

Laboratory Directed Research and Development Proposal  
Title: Development of Accurate Electron Spin Optical Polarimetry (AESOP)

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| **Date:** | 4/15/2014 |
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| **Other Personnel:** | Matt Poelker, Timothy Gay, Postdoc to be hired, grad student |
| **Proposal Term:** | **From:** 7/2014  **Through:** 7/2016  **If continuation, indicate year (2nd/3rd)**: |

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**Abstract**

Accurate electron polarimetry is essential for the next generation of parity-violation experiments at Jefferson Lab. Ongoing upgrades to the 5 MeV Mott polarimeter are designed to improve its precision to ~0.3%, but the device’s ultimate accuracy will be limited to ~1% by the calculation of the Sherman function. We propose to develop a polarimeter with 0.4% absolute accuracy based on the method of Accurate Electron Spin Optical Polarimetry (AESOP). In this technique, the beam of electrons whose spin polarization is to be determined excites Russell-Saunders transitions in noble gas targets. The polarization of the resultant fluorescence directly yields the incident electron spin, without the need for a dynamical calculation. Beyond the scope of this LDRD proposal, the electron beam characterized using the AESOP could be used for a calibration of the CEBAF 5 MeV Mott polarimeter to an absolute accuracy of 0.5%, aiding in the understanding of the systematics in all of the CEBAF polarimeters and yielding better results in upcoming high precision experiments such as MOLLER and SoLID.

# Summary of Proposal

## Description of Project

The purpose of this project is to build and demonstrate a polarimeter capable of an absolute measurement of electron beam polarization to 0.4% through Accurate Electron Spin Optical Polarimetry (AESOP). This accuracy will be achieved by exciting inert gases with the electron beam and measuring the optical polarization of the emitted light; the atomic transitions excited by the polarized electron beam are well characterized, and the polarization of the emitted light can be measured to an accuracy of at least 0.1%. Beyond the scope of this LDRD, successful demonstration of AESOP has the potential to be used to calibrate the 5 MeV Mott polarimeter at the CEBAF Injector to 0.5%.

## Expected Results

We propose to build an optical polarimeter for measurement of electron beam polarization. With the ability to measure polarization to 0.4%, electron beams with known polarization could then be used for a calibration of the CEBAF Mott polarimeter, which is anticipated to have a precision of 0.3% following upgrades currently underway, but is limited in accuracy due to the calculation of the Sherman function. Nuclear physics experiments, such as SoLID and MOLLER, where experimental uncertainties include the uncertainty in electron beam polarization, would benefit from having a calibrated 5 MeV Mott polarimeter in the CEBAF injector.

Additionally, the AESOP experimental procedure requires that the energy spread inherent in the electron beam emitted from high polarization strained superlattice GaAs:GaAsP be quantified and controlled. This experiment will also yield information about the inherent energy spread in electron beams emitted from GaAs photocathodes under both DC and RF pulsed laser illumination, with potential benefits in operation of high brightness, low emittance sources for electron cooling or light sources.

Finally, this LDRD proposal would be a joint research project between Dr. Timothy Gay’s University of Nebraska atomic physics group and the Center for Injectors and Sources at Jefferson Lab. The collaboration would benefit both Jefferson Lab and UNL by implementing Dr. Gay’s idea for an atomic physics electron beam polarimeter in a nuclear physics application, and through interaction between post-docs and grad students with atomic physics backgrounds and the accelerator physics community. This project would build on the successful prior collaborations between Dr. Gay’s group and JLab’s CIS. The “micro-Mott” low voltage retarding field polarimeter, designed and built by Dr. Gay’s group, was rebuilt, characterized, and used for high polarization photocathode characterization by numerous summer undergraduate students, a high school honors student, and a Ph.D. student whose dissertation centered on both commissioning and physics studies using the polarimeter.

# Proposal Narrative

## Purpose/Goals

The goal of this LDRD proposal is to build and characterize a new polarimeter that would be capable of calibrating the CEBAF 5 MeV Mott polarimeter to an accuracy of 0.5%. This requires that we demonstrate convincingly a method to measure the spin polarization of an electron beam to 0.4%.

