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**Final Report to the
Department of Energy
on
DE-FG05-91ER40620
Electromagnetic Studies of
Mesons, Nucleons, and Nuclei**

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Project Director and
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**ELECTROMAGNETIC STUDIES OF MESONS, NUCLEONS, AND NUCLEI:
DEPARTMENT OF ENERGY AWARD DE-FG05-91ER40620
FINAL REPORT**

Project Summary

This is the Final Report on the work supported by the Department of Energy Award DE-FG05-91ER40620, O.K. Baker, Professor of Physics, the Principal Investigator (PI) and Project Director. This work centered upon the study of nuclear and particle physics at intermediate energies, focussing upon the study of the electromagnetic structure of mesons, nucleons and nuclei using intermediate energy electromagnetic and hadronic probes. These studies were conducted primarily at the Thomas Jefferson National Accelerator Facility (Jefferson Lab), formerly the Continuous Electron Beam Accelerator Facility (CEBAF) in nearby Newport News, Virginia, with a smaller (by comparison) effort at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL).

During the eight years of DOE support, there were many achievements which are noteable and worthy of description. The following accomplishments are highlighted:

- Completion of the kaon electroproduction experiments at Jefferson Lab. This was one of the first experiments completed at the new Laboratory.
- Publication of results in Physical Review Letters. This was only the second of all JLab publications based upon the experimental work.
- Graduation of Ph.D. student supported by this award. This was the very first of the experimental nuclear physics students to graduate.
- Design, construction, installation, and maintenance of the HMS drift chambers in Hall C at Jefferson Lab.
- Completion of the Σ -hypernuclear spectroscopy experiment at BNL.
- DOE-supported personnel from Hampton University played a major role in the Jefferson Lab experiments, especially in Hall C.
- Publications and invited talks based upon this DOE-supported research and development.
- PI promotion to Associate Professor and then to Professor of Physics at Hampton University and, jointly, to Staff Physicist II at Jlab.
- PI has served on several national committees; currently serves on the Nuclear Science Advisory Committee.

During this period, the PI (Baker) and others supported by this DOE award made significant contributions to several projects at the Indiana University Cyclotron Facility (IUCF), at the Saturne Laboratory in France, at the Brookhaven National Laboratory (BNL), as well as at Jefferson Lab. This included calibration of detectors for research, collaboration on experiments and data collection and analysis, training of students, particularly students traditionally under-represented in physics research, and administrative service both within the University and nationally.

I Introduction

Most of the matter in the world around us is made up of hadrons which are believed to be composed of up and down constituent quarks, and gluons. It is possible to create artificially at Jefferson Lab, for example, hadrons which are made up of strange constituent quarks, and gluons. The K-meson, or kaon, is the lightest known hadron which is composed of a strange constituent quark. This DOE-supported experimental effort at Jefferson Lab centered around several programs in the broad area of kaon electroproduction; two in Hall C (E93-018 and E98-101) and one in Hall A (E94-108) where the PI (Baker) is the experiment Spokesman or Co-Spokesman. There are additionally, experiments E91-016 and E89-009 which are hypernuclear spectroscopy experiments where the PI (Baker) and students supported by this DOE award have played and are playing major roles.

Experiment 93-018, associated kaon electroproduction off hydrogen, was completed in the fall of 1996; it was one of the first experiments to be completed at Jefferson Lab. This experiment provides a fundamental measurement of the cross section for kaon electroproduction from the proton yielding information on the elementary amplitudes contributing to this process. From the measurement, we extracted the first separation of the longitudinal and transverse amplitudes for kaon electroproduction which, in principle, allow an extraction of information about the internal charge structure of the kaon. Both Lambda (Λ) and Sigma (Σ) hyperons (strange nucleons) were identified, and the individual amplitudes for these two reactions were studied over a large range of momentum transfer, from 0.5 to 2.0 GeV^2/c^2 . Some of the results of this work have been published in Physical Review Letters (PRL 81, 1805 (1998)). This was the second of all publications of experimental results from the Jefferson Lab research program. The first author on the paper was a Hampton University graduate student supported by this DOE award.

The results of the Hall C experiment will be used to better plan for the Hall A kaon electroproduction experiment (E94-108). The Hall A experiment will extend the measurements of the elementary amplitudes for kaon electroproduction up to 3 GeV^2/c^2 . It is anticipated that the experiment will commence in the 2000 calendar year. A second kaon electroproduction experiment in Hall C (E98-101; O.K. Baker, Spokesperson) is a novel approach to study polarization observables in this reaction mechanism. The experimental aim is to use polarized electrons scattered from an unpolarized hydrogen target to create polarized Λ -hyperons and kaons. The kaon and the proton from Λ decay will be detected in the same spectrometer (the SOS) while the HMS will be used to detect the scattered electron. The hyperon polarization will be determined from the information about the kaon and decay proton momenta.

