron,
a Cockcroft-Walton accelerator,
a nuclear reactor,
a large radiotelescope,
a high-field magnet facility.

There were shops and skilled staff to support its programs.

One part of the favorable collegiate atmosphere I found at NRL was due to the seemingly unlimited research funds available to the Laboratory, but another part was due to the pioneering efforts of Warren Henry to change the racially restrictive practices still prevalent in the Navy at that time. I am convinced that the favorable response to my application for employment was due, in part, to the earlier humanitarian efforts of Warren Henry.

As most of you already know, Dr. Henry has a strong leaning toward experimental research. He has pioneered studies in magnetic structures, and of materials at low temperature, as well as the development of instrumentation needed to conduct these studies. For example, while at NRL he developed, and published, a mathematical expression for computing the dimensions of a liquid helium cryostat of specified performance characteristics. He used such cryostats of his improved design to make magnetic measurements on a wide range of materials in high magnetic fields produced by a strong-field magnet he helped to construct. This magnet was originally designed by Francis Bitter of MIT, but it was later improved by Dr. Henry while at NRL.

To give you a flavor of his prolific activity during his stay at the Naval Research Laboratory, I have listed in Figure 1 some of his more than thirty scientific publications while there. While I cannot speak of all the work done by Dr. Henry during his tenure at NRL, I will attempt to explain a specific problem he solved while there and to proclaim his valuable assistance to me in my research endeavors.

The problem in question was one of determining the properties of an oxide of iron. The Navy has had a long romance with rusting iron. The specific iron oxide that Henry studied in 1955 was γ-Fe_2O_3. The experimental arrangement as he described it consisted of "two measuring coils wound in series opposition and in series with a ballistic galvanometer. The sample is moved from the center of one coil to the center of the other in a short time compared with the period of the galvanometer, whereupon the deflection of the galvanometer is proportional to the magnetic moment of the sample. The average moment

10. Henry, Warren E. "Metal Dewars for Liquid Helium" Proceedings of the London Meeting of the International Congress of Refrigeration, 1952, p. 106.

11. Henry, Warren E. "Anomalous Paramagnetism of Copper Sulfate Pentahydrate" Phys. Rev., Volume 87, 1952, 1133L.

12. Henry, Warren E. "Magnetic Saturation and Apparent Molecular Fields of MnCl24H2O" Phys. Rev., Volume 90, 1953, p. 492L.

13. Henry, Warren E. "Some Magnetization Studies of Cr+++, Fe+++, Gd+++ and Cu+++ at Liquid Helium Temperatures and Strong Magnetic Fields" Revs. Mod. Phys., Volume 25, 1953, p. 163.

14. Henry, Warren E. "Antiferromagnetic H-T Boundaries and Apparent Molecular Fields for MnCl2 (4H2O and MnBr2 • 4H2O" Phys. Rev., Volume 94, 1954.

Henry, Warren E. "A Strong Field Induced Paramagnetic Anomaly in NiSiF66H2O" Phys. Rev., Volume 95, 1954, p. 1449.

16. Henry, Warren E., Hansen, W.N. and Griffel, M. "Strong Field Magnetization of CrCl3 and CrF3" Proceedings of the Pittsburgh Conference on Magnetism and Magnetic Materials, American Institute of Electrical Engineers, Volume T76, 1955, p. 60.

17. Henry, Warren E. "Quelques etudes d'aimanation en champs forts et aux basses temperatures" Proceedings of the Conference de Physiques des Basses Temperatures. Paris, France, No. 60, 1956.

18. Henry, Warren E. "Intradomain Magnetic Saturation and Magnetic Structure of γ-Fe_2O_3" Phys. Rev., Volume 101, 1956, p. 1253.

19. Henry, Warren E. "Coordination Quenching of the Saturation Magnetization of Potassium Ferricyanide" Phys. Rev., Volume 106, 1957, p. 465.

20. Hein, R. A., Henry, Warren E. and Walcott, N. M. "Superconductivity of Uranium" Phys. Rev., Volume 107, 1957, p. 1517.

21. Henry, Warren E. "Strong Field Cryomagnetic Studies of Some Ferromagnetics, Ferrimagnetics and Antiferromagnetics" Proceedings of the Boston Conference on Magnetism and Magnetic Materials, Volume T91, 1957, p. 299.

22. Henry, Warren E. "Behavior of Some Magnetic Materials at Low Temperatures" Report of NRL Progress, Jan 1957, 1958.

23. Henry, Warren E. "Low Temperature Magnetic Studies of Uranium Hydride, Uranium Deuteride and Uranium Dioxide" Phys. Rev., Volume 109, 1958, p. 1976.

24. Henry, Warren E. "Magnetic Moments and Apparent Molecular Fields in Some Rare Earth Metals and Compounds" J. Appl. Phys., Volume 29, 1958, p. 524.

25. Henry, Warren E. "Magnetization and Possible Magnetic Structure of Barium Ferrate III" Phys. Rev., Volume 112, 1958, p. 326.

26. Henry, Warren E. "Saturation Magnetization and Molecular Fields of the Acetylacetonates of Chromium and Iron" Physica, Volume 24, S160, 1958.

Figure 1. Selected Publications by W.E. Henry

for γ-Fe2O3 was found to be 1.18 Bohr magnetons per iron atom, which supports the preferential distribution of iron vacancies on octahedral sites in a spinel structure" (1). The spinel structure had been previously determined by x-ray diffraction.

The completion, in 1956, of the construction of a nuclear reactor at NRL permitted a more detailed study of the magnetic structure of this interesting compound. As you recall, a neutron possesses an intrinsic magnetic moment. Because of this feature, it is a useful probe for determining the structure of magnetic materials when the technique of neutron diffraction is used. Believing that some are unfamiliar with this technique, I have provided the next three figures to help in the visualization of the experimental arrangement. The first of these figures shows the arrangement of the experimental apparatus. Shown here is the neutron source (nuclear reactor), the monochromator (a single crystal of lead in a protective shield), the sample, and a detector for measuring the scattered neutron intensity. The next figure shows the diffractometer. The third figure puts the diffractomenter in perspective relative to two tall experimenters. The data obtained in this measurement of a sample of γ-Fe2O3 is given in Figure 4. An analysis of this neutron diffraction pattern indicated a cubic defect spinel structure with vacancies located at the octahedral sites in agreement with the results obtained three years earlier by Dr. Henry.

This brief example illustrates the pioneering scientific work accomplished by Warren Henry while at the Naval Research Laboratory. The example omits the invaluable personal encouragement he provided to me and others during his stay there. My contact with him that began in 1955 continues to the present day. I confess that my life has not been the benefit to others that his has, but I shall continue to emulate him and to lift him up as a source of energy and inspiration to all.

I promised at the beginning of this presentation to give you my answer to the question "WHY DID HE DO THAT." Well, my answer is I don't know why he did that, but I shall always be grateful that he did.

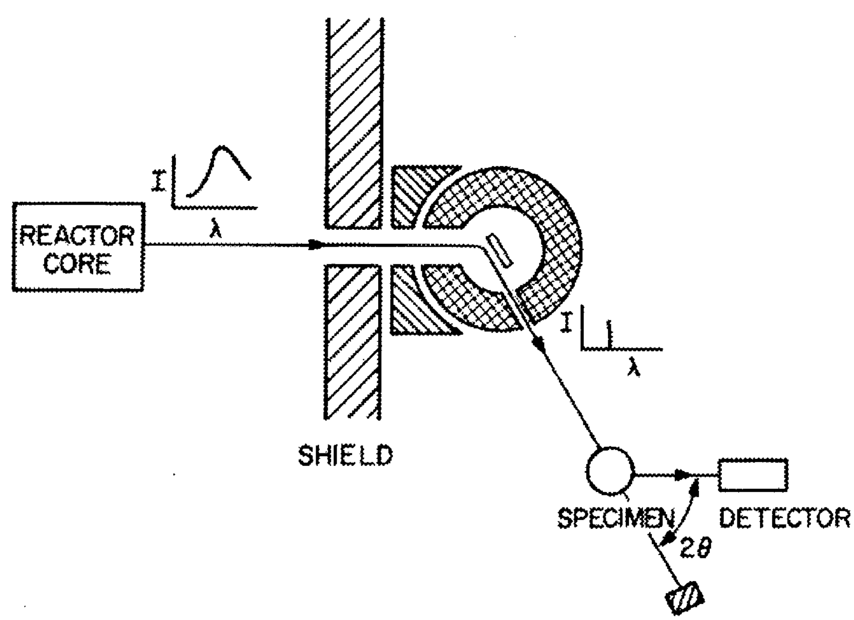


Figure 2.

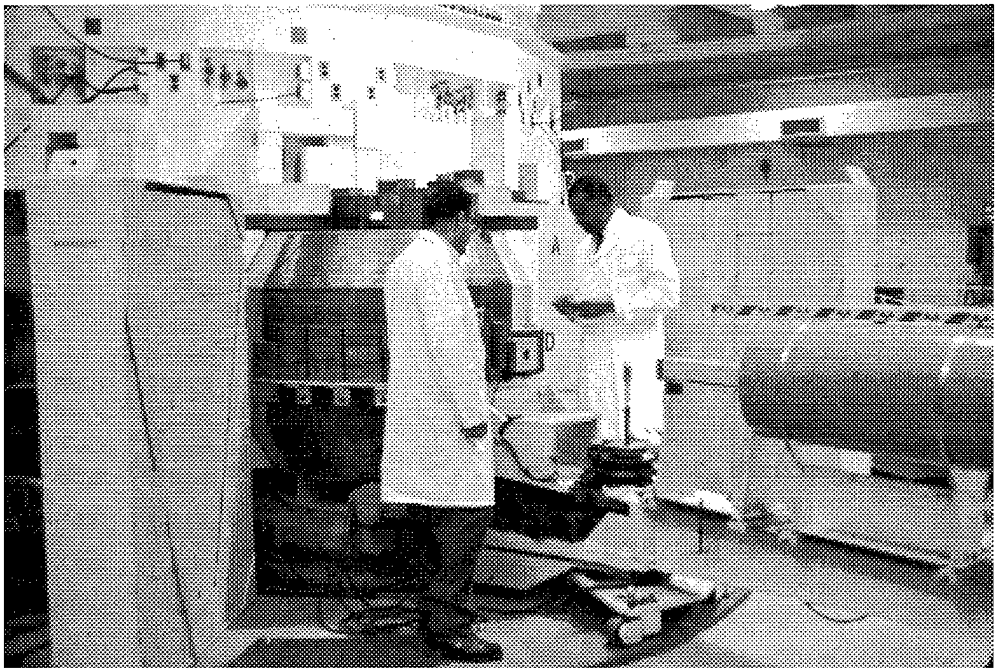


Figure 3.

