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Proceedings of the 24th Day of Scientific Lectures and 20th Annual Meeting of the National Society of Black Physicists

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March 1997

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**PROCEEDINGS
OF THE
24th Day of Scientific Lectures
and
20th Annual Meeting
of the
National Society of Black Physicists**

**EDITED BY
KEITH H. JACKSON, Ph.D.**

**Co-EDITOR
HATTIE V. CARWELL**

The 1997 Annual Meeting was sponsored by Lawrence Berkeley National Laboratory, Office of Naval Research, U.S. Department of Energy, Lawrence Livermore National Laboratory, Stanford Linear Accelerator Center. The meeting was held at the Lawrence Berkeley National Laboratory.

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FOREWORD

The XXIV Day of Scientific Lectures and the 20th annual meeting of the National Society of Black Physicists was held at the Lawrence Berkeley National Laboratory Berkeley, California on March 27-30th 1997.

The theme of the meeting was "25 years of progress and change in physics since day I." The idea was to review progress and change in different fields since the founding of the society. The invited speakers were charged with reviewing progress and challenges in their field, and providing the audience with their unique perspective on future research directions. This was a daunting task; however, the scientists chosen rose to the task. We attempted to cover as many different disciplines in physics, both theoretical and experimental, as possible.

There were also panel discussions, one on "Strategic Program Development in Physics" and another on "Physics in Mid-Career; Paradigm Shift." The first panel talked about the need to deviate from the usual career course in physics; i.e. a undergraduate degree, leads to a Ph.D., to a Post-doc and finally to an academic post. The realities of the job market, and the career aspirations of students, has led to a redesign in the way a physics program is structured. The second panel discussed the career paths of several African American physicists both in academic and industry.

NSBP 97 focused on where physics has been and where it is going in the future and the research challenges African Americans face in our disciplines and career aspiration we face in our lives.

Keith H. Jackson, Ph.D.
Editor

ACKNOWLEDGMENTS

NSBP 97 was a great success due in large part to the efforts of the conference organizing committee, Dr. Robert Bragg (UCB), Dr. Harry Morrison (UCB), Dr. Charlie Harper (Cal State Hayward), Ms. Hattie Carwell (DOE), Dr. Thorton (Ernie) Glover (LBNL). A special thanks go to Mr. Jabari Lee.

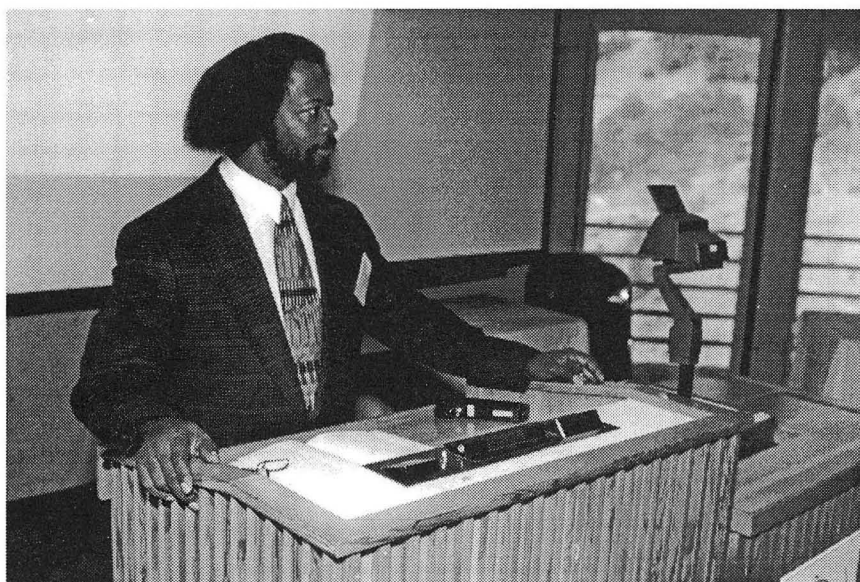
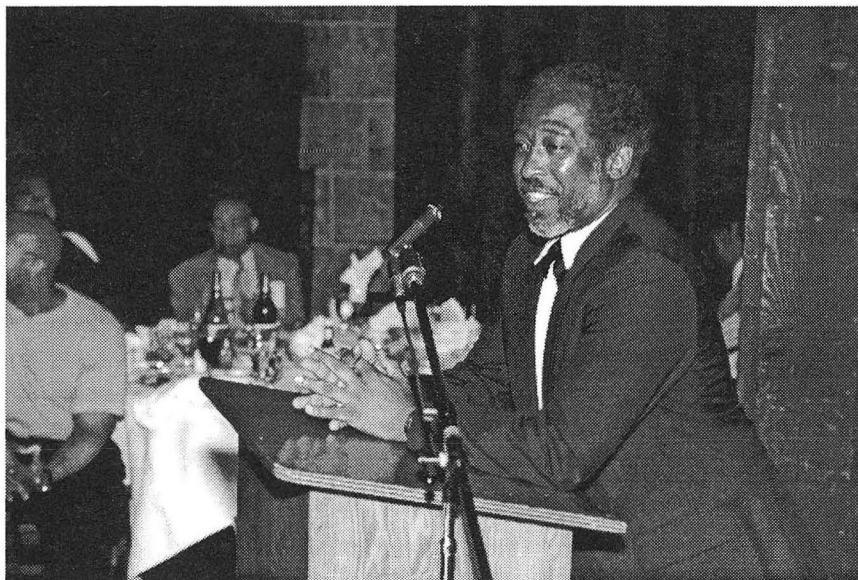
We would also like to recognize the help and assistance of Ms. Mollie Field, Michi Mason, and Betty Strausbaugh of LBNL for help with registration, travel, and logistics. Also special thanks go to Dr. Brian Kincaid for conducting a tour of the Advanced Light Source.

We gratefully acknowledge the financial support of the Lawrence Berkeley National Laboratory (LBNL), U.S. Department of Navy, Office of Naval Research (ONR), U.S. Department of Energy Basic Energy Sciences (DOW/BES), Stanford Linear Accelerator Center (SLAC), and Lawrence Livermore National Laboratory (LLNL). The combined support of all of these sponsors resulted in a very successful conference and the production of the proceedings.

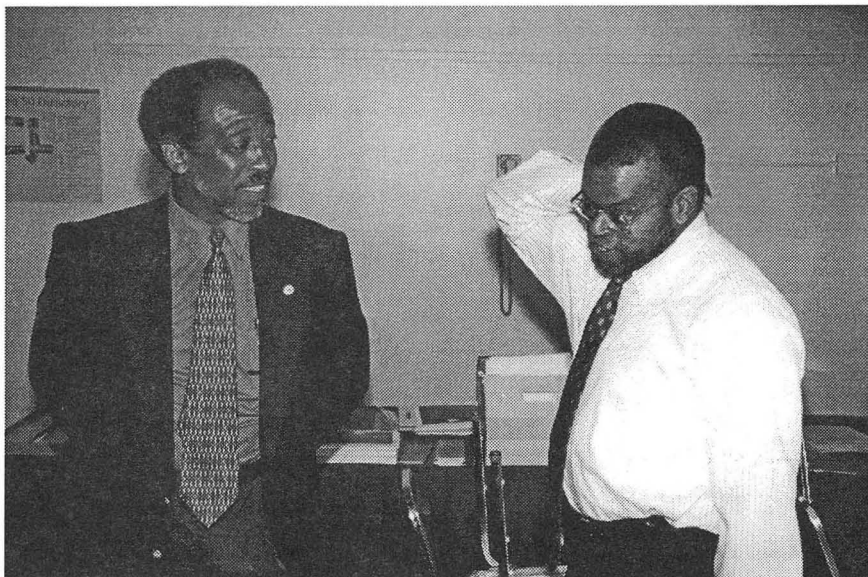
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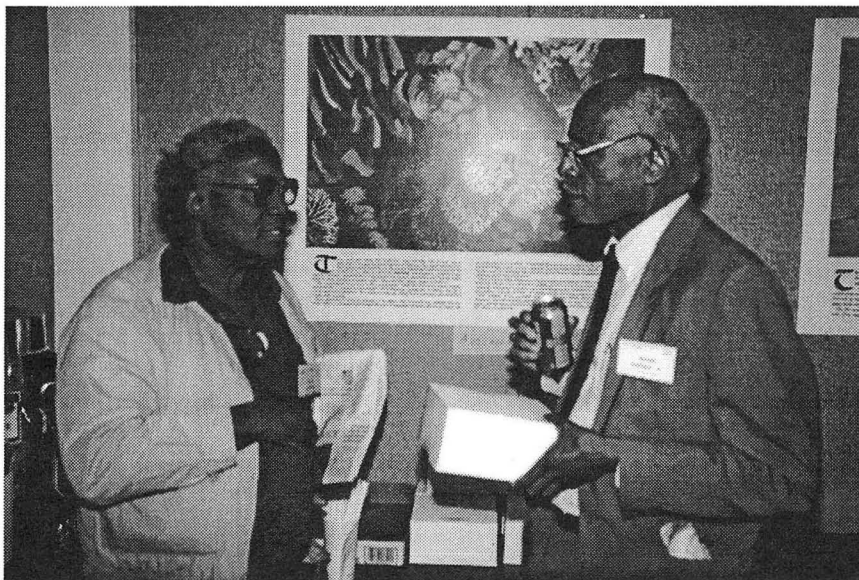
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CONFERENCE ORGANIZING COMMITTEE



Front Row, right to left: Molly Field, Charlie Harper, Ph.D.
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E. Glover, Ph.D., Jarabi Lee, and Robert Bragg, Ph.D.



Harry Morrison, Ph.D., an Organizing Committee member confers with
Alfred Phillips, Ph.D. of Cornell University.

PLASMA PHYSICS SESSION

NEW PLASMA PHYSICS FROM COLLISIONAL TURBULENT SYSTEMS

Joseph Johnson, Ph.D.



New Plasma Physics from Collisional Turbulent Systems

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Abstract

In a variety of situations, fluid-like turbulence is observed in collisional plasmas under circumstances where the underlying causes for the fluctuations are unclear. This includes fusion relevant plasmas (in the divertor regions), plasmas associated with film fabrication processes, plasmas in flames, and a host of astrophysical environments. Recent results suggest several new categories of explanations all, in some form or another, based on an important previously unsuspected role for microscopic and molecular phenomena in otherwise macroscopic events. An overview of these developments is provided here with special emphasis on measurements and analyses from our laboratory.

JOSEPH JOHNSON, III, PH.D.

Biography

Joseph Johnson is the Director of the Center for Nonlinear and Nonlinear Aeroscience at Florida A&M University. He received Ph.D. from Yale University.

His research interests include Shock Wave Dynamics in Weakly Ionized Plasmas. At the Center, he and his colleagues are focused on the characterization of shock wave propagation dynamics in plasmas for gases of aerodynamic interest; isolation of the specific mechanisms for apparent plasma drag reduction and the extrapolation of laboratory observations to the technology of supersonic flight.

He is a Fellow of the National Society of Black Physicists and recipient of the Edward Bouchet Award.

QUANTUM ELECTRONICS

ULTRAFAST OPTICAL PHENOMENA

Anthony M. Johnson, Ph.D.



Ultrafast Optical Phenomena

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Ultrafast optical phenomena refers to dynamical processes that occur in various forms of matter on the time scale of picoseconds (10^{-12} s, ps) or femtoseconds (10^{-15} s, fs). These phenomena have been relegated to the optical domain, primarily because only lasers have been fast enough to probe many of these processes. This field of ultrafast optical phenomena continues to be a highly prolific field of fundamental and applied research. One of the prime driving forces for the continued growth is the seemingly unending appearance of new and exotic sources of ultrashort pulses and the concomitant proliferation of commercially available sources. Today, one can literally buy the proverbial “black-box” with the attached label – “femtosecond pulses exit here.” Driven by unprecedented levels of coherence, bandwidth, spectral diversity, high power, and small size, ultrashort pulses of light have been utilized in fundamental studies of disciplines as diverse as semiconductor physics, plasma physics, lightwave transmission systems, and biological systems.

In 1987, the Bell Labs group headed by Shank and Fork generated 6 fs duration optical pulse by coupling 30 fs, 2 TW/cm² pulses (TW=Terawatt= 10^{12} Watts) from an amplified colliding pulse modelocked (CPM) dye laser into a 1-cm single-mode optical fiber and prism-grating compressor [1]. After a decade of intense activity, this 6 fs world record was finally broken by Wiersma’s group in The Netherlands – 5 fs via the fiber-prism-grating compression of intense 13 fs pulses from a cavity-dumped Kerr-lens modelocked (KLM) Ti:sapphire laser [2]. Limitations on the simultaneous control of the intracavity bandwidth and dispersion of KLM Ti:sapphire lasers has thus far prevented the generation of pulses shorter than 7.5 fs directly from the laser oscillator [3] – despite the fact that one can generate enough bandwidth in this laser system to support a 4 fs pulse!

Another very active area of research is in the generation of ultrahigh intensity lasers for strong field physics. Two recent examples of these ultrahigh intensity lasers involves the amplification of a KLM Ti:sapphire laser operating at a wavelength near 800-nm: 1) 1.1-J, 120 fs pulses with a peak power of 9.8 TW, focusable to an estimated intensity of 5×10^{19} W/cm² [4]; 800-mJ, 32 fs pulses with a peak power of 25 TW, focusable to an estimated intensity of 5×10^{19} W/cm² [5]. One application of these lasers is in the generation of laser-produced plasmas which are used in applications such as x-ray lasers, x-ray lithography, and x-ray microscopy. For example, soft x-ray radiation in the 1-6-nm range with durations of 2-7 ps has been observed for copper and tantalum plasmas produced by the excitation of a 400-fs, 1 TW tabletop laser [6].

Ultrashort pulses of light have found important applications in medicine and biology. The kinetics of the primary event in vision have been resolved with the use of ultrafast techniques. The retinal chromophore of rhodopsin was excited with a 35 fs pulse at 500-nm, and transient changes in the absorption were measured with 10 fs probe pulses. The first step in vision, the light-induced isomerization of the retinal chromophore, is complete in only 200 fs, making it one of the fastest photochemical reactions [7]. Compact ultrafast solid state lasers are having an impact in the medical field. Recently, a diode-pumped and modelocked Cr:LiSrAlF₄ laser producing 90 fs pulses at 860-nm was used as an excitation source for two-photon laser scanning microscopy – morphological and functional images of neocortical and cerebellar neurons were obtained with submicrometer three-dimensional resolution [8].

Recent advances in the use of wavelength-division multiplexing (WDM) technology have markedly increased the data transmission rates of high-capacity fiber-optic lightwave systems. Research teams in Japan and the United States broke the 1 Tbit/sec (trillion bits per second) data transmission barrier well before the predicted turn-of-the-century mark. Research teams from Fujitsu, Lucent Technologies/AT&T, and Nippon Telegraph & Telephone (NTT) reported successful terabit transmission experiments in post-deadline papers at the February 1996 Optical Fiber Conference (OFC '96), in San Jose, CA [9]. Indicative of the rapid pace of advancement in this field, the 1 Tbit/sec results were eclipsed by researchers at NEC (Kawasaki, Japan), who demonstrated the world's highest capacity optical data transmission of 2.6 Tbit/sec (132 channels x 20 Gbit/sec) [Gbit = billion bits] using WDM over 120 km of single-mode fiber. These results were presented several months after OFC '96

at the European Conference on Optical Communications (ECOC '96), September 15-19, 1996 in Oslo, Norway.

A high-speed camera capturing the trajectory of a speeding bullet would have an exposure time of approximately one microsecond (μs , 10^{-6} s) or equivalently 1,000,000,000 fs! In ultrafast spectroscopy, an “ultrafast snapshot” is taken by the interaction of two ultrashort pulses in the medium under study – the so-called “pump-probe” technique. A strong “pump” pulse excites or perturbs the sample. The changes initiated in the sample by the “pump” pulse are monitored by the weaker “probe” pulse. The time evolution of this excitation is investigated by varying the time delay between the “pump” and “probe” pulses, which can be performed with fs precision with commercially available optical delay lines. As examples of just how one makes measurements on these timescales, I will briefly describe time-resolved measurements of exciton dynamics and resonant tunneling phenomena in semiconductor multiple quantum wells that I performed with my group at Bell Labs [10,11].