The Hampton University graduate student working on experiment E93-108 and supported by this DOE award, Gabriel Niculescu, completed all of the requirements for the Ph. D. degree. This was the very first doctoral degree awarded to an experimentalist in

nuclear and particle physics at Hampton University. Dr. Niculescu accepted an offer from Ohio University and is now working in Hall B at Jefferson Lab. The University of Maryland graduate student working on this project is making good progress in his analysis. It is expected that this student will complete the analysis and all of the requirements for the Ph. D. degree there in this coming year. There was a second graduate student from Hampton University who acquired the majority of her dissertation data (parasitically) during the E93-018 running period. This student completed all of the requirements for her doctoral degree and has accepted a Postdoctoral Researcher position at the George Washington University. In all, a total of seven graduate students got at least part of their dissertation data from the Hall C kaon electroproduction experiments, four of them from Hampton University. The remaining two graduate students who are studying the kaon electroproduction reaction are expected to complete the requirements for the Ph.D. degree this calendar year.

The hypernuclear physics program activity at BNL which is supported by this DOE award is our attempt to form hypernuclei in normal nuclei by embedding a strange quark in the nucleus via the (K^-, π^-) reaction. The specific emphasis recently has been to perform a sensitive search for evidence of narrow Sigma-hypernuclear states in light hypernuclei. There has been some controversy surrounding the claimed existence of such states based upon recent experiments at KEK in Japan. In this present effort, we performed the first search with good statistical accuracy in ${}^6,{}^7\text{Li}$ nuclei using the Moby Dick spectrometer at BNL. This arrangement at BNL is particularly useful for such studies. The Hampton University doctoral dissertation student working on this experiment at BNL has completed the analysis of the data. Preliminary results have been published. It is expected that this dissertation student, Win Naing, will complete the requirements for the Ph.D. degree during the 1999 calendar year.

These funds also supported involvement of Hampton University personnel in planned measurements of the internal structure of the neutron at the Massachusetts Institute of Technology (MIT/Bates) and at Jefferson Lab. The charge and current distributions of the neutron provide fundamental input for understanding both nucleon and nuclear structure and for testing quark models. The proposed measurements probe the charge and current distributions of the quark constituents within the neutron. The measurement technique for extracting the charge structure makes use of a neutron polarimeter to measure the transverse polarization of the neutron scattered quasielastically in the $d(\vec{e}, e'\vec{n})p$ reaction. This technique has been demonstrated experimentally by the collaboration at MIT/Bates. The special advantage of this technique is that theoretical studies indicate that extraction of the electric form factor appears to be largely free from ambiguities. The neutron polarimeter to be used in the experiment has been calibrated at high neutron energies at the Saturne Laboratory in France in the Spring of 1996 and at lower energies at the Indiana

University Cyclotron Facility (IUCF) in 1995. The experiment will likely run at Jefferson Lab in the latter half of 2000. Funds from this DOE award were used to support the calibration studies at both laboratories.

There was, additionally, a small effort on the part of the PI to study rare kaon decays at BNL with the aim of relating the physics of these decays to the kaon electroproduction work at TJNAF. This work continues at BNL, however the PI (Baker) was only involved in the work and data collection during the 1995 and 1996 runs at BNL. The experimental aim is to search for physics outside of the Standard Model of Electroweak Interactions by the performance of a sensitive search for lepton family violating decays of the charged kaon. The experiment, E865, will get charged kaon decays statistics more than an order of magnitude better than currently exists for this decay mode. Hampton University personnel are no longer affiliated with this activity. This is mainly due to the more pressing needs at Jefferson Lab.

Brief descriptions of three experiments, which constitute the major work supported by this DOE award (where the PI (Baker) is either Spokesman or Co-Spokesman) and which were or are to be performed at Jefferson Lab are included in section II. These three experiments are (i) Longitudinal and Transverse Cross Section Separation in $p(e,e'K^+)\Lambda(\Sigma^0)$: (Jefferson Lab Experiment 93-018; O.K. Baker, Spokesman), (ii) Kaon Electroproduction at High Momentum Transfer (Jefferson Lab Experiment E94-108; P. Markowitz, G. Chang, F. Garibaldi, M. Iodice, and O.K. Baker, Spokespersons), and (iii) Polarization Transfer in Kaon Electroproduction (Jefferson Lab Experiment 98-101, O.K. Baker, Spokesperson).

II Major Accomplishments During The Project Period (1991 – 1999)

The Department of Physics at Hampton University has grown considerable during the period (1991- 1999). There Department prior to this period offered on B.S. and M.S. degrees in Physics, and enrolled about 18 undergraduate and 15 graduate students. Today, the Department offers the Ph.D. degree (the very first doctoral degree offered at Hampton University) and there are a total of over 20 undergraduate and 45 graduate students in the Department. There are now 14 faculty members, and more than a dozen staff associated with the Department.

The experimental nuclear and high energy physics group enjoyed success commensurate with that of the Department. The students funded under this grant have performed cutting-edge research at Jefferson Lab and at BNL. The PI and others in the Department made major contributions to, and in some cases led, experimental efforts at Jefferson Lab as well as several national and international laboratories, guided graduate students, post-docs, undergraduate students and technicians at Hampton University and Jefferson Lab, and presented results in refereed journals and scientific meetings.