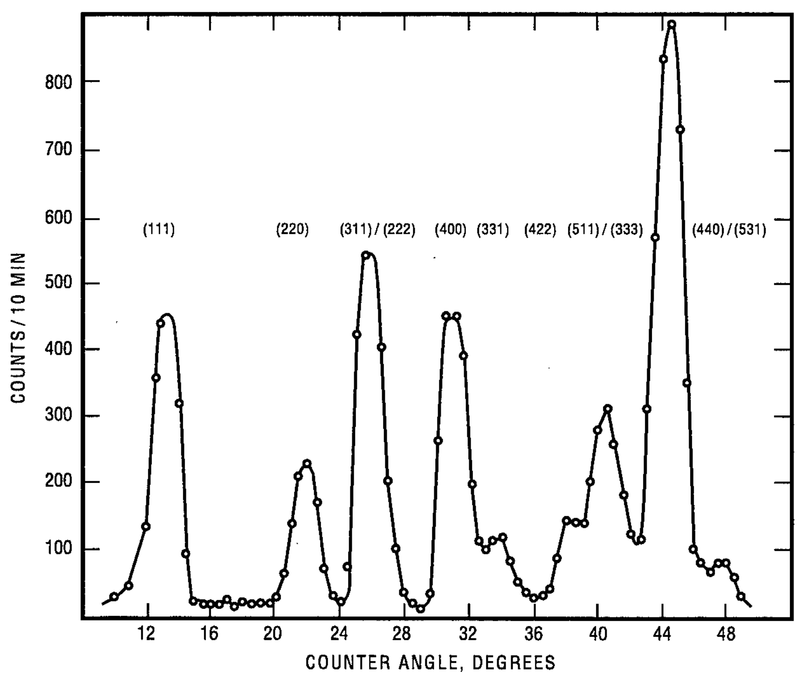
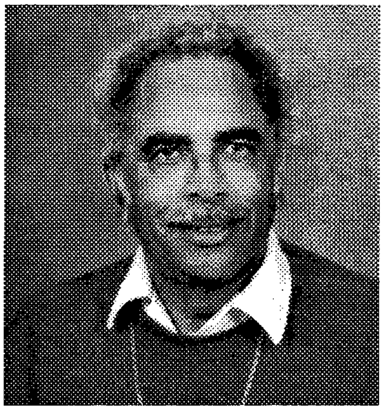


Figure 4.

REFERENCE

(1) W.E. Henry and Mary Jo Boehm, *Phys. Rev.*, 101,1253 (1956)

WARREN HENRY, THE SCIENTIST AND THE MAN



Emory Curtis

Retired, Lockheed Electrical Engineer

When Pete Bragg (Dr. Robert H. Bragg) first asked me to be on a program honoring Warren, I immediately said ,"Yes." The reason: my admiration for Warren as a scientist and a man with a social commitment.

I met Dr. Warren Henry, the scientist, as an engineer in the Lockheed Advanced Projects group when he worked at Lockheed. As an NAACP president, I observed Warren Henry as a man concerned with the social health of our community. He showed me that concern through his work in the open housing campaign that we had in the Palo Alto area and through his drive to get students to make the most of their ability.

In order for you to put my remarks about Warren's work with the Advanced Projects group in context, you need to know something about the tenor of those times in industry. In 1960, when Warren joined Lockheed, the words "affirmative action" and "diversity" were not in the lexicon of these companies' personnel departments. And their hiring and promotion actions showed that these words weren't there.

In those days, Black workers with aerospace companies were rare, period. The first day I started working at Douglass in Santa Monica after graduating from Cal, I saw a white man sweeping the floor as I walked down the hall. Right off that told me we were a rare species in that plant. I was right. In the year or so I was at Douglass, I think there was maybe another Black professional there wearing a tie.

It was two more companies and four or five years later before I saw a Black woman hitting a typewriter for a paycheck in an aerospace company. That was in Minneapolis at Minneapolis Honeywell. At Lockheed, three or four years later, I saw the second Sister sitting at a typewriter for pay.

It took me eight or nine years in the aerospace industry to see a Black man, Dr. Robert Bragg, with a science Ph.D. in that industry. I found out he got a Ph.D. in science because the Chicago plumbers union wouldn't take him in as an apprentice. I could understand that action, because in that day and time, craft unions were keeping us out of apprenticeships all across the country.

Later, I saw the second Black man with a science Ph.D., Dr. Warren Henry, when he joined the Lockheed department I was with, Advanced Projects. Warren, being a product of the South and the black college system, didn't need a union turndown to turn on to science.

At that time, Black professionals of any kind in aerospace companies were rare. Blacks with science Ph.Ds in aerospace were about as rare as hen's teeth. In the main, industries didn't go to Black colleges to recruit. Lockheed was formed in 1933; it was 1962 before they ever set foot in a Black college to recruit. That only happened when the company was pressured by the Kennedy administration's Alliance for Progress to hire minorities, by the NAACP for having segregated facilities and promotion lines in its Georgia plant, and by other companies over Lockheed's C141 contract.

To relieve some of that pressure, Lockheed sent recruiters to Black colleges that spring for the first time in its history even though they were reducing employment by 5% company-wide. Incidentally, because of that 5% reduction, Lockheed sent no recruiters to the majority white schools that year.

Warren was a rarity in many ways when he joined our small Advanced Projects group. For one thing, he was the group's one and only Ph.D. Also, his list of scientific publications easily exceeded by a factor of 10 the total written by the rest of us. Surprisingly, the scientist in Warren was able to be productive in our environment of quick studies and instant shallow expertise as needed for proposals. Our focus was proposals and early investigations of potential areas where Lockheed could focus for greater payoffs. In that environment, naturally decisions often were made with sparse back-up data or, in some cases, from a scientific standpoint, no data at all.

For instance, once we came up with the idea of putting a small motor on a two-seat sailplane for low level nighttime surveillance in the Mekong Delta during the Vietnam war. Various unclassified reports pointed to that problem. To get funds for that project, we met with our Division Manager, went over our solution to the problem, and gave him the performance data the unit would meet. (Actually, the performance data was what we felt the system had to meet for the military to buy it.)

The division manager, Starr Colby, sent us out of his office with these words, "Don, you are just hand waving, you have no data." Back at the office, Don Gailbraith, the manager of Advanced Projects, got flip chart paper and made charts using the same data we had presented to Colby. The next day a presentation was made to Colby, and he approved the project. In his view, spoken data is hand waving; the same information on flip charts is data.

Obviously, that type of environment must have been anathema to Warren because it was counter to his life as a scientist. Nevertheless, to Warren's credit, he turned out to be one of the very few Ph.Ds that I had ever seen operate successfully in that kind of environment. He tried to make us scientifically better than we were.

He did it with me on a microwave radiometer test I was running. He helped me interpret my data and encouraged me to contact Dr. Dickie, the father of microwave radiometry. It was some time later that I learned that Warren knew Dickie personally when both of them were working at the MIT Radiation Laboratory during World War II.

From working with Warren at Lockheed, I can see why he inspired so many students to be even better than they thought they could be. He is patient, has a wellspring of scientific knowledge, and gets a joy out of seeing someone use his words and logic to get a better grasp on a problem. I saw that same quality in him outside of work, in the community. A commitment to make things better.

Because of his broad and deep scientific knowledge and his community interest, in my mind Warren Henry is a true Scientific Renaissance Man. My hat is off to Warren, and I hope his good qualities, as a man and a scientist, rub off on more of us. The community needs more Warren emulators.

Zolili Ndlela, Ph.D.

Panel: Trouble the Waters
Associate Professor, Department of Physics & Astronomy
California State University, Sacramento

With profound delight and respect I am pleased to attend this symposium at the Lawrence Berkeley National Laboratory to honor a mentor, a friend, and a teacher, Dr. Warren Henry.

Let me start by giving you an outline of the context in which I view Dr. Henry. I want to trouble the waters, so bear with me.

Evidence today suggests that humanity probably originated in Africa, some two to four million years ago. With time these Africoid ancestors of humanity dispersed throughout the globe, leaving their footprints wherever they tread. With time, these Africoid people founded the rudiments of civilization, science, art, technology, agriculture, and other human enterprises. Some of the monuments they built still stand and their influence still remains.

One of the best known of their civilizations is Egypt-Ethiopia, perhaps because it has enthralled, entranced and influenced so many present day societies, especially western nations. But there were many, many others including the ancient Dravidians in Eurasia and India, and the Ainu in China and Japan. We, today, stand on the shoulders of these ancient people and by grace are able to extend their early discoveries and even make our own. The African contribution to civilization is broad and deep, and if in modern times the names of the men and women who have made their mark are not well known, or if they are lost, or ignored, their contributions are still important. Thus, I see Dr. Warren E. Henry as one more link in this chain dating back to antiquity, endowed with all the gifts of genius, compassion, and wonder that has characterized humanity.

So the next time you read a physics text that starts out, "The Greeks..., Aristotle" or some such remark, envision Warren Henry's noble and handsome face. Then you are certain to see another great face of science.

Now for some recollections. I had heard a great deal about Dr. Henry before even meeting him in person. I had spoken with several graduate students and some of his former students who were professional physicists themselves and who often gave very interesting anecdotes about Dr. Henry. One of the standard ones was that Dr. Henry would often leave you in the lab to work on a particular experiment and problem. Then just when you thought you could slacken up, believing everyone was gone and in bed, especially if it was 2 a.m. in the morning, Dr. Henry would show up and ask how things were going! The stories usually ended, though, with the remark that Dr. Henry was the kind of person who would go out of his way to assist his students and friends.