The 5 MeV Mott polarimeter measurement uncertainty depends on how well the analyzing power of the system, called the “effective Sherman function” (Seff), is known. This value cannot be calculated precisely but must rather be determined by the extrapolation of multiple measurements with different target foil thicknesses. In the limit of elastic single-atom scattering, Seff becomes the Sherman function S [1]. Ultimately, the accuracy of an uncalibrated Mott polarization measurement is limited by our theoretical knowledge of S. We expect in turn that the uncertainty in S will be mostly limited by the uncertainty in the radiative correction estimates for the Mott scattering. Upcoming work is expected to reduce the overall stand-alone accuracy ofthe 5 MeV Mott polarimeter to about 1% [2].

However, if we can send an electron beam of known polarization into the Mott polarimeter, its measurement uncertainties can be significantly reduced. We estimate that the improved Mott polarimeter can be used to measure the electron polarizations with a *precision* of 0.3%. Thus, for a calibration accuracy of 0.5%, we must know the incident electron polarization with an accuracy of 0.4%.

We propose here to build and characterize a polarimeter that can measure electron beam polarization to an accuracy of 0.4% using the technique of Accurate Electron Spin Optical Polarimetry (AESOP) [3,4]. In this scheme, the incident electron beam whose polarization is to be measured excites an inert gas to a Russell-Saunders triplet state. This ensures that the excited atoms contain the incident electrons that produced them, i.e., the states have been produced by exchange excitation. The resulting spin polarization of the excited states is subsequently converted to orientation of its orbital angular momentum through the atom’s internal spin-orbit coupling. As a result, the fluorescence produced when the excited state decays is circularly polarized. For a judicious choice of atomic transition, the circular polarization of this fluorescence is kinematically related to the incident electron polarization, i.e., one can determine the relationship without a dynamical calculation. The electron polarization Pe can thus be written as

, (1)

where P1 is the “Stokes parameter” corresponding to the light’s linear polarization fraction for horizontal (parallel to the beam’s axis) and vertical linear polarization, P3 is the Stokes parameter for circularly polarized light, and *a* and *b* are constants that depend solely on the quantum numbers of the upper and lower levels associated with the fluorescence transition. For energies of the incident electrons above the excitation threshold but below the threshold for exciting the first state that can decay into the one we wish to monitor, *a* and *b* are exactly calculable. There is a third Stokes parameter, P2, corresponding to the linear polarization fraction canted at 45o/135o to the electron beam axis. (In general, measurements of all three Stokes parameters P1, P2, and P3 are required to unambiguously specify the polarization state of an arbitrary beam of light.) Thus, with reference to equation (1), we see that P1 determines the analyzing power of our electron optical polarimeter and P3 yields Pe. The value of P2 is important as well; if our assumption that *a* and *b* are kinematically calculable is to hold, P2 must be identically zero. Thus it provides a check on the validity of the method.

While the ultimate goal of this work is calibration of the 5 MeV Mott polarimeter in service of the next generation of parity violation experiments, an ancillary science benefit is that we will, in effect, be testing theory for QED effects in spin-dependent high-Z scattering in the energy range below 10 MeV when we determine S for the 5 MeV Mott polarimeter. This is a regime that has not, to our knowledge, been studied before.