In this lecture, I will describe several of the techniques used by ultrafast opticians to measure events on this incredibly short time scale and review some of the latest advances in the field.

* Before January 1, 1995
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ANTHONY JOHNSON, Ph.D.

Biography

Anthony Johnson is Chairperson of the Federated Physics Department at the New Jersey Institute of Technology (NJIT) & Rutgers University (Newark, NJ Campus). His research focus is ultrafast Optical Phenomena. He has conducted fundamental research in this specialty at AT&T Bell Laboratories where he was a Distinguished Member of the Technical Staff Photonics Circuits Research Department. He was part of the research team which was the first to generate 6fs duration optical pulse.

Anthony earned the BS and Ph.D. degrees from City College of New York.

QUANTUM ELECTRONICS

FREE ELECTRON LASER BASICS

Earl D. Shaw, Ph.D.



FREE ELECTRON LASER BASICS

BY

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ABSTRACT

A back of the envelop description is given of the parameter regime for rf accelerators, undulators, and optical cavity design for free electron lasers. We demonstrate the need for improved electron beam quality to push the output of rf accelerator based free electron lasers to wavelengths shorter than that of visible light.

INTRODUCTION

The synchrotron science community has decided that “third generation synchrotrons” will be free electron lasers. Despite the current difficulty of building and funding free electron laser programs, this effort appears to reflect a consensus in the science community that free electron lasers are here to stay. Here, I present a tutorial that outlines the bare bones of the free electron laser technology. It is my hope that this tutorial will be helpful to those that desire to understand the limitations of the current free electron laser technology.

The free electron laser is a device in which relativistic electrons pass through a periodic transverse magnetic structure, an undulator, located on the axis of an optical cavity.⁽¹⁾ The unbound electrons of the beam allow highly tunable laser output through control of the undulator period and strength, or the electron beam energy. The theory of the amplification of the coherently generated light is complex.⁽²⁾ However, a few simple expressions elucidate the challenges of the accelerator technology and are described in Section A. Similarly, the challenges for the

undulator technology are described in Section B. In Section C the optimized optical cavity is described for free electron laser devices. It is these three elements that must be considered for the construction of a free electron laser.

A. ACCELERATION CRITERIA FOR FREE ELECTRON LASERS

We limit our discussions to free electron lasers that utilize helical undulators because this will permit a simpler presentation. The helical undulator is characterized by its normalized transverse magnetic field value K , given by

$$K = \frac{eB\lambda_u}{2\pi mc^2} \quad (1)$$

Here λ_u is the period of the helical undulator and $mc^2 \sim 1/2\text{MeV}$ is the rest mass energy of the electron. K is the ratio of the transverse canonical momentum of the electron (due to the transverse helical field) to mc . A high energy electron beam of energy $E = \gamma mc^2$ that traverses the undulator with parameter K and λ_u generates light at the wavelength:

$$\lambda = \frac{\lambda_u(1 + K^2)}{2\gamma^2} \quad (2)$$

The optical output of the free electron laser described in Ref. 3 tunes from 160 - 400 μm when K is tuned from 2 to 4, $\lambda_u = 20\text{ cm}$, and $\gamma = 40$. The helical undulator field, B , is “weakly focusing” and guides the electron beam through the undulator with an equilibrium electron beam area:

$$A_b \equiv \varepsilon \lambda_u \quad (3)$$

Here ε (the normalized emittance) measures the quality of the electron beam in that ε/π is approximately equal to the product of γ , the beam waist, and beam divergence. The value of ε is determined by the state of the current cathode technology. Attempts to develop laser assisted cathode emission and cold cathodes is an effort to lower the emittance of thermal cathode based rf accelerators. The large values of the emittance limit the application of rf accelerators as will be shown below.

The round trip amplification gain (g) is related to the undulator and accelerator parameters by the proportional relation:

$$g \cong \frac{N^2 K^2 I}{(1 + K^2) \gamma} \quad (4)$$

where N is the number of periods of the undulator and I is the peak current. For peak currents greater than an Amp, K approximately equal 1, and N of about 100, g is of the order of 10% or greater. The amplification factor arises due to a complex interaction between the electron beam and the stored optical field. The electron beam is bunched spatially at the optical wavelength as the electrons traverse the undulator. The bunching mechanism is increased by large optical fields but decreased in high energy electron beams. The area of the pumped optical mode is approximately given by:

$$A_{opt} = \lambda L \quad (5)$$

where L is the length of the optical cavity.

An analysis of equations 1, 2, 3, 4, and 5 gives the parameter regime for successful operation of free electron laser devices. The constraints of the parameter regime is determined by the state of the art of rf accelerators. In Table I, typical values for emittance (normalized), energy, peak current, and pulse time structure for two rf accelerators are given. These parameters represent rf accelerator based free electron lasers that have been operated in the far-infrared to 400 μm , near infrared, and infrared to about 1 μm .

To reach shorter wavelengths, higher energy electron beam energies must be used. Difficulty arises in maintaining gain for fixed current as illustrated by Eq. 5, but a more difficult problem arises from the decreasing optical mode area (A_{opt}) which must be greater than or equal to the electron beam area A_b . For $A_b \sim A_{opt}$, all electrons in the electron beam profile contribute to the gain of the optical mode. Equations 3 and 5 give a lower limit on the wavelength for free electron laser operation for a linac.

$$\lambda \geq \frac{\varepsilon \lambda_u}{L} \quad (6)$$

For $\varepsilon = 100\pi$ mm-mrad, $\lambda_u = 1\text{mm}$, $L = 1\text{m}$, a lower limit of $\lambda = 300\text{ nm}$ is calculated. This is about 1/3 the 1 μm operation that has been obtained with a linac. The emittance of storage rings are smaller than rf accelerators and a visible output free electron laser has operated at LURE.

B. UNDULATOR CONSTRAINTS

The normalized helical magnetic field, K , is given by Eq. 1. To maximize gain for a given current and electron beam energy, K must be approximately equal to 1. For $K=1$, Eq. 1 gives $B\lambda_u \sim 1$ Tesla-cm. This relation restricts undulator periods to values greater than 1mm to maintain large K . Undulators have been constructed from permanent magnets, iron electromagnets, and superconductors.⁽⁵⁾ This requires fields larger than 10 Tesla which are unlikely even for undulator constructed with superconducting wire.

C. OPTICAL CAVITY CONSTRAINTS

The optimum optical cavity designs for free electron lasers differ from that of conventional lasers. In conventional lasers, mirror diffraction losses are controlled by minimizing the optical mode area at the optical cavity mirrors. This is accomplished by choosing the radius of curvature (R_c) of the cavity mirrors to be slightly larger than the optical cavity length (L_c). For free electron lasers, it is more important to increase the gain to a value greater than that given in Eq. 4 by focusing the optical cavity field to enhance electron beam bunching. This is accomplished by reducing the optical mode waist in the center of the undulator by choosing:

$$R_c \cong \frac{L_c}{2} \quad (7)$$

At wavelengths approaching x-ray's, decreased material reflectivity becomes problematic for designing optical cavities. Storage rings again may overcome this problem by storing nearly a 1000 Amps thereby increasing the gain compared to that calculated from Eq. 4 to a much larger value in order to produce mirrorless laser operation (super-radiance). The spontaneous power (P) radiated in a undulator is given by:

$$P = \left(\frac{I}{e} \right) (\hbar\omega) \pi \alpha K^2 \quad (8)$$

where $\alpha \sim 1/137$ is the fine structure constant.

D. CONCLUSIONS

The operation of accelerator based free electron lasers at visible and ultra-violet wavelengths will necessitate improved electron beam quality from rf accelerators. The operation of x-ray free electron lasers will require storage ring technology development.

Table I rf Accelerator Model Parameters

Accelerator	Energy (MeV)	Emittance (Normalized)	Electron Beam Frequency (GHz)	Electron Beam Pulse width (picoseconds)	Current (Amps)
Linac	10 - 40	100π mm mrad	3	1	100
Microtron	10 - 20	40π cm mrad	3	20	2

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EARL SHAW, PH.D.

Biography

Earl Shaw is member of the graduate physics faculty at Rutgers/Newark Physics Department. Prior to joining the faculty at Rutgers University, he was a Distinguished Member of Technical Staff at AT&T at Murray Hills, New Jersey. He has also held teaching positions at Howard University, and University of Rochester.

Much of his research focused on the development of infrared lasers and recently he moved to far-infrared free electron laser work at the Rutgers Newark Campus. This laser generates short tuneable far-infrared light pulses that permit the analog of pulsed magnetic resonance techniques for the first time in this optical wavelength regime. He studies the time dependence of the vibrational motion of DNA and other biological molecules with the ultimate aim of enhancing biochemical activity with far-infrared radiation.

Professor Shaw is a fellow of the National Society of Black Physicists and the American Physical Society.

ASTRONOMY AND ASTROPHYSICS

ASTRONOMY REDISCOVERS PHYSICS

Arthur B.C. Walker, II, Ph.D.



Astronomy Rediscovered Physics

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Introduction: The beginning of modern observational astronomy can be identified with Galileo's invention of the astronomical telescope in 1609. More than 300 years elapsed before astronomers acquired a second observational window on the universe, when Karl Jansky detected the radio emissions of the core of the Milky Way galaxy in 1932. By the start of the last decade of the 20TH century, the observational electromagnetic window available to astronomy extends from radio waves through microwaves, millimeter waves, the near and far infrared, the vacuum and far ultraviolet, the extreme ultraviolet, x-rays, and gamma rays extending to 10^{21} eV. Furthermore, neutrinos have been detected from the sun, and from a supernova, samples from the moon and from Mars have been examined in terrestrial laboratories, and the National Science Foundation is investing \$300,000,000 in a pair of observatories to detect gravitational radiation from celestial sources. The most advanced technologies currently employed in terrestrial physics laboratories, including detectors operating at 0.1° K, are finding applications in astronomy. Perhaps the most compelling evidence of the current sophistication of astronomy is the widespread acknowledgment of the magnitude of the intellectual challenges that await us at the threshold of the 21ST century. By the middle of the 19TH century, many astronomers were convinced that a static universe of stars similar to the sun, centered on our solar system was completely described by Newtonian physics. It is now generally accepted that at most a few percent of the matter in the universe is observable in the visible, and that as much as 90% of the matter in the universe may be in the form of elementary particles that have not yet been identified. Furthermore, the large scale architecture, and the fate of the universe can only be understood if we are able to understand the fundamental nature of matter, and visa versa; physics and astronomy are once again as closely linked as they were when Newton's theory of gravitation simultaneously provided the physical basis for Copernicus heliocentric cosmology, and established physics as the preeminent experimental science.

Goals and Techniques of Contemporary Astronomy: A significant fraction of contemporary Astronomical research can be related to five primary questions;

i How were the sun and the planets formed, and what are the implications for the existence of planetary systems elsewhere in our galaxy? What mechanisms are responsible for the dynamic phenomena observed in the solar system and the heliosphere?

ii. How are stars formed, how do they evolve, and what is their fate? How does the evolution of stars effect the dynamics and evolution of our galaxy?

iii. How did the present organization of luminous matter evolve, and what is the nature, quantity and distribution of non luminous matter in the universe? What is the nature of active galaxies and quasars, and what is the nature of their remnants in the contemporary universe.

iv. How was our universe created, and what will be its ultimate fate?

v. Is there life elsewhere in our galaxy; and if there is, what is it's nature?

The power of astronomical observations outside the optical band lies principally in their sensitivity to matter at extreme temperatures. Radio observations permitted the discovery of the 2.7° K cosmic background radiation; microwave, millimeter wave, and infrared observations have revealed the importance of cool material in our galaxy and beyond. Radio observations also facilitated the discovery of quasars, because of the radio power radiated by the synchrotron emission

of very high energy electrons in weak galactic magnetic fields; x-ray and gamma ray observations have revealed that violent high energy phenomena are ubiquitous in the universe. The study of stars and stellar evolution provides insights to both the evolution of the galaxy, and the techniques of many observational branches of astronomy; this review begins with this topic.

Stellar Evolution: The first observation of a high temperature astronomical plasma was almost certainly achieved by humanity's earliest ancestors in Africa, when a full solar eclipse revealed the beautiful sight of the sun's extended atmosphere, the corona. This magnificent phenomena, doubtlessly caused the same consternation and confusion then, that it caused among 19TH and early 20TH century physicists and astronomers, who could not reconcile the large scale height of the corona with the sun's surface temperature of 6,000° K, or identify the coronal emission line spectrum with any of the then known elements. Awareness that the element helium had been first identified in the solar spectrum, prompted the proposal that the corona was composed of a new element, coronium, that was lighter than hydrogen (hence it would have escaped from the earth's weaker gravity). Edlen solved this dilemma, when he identified the coronal emission lines as forbidden transitions in highly ionized ions of iron, Fe X - Fe XIV, revealing that the coronal temperature is in excess of 1,000,000° K. Grotian subsequently discovered the same emission lines in the spectrum of a nova, revealing that the cataclysmic increases in luminosity of these stars also involves phenomena at very high temperatures. Clearly, study of the structure of the corona over the solar surface would require x-ray observations from above the earth's atmosphere. The first x-ray and far and vacuum ultraviolet images of the sun were obtained by Herbert Friedman and Richard Tousey and their colleagues at the Naval Research Laboratory, using captured German V-2 rockets. The first x-ray image of the corona, which was obtained using a simple pinhole camera, showed that the corona was highly structured by the solar magnetic field. The NRL group also obtained the first high resolution spectrum of the x-ray corona with a simple Bragg crystal spectrometer, also from a rocket, revealing a spectrum dominated by emission lines from ions such as C VI, O VIII, Ne IX, and Fe XVII, in the spectral range $10 < \lambda < 25 \text{ \AA}$. Shortly thereafter, my colleague H. R. Rugge and I obtained the first satellite spectra of the corona, extending from 3 Å to 25 Å, and revealing the dynamic nature of the coronal x-ray spectrum during flares. We, in collaboration with Alan Gabriel and Carole Jordan of Culham Laboratories, discovered the lines of doubly excited lithium-like ions that appear as satellites to the multiplet of helium-like ions such as O VII and Fe XXV. These lines have now been identified in a variety of hot low density astrophysical plasmas, and provide powerful diagnostics of temperature, density and abundance's. X-ray emission has now been shown to be a ubiquitous characteristic of late class stars (classes F, G, K, and M) that have convective envelopes {such envelopes are a consequence of the low temperature gradient in stars with a cool ($< 10,000^\circ \text{ K}$) surface temperature}. Although the exact mechanism or mechanisms that heat the quiescent corona have so far defied identification, the relationship between the intensity of coronal emission in convective stars, and the stellar rotation rate clearly demonstrates that the source of coronal energy is magnetic. Flares, which can increase the x-ray luminosity of the sun a thousand fold, are the result of the impulsive acceleration of a population of non-thermal particles to energies as high as 10's of GeV by magnetic reconnection of coronal magnetic fields. Some of these high energy particles escape from the sun, and create enhancements of the earth's ionosphere; the bulk of the particles heat the solar atmosphere, creating a transient local enhancement of the corona. The sun's corona also expands into interplanetary space, creating a wind of ionized plasma that creates a volume of space extending beyond the orbit of Pluto that is electrodynamically dominated by the sun. Flares regularly (typically once a day) eject enormous volumes of plasma into the heliosphere that, among other effects, generate magnetic storms in the earth's upper atmosphere. Phenomena such as planetary radiation belts, ionospheres, and magnetic storms, which are the subject of the space age discipline of Space Physics, are all consequences of the existence of the corona and solar wind. Stellar winds are ubiquitous in late class stars, and result in a substantial loss of angular momentum, and stellar spindown. The luminosity of the quiescent solar corona is $\sim 10^{-6}$ of the sun's bolometric luminosity, however x-ray luminosity increases for cooler stars, and class M

stars, with temperatures of $\sim 3,000^\circ$ K have giant flares that radiate a significant fraction of the stars bolometric luminosity.