Some of the major accomplishments of the funding period were:

II.1 Successful running of the initial experiments in Hall C at Jefferson Lab.

There were several experimental runs using the high energy electron beam at CEBAF. In December 1995, we completed a month and a half physics run to look for nucleon propagation inside the nuclear medium (E91-013; D. Geesaman spokesperson) using solid nuclear targets in Hall C. The runs used the HMS and SOS in Hall C as well as electron beam energies of up to 4 GeV (5 pass beam). This work was extended during the next run period in February 1996. Hampton University personnel were involved in more than one-half of the shifts during this experiment and played a major role in the data acquisition. The PI (O.K. Baker) was, additionally, the shift coordinator during part of the experiment as well as shift leader during a large fraction of the shifts. The results of this experiment were analyzed and the results were published in Physical Review Letters in 1998. This was the first Jefferson Lab publication on experimental results.

Immediately following the nucleon propagation experiment, an experiment was completed to investigate constituent counting rules in deuteron photodisintegration. The experiment (E89-024; R. Holt, spokesperson) was completed in mid-1996. Hampton University students, faculty, postdocs, and staff again played a major role in the experiment. The PI (O.K. Baker) was shift leader in many of the shifts. The data have been analyzed and the results published in Physical Review Letters. This was only the third of the Jefferson Lab experimental papers.

The next completed experiment (E89-008; D. Day and B. Fillipone, spokespersons) was a study of scaling at $x > 1$. The experiment was run during the period from August to early September. It is possible, in heavy nuclei, to observe scaling behavior at $x > 1$ using the Fermi momentum of the nucleons inside the nucleus. The data from this experiment have been analyzed and the results published in Physical Review Letters in January 1999.

The kaon electroproduction experiments (E93-018 and E91-016) completed data taking in the fall of 1996. The data are currently being analyzed. There have been several reports on the experiment and data analysis at conferences and workshops [1-2]. Some of the results of this work have been published in Physical Review Letters in 1998 [3]. This was the second publication of the experimental results from Jefferson Lab. This experiment has provided a fundamental measurement of the kaon electroproduction cross section in the reaction $p(e, e'K^+)\Lambda(\Sigma)$ in a way never before accomplished [4]. The cross section for kaon electroproduction in this experiment has four terms. These four terms arise from (i) unpolarized transverse, (ii) longitudinal, (iii) transverse-transverse interference, and (iv) longitudinal-transverse interference between, virtual photons [5-7]. This experiment succeeded in separating the four terms individually, and in particular, provide the first measurements of the longitudinal and transverse cross sections for $0.50 \leq Q^2 \leq 2.00 \text{ GeV}^2/c^2$.

Shown in Figs. 1-5 are the data from E93018 which has been analyzed so far: The Missing Mass distribution data from E93-018 for the kaon electroproduction reaction

$$e + p \rightarrow e' + K^+ + Y \quad (Y = \Lambda, \Sigma) \quad (1)$$

is shown in Fig. 1. In Fig. 2 is the world's data set of the kaon electroproduction total cross section for both Λ and Σ^0 hyperons in the final state, including the Jefferson Lab data. In Fig. 3 the separation of the longitudinal and transverse cross section (the L/T separation) for Λ is shown. The ratio of the longitudinal and transverse cross section versus momentum transfer is shown in Fig. 4 while the momentum transfer dependence of the longitudinal and transverse cross sections separately is shown in Fig. 5.

Now that this separation has been achieved, there are several physics issues that can be studied in ways not feasible before now. One of the most exciting of these topics is the kaon electromagnetic form factor at high momentum transfers. The t -dependence of the longitudinal cross section will be determined for $0.1 \leq t \leq 0.5 \text{ GeV}^2/c^2$ at $Q^2 = 0.5$ and $1.0 \text{ GeV}^2/c^2$. Then, employing the Chew-Low extrapolation technique, the kaon electromagnetic form factor can, in principle, be determined for these two Q^2 points. Preliminary results for extraction of the form factor have been reported in several meetings. A publication of the results is planned for the near future. Additionally, this experiment achieved the separation of the two interference cross sections at $Q^2 = 0.5$ and $1.0 \text{ GeV}^2/c^2$. In each case, the missing mass of both Λ and Σ hyperons is determined. Despite the importance of this measurement, no previous data exist for the separated contributions as this experiment achieved. Future experiments exploring this reaction on heavier nuclei and in various kinematic ranges will need the results of this experiment. This kaon electroproduction experiments provided dissertation data for seven graduate students. Four of these graduate students are or were from Hampton University. The Hall A kaon electroproduction experiment will extend the separation of cross sections up to $3 (\text{GeV}/c)^2$.

II.2 Maintenance and operations expertise for the HMS multiwire drift chambers in Hall C

The HMS optics depends critically upon the use of the multiwire drift chambers for charged particle trajectory reconstruction, angular and momentum resolution. These multiwire drift chambers performed up to and in some cases exceeded design specifications in these studies. The wire chambers for the HMS, a Hampton University responsibility, worked reliably and exceeded requirements in these early experiments.