## Approach/Methods

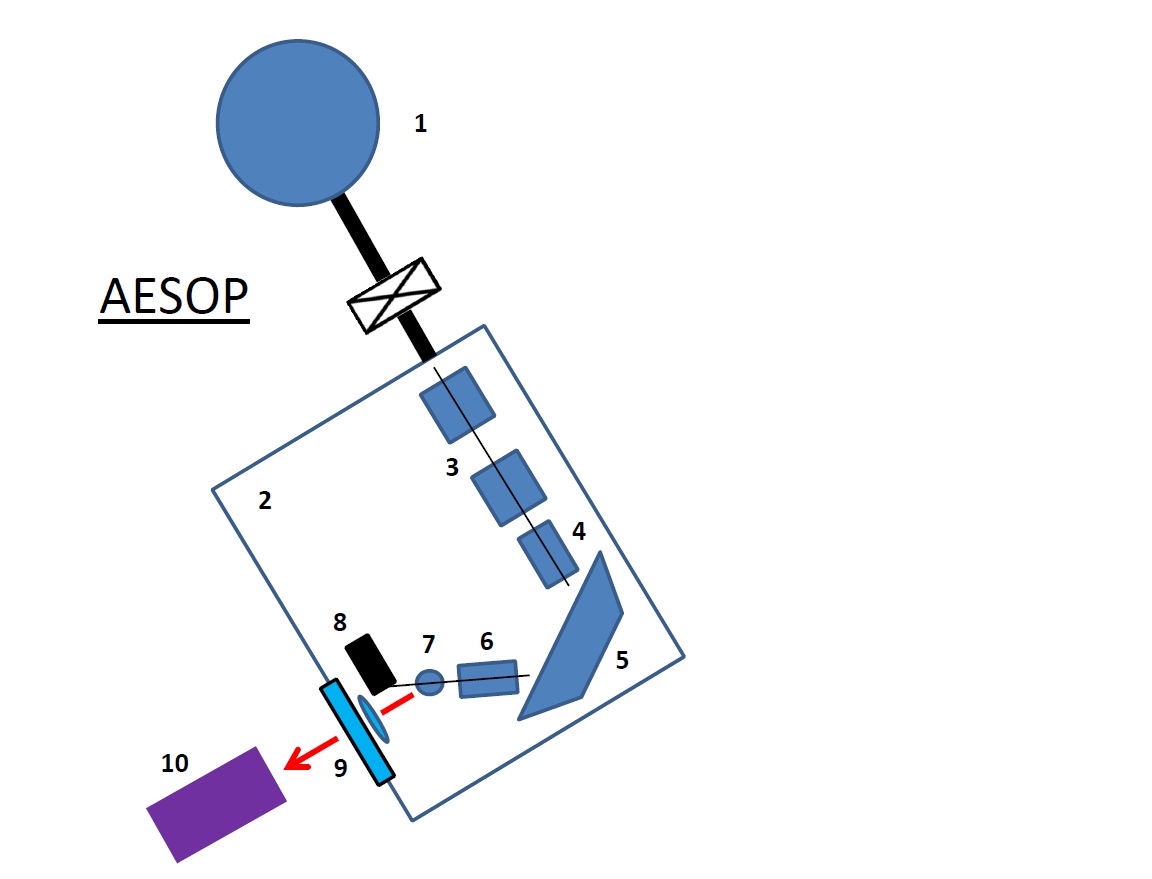
The AESOP polarimeter would be tested and commissioned in several stages, each designed to be compatible with installation at CEBAF in the future. All of the work encompassed by this LDRD would be done at the Center for Injector and Sources (CIS) laboratory space at Jefferson Lab. The goal of this work is to demonstrate a level of 0.4% accuracy for electron beam spin polarization measurements using the AESOP technique. For the success of the project, several independent milestones would need to be achieved. The AESOP requires four basic sections: an electron source, a low-energy electron transport and energy analysis system, a gas target, and an optical polarimeter. Each of these can be worked on in parallel or in segments depending on the personnel and resources available.

### Electron Source

The AESOP electron source must be capable of providing a polarized electron beam from high polarization strained superlattice photocathodes using either DC or RF optical excitation at a voltage of at least 1 kV. With the experience and equipment available in the Center for Injectors and Sources, building a low voltage electron source is straightforward. Beyond the scope of this LDRD proposal, the source chamber would need to compatible with 130 keV operation to generate beam to calibrate the CEBAF 5 MeV polarimeter. Therefore, designing an electron source for AESOP compatible with high voltage operation is desirable, and could be accomplished using largely existing, decommissioned equipment.

### Electron transport

The AESOP chamber is shown schematically in Figure 1. In the same way that two Wien filters are used to vary the polarization of the beam in the CEBAF injector in a systematic way, we will need two Wien filters to vary spin polarization at the upstream entrance of the AESOP apparatus. The beam will be decelerated from its transport energy of 1 keV to the desired atomic excitation energy, between 10 and 25 eV. Following these elements, the beam will traverse a 127o cylindrical electrostatic analyzer that will give us the ability to scan through the beam’s energy profile in 25 meV segments. This is necessary because it has been shown in previous studies that the electron polarization can vary across the beam’s energy profile [5].