The first non solar sources discovered, and the most intrinsically luminous galactic x-ray sources, have revealed that evolution of close binaries that can exchange mass can produce a wide range of unexpected behaviors. X-ray binary sources permit the study of matter under conditions of extreme density and temperature that we cannot expect to ever duplicate in terrestrial laboratories. The first non-solar x-ray source, Scorpius X-1 was discovered by a team lead by Ricardo Giacconi. Sco X-1, and other strong galactic sources were soon identified with blue stars, but their x-ray luminosity proved to be the predominate emission, with luminosity's as high as 10^{38} ergs/sec ($\sim 10^5$ solar luminosity's). One of these objects proved to be rather unique, it was a radio pulsar in the center of the Crab nebula, a luminous cloud of gas that was shown, by historic research, to be at the sight of a supernova that was meticulously recorded by Chinese court astronomers in 1003 AD. The Crab source also displayed regular and rapid x-ray pulses, as did most of the star like x-ray sources. These sources provided a link between stellar x-ray sources and radio pulsars, and provided verification of the proposal that radio pulsars are rapidly spinning neutron stars. The Crab source is rather unique in that it is a young rapidly spinning (millisecond period) neutron star that contains very high energy particles in a magnetosphere with a field of 10^{12} gauss that generate synchrotron radiation from radio to gamma ray wavelengths. The association of the Crab source with a supernova also established that neutron stars are the end stage of the evolution of massive stars. The mechanism underlying the explosion of a massive star to produce a Type I supernova was verified by the unique detection of energetic neutrinos from supernova 1987 A, which occurred in the Large Magellanic Cloud. The detection was made by detectors built to search for proton decay. Stars with initial masses in excess of 8 solar masses are able to generate core temperatures in excess of $2,500,000,000^\circ$ K, permitting stellar nucleosynthesis to proceed to the formation of an iron core. Since iron is the most tightly bound nucleus, once the energy that is available from the formation of an iron core is extracted, further contraction and heating of the core results in the runaway initiation of inverse beta decay that converts all of the core's electrons and protons to neutrons, and releasing most of the energy of the supernova in a flood of neutrinos. Once the electrons, that had supported the core against collapse by degenerate electron pressure are removed, the core collapses until it is stabilized by the degenerate pressure of neutrons at a density of 10^{14} gm/cm³. A model for the majority of the high luminosity x-ray sources soon emerged, they are close binary stars in an advanced stage of evolution, containing a neutron star and a companion that is sufficiently close to have overflowed it's Roche lobe, and is transferring mass to an accretion disk surrounding the neutron star. As material is accreted onto the neutron star, the intense gravitation of the neutron star liberates $\sim 90\%$ of the rest mass as thermal energy, generating temperatures of $1,000,000,000^\circ$ K and enormous x-ray luminosity's. Many exotic behaviors, including burst sources can result from these advanced evolutionary stages of close binaries. The accretion process is accompanied by the ejection of jets of very high energy particles along the magnetic axis of the rotating neutron star. The dual phenomena of accretion disks and high energy jets appears to occur on a variety of scales, from young stars to the central engines of quasars. The dynamics of the accretion process, the structure of neutron stars, and the possibility that the core collapse of the most massive stars (*i. e.* 25 solar masses) may result in a stellar black hole is the central focus of a recently launched NASA satellite, the X-ray Timing Explorer (XTE). Several strong black hole candidates, which appear to satisfy the criteria that the mass of the compact star exceeds 3.5 solar masses, the calculated upper limit for a neutron star, have been identified. Another intriguing possibility is that the cores of neutron stars may contain a quark/gluon plasma.

The model of accreting neutron stars as a prototype of the central engine in quasars, where the central object is a massive to supermassive ($\sim 10^6 - 10^9$ solar mass) black hole has recently found strong support from Hubble telescope images of the cores of active galaxies. There is also Hubble evidence that some nearby galaxies contain black holes in their cores that are inactive, because there is no accretion occurring.

The end state of low mass stars has long been known to proceed through a red giant phase that expels its outer layers to create a planetary nebula, leaving a degenerate core that cools to become a white dwarf. The detailed study of the central stars of planetary nebulae, which initially have surface temperatures of $200,000^{\circ}\text{K}$, is now possible with NASA's Extreme Ultraviolet Explorer. White dwarfs in close binary systems can produce phenomena that are no less intriguing than those associated with x-ray binaries. The long standing mystery surrounding novae was convincingly resolved when x-ray observatories were able to observe x-rays associated with the outbursts of novae. In these stars, accretion of hydrogen rich material onto the surface of the white dwarf produces nuclear burning, culminating in the explosive burning of helium into carbon, triggering the ejection of the outer stellar layer, and the nova outburst. This process can repeat, hence all novae are recurrent. If the repeated episodes of accretion onto a carbon rich white dwarf result in a mass that exceeds the Chandrasekhar mass limit of 1.44 solar masses, the star will experience a catastrophic detonation that destroys the star, and becomes a Type I supernova. Both types of supernova eject expanding shells of material containing the products of stellar nucleosynthesis into the interstellar medium (ISM) at velocities of $10,000\text{ km/sec.}$, generating an interstellar shock that can reach temperatures of $100,000,000^{\circ}\text{K}$. These shocks can eventually become tens of light years in diameter, and sweep up hundreds of solar masses of interstellar material. The Crab nebula and other "supernova" remnants (SNR's) were the first extended extra solar sources found. Grazing incidence optical systems, developed by Giacconi and his collaborators, and by Underwood and Hoover, based on the designs of Wolter, were initially used to image the solar corona. The first orbiting Wolter telescope, the Einstein Observatory obtained detailed images of the complex structure of SNR's, and discovered thousands of discrete x-ray sources, transforming x-ray astronomy into a major subdiscipline of astronomy, on a par with optical and radio astronomy. As the SNR shell expands, the dense shock front cools to form dense interstellar clouds, and the hot interior connects with other SNR's to form a web of tenuous (0.001 ion/cm^3) hot ($200,000^{\circ}\text{K} < T < 1,000,000^{\circ}\text{K}$) tunnels that occupy 70% of the volume of the ISM. This component of the ISM was first inferred to exist as a result of the discovery of absorption lines of O VI at $1032\text{ \AA}$ in the spectra of O and B stars by the far ultraviolet spectrometer on the Copernicus satellite. The extent of this component of the ISM was discovered by mapping the diffuse soft x-ray background. These discoveries have radically altered older views of the ISM as a static uniform entity; the hot phase of the ISM is in equilibrium with a dense ($\rho \sim 100 - 10,000\text{ atoms/cm}^3$), cool ($T \sim 100^{\circ}\text{K}$) phase of clouds. The hot phase fills most of the volume ($\sim 70\%$), the clouds contain the bulk of the mass. The warm interface between the hot ISM and the clouds, which occupies no more than 20% of the volume, was once considered the dominant phase of the ISM. The study of the cool dense molecular clouds, and the processes of star formation which occur there, has greatly benefited from the development of millimeter wave, microwave, and infrared techniques, since these low energy radiation's can penetrate dense clouds without being absorbed by the gas, or scattered by the interstellar dust grains. All of these observational modes have been greatly enhanced by the use of low temperature technologies in the development of detectors, and in the cooling of antennas and telescopes, which are themselves a source of background radiation at these wavelengths. The complex chemistry of molecular clouds has yielded surprising results, including the identification of complex organic molecules, which are formed on the surfaces of interstellar dust grains. These discoveries have lead to speculation that living molecules may have evolved in space, and been seeded onto the earth! Infrared observations have permitted the study of the process of star formation, showing that young stars generate polar outflows, and are surrounded by extended disks of cool gas and dust. These are presumably protoplanetary systems.

Before we turn to the study of our solar system, two additional comments on the advanced evolution of close binary stars. Joseph Taylor and Russell Hulse discovered a binary pulsar containing two neutron stars separated by 2.8 solar radii. Analysis of the orbital decay of this unique system has shown that the energy loss is in agreement with the gravitational radiation predicted by General Relativity. In 1963, the US DOD launched a series of satellites, called Vela, to detect clandestine nuclear tests in space. No nuclear bursts were observed, however, a series of

cosmic gamma ray bursts were found. The Compton Gamma Ray Observatory has found that "Cosmic Gamma Ray Bursts" occur approximately once per day, and have an isotropic distribution. These mysterious bursts have defied all attempts to identify their origin. One proposal that so far appears to be consistent with all observational constraints, is that the bursts are due to the merging of binary neutron stars, that they represent the most powerful source in the universe for the period of several seconds, and that the Compton Observatory can observe essentially all of the events occurring in the observable universe. If this model is correct, the Laser Interferometric Gravitational Observatory currently under construction will be a powerful tool for the study of this most powerful stellar phenomena.

The Solar System: Four developments regarding the solar system are particularly noteworthy: (i) The discovery of a belt of large comet-like bodies in a disk-like distribution beyond the orbit of Neptune. This population is called the Kuiper belt, and it now appears likely that Pluto, its moon Chiron, and Neptune's moon Miranda are members of this population. (ii) The crash of a comet into the planet Jupiter is a reminder that the process of orbital interaction and collision that built the planets is still active. The theory that the extinction of the dinosaurs 65 million years ago was caused by an asteroid collision with the earth now appears to be widely accepted. (iii) The analysis of a meteorite, found in Antarctica, that was ejected from Mars, has provided evidence that is consistent with the existence of simple life on Mars in the past. Although there are other explanations for the structures and residues found in this meteorite, there is strong evidence that profound climatic changes have occurred on Mars, and that in past epochs conditions on Mars were more consistent with simple forms of life than present conditions on Mars. (iv) The discovery of planets around other solar-like stars lends support to the theory of planetary formation from a circumstellar disk that has been developed to explain our own planetary system. However, the striking variety of the small number of planetary systems found suggests that evolutionary effects may very profoundly alter planetary systems once they are formed, and that our solar system may not be typical.

The Large Scale Distribution of Matter: It is now well known that the analysis of the rotation curves of spiral galaxies, including the Milky Way, provide strong evidence that there are significant amounts of dark matter in their disks and halos. The virial theorem, applied to clusters results in a similar conclusion. In the past 20 years, significant new phenomena that have revealed previously undetected baryonic matter have been discovered. These include: (i) a hot ($T > 100,000,000^\circ \text{K}$) x-ray luminous diffuse intracluster medium that contains masses comparable to the galaxies in a typical rich cluster, (ii) a diffuse cool gas in the voids between clusters that was discovered as red shifted Lyman α absorption in the spectra of quasars. This phenomena is sometimes referred to as the "Lyman α forest". (iii) the discovery of a class of low surface brightness large galaxies that are apparently still in the process of formation. Even with the addition of the matter in these phenomena, the baryonic density of the universe is less than 10% of the closure mass that "inflation cosmologies" predict. One constraint on the baryonic density of the universe is derived from the abundance of deuterium, whose synthesis during the big bang is strongly affected by the density of the universe a few minutes after the big bang. Recent measurements of deuterium abundances by the Keck telescope suggest that baryonic density cannot be greater than 10% of closure density. This strongly suggests that the dark matter is composed of some so far undiscovered elementary particle, although an important contribution by neutrinos cannot be ruled out.

The distribution of the dark matter in clusters of galaxies can, in principle, be determined by observing the arcs produced by the gravitational lensing of background quasars. Several programs to make such observations are currently underway. It should be noted that gravitational lensing has already been successfully used to discover dark compact objects in our own galaxy. These massive compact halo objects (MACHOS) may not resolve the dark matter problem in our galaxy, but they may represent a previously undetected galactic population.

ARTHUR BC WALKER II, PH.D.

Biography

Arthur Walker is Professor of Physics and Applied Physics at Stanford University. He is a member, Hansen Experimental Physics Laboratory and Center for Space Science And Astrophysics. His research interests are focused on the development of innovative space-borne instruments for the study of high temperature astrophysical phenomena such as the elemental abundance in the interstellar medium. From 1965-1975, Professor Walker and his former collaborator, H.R. Rugge carried out several of the pioneering studies of the X-ray spectrum of the solar corona, and in the early 1990's, Walker lead a group in pioneering the application of normal incidence X-ray optical systems to astronomical observations. He was the Associate Dean of Graduate Studies at Stanford from 1976-80.

He earned the BS degree at Case Institute of Technology, MS and Ph.D. degrees at the University of Illinois.

OPTICAL PROPERTIES OF NANOPHASE MATERIAL SYSTEMS

Clayton W. Bates, Ph.D.



Optical Properties of Nanophase Material Systems

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By a nanophase material system we will mean a dispersion in a given host or matrix of one or more materials with different properties and sizes on the order of 10-100nm. They may be dispersed in a random or periodic manner and the desired characteristic of the composite system may be some unique mechanical or optical property due to the arrangement. The structural arrangement is called tailoring and tailored microstructures is a term that has come into recent use in the electronic industry because thin film deposition procedures such as Molecular Beam Epitaxy (MBE) have permitted the preparation of thin film devices with a degree of control over spatial dimensions in the atomic domain. Such films can have some very novel electronic as well as optical properties because of the microstructure produced. A whole new class of structures called quantum well devices is an example of such "tailoring". It is added here however, that tailored microstructures are not new in the broadest meaning of the word tailored.

1. Reinforced concrete (though not a nanophase system) is a composite of concrete with steel rods to improve the tensile strength of the concrete which has excellent compressive properties.

2. Ni-TiC cermets (metal-ceramics) consist of spheroidal or prismatic carbide grains completely surrounded by Ni and are used in applications requiring great hardness and high temperature strength such as cutting tools. So the mechanical properties community has used "tailored microstructures" to produce definite mechanical properties for some time now. Other than quantum well devices the electrical and optical properties community have used tailoring to produce:

1. Optical confinement by optical waveguides,
2. Layered Synthetic Microstructures (LSM) for use as dispersive elements for x-ray and vacuum ultraviolet optics,
3. Bandgap tailoring using alloys such as $Hg_{1-x}Cd_xTe$ by varying the value of x .
4. Cermets such as $Au-SiO_2$ and $Ag-SiO_2$ with variable conductivities depending on the volume fraction of Au or Ag and their particle size distributions.

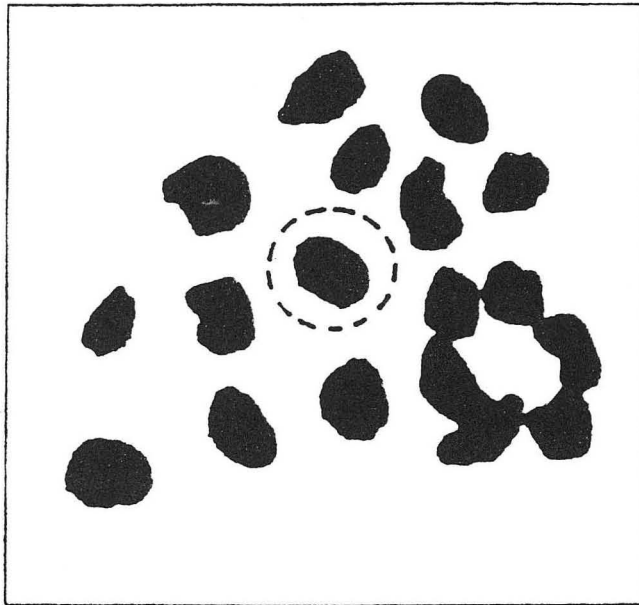
Optical waveguides, Layered Synthetic Microstructures and alloys are homogeneous structures, whereas the cermets are inhomogeneous.

A new class of materials called photonic crystals should be added to this list. Photonic crystals are materials fabricated with a periodicity in dielectric constant, which can have the effect of creating a range of forbidden wavelengths called a photonic bandgap. As with normal crystals photons with wavelengths lying in the photonic bandgap cannot propagate through the medium, providing an opportunity to control the flow of light for various applications. The fabrication of these structures however, requires state-of-the-art microlithography techniques.