I remember when I was a student at Howard University and had applied to the Graduate School of Physics at Stanford University. Dr. William Fairbank, whom Dr. Henry knew, was a noted physicist and a professor at Stanford University at that time. Dr. Fairbank had also been doing some work on fractionally charged particles and was scheduled to give a talk on his latest results at John Hopkins University, in Baltimore, MD. Dr. Henry found me, bundled me into his car, and drove me to John Hopkins University to hear the talk and to personally meet Dr. Fairbank. Dr. Henry in his quiet, nonassuming, yet persistent, and persuasive manner pushed through all the other "notables" in the auditorium, introduced me to Dr. Fairbank and explained to him that I was one of his students who was applying to Stanford. Now I don't know if this meeting increased my chances of getting into Stanford University or not. But what struck me was the effort that Dr. Henry was willing to go to on my behalf.

Like several other students I knew at the time, we often had "last minute" difficulty with the administration at Howard University. Dr. Henry was always there to help and to rescue. With a simple statement of "Let me see what I can do," Dr. Henry worked his magic. Whatever your problem, it was solved; whatever document, form, or approval that you needed, it was obtained, sent to the appropriate authority, and approved.

Dr. Henry also gave me a feeling of personal worth and pride in what I was doing. When I worked at NASA as part of my graduate research, Dr. Henry would be sure to keep in contact with my advisor to be certain that I had all the equipment, supplies, or services I needed. When a critical part of the experiment had been completed, Dr. Henry would come by to personally inspect it, to give words of encouragement, to compliment, or to make suggestions. One day, he notified me that he would "arrange" to take a couple of pictures of the lab. I didn't quite know what that meant at the time. What he did was to bring a professional photographer with him, who took pictures of the experimental setup. Then he had the photographer take pictures of me with the equipment, with my advisor, Dr. Harry Morgan, and with Dr. Henry. That may seem like a small matter, and it may be standard practice at some institutions, but it had never happened to me before! The fact that Dr. Henry had arranged all of this indicated to me that he thought my work was important enough to be preserved on film, and that he thought I was important enough to have this done. That kind of personal and professional concern has always marked my relation with Dr. Henry.

Whenever I was in the Washington, D.C. area and able to see Dr. Henry, it was sure to be a memorable and enjoyable occasion. Whether we were having dinner at his invitation and expense at the Cosmos Club, or at the Howard Inn, the evening was certain to be a delight. Conversation with Dr. Henry was always interesting, informative, and just plain enjoyable. It never ceased to amaze me that Dr. Henry could talk in detail about a topical area of physics, then amuse and regale you with some cultural, historical, or political story and insight.

Many of you may be aware that Dr. Henry obtained his Ph.D. from the University of Chicago. Then, the university was not particularly hospitable to Black students, especially one from a small town in Alabama. The story of how he passed his qualifying exam is one that I always like to repeat, so bear with me if you've heard it before.

With his usual spirit of cooperation, Dr. Henry approached all of his fellow graduate students regarding the upcoming qualifying examinations, explaining that if they studied together, each of them would have a better chance of passing. Since passing depended only on obtaining an established minimum score, there need not be any competition between the students. Dr. Henry was the only Black student in the department, and most of the students probably did not want to study with him for that reason alone, but they clearly dismissed his academic and intellectual ability as well. One particular student, in what was meant to be a gratuitous favor, offered that if he (Warren Henry) had any questions he could come to him and ask for help. Well, the day the examination grade was posted, Warren went to see how he had done, and passed the student who had proffered "help." (I'm told that Dr. Henry may already have known the results.) Warren asked, "How did we (all of the students who took the exam) do on the exam?" Somewhat angrily, the other student responded that only one person had passed the exam, and that he, Warren Henry, was the student who had passed! Well, need I say more?

Dr. Henry was a fighter, too! On many different fronts. But one that has stayed with me was his challenge of the continued and prevailing attitudes that view Black people as less intelligent or capable than other ethnic groups. He stood up to and confronted several of the "giants" of the physics community in the late 60s, like Dr. William Shockley, who claimed that Blacks were less intelligent than other people and had little aptitude for intellectual and scientific pursuits. Dr. Henry was quick to challenge such outrageous views and confronted them head on. With a small group of Black physicists and concerned supporters, Dr. Henry faced the issue at a national meeting of the American Physicist Society in the nation's capitol, which must have been a shock to everyone present. This same controversy also appeared in the "Letters" section of *Physics Today*. In one issue I recall, a white physicist wrote that the job market was shrinking and that any program to recruit Blacks into the discipline should be abandoned, adding that any job that went to a Black physicist was one job less for a white physicist! Of course Dr. Henry continued and still continues to resist any such suggestions and attempts to reshackle this portion of the American population.

Dr. Henry, I want you to know that several generations of Black (and non-Black physicists) owe you a great debt and consider you a real hero, an intellectual giant, and a role model. Personally, I thank you yet again for the privilege of having been one of your students, for having you as a mentor and a friend.

W Wise and knowledgeable, a true scientist He

A Affection for friends and Family

R Revered by all for unselfish Acts

R Respected and Loved for his graceful Tact

E Excellence in work he always Demands

N Noble of spirit, his loyalty Commands

H Honor surrounds him shining bright as if Gold

E Energy abounds such a part of his Life

N Nubian soldier fighting battles Untold

R Righteous and courageous never flinching from Strife

Y Yeoman for his people, brave, proud, and Bold.

Informal Remarks at the Dinner of the Warren E. Henry Symposium

Ronald E. Mickens, Ph.D.

Distinguished Callaway Professor of Physics, Clark Atlanta University and Historian of the National Society of Black Physicists

We are assembled here tonight to cap this day of celebration on the life and scientific contributions of Warren E. Henry. He is our friend and trusted colleague in the continuing search for truth, knowledge, and a just world. He is a gentleman and a gentle man.

Warren's life and various scientific contributions follow in the tradition of our forefathers:

Benjamin Banneker (1731-1806),
Edward Bouchet (1852-1918), and
Elmer Imes (1883-1941).

It should also be noted that Warren began his formal training during a period (1936-1945) when other giants in our community were starting their initiation into the world of research, scholarship, and teaching. These people include Herman Branson, James Lawson, Hubert Mack Thaxton, J. Ernest Wilkins, and others.

This gathering of colleagues, friends, and family of Warren E. Henry is but one aspect of our continuing effort to make known to the general society and various scientific and scholarly communities both his and our contributions, our concerns, and the joys/sorrows of our shared experiences as scientists and enlightened citizens of the world.

Today's W. E. Henry Symposium is but the latest in a series of celebrations devoted to the works and life of Warren as a scientist who has made fundamental measurements in a magnetism and low temperature physics. Accolades have included the following:

- "Second Awards Ceremony for Outstanding Black Physicists" Washington, DC - 1975 (Warren E. Henry honored, along with Herman Branson and James Lawson)
- "Magnetic Phenomena: The Warren E. Henry Symposium on Magnetism, in Commemoration of His 80th Birthday and His Work in Magnetism" Washington, DC - 1988
- NSBP's "Career Achievement Award" Newark, NJ - 1994
- Howard University Libraries "Excellence at Howard," 1997 Honoree - Warren Elliot Henry

His scientific work has received both national and international recognition. For example, he was a participant and discussant at the 1976 International Conference on Magnetism held in Amsterdam, The Netherlands, and he was invited to present a paper on magnetism at the December 1976 American Physical Society Meeting held at Stanford University.

It is of interest to note that most students and some scientists' first introduction to Warren's scientific work is in courses on solid state physics or material science where his research has been extensively quoted. In particular, all editions of Kittell's book *Introduction to Solid State Physics*, refer to Henry.

Another historically significant fact is that Warren E. Henry has had an extraordinary number of contacts with other world class scientists. A partial listing of Nobel laureates from whom he has taken courses/seminars, held scientific discussions, and/or interacted with on experiments, is as follows; Author H. Compton, Peter Debye, Enrico Fermi, Maria Goepert-Mayer, Robert Hofstadter, Robert Mulliken, Lars Onsager, Wolfgang Pauli, I. Rabi, Glenn T. Seaborg, and Harold Urey. Along with these associations, his distinguished scientific work was done in some of the most important research laboratories in the United States: University of Chicago (1938-41; 1946-47); The Radiation Laboratory, MIT (1943-46); U.S. Naval Research Laboratory (1948-60); and Lockheed Missiles and Space Company (1960-69). In most of these laboratories, Warren was the only "Negro" employed at the level of true scientific involvement in the activities of the institutions. Warren's scientific contributions and his public no-nonsense stance against racist practices generally forced his employees to change their policies. This cleared a path for other "Negro" scientists to follow.

Of equal importance are Warren's effective efforts as both teacher and mentor of students for over half a century. His participation in these activities ranged from being a high school principal in Alabama to teaching the fundamental principles of aviation physics to "The Tuskegee Airmen," and to becoming Professor of Physics at Clark, Morehouse, and Spelman Colleges, and Howard University. His further concern for the inadequate representation of minorities in physics and science in general, led to his initiation of the Committee on Minorities in Physics of the American Physical Society and to the formulation of policies at Bell Laboratories which eventually gave rise to their graduate scholarship and summer research programs. Warren's work in this area continues with his current involvement at Howard University in the Minorities Access to Research Careers Program.

In conclusion, we are gathered here tonight, after a full day of presentations and reminiscences, to salute Warren E. Henry as a respected elder in the world scientific community, a good family man, a true friend and comrade, a master teacher and mentor of students, and a person who has and continues to "light up" our lives by his presence and thought.

PERSONAL REMINISCENCES OF WARREN E. HENRY

by Glenn T. Seaborg, Ph.D.

Describing Warren E. Henry's contributions to science would take many pages. His work in the fields of superconductivity, magnetism, and low temperature physics is superb. Early on, he literally "wrote the book" on the magnetic susceptibility of materials in extremely low temperature environments. All these achievements are well documented. In this forum, however, I would like to recall my personal acquaintance with Dr. Henry.

I have known Warren Henry for nearly forty years. As I remember, it all began at UC Berkeley. Warren needed help securing the use of the Giauque Laboratory facilities on campus for his pioneering work in low temperature physics. I happened to be the Chancellor of Berkeley at the time, and was pleased to be able to assist him. We spoke often during his subsequent visits to conduct experimental work at UCB and kept in touch throughout the Sixties, when I was running the Atomic Energy Commission.

In the spring of 1972, he was continuing his extremely fine work on the magnetic susceptibility of plutonium metal. I wrote in my diary on Tuesday, April 18, 1972:

"He will use Pu242 first and then hopes to use Pu244 when it is available. He has learned that the Giauque magnet in the Low Temperature Laboratory on the campus will not be restored to the degree required, so he is making arrangements to use some of the magnets in LBL.
He said he will discuss this with Director (Edwin) McMillan this afternoon. He said he has found a technician in the Nuclear Chemistry Division who will help him encapsulate the Pu244 in a metallic aluminum container. I said that we would cooperate in every way to make his work possible."