**Figure 1.** *Schematic of the AESOP chamber showing: (1) the bending magnet; (2) the AESOP vacuum chamber; (3) X and Y Wien filters; (4) electrostatic deceleration optics; (5) 127o cylindrical electrostatic bender; (6) electrostatic steering and extraction optics; (7) gas target and gas containment cylinder; (8) Wood’s horn beam dump and Faraday cup; (9) collimating lens and non-dichroic vacuum window; (10) optical polarimeter.*

This possible variation of polarization with beam energy can lead to a potential systematic error in AESOP that we now discuss; we believe this to be the biggest skeleton in AESOP’s closet. Consider the use of an argon polarimetric target. We monitor the 5p 3D3 → 5s 3P2 811 nm optical transition whose excitation threshold is 13.07 eV [4]. The electron polarization is given formally by equation (1) with *a* = 2/3 and *b* = 2/9 as long as (a) the electron polarization does not depend on the energy of the beam within its energy width profile and (b) none of the beam’s individual electron energies are greater than 0.83 eV above the threshold energy. Above this energy, cascading from the 6s 3P2 state can begin to contaminate the fluorescence polarization, technically obviating equation (1). The reason for condition (a) is illustrated in Figure 2. In the region above the threshold for production of 811 nm light, but below the first cascading threshold, the excitation function for 811 nm fluorescence rises rapidly. However, if the polarization of the beam across its energy profile varies in an unknown way, one cannot *a priori* determine the beam’s average polarization, which we must know for the Mott calibration.

Energy width profiles measured for electron beams emitted from bulk GaAs at room temperature are as large as 0.5 eV, sufficient to be problematic if the polarization varies across this width as mentioned above. However, we plan to use strained superlattice GaAs:GaAsP for these studies, and results in the literature from similar material [6-8] suggests that energy spread should much lower, near 0.1 eV. The 127o analyzer will be used to measure the energy spread of the beam for both DC and RF laser illumination, and, more importantly, we will measure the polarization of narrow (25 meV) slices of the beam to characterize any energy dependence Pe may have.



Kirschner, Öppen, Ibach, Appl.Phys.A **30**, 177 (1983).

**Figure 2.** *The excitation probability as a function of incident beam energy (the “excitation function”) is shown by the blue line. The electron beam energy profile is shown in red, across which the polarization is varying. If this energy dependence function is not known precisely within an overall constant, the beam’s average polarization cannot be determined.*

### Electron excitation of inert gas

Following monochromatization of the beam, it passes into the target region, similar to that which we have described recently [9]. The (argon) gas effuses from a hypodermic needle into a vertical ~ 2 cm-diameter metallic cylinder whose purpose is to define the electrostatic potential of the excitation volume and to direct the gas flow into the mouth of a turbomolecular pump. Light from the collision volume is collimated by a high-quality quartz lens, after which it passes through a mechanically thick (to minimize the effect of vacuum-induced strain), optical quality non-dichroic window into the air and the entrance of an optical polarimeter.

The key to making accurate optical polarization measurements is to measure (by experiment!) all of the relevant optical constants (retardance, linear dichroism, etc.) of any element through which the light to be measured passes, and precise construction of the polarimeter itself in a way that minimizes stray light trajectories and background signal. The system can be tested using s-state atomic transitions excited by the electron beam, and, on an optical bench, by using light sources with known Stokes parameters. While Prof. Gay’s group has, to date, only measured Stokes parameters to an accuracy of 1%, they have extensive experience with polarization optics, and have made thorough analyses of potential systematic errors in such measurements. Moreover, astronomers routinely measure polarization to ~ 0.001%. The ultimate accuracy of our optical polarimetry will be tested in double-blind trials with known sources of light polarization using Glan-Air prisms and optically-flat zeroth-order quartz retarders.