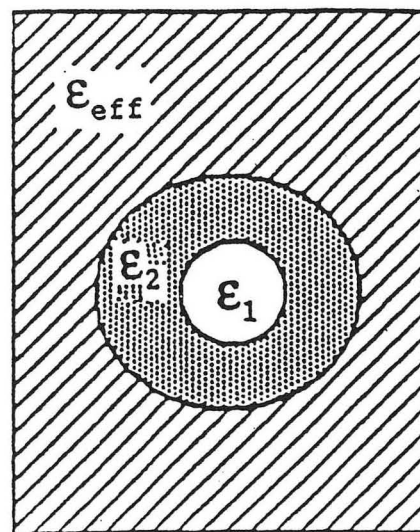
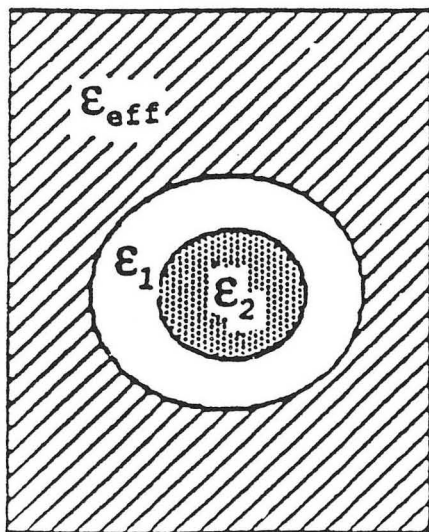
This talk will focus on another class of nanophase material systems which are relatively easy to fabricate by standard techniques and that is metal-semiconductor composites. Small metal particles (10nm in diameter) dispersed in semiconducting matrices can produce composite systems with optical properties which are radically different from either metal or semiconductor just as with photonic crystals. We can tailor these inhomogeneous composites to have sharp absorptions at selective wavelengths, or absorption over a broad range of frequencies.

Any theoretical description of inhomogeneous composites must begin with a particular microstructure and different versions of so-called effective medium approximations (EMA) which attempt to replace the inhomogeneous system with a homogeneous one are associated with different underlying microstructures. The EMA is the present method most widely used to describe these inhomogeneous systems. We consider the composite to be made up of two elementary structural units as shown in Fig. 1a. One unit consists of a metal particle surrounded by the host or matrix material and the other host material surrounded by a cluster of metal particles. This is consistent with many micrographs taken of composite systems, i.e. they usually show isolated and clustered particles. The relative amounts of each unit will depend on the deposition conditions. Fig. 1b shows how one replaces the inhomogeneous system with a homogeneous one consisting of an effective dielectric constant ϵ_{eff} that is a function of the dielectric constants of the components ϵ_1 and ϵ_2 . Each elementary structural unit is placed in the homogeneous medium and Maxwell's equations and the usual boundary conditions are used to solve for a_n and b_n , the scattering coefficients for the electric and magnetic multiple contributions due to scattering by the elementary structural units. If the radiation wavelength is much larger than these units, which we assume to be the case, then the particle shapes are relatively unimportant and we can solve for a_n and b_n assuming spheres. These coefficients will then be functions of the radii of the spherical units r , the dielectric constants of the metal and matrix, ϵ_1 and ϵ_2 and the effective dielectric constant of the homogeneous medium, ϵ_{eff} . These coefficients are then inserted into the forward scattering amplitude $S(o)$ whose average is set equal to zero. This self-consistency condition insures that the effective medium represented by ϵ_{eff} is homogeneous, on the average, because zero forward scattering amplitude means no interfaces with different dielectric properties. This condition gives ϵ_{eff} as a function of ϵ_1 , ϵ_2 and r . The relative volume fractions of each unit are included in $S(o)$. Knowing ϵ_{eff} one can calculate optical properties such as absorption, reflection and transmission.

We use this theory to compare with the optical properties of some A_g-S_1 composite films prepared by sputtering and electron-beam evaporation. We show absorption data for a $A_g-\alpha$ Si film on mica which behaves like a waveguide and discuss the properties of the first composite film made for infrared detection in the 8-12 μm range consisting of A_g particles dispersed in a matrix of CuInSe_2 .



1(a)



1(b)

Isolated and clustered particles (a) can be modeled as two microstructural units (b).

CLAYTON BATES, PH.D.

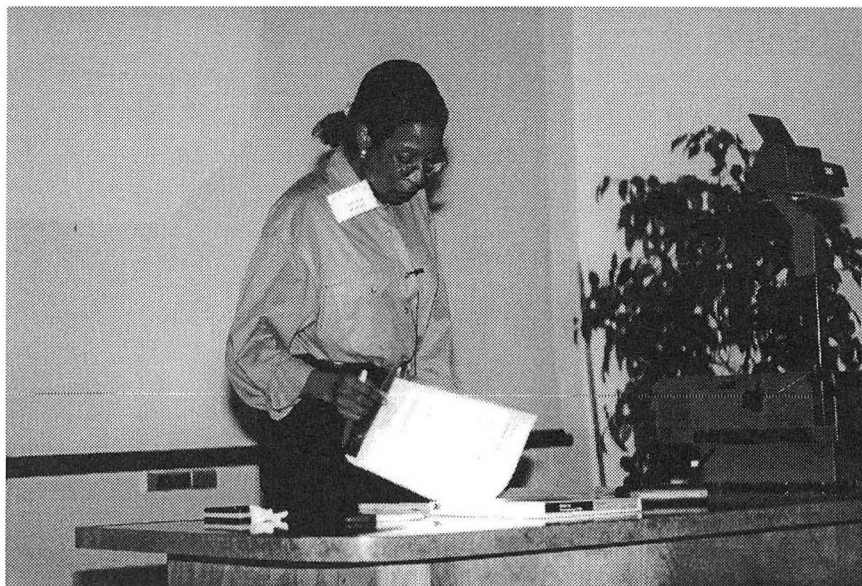
Biography

Clayton Bates is the Associate Dean for Graduate Education at Howard University and professor jointly with Materials Science and Engineering. His specialty is studying the optical transport properties of small metal particles embedded in semiconductors and electronic devices.

He earned the BS degree from City College of New York and the MS and Ph.D. degrees from Washington University (St. Louis, Missouri).

ELECTRONIC PROPERTIES OF STRUCTURAL MODIFIED (LAYERED) SEMICONDUCTOR

Cynthia R. McIntyre, Ph.D.



Electronic Properties of Structural Modified (Layered) Semiconductors

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Abstract

Computational modeling of materials is a new and expanding research thrust. This multidisciplinary research focuses on designing and building new materials at the atomic and molecular levels. One active area of experimental research involves growth and characterization of low dimensional materials. These engineered materials display fundamentally different physical properties compared to their bulk structures. Semiconductor materials, in particular, are now grown to engineer their electronic and optical properties. With the advent of structural modification of semiconductors, material interfaces and surfaces strongly influence overall physical characteristics.

Layered semiconductors are characterized by staggered bandgaps which dramatically change the electronic properties of the individual semiconductor component materials. These semiconductor quantum well structures allow for the localization of carriers within the materials. This electronic localization due to layered materials also introduces additional scattering mechanisms at the engineered interfaces. One dominant scattering mechanism affected by the introduction of interfaces is electron-phonon scattering.

Electron-phonon interactions in quantum well systems control carrier relaxation on picosecond time scales and determine their optical and transport properties at room temperature. In recent years there has been interest in how quantum well structure affects these scattering rates and also on the possibility of modifying these scattering rates with structuring of such systems. For example, in recent work Zhu et al¹ have considered

GaAs/Al_xGa_{1-x}As systems with additional structuring due to thin AlAs layers in order to modify carrier mobilities.

It is now well known that optical phonon spectra of quantum wells like the GaAs/AlAs system are modified significantly from plane wave states and are characterized by interface and confined optical phonon modes. It has been argued that in general these modifications in quantum well systems do not have a large effect on electron-phonon scattering rates. Here we are interested in the effects of additional structure in quantum wells on the phonon spectra and on the electron-phonon scattering rates, which control mobilities and relaxation rates. For our purposes we will take the electron wavefunctions to be unaffected by the additional structuring. In recent work Tsuchiya and Ando² have investigated the effects of the modification of the electron wavefunctions on carrier mobilities in quantum well systems with additional AlAs layers. Here we have studied theoretically the role of interface and confined phonons on the scattering of electrons both in simple GaAs/AlAs quantum wells (SQW) also structurally modified GaAs/AlAs quantum wells (SMQW). The structurally modified quantum wells of interest here contain a thin AlAs layer in the center of a GaAs well. The quantum wells range from 50-150 Å in width.

We use the macroscopic dielectric continuum model to describe the optical phonons in these systems. Based on lattice dynamical calculation, it has been demonstrated that the dielectric continuum model gives a good representation of the electron-phonon scattering rates in these systems. Here we use electromagnetic boundary condition for the phonons.

The longitudinal optical (LO) phonons of quantum well systems separate into confined modes which are strongly restricted to one or the other material and to interface modes. The dispersions of the symmetric and antisymmetric interface modes of the SQW and those of SMQW lie between the Reststrahl regions the two bulk materials. The SMQW displays additional modes due to the interfaces associated with the thin AlAs

layer. For small wavevectors the frequencies of the interface modes approach the bulk mode frequencies, and for large wavevector their frequencies approach those of a single interface, which lie in the middle part of the Reststrahl regions.

We have calculated the potentials of both the confined and interface phonons of the SQW and SMQW using the dielectric continuum approach. The confined and interface modes are either symmetric or antisymmetric with respect to a plane at the origin for both well configurations.

The effective mass approximation is used here for the electronic wavefunctions. We are primarily interested in the effects of changes in the phonon potentials on the scattering rates. We assume that the AlAs layers are thin enough that they do not significantly modify the electronic wavefunctions, and we will take the electronic wavefunctions to be the same in the SQW and in that with the SMQW.

We find that scattering of electrons from confined phonons increases with increasing well width for both the simple quantum well and the quantum well with the thin AlAs layer. The scattering rates for simple quantum wells and structurally modified quantum wells approach those for bulk GaAs for large well widths. The scattering from confined phonons is reduced for the structurally modified quantum wells as compared to the simple quantum well.

The electron-interface phonon scattering is strongly enhanced in the structurally modified system as compared to that of the simple quantum well. The AlAs-LO like interface phonons remain the dominant scattering mode for both the simple quantum well and the structurally modified quantum well.

We find that the introduction of a thin AlAs layer in the quantum well significantly reduces scattering of electrons from confined phonons but that this decrease is compensated by increased scattering from new interface phonons. The net overall

effect is a increase in the total scattering, which comes from the additional interface modes. Our results suggest that the enhancement of mobility reported by Zhu et al¹ is not expected to arise from decreased electron-phonon scattering due to the AlAs layer.

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- [2] N. Mori and T. Ando, Phys. Rev. B **40**, 6175 (1989).

CYNTHIA MCINTRYE, PH.D.

Biography

Cynthia R. McIntyre is an assistant professor of physics at George Mason University, Fairfax, VA. Her research focus is on the electronic and optical properties of semiconductor quantum well systems. She was awarded the National Research Council Research Associateship to conduct research on low-dimensional semiconductor system at the Naval Research Laboratory in Washington, DC. Previous research focused on the electronic properties of semiconductor quantum wires.

Cynthia earned the B.S. and Ph.D. degrees from the Massachusetts Institute of Technology in 1990. She is the National coordinator and one of the original founders of the National Conference of Black Physics Students.

MATERIALS ISSUES IN III-V COMPOUND SEMICONDUCTORS

Michael D. Williams, Ph.D.



Materials Issues in III-V Compound Semiconductors

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The advent of non-equilibrium growth techniques such as molecular beam epitaxy has allowed the growth of material systems that are not normally found in nature. The III-V compound semiconductors are prototypical examples of the fruit of these techniques. They possess a direct band gap at the zone center of the energy versus momentum dispersion curves for the crystalline phase. This property enables optical transitions to be made to and from the most energetic filled electronic states in the valence band of the material to the lowest energy empty states across the forbidden band gap in the conduction band. These materials can be found in general use as optical sources and detectors and in photovoltaic energy generation.

This talk will overview the issues relevant to the use of the III-V's in device physics. The topics to be covered include pseudomorphic growth, strain effects, and alloying effects. The majority of these effects are those associated with the surface and interfacial regions of the device structure. The manipulation of these effects by a judicious use of materials and geometries has resulted in a burgeoning field known as band gap engineering. In order to explore these phenomena, surface sensitive techniques are required. A brief survey of these techniques will be given with particular emphasis on ultraviolet photoemission spectroscopy.

The ability to monitor and tailor the evolution of a device structure *in situ* as it is being grown is of paramount importance for process control in bandgap engineering. An example of this type of

experimental analysis is presented by an overview of the photoemission study of the strained layer $\text{In}_{0.30}\text{Ga}_{0.70}\text{As}/\text{GaAs}$ (100) multiple quantum well system described below.

The strained layer $\text{In}_{0.30}\text{Ga}_{0.70}\text{As}/\text{GaAs}$ (100) multiple quantum well system has attracted considerable interest as an amplifier for Er-doped optical fibers at a wavelength of 0.98 μm . *In situ* ultraviolet photoemission spectroscopy and reflection high energy electron diffraction were used to study the growth front profile and pseudomorphism of single $\text{GaAs}/\text{In}_{0.30}\text{Ga}_{0.70}\text{As}$ heterojunctions. The interfaces were grown by solid source molecular beam epitaxy at different substrate temperatures under As_2 overpressure using interrupted and continuous growth mode techniques. The reliability of these optical sources depends on a good understanding of the growth characteristics of the material and ultimately upon the stability of the active layer quantum well structures. The potential energy profiles of InGaAs quantum wells grown will be progressively affected by the In segregation with increasing growth temperatures. We find that segregation occurs for growth temperatures as low as 400 $^{\circ}\text{C}$ under pseudomorphic conditions. The In concentration in the overlayer increased exponentially with temperature in a manner analogous to that of the diffusion constant for equilibrium growth conditions. This segregation is shown to consist of a fast component with an activation energy of 0.18 eV and a slow component with a 2.49 eV activation energy. There is also the possibility that this latter feature is due to misfit dislocations which would also greatly enhance the segregation. The injection of current across these structures for typical operation also causes defects to accumulate at the interface junctions. X-ray diffraction results show that this too will cause compositional grading of the quantum wells. Hence, the subsequent modification of the potential energy wells would degrade the device performance over time. The growth of high quality strained $\text{InGaAs}/\text{GaAs}$ multiple quantum wells under typical growth conditions is non-trivial. The segregation length is extremely long (116 ML at 540 $^{\circ}\text{C}$). Low temperature growth would limit the segregation but also increase the level of defects. Interrupted or modulated growth techniques appear to be the best approach to the growth of strained systems with a segregating species.

MICHAEL D. WILLIAMS, PH.D.

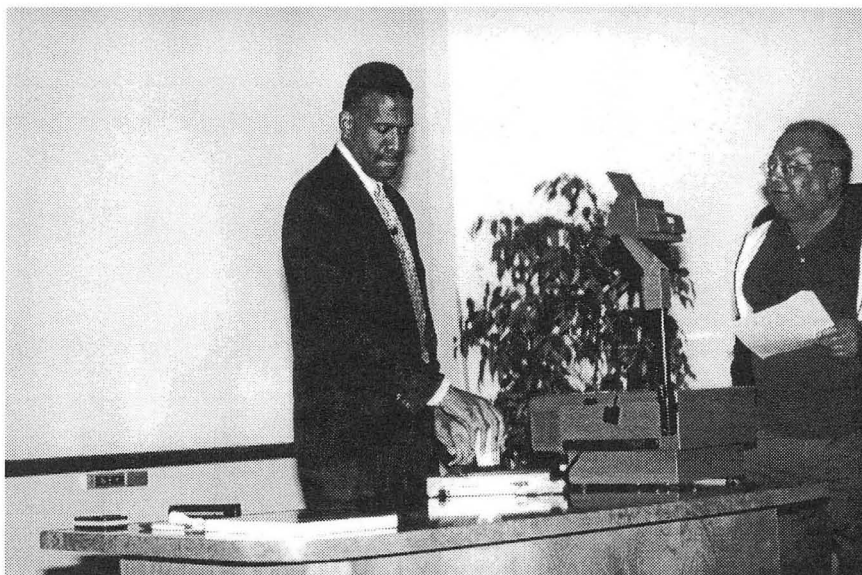
Biography

Michael Williams is an associate professor in the Department of Physics at Clark Atlanta University. His research interest is to investigate the physics and chemistry at surfaces and interfaces using surface sensitive techniques. Dr. Williams is formerly a member of technical staff in the Optoelectronics Research Department at AT&T Bell Laboratories' Holmdel, New Jersey facility.