The three full-sized HMS multiwire drift chambers are identical, with active areas of 110 cm by 50 cm [8]. There are six planes arranged in the order X, Y, U, V, Y', X' with 1.4-cm spacings between planes (between field wires of the planes). The X planes are orthogonal to the Y planes and the U,V stereo planes are inclined 15° from the X and X'

planes. The X' (Y') plane is offset from the X (Y) plane by $1/2$ cell (5 mm). There are 12 wire chamber planes in the detector stack used to reconstruct charged particle trajectories at the focal plane and then with the use of reverse transform (COSY) matrix elements, to traceback to the target. The cell scheme consists of $1\text{ cm} \times 0.8\text{ cm}$ drift cells with anode planes separated by two cm.

The sense wires (anodes) are $25\text{-}\mu\text{m}$ gold-plated tungsten, while the field wires (cathodes) are $150\text{-}\mu\text{m}$ gold-plated copper-beryllium or aluminum. These diameters ensure high multiplication at the vicinity of the sense wires compared to low multiplication at the field wires. All sense wires reside at ground potential, eliminating the need for decoupling capacitors between the wire and the readout electronics. The corner wires in the tests are held nominally around -2500 volts with the voltages on the remaining cathodes kept at -2250 and -1800 volts.

The electronic and high voltage connections on the feedthrough/crimp tube combination are patterned after similar feedthroughs developed and used in experiments at Los Alamos National Laboratory. Cambion connector jacks slip-fit over the uncrimped top of the copper crimp tubes. Electronic instrumentation is accomplished by soldering twisted pair cable to the connector jack. The twisted pair cable is mass terminated to card edge connectors suitable for the preamplifier/discriminator cards.

A 50:50 mixture (by weight) of argon and ethane is used for filling the chamber. This gas mixture is passed through an isopropyl alcohol bubbler at 0°C , thus doping the mixture with about one percent alcohol. Previous studies indicate that this procedure is preferable in a high incident particle rate environment. The gas flow through the chamber is approximately 400 cc/min. The chamber is operated at just a fraction above atmospheric pressure. The gas handling system (GHS) was designed by the Hampton University group and assembled by the Detector Development Group at TJNAF.

The signals from each individual anode are amplified and digitized in a LeCroy 2735DC drift chamber card. The delayed discriminated signal form the stop of LeCroy 1879 Time-To-Digital Converters (TDC's); fast scintillator signals form the TDC starts. The data are stored on disk using a Hewlett Packard 735/125 computer for data acquisition. Hampton University personnel will continue to maintain and upgrade, where necessary, the HMS wire chambers.

II.3 Newly Approved Experiment E98-101: Polarization Transfer in Kaon Electroproduction at Jefferson Lab

This newly approved experiment aims to study the mechanism of polarization transfer in kaon electroproduction in Hall C. The physics goal is to extract information about the hyperon electromagnetic form factor at large momentum transfer. In the electromagnetic production of kaons from a proton, the associated Λ -hyperon will be identified by missing

mass in the reaction, and the decay proton from the hyperon will be detected. Since the Λ -hyperon decay is self-analyzing, a determination of the proton momentum vector can be used to measure the hyperon spin polarization vector. Thus the experiment will serve to elucidate the process of polarization transfer from the polarized electron to the Λ -hyperon.

The polarization transfer response functions will be determined for Q^2 of up to 2.1 (Gev/c)^2 , with kaons (hyperons) detected along (opposite to) the momentum transfer direction (in the center of mass frame). In the laboratory frame, both the kaon and hyperon momentum vector lie parallel to the momentum transfer direction. The experiment uses standard equipment in Hall C; the HMS and SOS with the same detector packages as were used in the kaon electroproduction experiments which were completed in the fall of 1996, and the cryogenic (unpolarized) hydrogen target. It is anticipated that this experiment will run in the year 2000.

II.4 G_E^n Neutron Polarimeter Calibrations; Collaboration on LNS E276 at Saturne National Laboratory

Experiment 276 calibrated a neutron polarimeter that was designed to measure the electric form factor of the neutron G_E^n in experiments approved at TJNAF and MIT-Bates. The analyzing power and the efficiency of the neutron polarimeter were extracted at mean neutron energies of 160, 266, 533, 752, 922, and 1054 MeV; at three of these neutron energies (viz., 266, 533, 922 MeV), the analyzing power was measured with and without a Fe-Pb-Fe sandwich ahead of the neutron polarimeter to determine the depolarization caused by the sandwich material.

The neutron polarimeter consists of 20 plastic scintillation detectors: eight front analyzers and two rear arrays parallel to the central ray of the incident neutron flux. Each rear array consists of two staggered layers of detectors; each layer is composed of three adjacent scintillator bars.

In the G_E^n experiment, the polarimeter will be housed in a shielding enclosure. The front wall of the enclosure consists of ~ 10 -cm Pb sandwiched between ~ 2.9 -cm Fe to degrade electromagnetic radiation and to attenuate charged particles from the target.