In 1974, Warren Henry came to my assistance when my son-in-law, Bill Cobb, decided to change careers and go to medical school. Although his previous academic record at Harvard was excellent, Bill was nearly 30, too old by the narrow standards of many medical schools to be considered for admission. Warren, bolstered perhaps by his understanding of how talent can be hampered by societal prejudices, supported Bill's application to Howard University Medical School. His assistance came at a crucial time for Bill, who excelled at Howard and has gone on to a successful medical career as an expert on infectious diseases. My wife, Helen, and I remain indebted to Warren for his foresight and kindness.

Our paths have continued to cross over the ensuing years. He still maintains the unflagging commitment to research, education and public service that has distinguished his career. Always a productive scientist, Warren Henry can count significant achievements as an inventor, educator, writer (including contributions to a number of seminal textbooks), international lecturer, and a champion of physics education for minorities. How many of us can say we accomplished as much and so well?

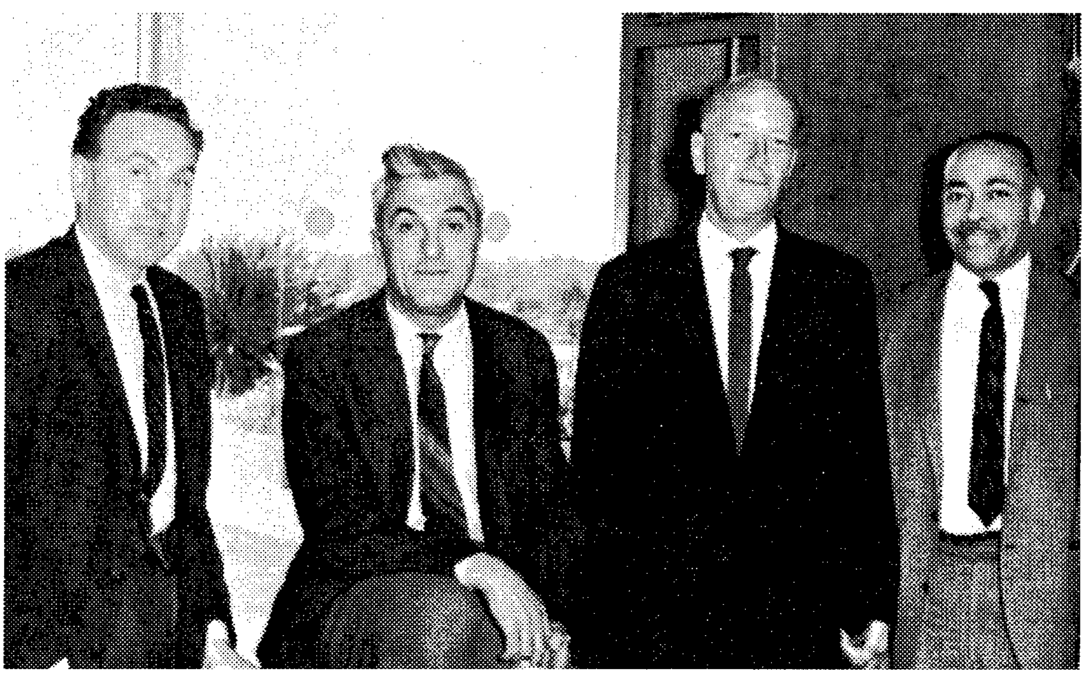
I am delighted to see him honored at this richly deserved symposium, and am pleased to contribute to the program booklet commemorating the event. To Warren Henry, let me say that I look forward to many more years of fruitful endeavor and friendship.

Bio Sketch of Dr. W.E. Henry

Physicist Warren E. Henry, who has worked nearly seven decades in the fields of magnetism and superconductivity, has earned praise as one of the most eminent African-American scientists in this nation's history. The scientist, educator and inventor who grew up in Alabama was a colleague of George Washington Carver at Tuskegee Institute and over time a colleague of 17 Nobel Laureates, including Dr. Glenn Seaborg. His science career took him through top-secret radar research during World War II at the MIT Radiation Laboratory (1943-1946) and guidance systems designed for missile detection in submarines at Lockheed (1960- 1969). During this period he also worked at UC Berkeley as a guest investigator at the Giauque Laboratory under the auspices of Dr. Glenn Seaborg. The Independent Research Fund at Lockheed paid for the cost of using the Giauque magnet and other support equipment. Within his broad and diverse portfolio was a period of teaching special physics courses to young officer candidates of the Army Air Corps who became famous as the Tuskegee Airmen of World War II.

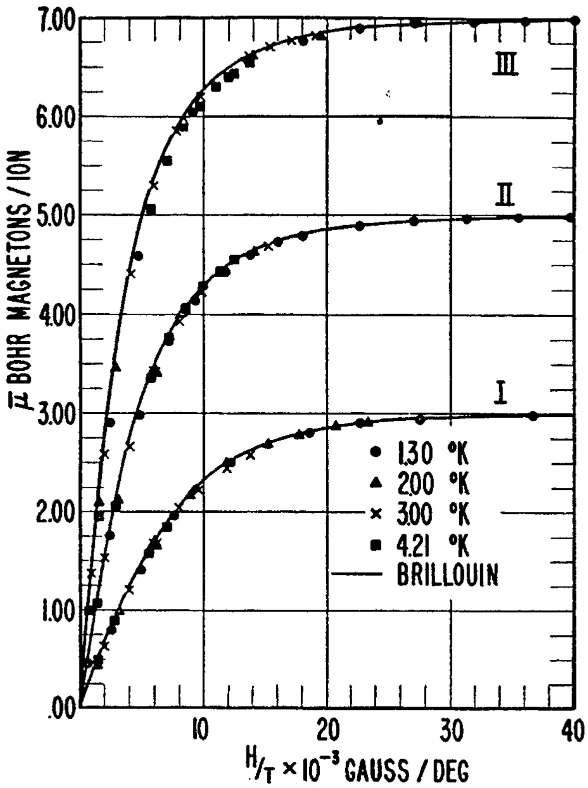
Reunion at MIT of researchers and staff that worked on research related to the war effort. Dr. Henry worked to improve radar signaling capability. Locating enemy aircraft with radar was critical to the US success during World War II.

Dr. Warren Henry as a research physicist at the Naval Research Laboratory, Washington D.C., May 1956

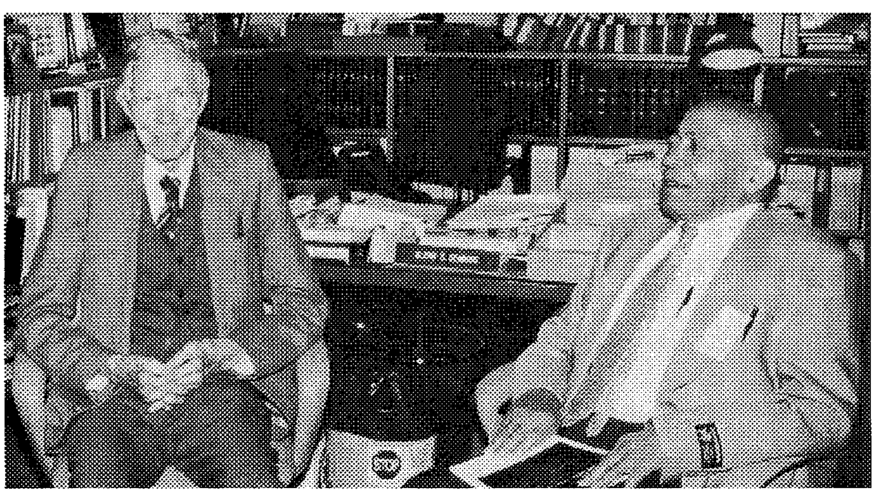


BRAINPOWER-LMSC's weekly research colloquia are attended by some of the world's top scientists. At a recent session at which the internationally famed Dutch physicists Dr. C.J. Gorter, second from right, spoke on superconductivity, attendees included two Nobel Laureates, from left, Prof. Robert Hofstadter and Prof. Felix Bloch, both of Stanford. Right is Dr. Warren Henry, colloquium chairman.

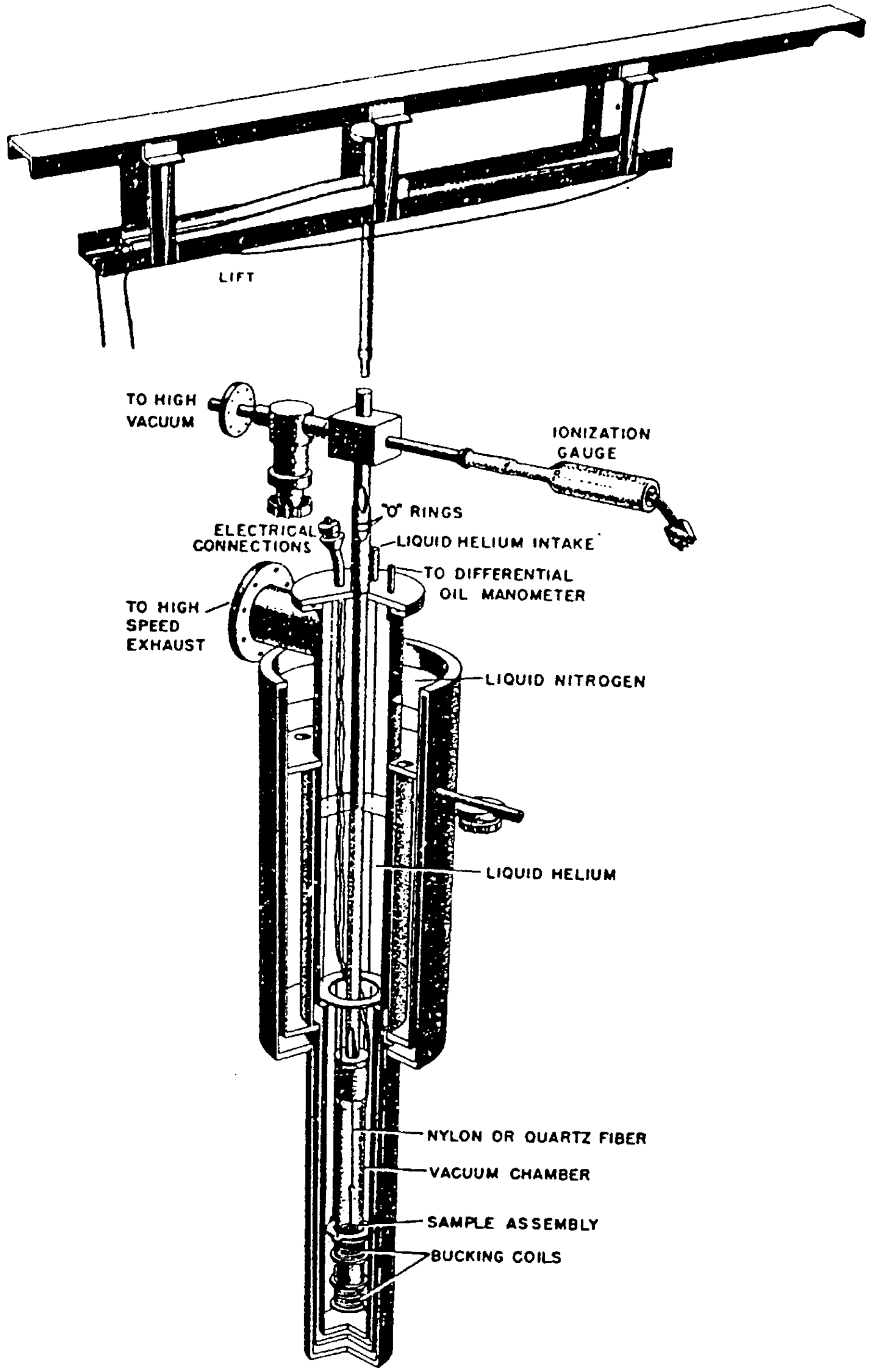
–Lockheed Missile and Space Company's August 1962 "Star" newsletter.