He earned a BS degree from Morehouse College (Atlanta, Georgia), MS degree in Nuclear Engineering from Georgia Institute of Technology (Atlanta, Georgia), and MS. and Ph.D. degrees in Physics from Stanford University (Stanford, California). He is a member of the American Physical Society, the American Vacuum Society, the National Society of Black Physicists, Sigma Pi Sigma, Beta Kappa Chi, and Sigma Xi.

USING SUPERCOMPUTERS TO DESIGN NOVEL MATERIALS

Steven L. Richardson, Ph.D.



Using Supercomputers To Design Novel Materials

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ABSTRACT

Modern supercomputers are special-purpose machines which possess multiple central processing units (CPUs), very large and fast memories, and multistaged or pipelined functional units. They also contain vector or parallel processors and employ software to exploit all of these properties in a highly efficient manner. In particular, supercomputers have very large random-access memories (RAM) of about 16 Gbytes and can perform floating point operations at speeds of gigaflops (Gflops: a billion floating point operations per second) or even teraflops (Tflops: a trillion floating point operations per second). This should be compared to the average personal computer or workstation which typically possesses only 32 Mbytes of RAM and works at speeds of the order of megaflops (Mflops: a million floating point operations per second)! A useful example of how fast a supercomputer works can be seen with the INTEL Paragon Supercomputer, which was developed through a collaboration between Caltech and INTEL, and in 1994 has been clocked as performing a typical calculation involving a double precision complex LU (linear algebra) factorization code at 38 Gflops. The same calculation would require a human being 11,240 years using a hand-held calculator!

It is both ironic and sad to mention in this talk that Seymour Cray (1925–1996), the father of modern supercomputers, died last year due to injuries suffered in an automobile accident in Colorado Springs. His contributions to the development and use of supercomputers are legendary and he will go down in history as being one of the pioneers of this important field. Because of Mr. Cray's technical insight and vision, the supercomputer industry has developed within the past twenty years into an international consortium of vendors which include: CRAY Research, INTEL, IBM, Silicon Graphics, Fujitsu, Hitachi, and NEC.

This novel technology, together with the National Information Infrastructure (INTERNET) project of the U.S. Government, has created a "third area of science" known as *computational science and engineering*. In this new field, supercomputers have been used to tackle a myriad of problems including drug design of protease inhibitors for diseases such as HIV/AIDS, the fabrication of the Boeing 777 modern superjet, the possible prediction of global climate patterns, and the use of virtual surgery, such as endoscopic sinus surgery, for educating medical students.

Supercomputers have also enabled scientists and engineers to make considerable progress in understanding the microscopic behavior of materials. In particular, through a *first-principles* solution of the Schroedinger wave equation for describing the quantum mechanics of microscopic matter, it is now possible to calculate the electronic, vibrational, and structural properties of materials and compare such theoretical results with experiment. What also makes this field of computational materials science fascinating is that it is sometimes possible to use these supercomputer calculations as a guide for novel experiments.

We would now like to illustrate a few representative examples of some interesting problems in computational materials science which have been solved using supercomputers. As a first case,

J. Bernholc and his colleagues at North Carolina State University have performed calculations on the NSF-supported CRAY T3D supercomputer at the Pittsburgh Supercomputing Center. In particular, they have studied the growth of adatoms on a silicon surface using *first-principles* techniques to explore important problems in surface diffusion. Our next example is from the group at Iowa State where C-T. Chan and B. N. Harmon have performed a quantum mechanical molecular dynamics simulation of the melting of a "solid" of 512 carbon atoms at temperatures above 4000K. This "computer experiment" was performed on the INTEL Paragon Supercomputer. Finally, we wish to discuss some of our own work on the *first-principles* determination of the structural, vibrational, and electronic properties of energetic materials, in collaboration with Prof. José Luís Martins at the University of Lisbon and the Institute de Engenharia de Sistemas e Computadores (INESC) in Lisbon, Portugal.

While there has been an enormous amount of experimental and theoretical interest in the structural, electronic, and vibrational properties of the fullerenes¹, there exists an even simpler class of carbon-based structures which not only have cage-like properties analogous to the fullerenes, but, in addition, possess highly energetic properties due to their strained molecular geometries. These energetic materials are hydrocarbons such as cubane C_8H_8 , pentaprismane C_5H_5 , and tetrahedrane C_4H_4 , and they all possess molecular units in which there is a significant amount of strain in their chemical bonds. Such excess strain energy is due to a deviation from the normal C-C bond angles of 109.8° in the tetrahedral sp^3 -hybridized form of carbon, to the highly strained C-C bond angles which exists in these materials.

The first of these energetic materials, cubane C_8H_8 , was synthesized by Eaton and Cole² in 1964 and its crystalline structure was determined by Fleischer³ to be rhombohedral with one molecule of cubane per unit cell. Richardson and Martins⁴ have recently performed the first *ab initio* total energy calculation on the structural properties of solid cubane and found that there is a significant distortion from the cubic form of the C_8H_8 unit structure, due to crystal field effects of the rhombohedral Bravais lattice, in confirmation with the experimental data of Fleischer. In fact, there has been a significant amount of interest in cubane not only for its properties as a potential energetic material, but nitro-substituted (NO_2) forms of cubane (i.e. 1, 7-dinitrocubane), as well. Materials such as cubane may have unique properties as energetic materials or explosives, interesting uses as antiviral agents, and novel electro-optic characteristics.

While a considerable amount is known about the electronic, structural, and vibrational properties of the molecular forms of these materials^{5,6,7}, very little is known about the solid state or crystalline form of these materials from a theoretical or computational point of view. Recent advances in computational materials science and theoretical condensed matter physics have enabled scientists and engineers to predict such equilibrium properties as cohesive energies, bulk moduli, lattice parameters, elastic constants, and vibrational frequencies of solids from *first-principles*, which only requires the atomic number and structure of the materials in question. Furthermore, significant theoretical advances have also been made in this field with the pioneering work of Car and Parrinello⁸ in developing *ab initio* molecular dynamics techniques to determine the optimum metastable structures of materials at a given pressure and temperature. Such theoretical approaches are powerful not only in their ability to explain existing experimental phenomena but to predict novel properties of materials as well.

In particular, our calculations have employed the plane wave local density formalism momentum space^{9,10,11}, with the Ceperley and Alder¹² form of exchange correlation, as parametrized by Perdew and Zunger¹³. The *ab initio* pseudopotentials which we used were originally developed by Troullier and Martins and have been well tested for a number of first-row elements such as carbon¹⁴⁻²⁰. Our work has shown that the use of density functional theory in the local density approximation (LDA) to determine the structural properties of cubane gives results which are roughly 10–15% of the experimental data. It is well-known that with the van der Waals type of bonding that exists in such molecular solids as cubane, this result is quite good for a calculation on the level of LDA, and we are exploring the use of the generalized gradient approximation (GGA) as an improved scheme to treat the effect of hydrogen bonding in these molecular solids. This study is especially warranted in light of recent neutron scattering data from researchers at the University of Chicago and NIST on the structural and vibrational properties of solid cubane.

In summary, as modern supercomputers become even faster and cheaper with the advent of technological breakthroughs in the computer industry, the scope of problems in computational materials science will continue to expand. The third branch of science, *Computational Science and Engineering*, in addition to experimental and theoretical science, will have an even more important role to play in the simulation and design of novel materials for both their fundamental and technological importance in society's future. It is now left for the next generation of Seymour Cray's to take us into the 21st century of computational materials science where important discoveries await us.

*National Lecturer, Sigma Xi, The Scientific Research Honor Society, 1996–1998

ACKNOWLEDGMENTS

We wish to thank the Department of Energy and the National Science Foundation for support of this work. SLR is also grateful to the National Science Foundation for a Career Advancement Award in support of this research.

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STEVE RICHARDSON, PH.D.

Biography

Steve Richardson is Professor of Electrical Engineers at Howard University. He was formerly Program Director, Condensed Matter Theory Program in the Division of Materials Research at the National Science Foundation, as well as, Senior Research Scientist at Eastman Kodak.

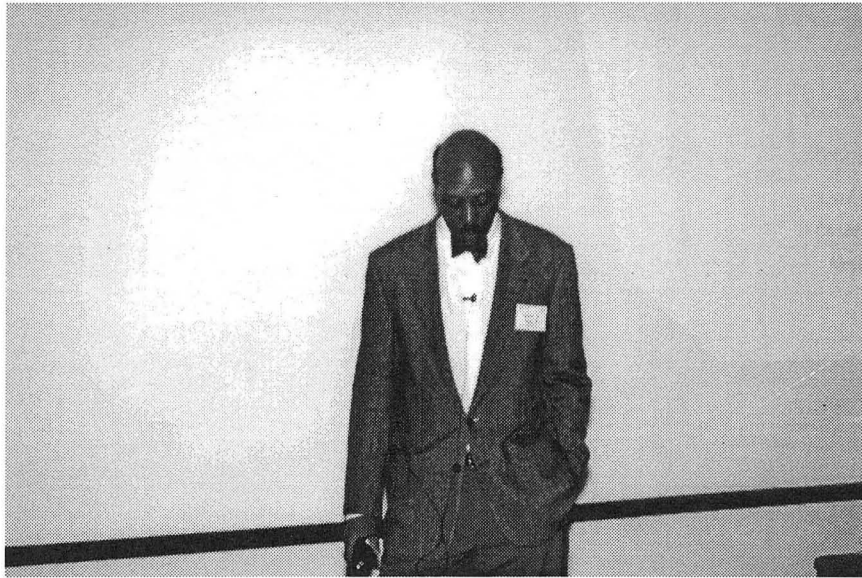
His research interest include Ab initio and empirical pseudopotential calculations of the electronic, structural, and vibrational properties of materials; Theoretical investigations of multiple-barrier resonant tunneling in semiconductor heterostructures; Calculations of magnetic bulk and surface polaritons in modulated antiferromagnetic/nonmagnetic superlattices; and Ab initio quantum chemical studies of photochemical reaction intermediates in extraterrestrial atmospheres.

His awards include National Lecturer, Sigma Xi, The Scientific Research Honor Society, Visiting Professor, University of Lisbon and the Institute de Engenharia de Sistemas e' Computadores (INESC), Lisbon, Portugal. He is a member of the New York Academy of Science, American Physical Society and American Association for the Advancement of Science.

HIGH ENERGY PHYSICS

A BRIEF REVIEW OF LIGHT QUARK PHYSICS

Warren W. Buck, III, Ph.D.



A Brief Review of Light Quark Physics

Warren W. Buck, III, Ph.D.

**Professor and Director of the Nuclear/High Energy Physics Research Center of Excellence
Hampton University
Hampton, Virginia 23660**

Abstract

The Standard Model of Quantum Chromodynamics (QCD) is simply stated through its Lagrangian but is not simply solved through any technique or measurement. For this reason theorists and experimentalists, alike, are pursuing directions that explore energy domains that have an opportunity to verify and elaborate on the predictions of the Standard Model, as well as continue to look for rare predictions of the Standard Model, as well as continue to look for rare exceptions that extend or identify anomalies to the Standard Model. The high duty factor 4-6 GeV electron beam energy of the Jefferson Lab provides an excellent tool to explore many aspects of the light quark (u,d. and s) sector and, with an upgrade, the Jefferson Lab could explore portions of the charm sector as well. This presentation intends to convey the general status of both the theory and the experiment. The emphasis will be on hadronic electroproduction and the incorporated form factors.

WARREN BUCK, PH.D.

Biography

Warren Buck is the Director of the Nuclear/High Energy Physics Research Center of Excellence of Hampton University, Advisor to CEBAF Director, Professor of Physics at Hampton University, Hampton University's Liaison with The Continuous Electron Beam Accelerator Facility (CEBAF) and a Theory Group Member at CEBAF. He has served as a visiting professor of Physics at The Gutenberg University, Mainz, Germany, Michigan State University, East Lansing, Michigan, Morehouse College, Atlanta, Georgia and The College of William and Mary.

He earned his bachelors degree in mathematics at Morgan State University, Baltimore, Maryland, and M.S. and Ph.D. degrees at The College of William and Mary, Williamsburg, Virginia. He has received several awards such as the Outstanding Service Award from the User's Group of The Continuous Electron Beam Accelerator Facility (CEBAF), Honorary Superior Accomplishment Award from NASA/Langley Research Center for significant contributions in radiation physics enabling practical shield designs for manned space missions.

WHY EINSTEIN WOULD LOVE SPAGHETTI IN FUNDAMENTAL PHYSICS

Sylvester James Gates, Jr., Ph.D.



Why Einstein Would Love Spaghetti in Fundamental Physics

Sylvester James Gates, Ph.D.
Physics Department
University of Maryland, Maryland

Abstract

There are some questions in physics that we cannot answer due to the lack of a complete theory of gravitation. Some of these are, "How does the force of gravity work on objects a billion times smaller than the force of gravity work on objects a billion billion times smaller than the hydrogen atom?" or "What is the complete physics of Black Holes?" For such questions it is critical to know how the force of gravity can be consistent with the principles of quantum mechanics. In these arenas, the effects of gravity and all the other forces must be very different from those seen in everyday experience. Einstein suspected this and it led him to the belief that there must exist a "unified field theory" to describe our world. He spent the last forty years of his life unsuccessfully searching for this construction. More recently there appeared new ideas called "superstring theory" that have apparently succeeded. This talk is an accessible introduction to the idea of superstrings as well as a progress report on the status of the topic.

JAMES GATES, PH.D.

Biography

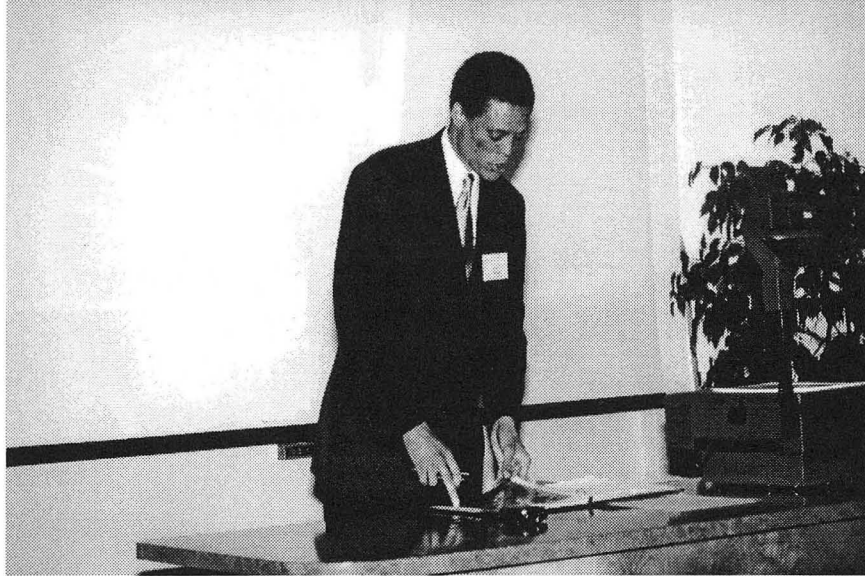
S. James Gates, professor of physics at the University of Maryland. He obtained his Ph.D. from MIT in the area of elementary particle physics and quantum field theory.

Gates' study of the mathematical laws that govern various forms of energy and matter have paved the way for 21st Century exploration of the universe at tiny scales previously inaccessible. New particles called "superpartners" may soon be observed for the first time in the laboratory Gates' work, if verified by experiment, will lead to a new constant of nature that he named "gamma-ess."