### Vacuum system design and isolation

The vacuum system must be designed with sufficient isolation between the gas target and the high polarization electron source. Vacuum isolation would be accomplished through differential pumping, with calculations using the Monte-Carlo MOLFLOW+ vacuum modelling software to determine the optimal pumping configuration to isolate the vacuum sensitive photocathode from the noble gas target. The AESOP chamber itself will be pumped by magnetically-levitated turbomolecular pumps backed by dry pumps, and additional differential pumping elements with turbo pumps, best able to handle relatively large gas loads of noble gasses, will be used as necessary. Verification of sufficient vacuum isolation of the electron source from the gas target will be verified both by vacuum analyses and by photocathode lifetime measurments. Preliminary calculations indicate that pressures in the low 10-10 Torr range can be achieved with a 2,500 L/s turbo pump for the target isolation chamber with a target at 1x10-5 Torr of argon, with 1 cm diameter orifices into the isolation chamber for the electron beam and optical port. The additional two orders of magnitude difference in pressure between the target isolation chamber and electron source will be accomplished using turbo pumping on the electron transport chamber.

### Measurement procedures

The electron source photocathode will be an activated strained superlattice GaAs:GaAsP as is used in the CEBAF nuclear physics program, grown on GaAsP which is a non-photoemitting substrate. This photocathode is expected to yield an electron beam with low energy spread, as noted above. Any energy dependence of polarization will be monitored carefully over time. We will demonstrate an AESOP statistical and systematic precision (including effects due to possible variation of Pe across the electron beam’s energy profile) to at least 0.4%. Assuming that our beam energy profiles are well understood, and that we demonstrate our ability to do optical polarimetry to better than 0.1% using light sources of known polarization, our accuracy will be limited solely by counting statistics, since no atomic physics calculations are required.

Successful completion of this LDRD program will require demonstration of an electron spin polarization measurement to an accuracy of 0.4% and sufficient vacuum isolation between the target and electron source.

### Notes regarding the MAMI POLO optical polarimeter

During a preliminary discussion of these ideas at J-Lab in late March, Rolf Ent asked us why MAMI hadn’t continued using POLO (their version of AESOP) to calibrate their polarization. We subsequently wrote to Prof. Kurt Aulenbacher posing this question. He responded as follows:

*Dear [Prof. Gay],*

*We stopped it because of lack of manpower. The French group who proposed POLO evaporated and we saw no realistic chance to pursue the project within our own resources. The experimental problems were mainly that due to lack of space, POLO was 10 meters apart from the source and having stable operational conditions was difficult.*

*But these were no fundamental problems which would speak against an optical device. However, we at Mainz follow now similar projects but we have voted in favor of double scattering polarimeter at 100keV. This method was explored at Umiversity at Münster* [sic] *and refined in a way that it allowed elimination of the requirement of "identical" scatterings. .......*

The calibration effort mentioned at the end of this email benefits from the fact that MAMI inherited the rather extensive Münster apparatus needed to make these measurements. We are aware of this method (indeed, Prof. Gay was the referee of the paper in RSI describing the Münster work [10]). To date, it has proved accurate to no better than 1%, although this could almost certainly be improved. In our opinion, the optical method proposed above is easier and more reliable, at least starting from scratch as we would be if this work is funded.

## Specific Location of Work

The work proposed in this LDRD would all take place in the JLab Center for Injectors and Sources laboratory space.

Beyond the scope of this project, the goal of the research is to use the AESOP to calibrate the CEBAF 5 MeV Mott polarimeter by using a beam of polarization, measured to 0.4%, to calibrate its effective Sherman function. This would require installing the AESOP in a compatible location in the CEBAF injector.

There are two possible configurations that could be used in the CEBAF injector. The first would be to install the new polarimeter, with a 130 kV compatible electron source, where gun 3 is located, adjacent to gun 2 which is used for the CEBAF nuclear physics program. The CEBAF drive laser would then be used to illuminate the photocathode at 1 kV for measurement using AESOP. Subsequently, the AESOP could be valved out and 130 keV beam sent from the same electron source to the Mott polarimeter for calibration. This uses the device in the same way it was used in the lab, and allows for access to the area during optical polarization measurements.