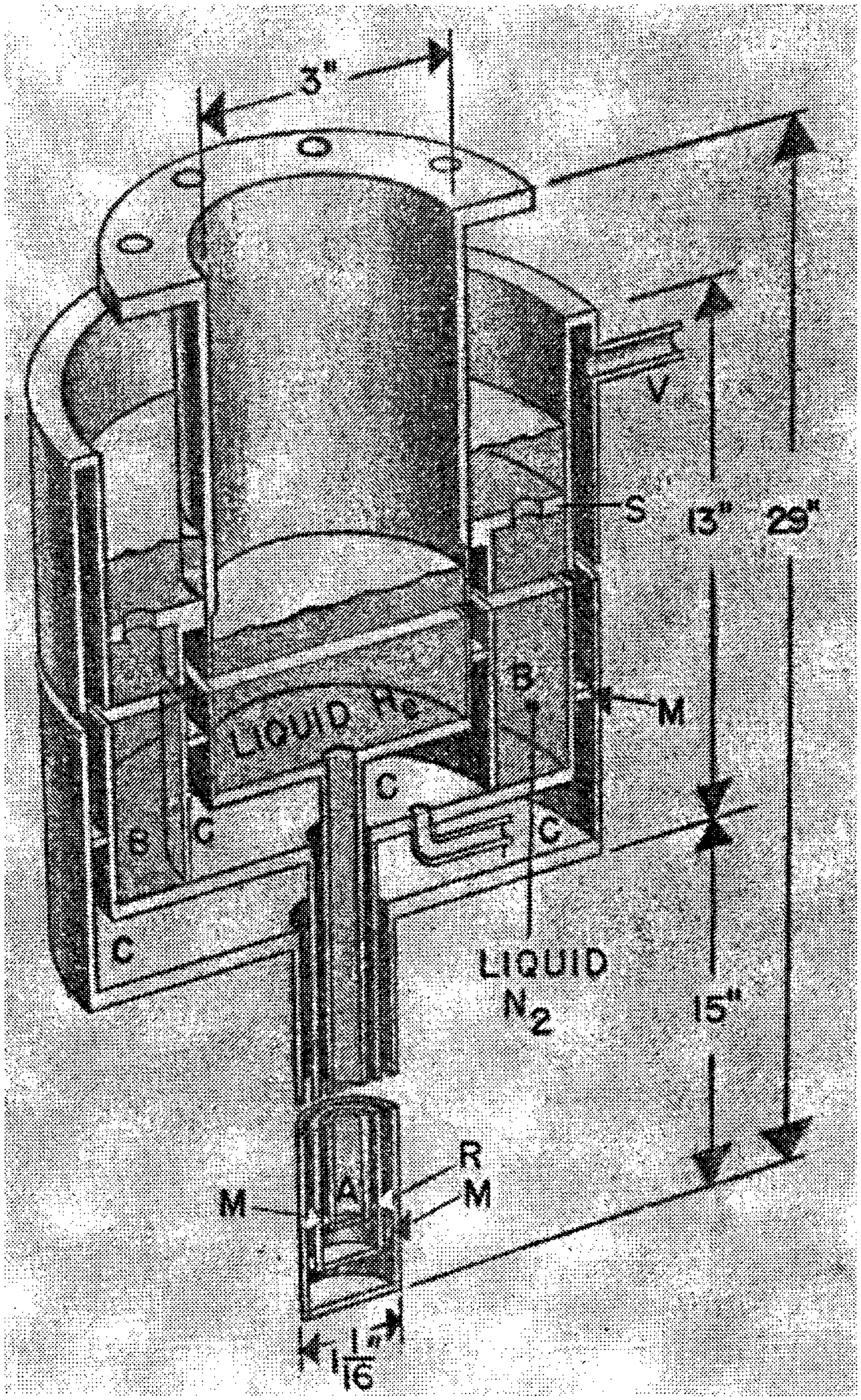
This is a plot of the average magnetic moment per ion for potassium chromium alum, iron ammonium alum, and gadolinium sulfate octahydrate. The magnetic moment was measured using the experimental equipment illustrated on pages 6 and 7. This data appears in the physics text, Introduction to Solid State Physics *by Kittel, 4th edition, page 503* .



Dr. Glenn Seaborg and Dr. Warren Henry renew their acquaintance during the National Society of Black Physicists Conference held at LBNL, March 1997

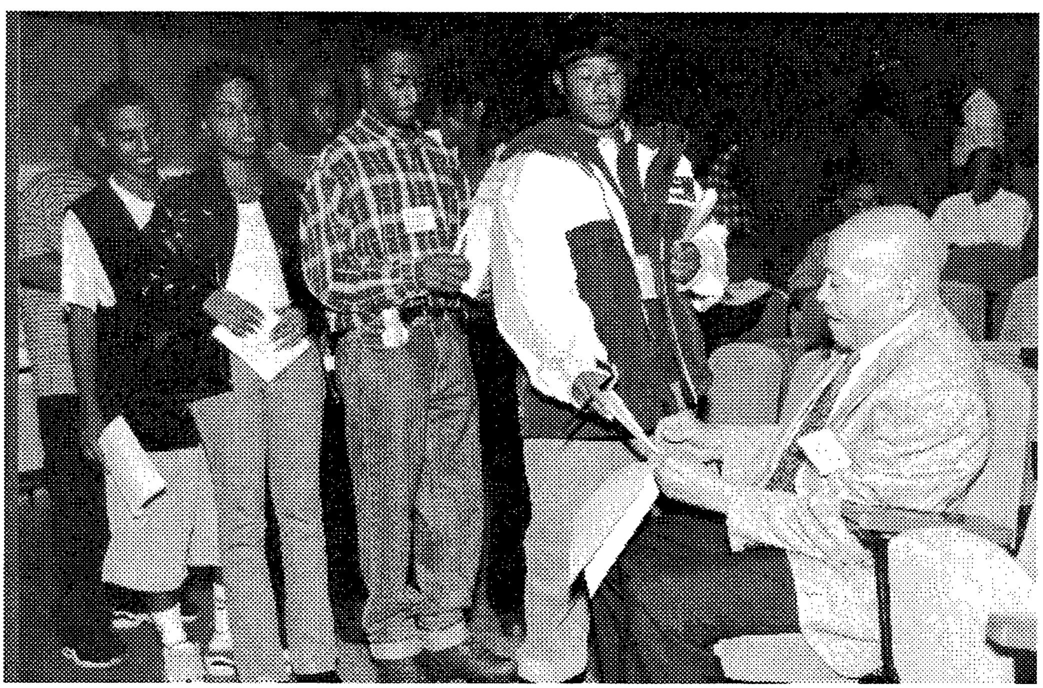


The Magnetic Moment Differential Fluxmeter in the figure above is a device invented by Dr. Warren Henry. It was used to make the paramagnetic measurements which appear in the graph on the cover of this booklet. It consisted of a sample displacement lift, and a flux change indicator comprised of a self-buckling coil system in series with a controllable resistance and a ballistic galvanometer with a 27-second period. The sample displacer was designed to avoid mechanical shock and motion of the coil system with respect to the magnet. The coil system consisted of about 2000 turns of No. 40 wire on each of the oppositely wound bobbins (3.5 cm in diameter). The measurements were made by causing the sample to shuttle, in about .5 second, from the middle of one coil to the middle of the other. The positions at the ends of the 4-cm excursion were reproduced to + 0.003 cm. The net flux change in the coils (due to the motion of the sample), and accordingly the deflection of the ballistic galvanometer, was proportional to the moment of the sample.

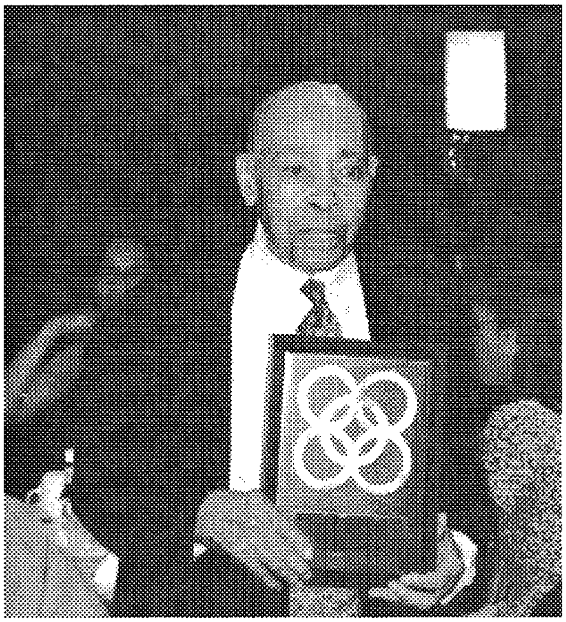


This Metal Dewar for Helium was invented by Dr. Henry in 1950 to allow magnetic moment measurements to be made at temperature as low as 1.3° K. The magnetic moment of the sample, a solid sphere, was kept in contact with liquid helium in the Metal Dewar (the vacuum chamber around the sample was removed). A Bitter type solenoidal magnet capable of producing fields of over 50,000 gauss was used.