Objectives of LNS276 at Saturne were (1) to assess the contribution of carbon to the analysing power for neutron energies above 100 MeV, (2) to determine the amount of depolarization caused by the Fe-Pb-Fe shield in front of the polarimeter in a G_E^n measurement, (3) to assess the effect of neutron multiple scattering in the analyzer scintillators of the polarimeter on the analyzing power and on the efficiency of the polarimeter, and (4) to determine the sensitivity of the analyzing power to position of the neutron interaction in the front analyzers relative to the rear detectors.

The experiment was run from May 7 to May 14, 1996 in France. Preliminary online analysis revealed (1) higher analyzing power when only single scattering events are con-

sidered, (2) higher efficiency when multiple scattering events are considered, (3) a higher figure-of-merit for multiple scattering events, (4) depolarization in the Fe-Pb-Fe sandwich that increases with neutron energy, and (5) a contribution to the analyzing power from energetic protons produced in charge exchange processes.

II.5 Collaboration on Experiment 865 (a rare kaon experiment) at BNL

This experiment is an improved search for the rare lepton family nonconserving decay $K^+ \rightarrow \pi \mu e$ at BNL [9-10]. The goal is to improve the sensitivity for this decay from the present 90% confidence limit of 2.1×10^{-10} to $\approx 3 \times 10^{-12}$. Since there is little theoretical guidance as to what level this decay might appear, there is difficulty in knowing what minimum level of improvement is required to see such a decay mode. Nevertheless, the two orders of magnitude improvement as well as the importance of the search is sufficient motivation for performing the new experiment. There is a decay volume upstream where approximately 10 % of the kaons from the D2 beam line decay. Four multiwire proportional counters P1 - P4 serve for particle tracking. Two Cherenkov detectors C1 and C2 are used for particle identification. There is an electromagnetic calorimeter (CAL) and a muonodoscope (MUON) as shown. Magnets 48D48 and 120D36 serve to separate the charge states. There may be some connection to the Jefferson Lab experiment which attempts to determine the kaon electromagnetic form factor at high momentum transfers (E93-018) [4]. This is the reason for the involvement of the PI.

The Hampton University effort has been to assist the group from the University of Pittsburgh (Professor Julia Thompson, group leader) in optimising the performance of the gas Cherenkov counters used for particle identification. The PI and a graduate student used a setup at Hampton University to study the efficiency for detection of ultraviolet light using a Burle 8854 photomultiplier tube with a wavelength shifting (wls) coating on the face of the tube. Ultraviolet wavelength (244 nm) light from an argon gas laser was launched through a UV transmitting optical fibre using a UV transparent microscope objective lense. This fibre was coupled to two UV transmitting fibres with one fibre directed onto the face of the 8854 pmt and the other leg of the split fibre directed onto a fast scintillator detector. The fast scintillator signal was used to form an ADC gate while the Burle 8854 pmt signal was put into the ADC input. We tested the response to the 244 nm wavelength light for the 8854 pmt tube face with and without p-Terphenyl wls coating. The wls made an enormous effect as expected. Similar studies using other techniques have shown that wls coatings can improve the UV light detection efficiency. This present study is believed to be the first use of monochromatic light from a tunable laser used to make this study in the way described (with optical fibres, microscope objectives, etc).

II.6 Personnel Changes and Progress

There are now a total of 22 graduate students in the Department of Physics at Hampton University who are pursuing nuclear or high energy physics research towards the doctoral degree. Two of these students were or are supported by this DOE award. The personnel engaged in experimental research are listed in Table I below. Hampton University personnel listed in Table I are spokespersons on five approved experiments at TJNAF.

TABLE I
EXPERIMENTAL NUCLEAR PHYSICS PERSONNEL

Category	Personnel
Associate Professor	O. K. Baker (Principal Investigator)
Assistant Professor	C. Keppel
Associate Professor	L. Tang
Technical Assistant	A. Gasparian
Postdoctoral Researcher	L. Gan
Graduate Student	S. Avery
Graduate Student	J. Cha
Graduate Student	M. Harvey
Graduate Student	W. Hinton
Graduate Student	L. Reynolds
Graduate Student	W. Naing
Graduate Student	E. Egbafe
Graduate Student	L. Li
Graduate Student	L. Cole
Graduate Student	A. Johnson
Adjunct Professor	B. Zeidman (Argonne National Lab)
Adjunct Associate Professor	R. Ent (Jlab)

The first of these DOE-supported graduate students, Gabriel Niculescu, completed all of the requirements for the Ph.D. degree in Physics this past year and was awarded the Ph.D. degree in December, 1998. Dr. Niculescu accepted an offer for a Postdoctoral Researcher and is now working in Hall B with Ohio University. Dr. Niculescu was the very first of the graduate students at Hampton University in experimental nuclear and high energy physics to get a Ph. D. degree.