He is a past President of the National Society of Black Physics. He is the recipient of the Technical Achiever of the Year Award of the National Technical Association, VML Award of the American Physical Society. He is also a Fellow of the American Physical Society.

EXPLAINING THE **U**NIVERSE FROM **T**OP TO **B**OTTOM

Larry Gladney, Ph.D.



Explaining the Universe from Top to Bottom

**Larry Gladney, Ph.D.
Physics Department
University of Pennsylvania
Philadelphia, Pennsylvania**

Abstract

Since 1974, particle physics has had a remarkable run of success in filling in a complete picture of the fundamental particles and the forces that govern their behavior. The measured properties of “heavy” quarks, leptons, and bosons discovered since that year have not only matched expectations of the Standard Model, the most successful quantitative scientific theory to date, but have allowed us tantalizing glimpses at answers to profound questions about the early evolution of the universe just after the Big Bang. These glimpses, coupled with the overwhelming success of the theory, are powering the curiosity that is driving the next round of experiments to take place in the 21st century. This talk will be a quick tour of highlights in particle physics over the next 25 years and a modest projection of what the next 25 years of experiments may be like.

LARRY GLADNEY, Ph.D.

Biography

Larry Gladney is an Associate Professor of Physics at the University of Pennsylvania. Gladney received his B.A. in physics from Northwestern University and the Ph.D. at Stanford University. He has worked with the Collider Detector at Fermilab collaboration (which discovered the sixth quark, top) at Fermi National Laboratory.

He now works on the BABAR experiment at the Stanford Linear Accelerator Center where he and other physicists are assembling a new experiment to collide matter and antimatter electrons to do research into the fundamental structure of matter. His scientific interests lie in the exploration of CP-violation, which may ultimately explain why matter and antimatter did not completely annihilate each other soon after the birth of the universe. His technological interest currently center around a collaborative research project on application of high-speed, networked supercomputers to high-energy physics, done in collaboration with Prairie View A&M.

His awards include, the Lilly Foundation Teaching Excellence Award in 1990, the Martin Luther King Lectureship at Wayne State University in 1996, and the Edward Bouchet Award from the American Physical Society in 1997.

INTERDISCIPLINARY CAREER

Speaker: Howard Smith



Interdisciplinary Careers

Howard Smith
Clarity Software
Mountain View, California

So you have a degree in Physics and would like to know what are your career options. This question may occur either at the beginning of your career, mid way or at the sunset. Although my degrees are in Mathematics not Physics, I have had to deal with many of the issues you are facing.

I am the founder of a Computer Software Company, a previous Vice President of Engineering managing the design and development of new Computer Systems for HP and SGI, and a previous researcher in artificial intelligence for IBM.

No degree in Engineering, Computer Science, nor Management. I have know formal training in Computer Science yet I did research in Artificial Intelligence and led teams that developed 3-D H/W and Software products. I had no training in electronics yet I was responsible for a team that designed leading edge computer CPU's and I/O interfaces. I do not have an MBA yet I have managed 100's of people and provided management training for some of the top technical officers in the computer business.

Am I unique or is this type of career path open to you? The answer is yes!

How Did I View Degrees In Mathematics?

To explain how a degree in Mathematics was viewed by my generation of African Americans in the sixties I will quote parts of a letter I received from a very close friend. "I have been thinking of your choice of majors and I think I will be during you a disservice by not telling you my views. On the one hand you indicate that you are not interested in a teaching career yet you major in a career that has only two options as I see it. Either you can go to work in the Post Office or you can be a teacher. To ignore this is to ignore the facts. How many Mathematicians have you met that weren't teachers? I would suggest you change careers to something more practical such as Graphics Arts or go to a professional school such as Law or Medicine." He was correct. I had never met an African American that wasn't a doctor, lawyer, or teacher. However, I knew I loved Mathematics, Chemistry, and Physics.

With a BS in Mathematics in my hand, I created a called numerical analyst and started looking for that position. (I had not met a numerical analyst either.) Therefore, to me the degree simple opened doors and trained me to think rationally. The rest of my training occurred in ways that are open to you. In summary, my college training and degree provided valuable training in analytical thinking but was not an end in themselves. Where I went to school and the degrees I hold were never important to me.

How Did I Accomplish What I Have With Degrees In Mathematics?

Have Fun

I was hooked on Computer Science in my first research project on Robotics. However, the thrill I received seeing people using a computer language I helped developed was unmatched. I always liked people. Most importantly, the pursuit of areas of interest was of higher priority than reducing risk to me or my career. It is important that you understand what you really enjoy. Be honest!

Develop New Skills / Knowledge

A degree in mathematics gave me tools to solve certain problems logically and to locate information. My leadership skills were developed in church and civic organizations but were honed in company management classes. Read! Read! The advice given to me early in my career by the person generally credited with starting the Random Access business. This person had a degree in secondary education and no formal technical training. Through books I obtained the basic knowledge needed to understand as diverse areas as Artificial Intelligence, 3-D Graphics, Processor design, etc. What you need is usually written somewhere if you take the time to read it.

Take Control Of Your Career

The first step in pursuing a career different than that you were formally trained is truly taking charge of your career. You must set your own goals. Decide what skills and knowledge you need and develop those using whatever resources available. However, you must make other decisions that only you can make. Are you an entrepreneur or do you prefer large companies, or you a leader or follower, manager or individual contributor. Make the decision that only you can make.

Summary

Pursuing a career different than the one you were formally trained can be pursued at any time. Just become responsible for all aspects of the pursuit. It requires first that you be honest with yourself in looking at your interest goals and skills. Second that you understand how the skills and knowledge acquired in your formal training can be of benefit. Third, that you are willing to work hard in pursuing the career and in acquiring the necessary skills.

Using this process enable me to do research in Artificial Intelligence, developed products that are used by thousands of people, to manage and lead some of the most successful engineering teams, and to be a successful businessman as a founder and co-founder of two startups.

If you work hard, prepare, persist, and believe in yourself you can make the change.

HOWARD SMITH

Biography

Howard Smith is Founder, President and Chief Executive Officer of Clarity Software, Inc. Howard has over thirty years of experience in the computer industry. From 1984 to 1990, Howard was with Silicon Graphics, Inc. in the position of Vice President and General Manager of the Workgroup Products Division and Vice President of Engineering, responsible for all product development. Prior to Silicon Graphics, Howard spent twelve years at Hewlett-Packard where his last position was Engineering Manager for the Computer Systems division.

Howard earned BS and MS degrees in Mathematics from California State University. He is an advisor to the Santa Clara Black Chamber of Commerce, member of the Board of Trustees of Nueva School, Board of Governors for the Santa Clara region of The National Conference of Christians and Jews, and United Way Advisory Council.

SPECIAL FUNCTIONS

Charlie Harper, Ph.D.



Special Functions

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Department of Physics
California State University, Hayward
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This paper is devoted to the theory and applications of a set of higher transcendental functions that arise naturally in mathematical physics. These higher transcendental functions are referred to as special functions, and they arise

1. when solving, in certain curvilinear coordinate systems, partial differential equations that are defined by physical problems and/or
2. when finding eigenfunctions and eigenvalues of differential operators.

The partial-differential-equations approach to special functions involves use of the separation of variables method and either the Frobenius-Fuchs power series solutions of one or more resulting ordinary differential equations or an Infeld-Hull type factorization procedure for finding eigenfunctions and eigenvalues of second-order ordinary linear differential equations.

Our focus is on a class of physical problems whose differential equation formulation involves the Laplacian operator, ∇^2 . The resulting partial differential equations include the Laplace equation, heat conduction (diffusion) equation, mechanical wave motion equation, and Schrödinger wave equation. After applying the separation of variables method, the resulting time-independent parts of all these partial differential equations may be written in the form of the Helmholtz differential equation, $\nabla^2 u + k^2 u = 0$. Problems involving the Helmholtz differential equation in spherical coordinates lead to spherical harmonics, Legendre polynomials and associated Legendre functions, Laguerre and associated Laguerre polynomials, and spherical Bessel functions. Problems modeled by use of Helmholtz's differential equation in cylindrical coordinates involve the various types of Bessel functions. Solutions of the Schrödinger wave equation for a linear harmonic oscillator are expressed in terms of Hermite polynomials.

Special functions such as Hermite polynomials, Legendre polynomials and associated Legendre functions, spherical harmonics, Laguerre and associated Laguerre polynomials and Bessel functions are widely used in mathematical physics and are the main focus of this paper; these special functions are special cases of the hypergeometric, ${}_2F_1(a, b, c; z)$, or confluent hypergeometric, ${}_1F_1(a, c; z)$, functions. There exist other useful special functions in mathematical physics that are not expressible in terms of ${}_2F_1$ or ${}_1F_1$. The functions ${}_2F_1$ and ${}_1F_1$ may be developed from the following main viewpoints:

1. ordinary differential equations and the Frobenius-Fuchs power series method,
2. factorization of ordinary differential equations, and
3. representation theory of local Lie groups.

In a lecture course, *The Application of Group Theory to the Special Functions of Mathematical Physics* (unpublished lecture notes, Princeton University, Princeton, NJ, 1955), Wigner pointed out that certain classes of special functions arise as matrix elements of the representations of local Lie groups such as the groups of rotation in two, three, and four dimensions or the Euclidean groups in two and three dimensions. Since Wigner's

work, many other group theoretical approaches to special functions have been developed. The purposes of these various group theoretical approaches are (a) to show unity (or demonstrate a central foundation) among the extremely large number of special functions and (b) to derive their various known basic properties. It, however, is important to note that there exist no single approach to special functions that unites all special functions and illuminates all of their various properties.

Section 1 is devoted to a treatment of the Sturm-Liouville theory and orthogonal polynomials since these concepts provide insight into properties of solutions of the second-order ordinary linear differential equations that lead to the special functions. The orthogonality condition and completeness of eigenfunctions in the Sturm-Liouville theory are shown to lead naturally to the Fourier series, Legendre series, Hermite series, and other series involving orthogonal polynomials (or orthogonal functions). Also, solutions of Sturm-Liouville (Schrödinger-type) type differential equations by use of the Infeld-Hull factorization method are discussed in Section 1.

The factorization method for finding eigenfunctions and corresponding eigenvalues of a large class of Schrödinger-type equations was introduced by Schrödinger (1940); in a clearly written paper, Infeld and Hull (Reviews of Modern Physics; 1951) further developed the method. By use of the factorization method, a second-order differential equation is factored (transformed) into a product of first-order differential operators which results in a pair of first-order differential equations that are equivalent to the original second-order differential equation. The form of the potential function determines if the factorization method will be successful. In terms of the forms of the potential function, Infeld and Hull classified factorizations into six (A, B, C, D, E, and F) general factorization types. Many examples of the various factorization types are presented in the paper by Infeld and Hull.

We show that the Infeld-Hull factorization method is equivalent to the representation theory of complex local Lie groups with four-dimensional Lie algebras $\mathcal{G}(a,b)$ and six-dimensional Lie algebra $\mathcal{F}_6$. Local Lie group theory provides a unifying approach to a large class of special functions and their properties. Local Lie group theory was developed in the nineteenth century and is (a) based on the use of local coordinates (needed for a discussion of special functions) and (b) concerned with groups that are analytic only in the neighborhood of the group identity element. A global Lie group involves coordinate free considerations and is an abstract group.

The Lie algebra (vector space) $\mathcal{G}$ of the local Lie group G is the set of all tangent vectors (generators) at the identity element together with commutation relations $[\alpha, \beta] \in \mathcal{G}$ defined for all tangent vectors $\alpha, \beta \in \mathcal{G}$. Lie's three fundamental theorems and their converses together with the Taylor expansion theorem provide a mechanism for constructing the Lie algebra associated with a Lie group. For local transformation groups which are important in our analysis, the commutation relations involve Lie derivatives, $[L_\alpha, L_\beta]$ or generalized Lie derivatives $[D_\alpha, D_\beta]$.

In Section 2, a discussion of the properties of the (a) hypergeometric differential equation and (b) hypergeometric function ${}_2F_1$ is given. The Legendre polynomials and associated Legendre functions are special examples of ${}_2F_1$, and their important properties are developed in Section 2. Also, some discussion of the Chebyshev polynomial, Gegenbauer polynomial, and Jacobi polynomial is given in Section 2.

Important members of a large subset of special functions are related to a class of functions called hypergeometric functions which are solutions of the hypergeometric differential equation (also known as Gauss's differential equation). The hypergeometric differential equation has three regular singular points, and it can be shown that any second-order ordinary linear differential equation with three regular singular points can be transformed (reduced) to the hypergeometric differential equation form. The solutions of many physical problems involve special functions that result from solving second-order ordinary linear differential equations with regular singular points. It is, therefore, natural to expect a connection among hypergeometric functions and certain special functions. The hypergeometric differential equation has the form

$$z(1-z)\frac{d^2w}{dz^2} + [c - (a+b+1)z]\frac{dw}{dz} - abw = 0. \quad (1)$$

Note that Eq.(1) has regular singular points at $z = 0, 1, \infty$. In Eq.(1), parameters a, b , and c are arbitrary complex constants. The hypergeometric differential equation is solved by use of the Frobenius-Fuchs power series method.

The Gegenbauer (also known as ultraspherical), Legendre and associated Legendre, and Chebyshev polynomials are special cases of the Jacobi polynomial (sometime called hypergeometric polynomial). Chebyshev polynomials involve solutions of separated equations in spherical, parabolic, prolate, and oblate spheroidal coordinates. Chebyshev polynomials converge rapidly and have the special property that $\text{Max}T_n(x) = +1$ and $\text{Min}T_n(x) = -1$; because of this property, Chebyshev polynomials are useful in numerical analysis. Gegenbauer functions result from separated equations in circular cylinder and spherical coordinates with two regular singular points at ± 1 rather than at 0 and 1.

Three ordinary differential equations are obtained when the separation of variables method for $u(r, \theta, \phi) = R(r)\Theta(\theta)\Phi(\phi)$ is applied to the Helmholtz differential equation in spherical coordinates. General solutions of the theta and phi (angular parts) equations are independent of the specific problem under investigation but are common to all problems that involve the Laplacian operator in spherical coordinates. Solutions of the angular parts with separation constant $-m^2$ are called spherical harmonics (also known as surface harmonics of the first kind), $Y_\lambda^m(\theta, \phi)$. For square integrable solutions, a replacement of the form $\lambda = n(n+1)$ is required. Tesseral harmonics is the name given to $Y_n^m(\theta, \phi)$ when $m < n$, and the term sectoral harmonics is used when $m = n$. Tesseral and sectoral harmonics may be written as $C_n e^{im\phi} P_n^m(\cos\theta)$ where $P_n^m(\cos\theta)$ are associated Legendre functions of the first kind. When $m = 0$, the spherical functions are called Legendre polynomials of the first kind (also known as zonal harmonics and Legendre coefficients).

Section 3 is devoted to special functions that are special cases of the confluent hypergeometric function, ${}_1F_1$. These special functions include the various Bessel functions, Laguerre and associated Laguerre polynomials, and the Hermite polynomials. Also, discussions of some properties of the confluent hypergeometric differential equation and properties of confluent hypergeometric function are given in Section 3.

The confluent hypergeometric differential equation (also called the Kummer differential equation) has the form

$$xy'' + (c - x)y' - ay = 0. \quad (2)$$

Equation(2) is obtained from the hypergeometric differential equation by use of substituting $z = bx$ and letting b approach infinity; this substitution causes a merging or confluence of the two upper singular points. In the confluent hypergeometric differential equation, there is a regular singularity at $x = 0$ and an irregular singularity at $x = \infty$. Equation (2) is solved by use of the power series method.

In Section 4, a comprehensive treatment of the Helmholtz differential equation in cylindrical coordinates and the resulting Bessel functions is given. Problems in mathematical physics that involve cylindrical geometry are in general simpler to solve in cylindrical coordinates (ρ, ϕ, z) than in Cartesian coordinates. By use of the separation of variables method for $u(\rho, \phi, z) = P(\rho)\Phi(\phi)Z(z)$ in the Helmholtz differential equation in cylindrical coordinates, the ordinary differential equation involving $P(\rho)$ leads to the Bessel differential equation. The various Bessel functions are solutions of various forms of Bessel's differential equation.