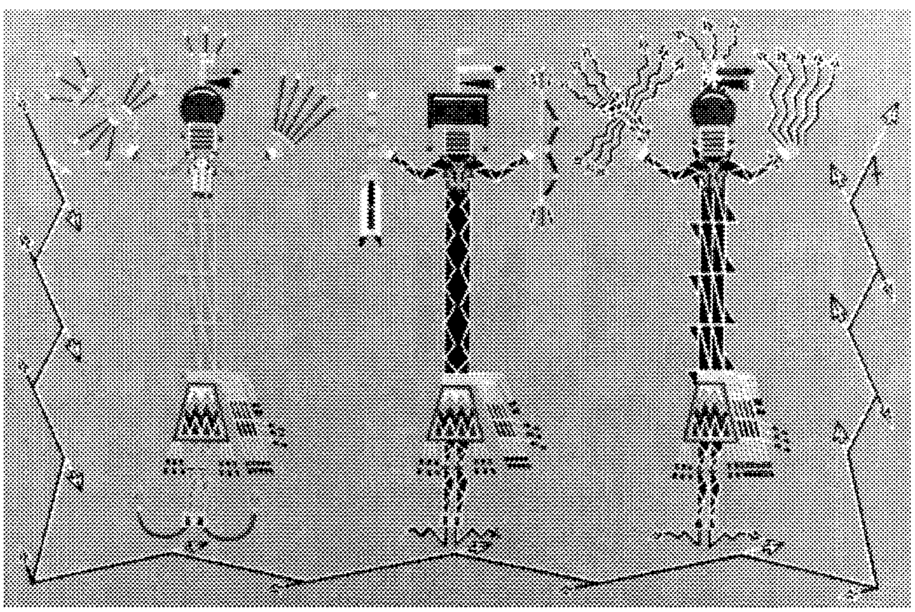
Left is Eva Henry, Dr. Henry's daughter; Center is Dr. Henry; Right is Dr. Glenn Seaborg



Students from McClymonds High School in Oakland line up for autographs.



Pictured is the Ghanian Adinkra symbol, Kuntinkantan (for humility and servitude) mounted on a plaque which was presented to Dr. Henry at the Banquet held in his honor following the Symposium. The symbol was cast in Ghana and shipped to the US through the collaborative efforts of Dr. Francis Allotey, a research physicist at the Ghanian Atomic Energy Commission.



Pictured is a Navajo sandpainting commissioned by physicist, Dr. Fred Begay of the Tsidlaad family and painted by Lynn Stevens of the Astsidi family. It was made to pay tribute to Dr. Henry for his contributions to Navajo education.

The sandpainting is a geometric representation of the structure of light forms in Nature and its use in sacred health healing ceremonies. The painting depicts the supernatural family: mother (Changing Woman, Asdzaa Nadleeche) protected by her twin sons with weapons (right side-Naayee'Neezghani (monster slayer) armed with Hatsoo'algha, LAS ER, and left side Bajish Chini (child born of water) armed with Atsiniltl'ish, electrical discharge, given to them by their father (the sun)).

The Organizing Committee (left to right): Harry Morison, Hattie Carwell, Harry Reed, Robert Bragg, not pictured is Keith Jackson.

CURRICULUM VITAE

WARREN E. HENRY

PROFESSOR OF PHYSICS, HOWARD UNIVERSITY, WASHINGTON, DC

SPECIALTY:	Magnetism, Low Temperature Physics Solid State Physics
DATE OF BIRTH:	February 18, 1909
PLACE:	Evergreen, Alabama
MARRIED:	Jeanne Pearlson Henry
CHILDREN:	Daughter, Eva
EDUCATION:	**Postdoctoral Study**

1944-46	Mathematics - Massachusetts Institute of Technology
1946-47	Physics - University of Chicago Postdoctoral Fellowship
1948-51	Physics - University of Maryland
1950-51	Physics - Catholic University of America

Ph.D., Physical Chemistry and Physics

1941	University of Chicago Advisor: Dr. T. F. Young
Dissertation:	"I. Resistance Thermometry and II. An Experimental Investigation of the Possibility of Using Alternating Current Techniques in the Measurement of Small Temperature Differences."

M.S., Organic Chemistry

1937	Atlanta University Advisor: Dr. Kimuel A. Huggins
Thesis:	"The preparation and Arornination of 1-Meta-bromphenyl 4-Phenyl Butadiene."

B.S., Mathematics

1931	Tuskegee Institute

SPECIAL ASPECTS OF EDUCATION AND TRAINING

College Majors - Mathematics, English and French
College Minors - Physics, Chemistry and German

- At the University of Chicago, there was some additional exposure to mathematics, such as systems of differential equations and certain courses in applied mathematics and Logical Foundations of Mathematics in the Philosophy Department under Rudolph Carnap. There was exposure to all courses offered in Physics and in Chemistry between 1939-41.
- At the Massachusetts Institute of Technology, there was exposure to all courses offered in Mathematics that had not been taken elsewhere.

SPECIAL COURSES

- At the University of Chicago, a course in "Carcinogenic Compounds" given by Professor J.W. Cook of the London Cancer Hospital.
- At Lockheed, courses in Reliability, Oceanography, Mewtrix Calculus (Van der Korput) were taken.

COURSES AND SEMINARS WITH NOBEL LAUREATES

1. A. H. Compton. Course in Quantum Mechanics, University of Chicago
2. James Franck. Course in Physical Basis of Photochemistry, University of Chicago
3. Maria Goeppert-Mayer. Statistical Mechanics, University of Chicago
4. Wolfgang Pauli. Nuclear Forces (Series of 10 Lectures), Massachusetts Institute of Technology
5. Robert Mulliken. Course in Molecular Spectra, University of Chicago

OTHER ASSOCIATION WITH NOBEL LAUREATES

6. W. F. Giauque. Independent Research in Professor Giauque's Low Temperature-High Temperature-High Magnetic Field Laboratory over the 8-year period, 1961-69. University of California, Berkeley.
7. Robert Hofstadter. Worked a short time in the High Energy Laboratory at Stanford University considering plans to determine shapes of atomic nuclei from scattering of high energy electrons. 1955.
8. P. Debye. Learned from him how to make color slides for presentations at scientific meetings.
9. H. Urey. Heard lectures by him and participated in seminars with him.
10. Enrico Fermi. Heard some lectures by him and also had the pleasure of playing tennis with him.
11. Glenn T. Seaborg. Had many conferences with him. While Glenn was Chancellor at the University of California, Berkeley, he arranged for me to use facilities for my research at the university.
12. L. Neel. Conferences with him at the University of Grenoble. Participated in colloquia there.
13. I. Rabi. Collaborated with him on a K-band radar project in the Radiation Laboratory at Massachusetts Institute of Technology.
14. Lars Onsager. Had many conferences with him on statistical mechanics at international meetings and at a meeting of the National Academy of Sciences. California Institute of Technology, 1968.
15. F. Bloch. Had many conferences with him. Also, in business meetings when he was President of the American Physical Society.
16. Albert Szent-Gyorgi von Nagyrapolt. Discussions and seminars on Thermodynamics of Muscle Action in Mussels. Bethesda Naval Hospital Institute of Technology Radiation Laboratory.
17. Julian Schwinger. Series of ten Lectures on Electrodynamics of Nuclear Forces. Massachusetts Institute of Technology Radiation Laboratory.

ACTIVITIES AT HOWARD UNIVERSITY

- Professor of Physics
- Head, Task Force on Environmental Studies
- Chairman, Committee on Preservation and Protection of Creative Ideas and Work of Faculty, Students and Staff of Howard University
- Coordinator of the Affiliation between Howard University and the University of California
- Research Director, Masters and Ph.D. Theses

ACTIVITIES OUTSIDE HOWARD UNIVERSITY

- Chairman, American Physical Society Committee on Minorities in Physics
- President, Committee on Minority Participation in Physics, Inc.
- Chairman, Committee on Education, Society for Social Responsibility in Science
- Representative, Washington Academy of Sciences to the Joint Board on Science and Engineering Education for the District of Columbia, Northern Virginia and Maryland
- Member, Committee on Minority Participation in Physics

PRIOR EXPERIENCE

1969- Professor of Physics, Howard University

1968-69 Visiting Professor of Physics, Howard University

1960-69 Lockheed Missiles and Space Company

1967-69 Senior Staff Engineer and Senior Staff Scientist, Advanced Concepts Division, Advanced Programs

Brought into being new concepts and combinations of old concepts relating to space and other related activities, oceanographic programs, electronic programs, thermophysics programs, aeromechanics programs, magnetic programs and cryogenics programs.

1965-67 Senior Staff Engineer, Guidance and Control Design, R & D

Consulted on design and reliability of electron-optical and electromechanical components and systems, as well as sensors for use in space systems and ocean systems. Also advised on magnetism, low-temperature physics, radiation effects, and solid state physics. Planned and conducted research on magnetic atomic constants and inter-atomic interactions in materials; published research results.

1963-65 Senior Staff Engineer, Advanced Systems, Information Technology, R &D

Responsibilities same as 1965-67.

1960-63 Senior Staff Scientist, Electronic Sciences

Consulted on applications of the magnetic and cryogenic properties of materials to space and aeronautical design problems. Discovered several new superconductors and a new type of magnetic behavior, namely, non-monotonic dependence of magnetization on magnetic fields in an itinerant electron ferromagnetic alloy. Produced highest intensity of magnetization in a magnetic material through the use of high magnetic fields and low temperatures. Studied threshold fields in materials exhibiting ferromagnetic-antiferromagnetic exchange inversion. Initiated theoretical study of correlation of magnetic-electrical anomalies with optical properties of special materials. Designed special equipment for magnetic and electrical measurements at low temperatures and high magnetic fields. Presented research papers at international meetings and at meetings of the American Physical Society. Gave numerous invited lectures, and industrial research laboratories.