The second student, Win Naing, participated fully in BNL Experiment 887 to search for narrow bound Sigma-Hypernuclear states and will use the data for his Ph.D. degree. The BNL experiment was run during the summer of 1994 for 800 hours in order to make a systematic high-statistics search for narrow bound states of Sigma hyperons in nuclei. The dissertation research for this student was to use the ${}^7\text{Li}(\text{K}^-, \pi^-)$ reaction to search for

such states [11-13]. The experiment used the Moby Dick spectrometer at BNL to detect the π^- signalling hypernuclear formation. The acceptance corrected spectrum for lithium is shown in Fig 6. The data below missing energy of zero (horizontal axis) is where there could be evidence for bound state Σ hypernuclei. The interpretation and some analysis of the data continues. Mr. Naing has completed most of the analysis of the data and is currently writing his Ph. D. Dissertation. It is anticipated that Mr. Naing will complete all of the requirements for the Ph. D. degree this calendar year.

A new graduate student has been hired to work in the group. The student, Alicia Johnson, is an African-American woman. She has completed all of her core course work and successfully passed the PH.D. Qualifying exam (on the first attempt). Alicia will likely work on a Kaon Electroproduction experiment in Hall C for her dissertation.

The DOE award PI (Baker) was promoted to Full Professor of Physics in the School of Science at Hampton University. Additionally, the PI serves on the Nuclear Science Advisory Committee (NSAC). This is the body which makes recommendations to the NSF and DOE on funding priorities in the area of Nuclear Science. The PI has served on several committees within Hampton University as well as nationally. Highlights are in the PI vitae which is attached as an Appendix to this report.

The students and PI have presented results of the research at conferences and workshops, both national and international, during the course of this work. Titles of these are presented in the next section.

II.7 Several publications and invited talks during this Project Period resulting from DOE support.

G. Niculescu, O.K. Baker et. al., Associated Λ Electroproduction at Jefferson Lab, Nucl. Phys. A639, 189c (1998).

J. Reinhold et. al., Kaon Electroproduction on Deuterium, Nucl. Phys. A639, 197c (1998).

W.L. Hinton et. al., Feasibility Test Run of $^{12}\text{C}(e, e'\text{K}^+)\Lambda$ reaction at Thomas Jefferson National Accelerator Facility, Nucl. Phys. A639, 205c (1998).

C. Bochna et. al., Photodisintegration of the Deuteron up to 4.0 GeV, Phys. Rev. Lett (accepted for publication) (1998).

O.K. Baker, Kaon Electroproduction and the Kaon Form Factor, Nucl. Phys. A (accepted for publication) (1998).

G. Niculescu et al, Longitudinal and Transverse Cross Sections in the $\text{H}(e, e'\text{K}^+)\Lambda$ Reaction, Phys. Rev. Lett. 81, 1805 (1998).

D. Abbott et. al., Quasifree $(e, e'p)$ Reaction and Proton Propagation in Nuclei, Phys. Rev. Lett. 80, 5072 (1998).

V.V. Frolov et. al., Electroproduction of the $\Delta(1232)$ Resonance at High Momentum Transfer, Phys. Rev. Lett. (accepted for publication) (1998).

C.S. Armstrong et. al., Electroproduction of the $S_{11}(1535)$ Resonance at High Momentum Transfer, submitted to Phys. Rev. Lett (1998).

I. Niculescu et. al., IEEE Trans on Nucl. Sci **45**, 68 (1998).

"Kaons and Polarization", invited talk at the Jefferson Lab Workshop at the Texas American Physical Society Meeting, El Paso, TX, October, 1998.

"The Kaon Form Factor", invited talk at the International Conference on Mesons and Nucleons in Prague, Czech, September 1998.

"Kaon Electroproduction: The Elementary Reaction" invited talk at the Electron-Nucleus Scattering Conference, Elba, Italy, June 1998.

AIP Conf. Proc **338**, 626 (1995), The Electromagnetic Production of Strangeness at CEBAF. O.K. Baker

AIP Conf. Proc **338**, 789 (1995), MEGA: A Search For the Decay $\mu \rightarrow e\gamma$. J.J. Szymanski et. al.

Nucl. Inst. and Meth, **A367**, 92 (1995), The High Momentum Spectrometer Drift Chambers in Hall C at CEBAF. O.K. Baker, J. Beaufait, R. Carlini, J. Cha, S. Danagoulian, A. Johnson, B. Kross, S. Majewski, A. McCauley, W. Naing, G. Niculescu, I. Niculescu, T.S. Shin, W. Vulcan.

Nucl. Inst. and Meth, **A354**, 309 (1995), Preliminary Study of a New Type of Microstrip Gas Chamber on Sapphire Substrate. Y. Grishkin, A. Martemyanov, A. Akindinov, M. Chumakov, O. Pogoreiko, S. Posdnyakov, P. Shishov, V. Ushakov, B. Kross, S. Majewski, A. Weisenberger, R. Wojcik, O.K. Baker, I. Hwang, D. Lyons, G. Niculescu, I. Niculescu, G. Smith, P. Geltenbort, A. Oed.