The alternate location for installation in the CEBAF tunnel would be in the 130/500 keV spectrometer line, where beam from the operational CEBAF electron gun could be directed first into the AESOP line and polarization measured to 0.4%, then redirected into the 5MeV Mott line for calibration of the Sherman function. This has the advantage of using the same emission voltage for both electron beams, but would require redesigned optics to decelerate 130 keV beam prior to the AESOP optics, remote operation of the optical polarimetry equipment.

## Anticipated Outcomes/Results

Accurate, precise knowledge of the electron beam polarization is increasingly important for nuclear physics experiments and is of particular importance for the high precision SoLID and MOLLER experiments which demand measurements of the electron beam polarization to precision of 0.5% or better. The combination of Compton and Moller polarimetry has proven to be capable of precisions of 1% or better in both Halls A and C. Higher precision measurements from the Hall A Compton polarimeter are greatly aided by the increased analyzing power of the Compton reaction at the maximum 11 GeV, and plans are underway to improve the precision of the Hall A Moller polarimeter. Nonetheless, the fact remains that there has been only one electron polarimeter (the SLD Compton) in the literature with a quoted precision of 0.5% [11]. Years of experience with the existing JLab Compton and Moller polarimeters have increased their precision, but this same experience, and the present level of (dis)agreement between the techniques, raises the specter of implicit or unconscious bias. A third measurement of comparable precision would be enormously beneficial to augment the case for having achieved 0.5%-level electron polarimetry. A higher-precision Mott polarimeter will facilitate the next generation of spin dance measurements [12], enabling the direct comparison of five polarimeters capable of <1% polarization measurements.

Attached are two letters of support, from Prof. Gordon Cates and Prof. Paul Souder, expanding on the benefits of accurate, absolute polarimetry for the nuclear physics program at Jefferson Lab.

# VITA Marcy L. Stutzman (Lead Scientist)

**Staff Scientist, Center for Injectors and Sources, 2001-present**

-Research and development to optimize, characterize, and implement extreme-high vacuum chambers for successful operation of high polarization photocathodes for the CEBAF polarized electron source.

-Collaborator with Dr. Timothy Gay “micro-Mott” Polarimeter.

-Co-PI for DOE ARRA grant to investigate integration a bakable cryopump for electron sources.

-CRADA work agreement with BNNT, LLC.: Boron nitride nanotube cryosorption properties.

-Regular reviewer for JVST journal and SBIR grant program.

-DOE Outstanding Mentor Award, 2006.

-Mentor for SULI, REU and high school programs, 2006-07, 2011-14.

-Patents: Provisional 61838450 and 61913257,(2013) Nano-Materials for adhesive-free adsorbers for cryopump surfaces, and Boron Nitride Nanotubes as adsorbers for cryopump surfaces.

Full patent covering both Provisional 61838450 and Provisional 61913257 in submission process.

**Academic Background**

Ph.D., Physics, 2000, University of Virginia “Coulomb effects in insulating Si:B”

B.S. in Physics with Honors in physics, 1994, Pennsylvania State University

Adjunct Professor of Physics, Thomas Nelson Community College, 2000-2001

Adjunct Instructor of Mathematics, Christopher Newport University, 2001

**Professional Involvement**

American Vacuum Society, Vacuum Technology Division

Program Chair (2012, 2013), Chair (2011), Treasurer (2014), Board (2007-10)

American Vacuum Society, Mid-Atlantic Chapter, Local meeting organizer(2008-14), Board(2004‑14)

Particle Accelerator Conference Scientific Program Committee, Accelerator Technology, 2008,10

Polarized Electron Sources and Polarimeters, Local organizing committee 2008

Director's Review of Proposed Pilot Experiments at the JLab VUV/FEL, May 2011

**Selected Publications and Presentations**

**Invited talks**

* “Vacuum Improvements for the Jefferson Lab Polarized Electron Source” 19th International Vacuum Congress, Paris 2013
* “Extreme High Vacuum: The Need, Production and Measurement” 2006 AVS Symposium
* “High Polarization Photocathodes” May 2014 AVS Mid-Atlantic Chapter meeting at NIST