1948-60 U.S. Naval Research Laboratory

Supervisory Physicist in Cryogmagnetism. Directed research on Fermi surface of metals, studies on oscillation in resistance and magnetic susceptibility with magnetic field, transport properties of alkali metals, properties of matter below 1°K, Faraday effect and resistance minima. Conducted research on saturation magnetization of paramagnetic salts; experimental determination of molecular fields and exchange integrals of ferromagnetic and antiferromagnetic substances; magnetic structures of ferromagnetic materials; magnetic radiation damage and experimental determination of atomic displacement energies; crystalline electric field effects on energy levels in magnetic materials, superconductivity of uranium; contribution of 4f electrons to magnetic properties of lanthanide metals; ferromagnetism of uranium compounds; and transport properties of germanium. Also supervised the development of high magnetic field facility at NRL which produced the highest steady magnetic fields in the world up to that date (precision was increased and efficiency more markedly improved by decreasing the contact resistance at the pressure contacts). Invented a metal Dewar for liquid helium, a magnetic-moment lift and a controlled-atmosphere chamber. While with NRL, published about 30 technical articles and 25 abstracts in domestic and foreign scientific journals; and presented more than 12 research papers at meetings.

1954-58 Lecturer, Howard University

Taught courses in solid state physics.

1947-48 Acting Head, Department of Physics, Morehouse College

Taught electricity and magnetism. On an exchange basis, taught a course in atomic structure at Atlanta University. Graduated 6 Physics majors.

1946-47 Research Associate in Physics, University of Chicago, Institute for the Study of Metals

Did research on internal friction of brass. Also taught at the university.

1943-46 Radiation Laboratory, Massachusetts Institute of Technology

(On leave from Spelman college.) Did research on the electrical and magnetic properties of germanium for use as second detectors in radar systems. Did design work on radar components such as video amplifiers, IF amplifiers and anti-jamming devices. Designed test equipment, such as pulsers and high-impedance probes. At the end of the war, worked on technical publications and in the basic research program of the new Electronics Laboratory at MIT. Worked out the heat dissipation tests for the helium liquefier under development and design by Professor Collins. Collaborated in experiments on microwave skin effect in superconductors and on low-temperature electrical properties of germanium. Initiated a program on expansion coefficient of germanium as a function of temperature and designed an instrument for this investigation.

1943-46 Associate Professor of Chemistry and Physics

Taught chemistry and thermodynamics at Atlanta University on an exchange basis.

1941-43 Taught chemistry, physics, and radio, Tuskegee Institute.
1936-38

1939-41 Graduate Studies at University of Chicago

1934-36 Taught physics, Spelman College and Morehouse College.

1931-34	Principal, Escambia County Training School, Alabama Taught mathematics, French, physics, and chemistry.

SPECIAL ACTIVITIES

1958	Chairman, NRL - RESA Scientific Awards Board
1958	Chairman, Washington Chapter, Federation of American Scientists
1957-58	Member, Ad Hoc Committee on Science Education, Naval Research Laboratory
1956-58	Scientific Representative, Board of Prince Georges County Science Fair Association, 1956-57; Financial Secretary, 1958
1956	Solid State Representative, Naval Research Laboratory's Science Teacher Research Scientist Exchange
1954-55	Vice-President, Naval Research Laboratory Branch, Scientific Research Society of America, 1954; President, 1955
1952-53	Secretary, Naval Research Laboratory Branch, Scientific Research Society of America
1952	Member, Scientific Editorial Board for Proceedings of the Conference on Cryogenics Lectured at various companies and universities on research in low-temperature physics, germanium and magnetic properties of materials. Lectures were given at the University of Grenoble (France), University of Leiden (Holland), Johns Hopkins University, Duke University, University of North Carolina, Howard University, Illinois Institute of Technology, Fisk University, Stanford University, Massachusetts Institute of Technology, Atlanta University-Morehouse College, Tohoku University (Japan), U.S. Naval Postgraduate School, Brookhaven National Laboratory, Lawrence Radiation Laboratory (Livermore), Ampex Corporation, United Aircraft Company, and Lockheed Missiles and Space Company.

SOCIETIES

- American Physical Society (Fellow)
- American Association for the Advancement of Science (Fellow)
- Scientific Research Society of America
- Institute of Electrical and Electronics Engineers
- American Chemical Society
- Philosophical Society of Washington
- Washington Academy of Sciences
- New York Academy of Sciences
- Institut International du Froid (Paris)

- Nederlandse Natuurkundig Vereniging (Amsterdam)
- Society of the Sigma Xi
- Sigma Pi Sigma
- Society for the Encouragement of Literature and the Arts

LISTED IN

- Who's Who in the West, 1975
- American Men of Science, 10th, 11th, 12th, 13th, and 14th editions (now *American Men and Women of Science*), p.783, 1995-6
- Leaders in American Science
- Who's Who in America, 38th edition, 1974-75; vol. 1, p. 1402, 1976
- Who's Who Among Black Americans, 1980-81; 1985

AWARDS

- Tuskegee Alumni Award
- Carver Award
- Selected as an Outstanding Educator in America, 1974-75
- Recipient of Outstanding Black Physicists Award presented by the Ad Hoc Committee for the Afro-American Awards Program, May 1, 1975
- Recipient of the Lifetime Achievement Award in Community Service presented by the National Science Foundation, 1994
- Recipient of the Excellence at Howard Award presented by Howard University, April, 1997
- Recipient of the Technical Achiever of the Year Award presented by the National Technical Association, November 8, 1997 in Philadelphia

INVENTIONS

The Following inventions have not been patented:

- Video amplifiers (2 designs)
- IF amplifier
- High-impedance probe
- Metal Dewar for liquid helium
- Magnetic-moment lift
- Controlled-atmosphere chamber
- Hospital bed position indicator
- Fiber-optic subsystem for deep submergence rescue vessels

PARTIAL LIST OF TEXTBOOKS IN WHICH RESEARCH IS QUOTED

1. *Introduction to Solid State Physics,* by Kittell, 4th, 5th, 6th and 7th editions (1996)
2. *Heat and Thermodynamics,* by Zemansky
3. *Elementary Physics,* by Halliday and Resnick
4. *Electricity and Magnetism,* by Bleaney & Bleaney

REFERENCES TO MY PARTICIPATION IN PUBLISHED RESEARCH WITHOUT BEING AN AUTHOR

"Superconductivity of Lead at 3-Cm Wave-Length" by F. Bitter, J. B. Garrison, Halpern, E. Maxwell, J. C. Slater and C. F. Squire. *Physical Review,* Volume 70, pp. 97-98, 1946.

"Critical Field for Superconductivity in Niobium-Tin" by R.M. Bozorth, A. J. Williams and D. D. Davis. *Physical Review Letters,* Volume 5, Number 4, p. 148, 1960.

ADDITIONAL INFORMATION

A. Attended the International Conference on Magnetism held in Amsterdam, the Netherlands, as a participant and discussant, September 6-10, 1976.

B. Participated in the Homecoming Activities at Tuskegee Institute and presented the Eulogy for Dr. Booker T. Washington. The November 13, 1976 Homecoming honored the Class of 1931, of which Dr. Henry is a member.

C. Invited to return to the Massachusetts Institute of Technology for the Reunion of Inventors and Innovators of the Radiation Personnel, November 15, 1976.

D. Responsible for four graduate students on the graduate level, supported by the Howard University Biomedical Interdisciplinary Project, presenting papers on their research at the MSB Symposium held at Virginia State College on December 3, 1976.

E. Honored by the Physics Department at the Winter Festival at Howard University, sponsored by the Graduate School of Arts and Sciences, December 3, 1976.

F. Invited to present a 30-minute paper at the December 20-22, 1976 American Physical Society Meeting held at Stanford University.

G. Responsible for two graduates attending and two additional graduate students presenting research at the Xavier MBS Symposium in New Orleans, Louisiana, April 11-13, 1977.

H. Two graduate students completed the University requirements for the Ph.D. degree in Physics in the May 1977 Commencement (Mrs. Elvira D. Shaw and Mr. Matthew E. Edwards). Two other Ph.D. students, Dr. Henry Neal and Dr. Harry Morgan.

I. Attended and participated in the American Physical Society, meetings held in Chicago, IL, San Diego, CA, and Palo Alto, CA.

PUBLICATIONS

1. Henry, Warren E. and Williamson, John T. *Procedures in Elementary Qualitative Chemical Analysis,* Tuskegee Institute Press, 1937.

2. Henry, Warren E., Brown, Paul and Frederick, A. H. "A/R Range Scope" MITRL Report 755, 29 June 1945.

3. Henry, Warren E., Bell, P. R., Jr. and Young, T. F. "Semiconductors in Impedance Thermometers for Measuring Extremely Small Temperature Differences" Proceedings of Chicago Meeting, American Chemical Society, September, 1946.

4. Henry, Warren E. "Estimation of the Critical Temperature of Reorientation of Pairs of Zinc Atoms in Alpha Brass" Third Quarterly Report on Deformation. Submitted to ORI by Institute for the Study of Metals, 1947.

5. Henry, Warren E. and Dolecek, R. L. "A Metal Dewar for Liquid Helium" Rev. Sci. Instr., Volume 21, 1950, p. 496.

6. Henry, Warren E. "A Finite Difference Treatment of a Liquid Helium Cryostat Design Problem" J. Appl. Phys., Volume 22, 1951, p. 1439.

7. Henry, Warren E. "Spin Paramagnetism of Cr+++ at Liquid Helium Temperatures and High Magnetic Fields" Phys. Rev., Volume 85, 1952, p. 487L.

8. Henry, Warren E. "Some Laboratory Aids to Cryomagnetic Research" National Bureau of Standards Circular 519, Low Temperature Physics, 1952, pp. 237-242.

9. Henry, Warren E. "Spin Paramagnetism of Cr+++, Fe+++ and Gd+++ at Liquid Helium Temperatures and in Strong Magnetic Fields" Phys. Rev., Volume 88, 1952, p. 559.

10. Henry, Warren E. "Metal Dewars for Liquid Helium" Proceedings of the London Meeting of the International Congress of Refrigeration, 1952, p. 106.

11. Henry, Warren E. "Anomalous Paramagnetism of Copper Sulfate Pentahydrate" Phys. Rev., Volume 87, 1952, 1133L.

12. Henry, Warren E. "Magnetic Saturation and Apparent Molecular Fields of MnCl24H2O" Phys. Rev., Volume 90, 1953, p. 492L.