Nucl. Inst. and Meth, **A348**, 307 (1994), Second Coordinate Readout in Resistive Straw Drift Tubes. S. Majewski, J. Gerbi, B. Kross, A. Weisenberger, and K. Baker.

"CEBAF Highlights", presented at the Univ. of Pittsburgh, Pitt, PA, Aug, 1995.

"The CEBAF Project", presented at Nat. Soc. of Black Physicists Meeting, Apr, 1995.

"Neutron Polarimeter Calibrations", R. Madey et. al., Saturne Annual Report (1996); and Bull. Am. Phys. Soc. (Fall, 1996).

"Polarization-Transfer Experiments to Measure the Electric Form Factor of the Neutron at Bates and Jefferson Lab", T. Eden et. al., Bull. Am. Phys. Soc. (Fall, 1996).

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I. Niculescu et. al., Inclusive Nucleon Resonance Electroproduction Results from TJNAF, DNP-96, MIT (1996).

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V Figures

Fig. 1. The missing mass distribution of the kaon electroproduction reaction showing clearly the Λ and Σ^0 particles in the final state.

Fig. 2. The world data set on kaon electroproduction cross section with a Λ -hyperon (left side) and Σ^0 -hyperon (right side) in the final state.

Fig. 3. The separation of the longitudinal and transverse parts of the cross section in kaon electroproduction. The slope of the linear least squared fit gives the longitudinal cross section while the intercept gives the transverse cross section.

Fig. 4. The ratio of longitudinal and transverse cross section as a function of momentum transfer. The Jefferson Lab data is a factor of three better than previous data.

Fig. 5. The Q^2 dependence of the longitudinal and transverse cross sections.

Fig. 6. The acceptance corrected spectrum in the search for Σ hypernuclei in lithium.

Missing Mass Distribution

$Q^2=0.50 \text{ GeV}^2$ $W=1.80 \text{ GeV}$ $\Theta_{\gamma K}=0^\circ$

General Q^2 behaviour

All data scaled to $W=2.15$ GeV assuming

$$\frac{d\sigma}{d\Omega_{CM}} \propto \frac{p_K^{CM}}{W(W^2 - M_p^2)}$$

Rosenbluth Separation for $p(e,e'K^+)A$

Q^2	σ_T	σ_L	R	$\chi^2/D.F.$
2.00	76.2 ± 9.6	42.4 ± 18.0	0.56 ± 0.24	0.43
1.00	193.4 ± 38.3	125.9 ± 51.2	0.65 ± 0.29	1.05
0.75	199.9 ± 21.2	192.0 ± 29.0	0.96 ± 0.16	1.63
0.52	309.6 ± 39.0	254.6 ± 50.2	0.82 ± 0.18	0.86

σ_L/σ_T - ratio

σ_T and σ_L as function of Q^2

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Appendix A

Resume of OLIVER KEITH BAKER

EDUCATION

STANFORD UNIVERSITY, Stanford, CA.

6/87 Ph.D. Physics
Thesis Advisor: Walter E. Meyerhof
Thesis Topic: Nuclear Resonance Effect on Atomic
Electron Capture

6/84 M.S. Physics

6/84 M.S. Mathematics

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, MA.

6/81 B.S. Physics
Thesis Advisor: T. William Donnelly
Thesis Topic: Neutrino-Nucleus Scattering

EXPERIENCE

PROFESSOR, PHYSICS, Hampton Univ, Hampton, VA. (4/99 - present)

FUNDED RESEARCH GRANTS

Research funding in excess of \$3 million

STAFF SCIENTIST, Physics Division, Jlab, Newport News, VA. (9/89-present)

ASSOCIATE PROFESSOR, PHYSICS, Hampton Univ, Hampton, VA. (9/93-3/99)

ASSISTANT PROFESSOR, PHYSICS, Hampton Univ, Hampton, VA. (9/89 - 8/93)

CONSULTANT, Los Alamos Nat Lab, Los Alamos, N.M.(5/90-4/94)

INSTRUCTOR, PHYSICS, N. Carolina State Univ, Raleigh, N.C. (7/88-8/89)

POSTDOCTORAL FELLOW, Los Alamos Nat Lab, Los Alamos, N.M. (10/86-7/88)

RESEARCH ASSISTANT, Stanford Univ, Stanford, CA. (9/81-10/86)

TEACHING ASSISTANT, Stanford Univ, Stanford, CA. (9/82-6/84)

RESEARCH ASSISTANT, Los Alamos Nat Lab, Los Alamos, N.M. (6/81-9/81)

TEACHING ASSISTANT, Mass Inst of Tech, Cambridge, MA. (10/78-6/81)

AWARDS AND OFFICES HELD

1997 - present Nuclear Science Advisory Committee
 1997 National Award for Innovation in Teaching, Technology, and Learning
 1994-95 Edward Hamm Sr., Distinguished Teaching Award
 1985-86 Dorothy Danforth Compton Fellow
 1981-83 Government Professional Opportunities Program Fellow
 1983-86 San Jose, CA Spokesman Club, president, 85-86, secretary 84-85
 1987-88 Santa Fe, N.M. Spokesman Club, secretary 87-88

Directed or directing three doctoral dissertations and eight M.S. theses (including two as co-director). Supervised three postdoctoral research associates. Served as mentor to many graduate students as evidenced by co-authorship of over 50 articles.