In Section 5, a summary of certain other useful special functions is given. As explained in the introduction of the paper, the list of special functions is extensive. The Handbook of Mathematical Functions (Abramowitz and Stegun, 1964) contains a fairly comprehensive list of special functions. The focus in our paper is on special functions that are widely used in mathematical physics to solve classes of problems whose formulations involve special cases of the Helmholtz differential equation. In general, special functions may be classified as (a) Type 1 - those special functions that satisfy a differential equation or (b) Type 2 - special functions that do not satisfy a differential equation; for example, the gamma function is a Type 2 special function.

Some other special functions that satisfy a differential equation are

1. Airy functions are solutions of the Airy differential equation which has the form $y'' - xy = 0$; the Airy differential equation characterizes constant force-type problems in quantum mechanical and in elementary particle physics,
2. Mathieu functions are solutions of the Mathieu differential equation which has the form $y'' + (a - 2b\cos 2x)y = 0$; the Mathieu differential equation results when a cosine-type potential is substituted into the one-dimensional time-independent Schrödinger wave equation, and
3. parabolic cylinder functions are connected with confluent hypergeometric functions and with Hermite polynomials; they are solutions of differential equations of the form $y'' + (ax^2 + bx + c)y = 0$.

Some special functions used in mathematical physics that do not satisfy a differential equation are

1. Einstein and Debye functions which are used in representing the specific heats of solids due to lattice vibrations,
2. error function,
3. gamma function, and
4. beta function.

CHARLIE HARPER, PH.D

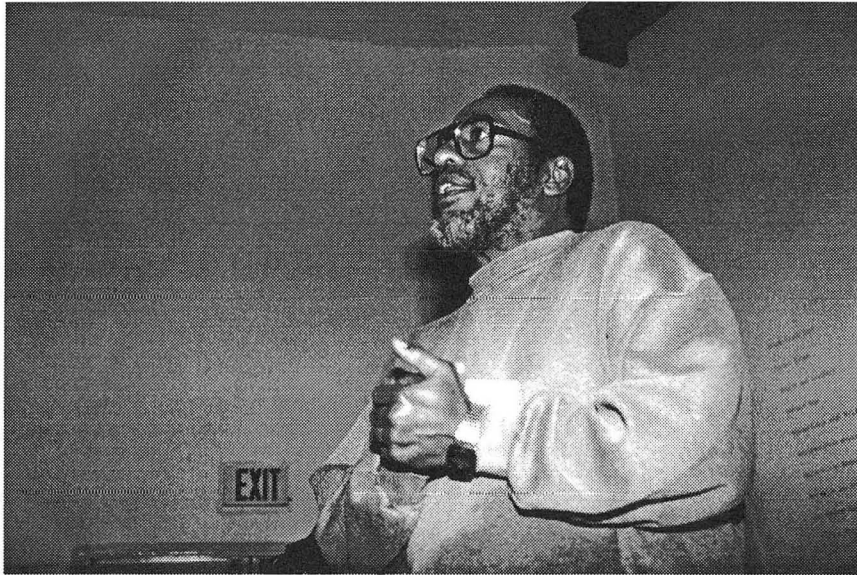
Biography

Charlie Harper is the Chair of the Physics Department at California State University, Hayward. He received his Ph.D. degree from Howard University. His area of research interest is Quantum Solids. Currently, he is looking at the quantum corrections to thermodynamics.

He is the author of the books, *Introduction to Mathematical Physics* and *Analytic Methods in Physics*. He is a member of the American Physical Society, American Association of Physics Teachers, and Sigma Pi Sigma.

THE GENESIS OF THE NATIONAL SOCIETY OF BLACK PHYSICISTS

Ronald Mickens, Ph.D.



The Genesis of the National Society of Black Physicists

Ronald E. Mickens
Distinguished Fuller E. Callaway Professor of Physics
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The following gives “my story” of the formation of what is now called the National Society of Black Physicists (NSBP). This chronology is based on my personal records/documents(1) and the first two newsletters of the Society of Black Physicists(2,3).

As a graduate student in physics at Vanderbilt University, I attended my first Southeastern Section Meeting of the American Physical Society in 1966 at Clemson University. There, I met Howard Foster, the Chair of the Physics Department at Alabama A and M University. We formed an immediate friendship which lasted up to his premature death in the early 1970's. For several years, Howard collected the names and other significant information on Blacks having degrees in physics: Roster of Blacks in Physics. After his death, I continued this activity for another decade.

I completed my doctorate in 1968 and with a National Science Foundation Postdoctoral Fellowship spent the next two years at the Center for Theoretical Physics, MIT. One of the most interesting persons at the Center was James Young, then on leave from Los Alamos National Laboratory, who would soon become Professor of Physics at MIT. In addition to our friendship and mutual respect for each other's scientific accomplishments, our discussions would often turn to the senior physicists in the black college community who mentored several generations of students who went on to achieve doctorates in physics. These “elders” served as role models, provided the required intellectual tools for success in graduate school, and gave (when needed) both emotional and financial support to their students. In early 1972, we decided to organize a gathering to honor three persons: Halson Eagleson (Howard University), Donald Edwards (North Carolina A and T College), and John Hunter (Virginia State College). All these individuals were well known in our community, were considered excellent teachers, and had trained large numbers of students who completed the requirements for advanced degrees in physics. Fisk University was selected as the site. There were three reasons for this decision: first, by this time, I was a member of the Fisk physics faculty; second, Fisk had a long tradition in both physics education and research; and, third, Nashville was a convenient location for travelers coming from both coasts of the country.

Jim Young and I asked Joseph Johnson III (Southern University) and Harry Morrison (on leave at Howard University from the University of California-Berkeley) to serve with us as an Awards Committee. However, it was understood that the detailed planning and related activities were to be done by me. A major time-saver in this effort was Howard Foster's Roster of Blacks in Physics. I wrote a letter explaining the purpose of the

gathering in Nashville and requested a contribution of \$50.00 per person to cover expenses of the affair.

At 5:30 p.m., 9 December 1972, approximately sixty friends, colleagues, and former students of the three guests of honor met at the Fisk University Faculty Club House for a pre-dinner social hour. The three awardees were interviewed in a separate room by representatives of the local print and broadcast press. Excerpts of these discussions, along with comments from others in attendance, appeared that night on two local television stations; the next day each of the newspapers published short articles on the event.

The Master-of-Ceremonies for The Awards Dinner for the First National Physics Fellows was Rutherford Adkins (Fisk University). After an excellent meal, historical perspectives were given by James Lawson (Fisk University), Warren Henry (Howard University), and Harry Morrison. This was followed by the presentation of each recipient's biographical sketch by a former student and individual remarks by each awardee. The three each received a plaque and a certified check for \$250.00. The citation text read as follows:

In recognition of distinguished service to physics and society, we the undersigned present to _____ the first National Physics Fellows Award. This Citation is gratefully awarded to the aforementioned by a group of his colleagues and friends who observe that the black experience in physics and science generally has been enriched by his gift and humanity. Presented by the Awards Committee, Nashville, Tennessee, 9 December 1972.

The Second National Physics Award Ceremony was held at Howard University on May 1, 1975. The planning committee consisted of Anna Coble and Arthur Thorpe, both of the Howard University Physics Department, and myself. It was decided that the Awards Dinner would be preceded by a full day of formal scientific lectures. The scientific program is listed below:

Speaker	Title of Talk
* Walter Massey	"The Surface of Quantum Liquids"
* William Jackson	"Laser Induced Photo-Luminescence Spectroscopy"
* William Lester	"Theoretical Studies of Low Energy Inelastic Molecular Scattering"
* Ernest Coleman	"Research Advances in High Energy Physics"
* James Young	"Interactions: Prognosis for the Future"
* Warren Henry	"Historical Perspective on Magnetism"

The three awardees were Herman Branson, Warren Henry, and James Lawson. The Awards Dinner ceremony followed closely the format established at Fisk University. In particular, each awardee was presented with a citation plaque and a certified check for \$250.00. Several hundred persons attended the Awards Dinner.

The enthusiasm generated by the Fisk and Howard events led to a Day of Scientific Lectures and Seminars that was held the following year (April 1, 1976) at Morehouse College. The prime organizers were Carl Spight and myself. At the end of the meeting, representatives from Morgan State University volunteered to put on a similar program in 1977. Another important feature of the Morehouse meeting was that many discussions took place on the possibility of establishing some type of national black physics organization. The following are some of the persons who made significant contributions, in the period 1976-77, to the plans for creating the proposed organization: James Davenport, Warren Henry, Walter Massey, Harry Morrison, Carl Spight, and James Young.

The statements now to be presented provide a concise summary of what took place at the Morgan State University meeting (April 28, 1977) and the following meeting, held again at Morehouse College (March 29-30, 1978). These statements are excerpted from reference(2):

“... The Society was inaugurated on Thursday, April 28, 1977 at Morgan State University, Baltimore Maryland with interim structures and officers. The general purpose of the Society is to promote the professional well-being of black physicists within the scientific community and within society at large, and to develop and support efforts to increase the opportunities for, and numbers of, Blacks in physics. The Society is not in conflict with either the goals or the mission of the A.P.S. or the A.A.P.T. or any other of the mainstream professional organization and is not intended to supplant any of them. Rather, the Society expresses the need for an organization in which Blacks play a major role in creating and developing activities and programs themselves for themselves. ...”

“...The first business meeting of the Society of Black Physicists was held in the early afternoon of Friday, March 31, 1978 at Morehouse College, Atlanta, Georgia at the end of the Fifth Annual Day of Scientific Lectures. ... At the business meeting reports were given by Walter Massey and James Davenport who served ably on an interim basis as, respectively, Society president and secretary-treasurer. ...”

The Society then elected its first full-time officers:

President: Carl Spight (Morehouse College),
Treasurer: Walt Massey (Brown University), and
Executive Member: James Davenport (Virginia State College).

These three individuals constituted the executive committee and were(2) “charged with the following short-term activities:

- a) Drafting of a formal statement of purpose and Bylaws of the Society
- b) Continuing the membership drive

- c) Continuing the complication of the roster of black physicists (under the direct supervision of Ronald Mickens)
- d) Initiating a Society "newsletter"
- e) Establishing liaison with the Minorities Committee of the AAPT and APS
- f) Representing the Society to all meetings of the (newly formed) Council of Black Scientific and Technical Organizations
- g) Continuing the annual Day of Scientific Lectures and Banquet. ..."

Two important points should be noted. First, the original name of the organization was the Society of Black Physicists. Second, the 1978 meeting at Morehouse College was called the Fifth Annual Day of Scientific Lectures. There existed in the thoughts of many one major line of reasoning for using "fifth" in the title of this meeting. The new Society was about to involve itself with other national organizations on a variety of issues related to both minority science education and the full participation in the scientific affairs of this nation. It was felt that in the deliberations to come and in the search for funds to support Society projects, advantages would accrue from having an organization with a "history." Consequently, starting with the first ceremony at Fisk and counting the Howard ceremony as second, it follows that the meetings at Morehouse (1976), Morgan (1977), and Morehouse (1978), would, respectively, be the third, fourth, and fifth Day of Scientific Lectures! Following this "logic," the second meeting of the Society of Black Physicists was held at Knoxville College(3) along with the Sixth Annual Day of Scientific Lectures during 26-27 April 1979.

Now that you have this history or "my story" of the genesis of the National Society of Black Physicists, I would hope that any questions related to the numbering of the annual Society meetings and the Day of Scientific Lectures can be finally (or at least partially) resolved.

References

1. R. E. Mickens, personal records.
2. C. Spight (Morehouse College), editor, *Society of Black Physicists Newsletter*, Volume 1, Number 1, June 1978.
3. C. Spight (Morehouse College), editor, *Society of Black Physicists Newsletter*, Volume 1, Number 2, April 1979.

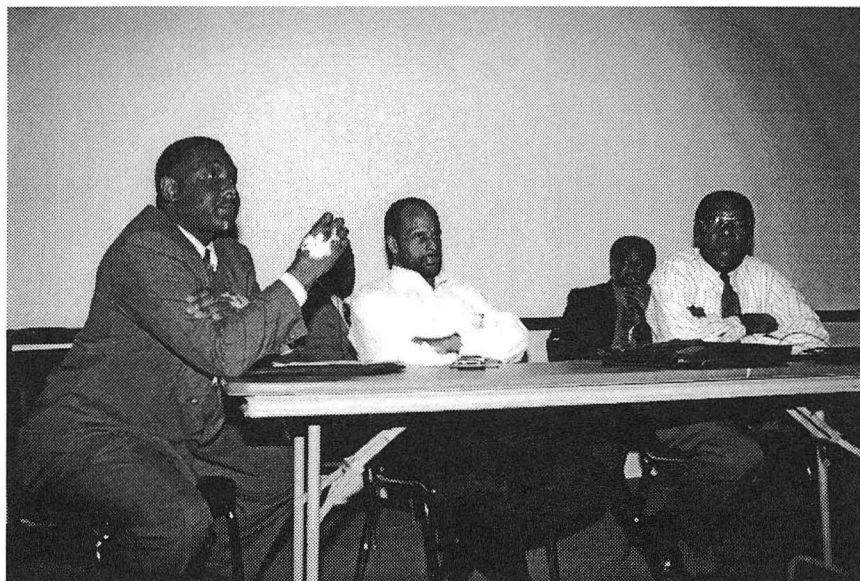
RONALD MICKENS, Ph.D.

Biography

Dr. Ronald Mickens is currently the Calloway Professor of Physics at Clarke Atlanta University. He is a past President of the National Society of Black Physicists (NSBP).

His research interest is the area of Nonlinear Differential and Difference Equations. He has authored more than 180 publications and six books. He is a Fellow of NSBP and the historian.

PANEL: STRATEGIC PROGRAM DEVELOPMENT IN PHYSICS



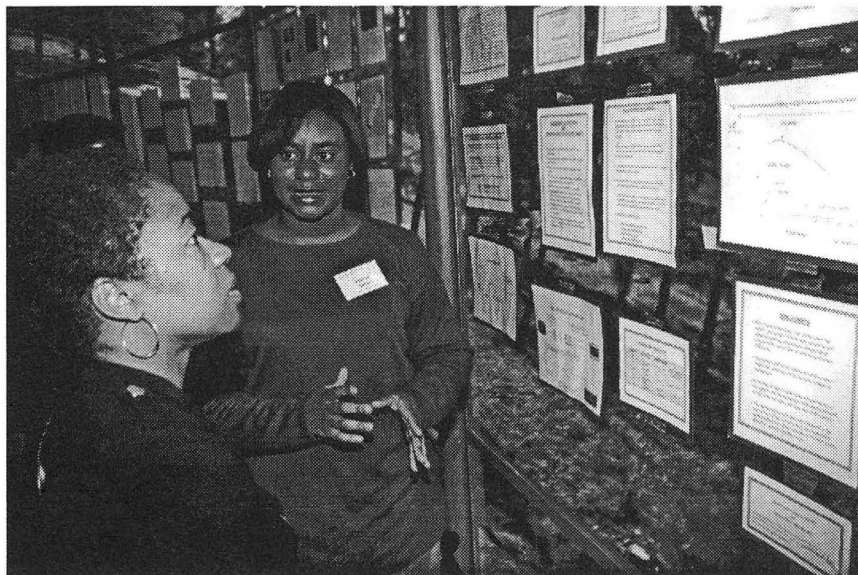
Right to left: John Hopps, Ph.D., Charlie McGruder, Ph.D., Eugene Collins, Ph.D., Lonzy Lewis, Ph.D.