13. Henry, Warren E. "Some Magnetization Studies of Cr+++, Fe+++, Gd+++ and Cu+++ at Liquid Helium Temperatures and Strong Magnetic Fields" Revs. Mod. Phys., Volume 25, 1953, p. 163.

14. Henry, Warren E. "Antiferromagnetic H-T Boundaries and Apparent Molecular Fields for MnCl2 (4H2O and MnBr2 • 4H2O" Phys. Rev., Volume 94, 1954.

Henry, Warren E. "A Strong Field Induced Paramagnetic Anomaly in NiSiF66H2O" Phys. Rev., Volume 95, 1954, p. 1449.

16. Henry, Warren E., Hansen, W.N. and Griffel, M. "Strong Field Magnetization of CrCl3 and CrF3" Proceedings of the Pittsburgh Conference on Magnetism and Magnetic Materials, American Institute of Electrical Engineers, Volume T76, 1955, p. 60.

17. Henry, Warren E. "Quelques etudes d'aimanation en champs forts et aux basses temperatures" Proceedings of the Conference de Physiques des Basses Temperatures. Paris, France, No. 60, 1956.

18. Henry, Warren E. "Intradomain Magnetic Saturation and Magnetic Structure of γ-Fe_2O_3" Phys. Rev., Volume 101, 1956, p. 1253.

19. Henry, Warren E. "Coordination Quenching of the Saturation Magnetization of Potassium Ferricyanide" Phys. Rev., Volume 106, 1957, p. 465.

20. Hein, R. A., Henry, Warren E. and Walcott, N. M. "Superconductivity of Uranium" Phys. Rev., Volume 107, 1957, p. 1517.

21. Henry, Warren E. "Strong Field Cryomagnetic Studies of Some Ferromagnetics, Ferrimagnetics and Antiferromagnetics" Proceedings of the Boston Conference on Magnetism and Magnetic Materials, Volume T91, 1957, p. 299.

22. Henry, Warren E. "Behavior of Some Magnetic Materials at Low Temperatures" Report of NRL Progress, Jan 1957, 1958.

23. Henry, Warren E. "Low Temperature Magnetic Studies of Uranium Hydride, Uranium Deuteride and Uranium Dioxide" Phys. Rev., Volume 109, 1958, p. 1976.

24. Henry, Warren E. "Magnetic Moments and Apparent Molecular Fields in Some Rare Earth Metals and Compounds" J. Appl. Phys., Volume 29, 1958, p. 524.

25. Henry, Warren E. "Magnetization and Possible Magnetic Structure of Barium Ferrate III" Phys. Rev., Volume 112, 1958, p. 326.

26. Henry, Warren E. "Saturation Magnetization and Molecular Fields of the Acetylacetonates of Chromium and Iron" Physica, Volume 24, S160, 1958.

27. Henry, Warren E. "Some Magnetic Atomic Constants and Exchange Energy Density in Cobalt Fluosilicate Hexahydrate" *Low Temperature Physics and Chemistry*, Joseph R. Dillinger, ed. , 1958, p. 586.

28. Henry, Warren E. "Study of Some Turbulent Flow Parameters of Fluids in High Powered Magnets" Reports of NRL Progress, Nov. 1958.

29. Henry, Warren E. "Aimantation dans les champs forts et approche a la saturation absolue du neodyme et du dysprosium" Le Journal de Physique et le Radium, Volume 20, 1959, p. 192.

30. Henry, Warren E. "Saturation Magnetization and Ferromagnetic Interaction in Terbium Metal" J. Appl. Phys., Volume 30, 1959, 99S.

31. Henry, Warren E. and Salkovitz, E. I. "Reduction of Saturation Magnetization of (-Fe2O3 and Fe3O4 by Pile Irradiation" J. Appl. Phys., Volume 30, 1959, p. 286S.

32. Henry, Warren E. "Magnetic Interactions of Free Radicals at Very Low Temperatures and in Strong Magnetic Fields" Proceedings of the Fifth International Conference on Trapped Free Radicals, Washington, DC 31 Aug. - 2 Sept., 1959.

33. Henry, Warren E. "Strong Field Magnetization at Low Temperatures and Approach to Absolute Saturation of Thulium Metal" J. Appl. Phys., Volume 31, 1960, p. 323S.

34. Henry, Warren E. "Strong Field Low-Temperatures Studies of the Magnetization of Europium Metal" Bull. Am. Phys. Soc., Volume 5, 1960, p. 492.

35. Henry, Warren E. "Coercive Force, Magnetization Energy and Implied Anisotrophy of Uranium Hydride and Uranium Deuteride" Bull. Am. Phys. Soc., Volume 6, 1961, p. 169.

36. Henry, Warren E. and King, V.J. "High Field Studies of the Ferromagnetic-Antiferromagnetic Exchange Inversion in Mn2-XSbCrX" Bull. Am. Phys. Soc., Volume 6, 1961, p. 511.

37. Henry, Warren E. "Saturation Magnetization, Interatomic Interactions and Remanence of Some Rare Earth Metals and Compounds" *Rare Earth Research*, E. V. Kleber, ed., Macmillan, 1961, p. 165-177.

38. Henry, Warren E. "High-Field Low Temperature Magnetization Studies of Praseodymium Substituted Yttrium Iron Garnet -Fe2O3XPr2O3 x Nd2O3 (3-x) Y2O3" Conference on Magnetism and Magnetic Materials, Phoenix, Nov. 13-16, 1961.

39. Henry, Warren E. "The Absolute Saturation Magnetization and Remanence of Substitute Yttrium Iron Garnets - 5Fe2O3 x La2O3 and 5Fe2O3 x Nd2O3 (3-x) Y2O3" J. Phys. Soc. Japan, Volume 17, 1962, p. 361 (Suppl. B-1).

40. Henry, Warren E. "Susceptibility and Magnetization of Rare Earths" *High Magnetic Fields*, MIT-Wiley Presses, Cambridge and New York, 1962, p. 552.

41. Henry, Warren E. "Recent Developments in Magnetic Studies of the Rare Earths" Rare Earth Research Notes, Volume 1, No. 2, 1962

42. Henry, Warren E. "The Effect of Crystalline Environment on the Approach to Magnetic Saturation in Holmium" Bull. Am. Phys. Soc., Volume 7, 1962, p. 557.

43. Henry, Warren E. "Zero and High Field Study of Itinerant Electron Ferromagnetism inScandium-Indium Alloy" Bull. Am. Phys. Soc., Volume 7, 1962, p. 726.

44. Henry, Warren E., Muir, M. and Betz, C. "Observation of Superconductivity in Lanthanum Disilicide" Bull. Am. Phys. Soc., Volume 7, 1962, p. 474.

45. Henry, Warren E. and Muir, H. "Observation of Superconductivity in La5Si3" Bull. Am. Phys. Soc., Volume 7, p. 621.

46. Henry, Warren E. "Non-monotonic Dependence of Magnetization on Magnetic Field in an Itinerant Electron Ferromagnetic" Bull. Am. Phys. Soc., Volume 8, 1953, p. 382.

47. Henry, Warren E., Tecotzky, M. and Ring, S. A. "High Field Magnetic Properties of Praseodymium and Gadolinium Polysulfides at Low Temperatures" Bull. Am. Phys. Soc., Volume 8, 1963, p. 468.

48. Henry, Warren E. "Ferromagnetic Interaction in Au0.95Fe0.05" Meeting of the American Physical Society, California Institute of Technology, Dec. 1963. Bull. Am. Phys. Soc., Volume 8, 1963, p. 600.

49. Henry, Warren E. "Remanence and Approach to Saturation in Au0.95Fe0.05" Phys. Rev. Letters, Volume 11, 1963, p. 468.

50. Henry, Warren E. "Non-Monotonic Dependence of Magnetization on Magnetic Field in an Itinerant Electron Ferromagnetic Alloy" Physics Letters (Netherlands) 5, #5, 311 (1963).

51. Henry, Warren E. "Saturation Magnetization of Europium Selenide and Europium Telluride" Bull. Am. Phys. Soc., Volume 9, 1964, p. 114.

52. Henry, Warren E. "High Field Magnetization of Rare Earth Metals and Alloys" Proceedings of the Fourth Rare Earth Research Conference, sponsored by University (Temple) and USAF Office of Scientific Research, Phoenix, Arizona, April, 1964.

53. Henry, Warren E. "Magnetic Interactions in Science and Technology" Beta Kappa Chi Symposium, Atlanta University, 2 April, 1965.

54. Henry, Warren E. "High Field Saturation Magnetization of Holmium, Ho0.92In0.08 and Ho2O3" Meeting of the American Physical Society, New York, 23-25 June, 1965. Bull. Am. Phys. Soc., Volume10, 618 (1965).

55. Henry, Warren E. "High Field Magnetization, Remanence and Coercive Force os Au0.98Fe0.02" Meeting of the American Physical Society, New York, 23-25 June, 1965. Bull. Am. Phys. Soc., Volume 10, 592 (1965).

56. Henry, Warren E. "Remanence, Coercive Force and Ferromagnetic Interaction in Dilute Alloys of Iron in Gold" Bull. Am. Phys. Soc., Volume 10, 1101 (1965).

57. Henry, Warren E. "Magnetization of Au1-XFeX at Liquid Hydrogen Temperatures" Bull. Am. Phys. Soc., Volume 11, 1966, p. 377.

58. Henry, Warren E. "High Field Magnetization of Rare Earth Metals and Alloys" *Rare Earth Research,* Laroy Eyring, ed., Gordon Breach Publishers, New York, 1966.

59. Henry, Warren E. "Low Temperature Effects on Materials for Aerospace Mechanisms"First Aerospace Mechanisms Symposium, sponsored by Jet Propulsion Laboratory, University of Santa Clara and LMSC, May 1966. Symposium Proceedings, pp. 167-180, 1967.

60. Henry, Warren E. "Application des Champs Magnetiques Continus Intenses a l'Etude des Transitions Antiferromagnetiques et a Celles des Interactions Ferromagnetiques dans les Alliages Dilues de Fer Dan l'Or" Colloques Internationauz du Centre National de la Recherche Scientifique No. 166, Grenoble, Sept. 1966. Proceedings of Les Champs Magnetiques Intenses, 1967, pp. 151-167.

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