BIOGRAPHICAL SKETCHES

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A. Vitae

Positions

Hampton University 1999 – present, Professor of Physics; 1993 – 1999, Associate Professor of Physics; 1989 – 1993, Assistant Professor of Physics. 1995, Acting Director NuHEP research center.

Jefferson Lab 1989 – present, Staff Scientist.

Los Alamos National Laboratory 1990 – 1993, Consultant; 1986 – 1988, Post-doctoral Fellow.

N. Carolina State University 1988 – 1989, Instructor.

Wayne State University 1993, Visiting Scientist

Stanford University 1981 – 1986 Research Assistant.

Research experience

Building and testing drift chambers and multi-wire proportional chambers and their associated electronics, including chambers for JLab HMS. Kaon electroproduction experiments at Jefferson Lab.

Teaching experience

Mathematical Physics, Quantum Physics, Nuclear Physics, Experimental Physics, and Electricity and Magnetism.

Awards

1994 - 95 Edward Hamm Sr., Distinguished Teaching Award, Hampton University
1997 National Innovative Teaching Award
1999 Black Issues in Higher Education Recognition Award

Education

Ph.D. Stanford University, Stanford, CA (1987), *Nuclear Resonance Effect on Atomic Electron Capture.*

M.S. Stanford University, Physics (1984)

M.S. Stanford University, Mathematics (1984)

B.S. Massachusetts Institute of Technology, Cambridge, MA (1981), *Thesis topic: Neutrino-Nucleus Scattering.*

BIOGRAPHICAL SKETCHES

B. Selected Publications

1. Coherent π^0 photoproduction on the deuteron up to 4 GeV, D.G. Meekins, et al., Phys.Rev.C60, 2201(1999).
2. C.S. Armstrong et al., Electroproduction of the S(11)(1535) resonance at high momentum transfer, Phys. Rev. D60, 052004 (1999).
3. K. Assamagan, O.K. Baker, Time-zero fission-fragment detector based on low-pressure multiwire proportional chambers, NIM A426, 405 (1999).
4. V.V. Frolov et al., Electroproduction of the $\Delta(1232)$ Resonance at High Momentum Transfer, Phys.Rev.Lett.82, 45 (1999).
5. G. Niculescu et al, Longitudinal and Transverse Cross Sections in the $H(e,e'K^+)\Lambda$ Reaction, Phys. Rev. Lett. 81, 1805 (1998).
6. Measurements of deuteron photodisintegration up to 4.0 GeV. By E89-012 Collaboration (C. Bochna et al.). Phys.Rev.Lett.81, 4576 (1998).
7. G. Niculescu, O.K. Baker et al., Associated Λ Electroproduction at Jefferson Lab, Nucl. Phys. A639, 189c (1998).
8. J. Reinhold et al., Kaon Electroproduction on Deuterium, Nucl. Phys. A639, 197c (1998).
9. W.L. Hinton et al., Feasibility Test Run of $^{12}\text{C}(e,e'K^+)$ reaction at Thomas Jefferson National Accelerator Facility, Nucl. Phys. A639, 205c (1998).
10. D. Abbott et al., Quasifree (e,e'p) Reaction and Proton Propagation in Nuclei, Phys. Rev. Lett. 80, 5072 (1998).
11. O.K. Baker, The Space-like Kaon Electromagnetic Form Factor, Nucl. Phys. A623, 351c (1997).
12. Preliminary Study of a New Type of Microstrip Gas Chamber on Sapphire Substrate. Y. Grishkin, et al., Nucl. Inst. and Meth, A354, 309 (1995).
13. The High Momentum Spectrometer Drift Chambers in Hall C at CEBAF. O.K. Baker et al., Nucl.Instrum.Meth.A367, 92 (1995).

C. Collaborators

Recent and current collaborators: Harold Ogren (Indiana University), Seog Oh (Duke University) and others in the ATLAS Collaboration. The Jefferson Lab Hall C collaboration.

D Graduate students and post-doctoral scholars

Post-doctoral scholars: Shelton Beedoe (NCATSU), Paul Gueye (Hampton University), Ketevi Assamagan (Hampton University), Geoffery Savage (Hampton University), Kevin Beard (JLab).

Masters degree students: W. Naing, M.S. (1993) Thesis topic "Planar Multiwire Drift Chamber"; T. Shin, M.S. (1993) thesis topic "Straw Tube Drift Chamber."

Ph.D. Students: Gabriel Niculescu (1998) Thesis topic: "Kaon Electroproduction," Win Naing (1999) Thesis topic: "Hypernuclear Spectroscopy."

E. Advisors

Ph.D. thesis advisor: Walter E. Meyerhof (Stanford). B.S. thesis adviser: T. William Donnelly (MIT). Post-doctoral advisors: Michael Paciotti (LANL).