PANEL: PHYSICS IN MID-CAREER PARADIGM SHIFT

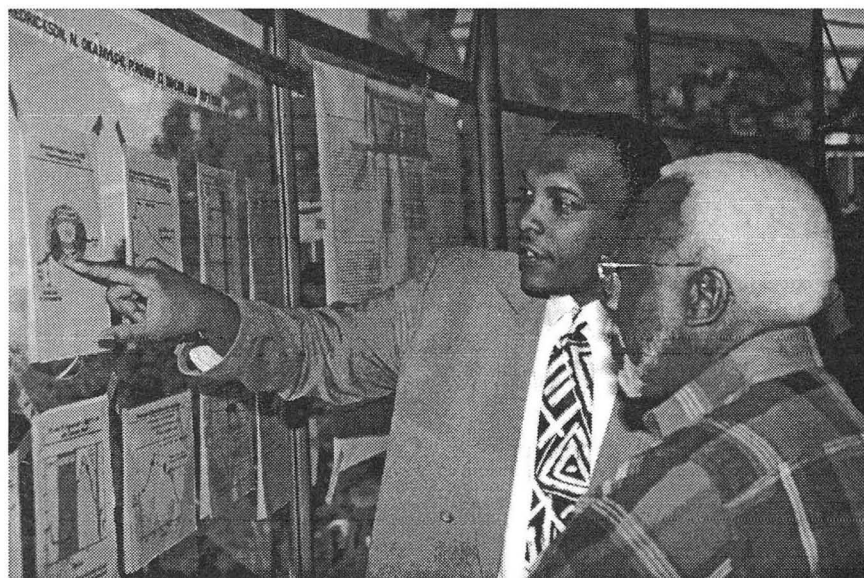
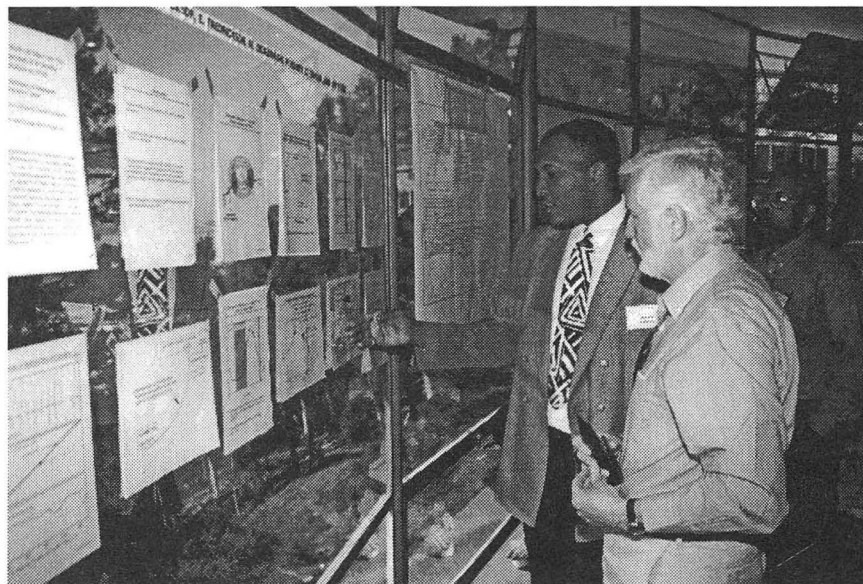


Right to left: Harry Morrison, Ph.D., UC Berkeley, Sekazi K. Mtungwa, Ph.D., North Carolina A&T State Univ., Debra Jackson, Ph.D., Jet Propulsion Laboratory, Pete Jupiter, Ph.D., Hughes Air Craft Corporation, James Turner, Ph.D., U.S. Dept. of Energy, Oakland

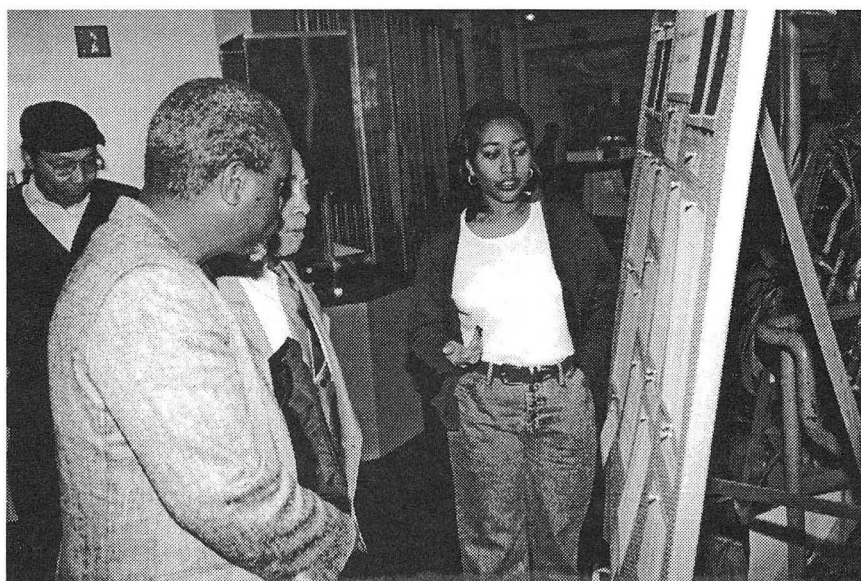
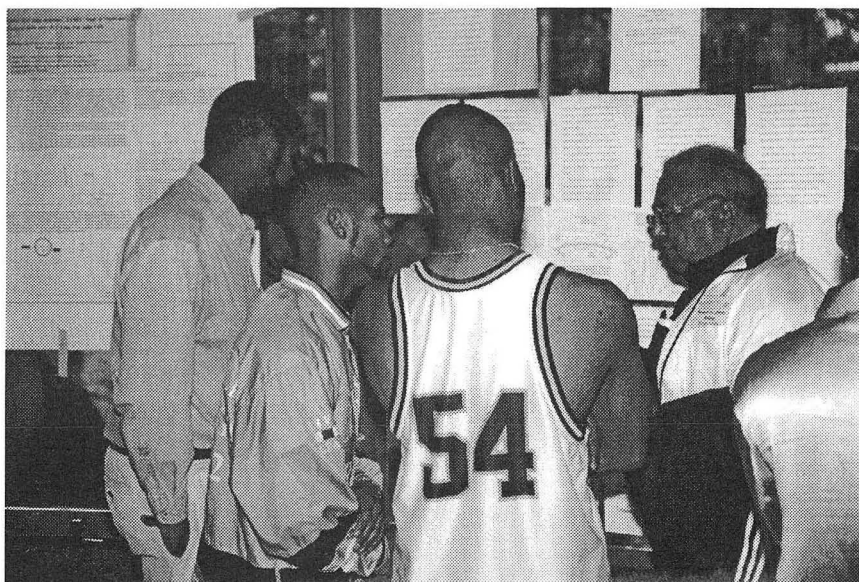
STUDENT POSTER SESSION



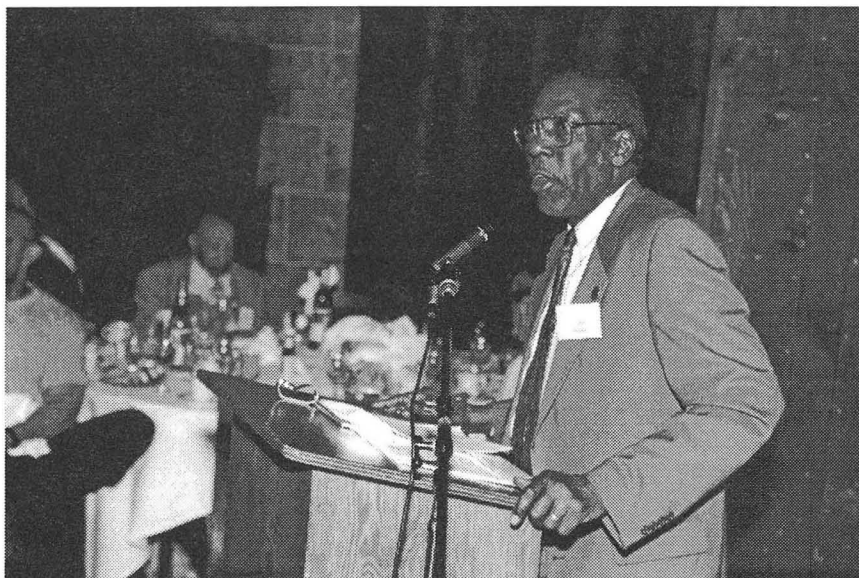
SCENES FROM STUDENT POSTER SESSION



SCENES FROM STUDENT POSTER SESSION



BANQUET



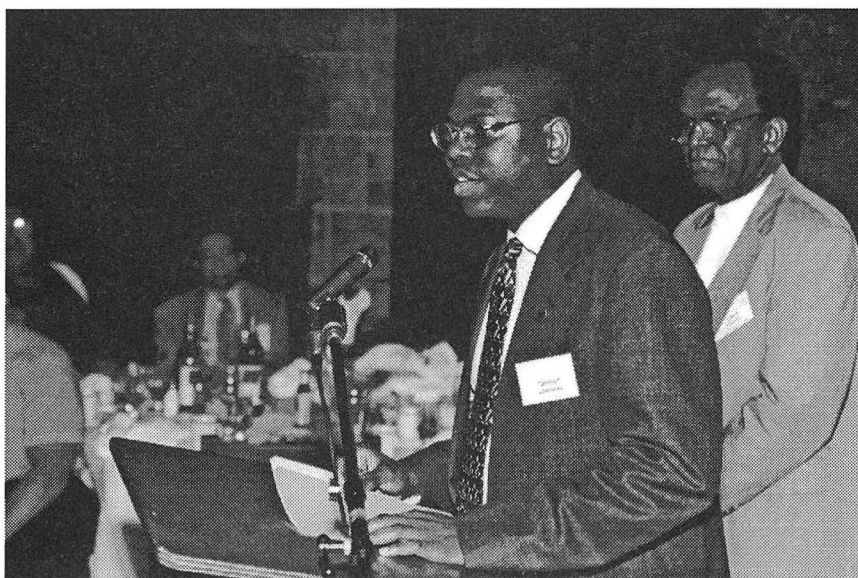
John Hopps, Ph.D. Vice Provost of Academic Affair, Morgan State University was the keynote speaker at the Conference Banquet held at the UC Berkeley Faculty Club.



Keith Jackson, Ph.D., Lawrence Berkeley National Laboratory serves as Master Ceremony at the Conference Banquet.

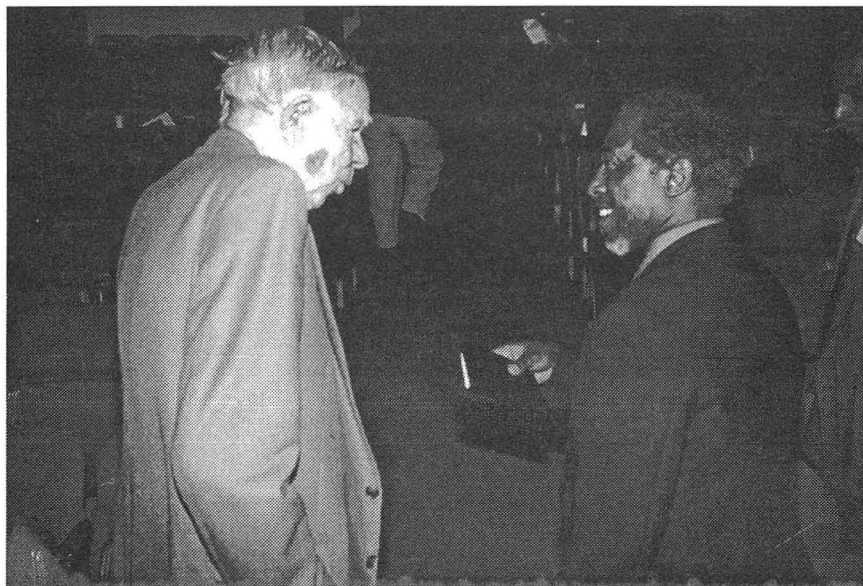


James Gates, Ph.D. of University of Maryland receives 1997 NSBP Award in recognition of service as President.



Willie Rockward, Ph.D. receives NSBP Dissertation Award.

CONFERENCE IN THE ROUND



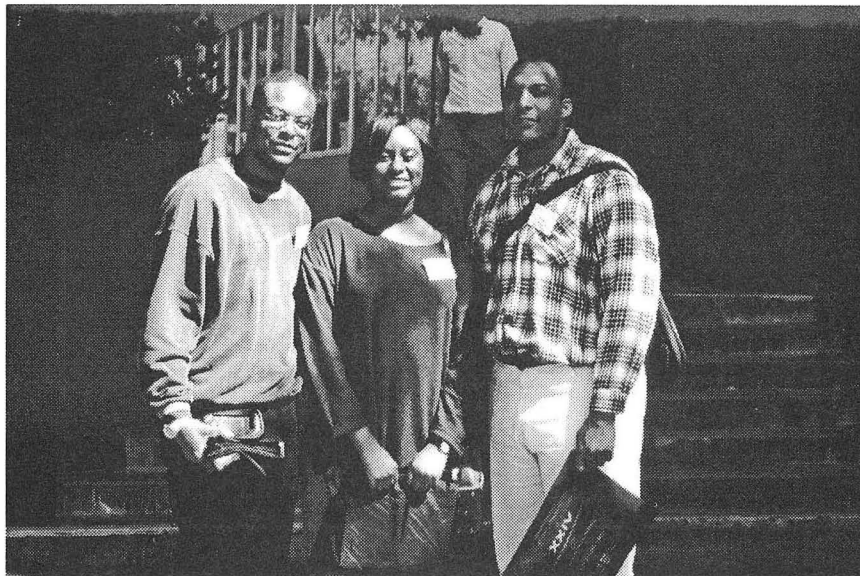
NSBP President, Dr. Lonzy Lewis with Nobel Laureate Dr. Glenn Seaborg



Dr. Warren Henry, the most eminent African American physicist met with Nobel Laureate Dr. Glenn Seaborg to discuss old times.

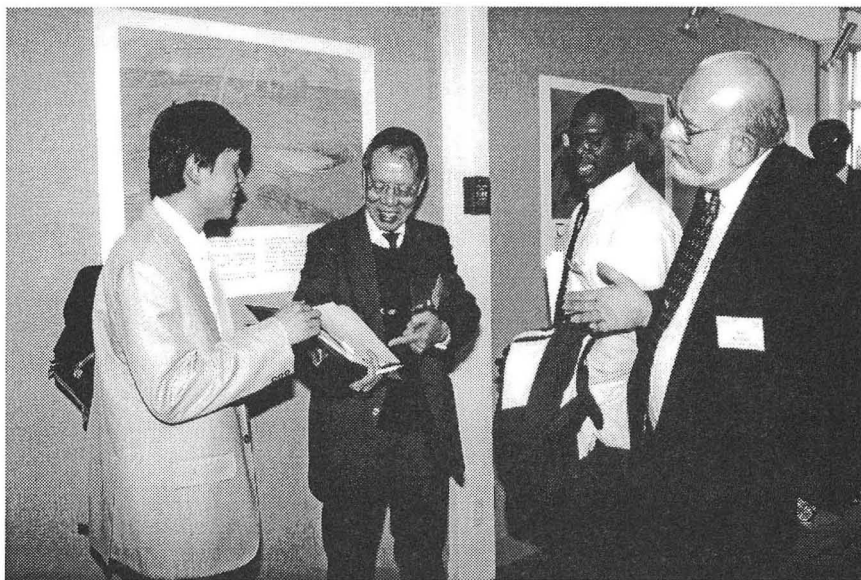


Robert Bragg, Ph.D., Professor Emeritus at UC Berkeley, and Warren Henry, Ph.D., Professor Emeritus at Howard University, the elder statesmen of the National Society of Black Physicists, are excellent role models.



The future of NSBP rest with the students.

INFORMAL COLLEAGUAL DISCUSSIONS





Physicists who are Morehouse Alumni gather at the conference.



Women at the Conference caucus to focus on problems unique to them.



Carl Spight, Ph.D. of Jackson Tull & Graham sparks a provocative discussion.



Ryan Swain received NSBP undergraduate scholarship award (sponsored by Lawrence Livermore National Lab) from Kennedy Reed, Ph.D.

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