**Selected Publications**

* M.A. Mamun, A.A. Elmustafa, M.L. Stutzman, P.A. Adderley and M. Poelker, “Effect of Heat Treatments and Coatings on the Outgassing Rate of Stainless Steel Chambers”, JVSTA**32** (2014) 021604.
* V. Shutthanandan, Z. Zhu, M.L. Stutzman, F.E. Hannon, C. Hernandez-Garcia, M.I. Nandasiri, S.V.N.T. Kuchibhatla, S. Thevuthasan, W.P. Hess, “Surface science analysis of GaAs photocathodes following sustained electron beam delivery”, PRSTAB **15** (2012) 063501.
* J. L. McCarter, M.L. Stutzman, K.W. Trantham, T.G. Anderson, A.M. Cook and T.J. Gay, “A low-voltage retarding-field Mott polarimeter for photocathode characterization”, NIM A, **618** (2010) 30.
* M.L. Stutzman et al., “Characterization of the CEBAF 100-kV DC GaAs photoelectron gun vacuum system”, NIMA **574** (2007) 213.
* M.L. Stutzman and J. Grames, “Superlattice photocathode damage analysis”, AIP Conf. Proc. **1149** (2009) 1032.
* C. Hernandez-Garcia, P.G. O'Shea and M.L. Stutzman, “Electron Sources for Accelerators”, Physics Today, February 2008, p. 44-49.

# Budget Explanation

We propose that this work be funded by a Jefferson Lab LDRD that would last for two years. The personnel would be Drs. Stutzman, Poelker, and Gay, a postdoc to be hired based at JLab, and a graduate student from the University of Nebraska from Dr. Gay’s group, based at Jefferson Laboratory. The fulltime postdoc would start as soon as possible; the student would start in the summer of 2015.

Labor expenses are broken down into staff: 20% time for M.L. Stutzman and full time for a postdoc to be hired, and contract labor: a graduate student to begin full time in May 2015 and 1 month of summer salary yearly for T.J. Gay. Additionally, travel money has been requested for visits quarterly for T.J. Gay from Nebraska for work on the project and supervision of the graduate student.

During the first year, we would model, fabricate and build the electron source, the transport and energy analysis optics and the transport vacuum system. In parallel, the optical polarimeter would be designed, built and tested. By the end of the first year of work, we anticipate having equipment ready for initial electron beam polarization measurements. Materials and supplies budget would be required for consumables for the vacuum system (gaskets, bakeout heat tapes, ancillary expenses, cesium strips, target gas, etc.), and equipment expenses are estimated in the following table.

**Year one equipment budget summary**

|  |  |
| --- | --- |
| **Cost ($k)** | **Item** |
| $50k | Turbo pump |
| $22k | Optics for polarimeter |
| $15k | Transport vacuum chamber and optical elements (Valves, chamber, Wien, deceleration, 127°energy analyzer) |
| $7k | Source vacuum chamber (cesiators, leak valves) |
| $3k | Transport and energy analysis power supplies |
| $3k | Target isolation chamber (vacuum chamber with target cell, orifices, roughing pump for target) |

During the second year of the project, it is anticipated that we would demonstrate measurements of electron polarization while characterizing systematic uncertainties in this measurement. For the second year, labor would continue for all involved with the project with the equipment budget for continuing hardware development and optimization as required, and materials budget continuing for operational expenses.

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# Attachments

## BIOGRAPHICAL SKETCH: Timothy J.Gay

**i) Professional Preparation**

California Institute of Technology: Physics, B.S. 1975

University of Chicago: Physics, S.M. 1975;Ph.D. 1980

Yale University (Postdoctoral Institution):1980-1983

**ii) Appointments**

University of Nebraska Department of Physics and Astronomy

Professor (1993- )

University of Missouri–Rolla Physics Department; Professor (1992–93)

Associate Professor (1989–92)

Assistant Professor (1984–89)

Research Assistant Professor (1983–84)

Yale University Physics Department

Research Associate and Lecturer (1982-1983)

Research Staff Physicist and Lecturer (1980-1982)

Argonne National Laboratory Physics Division

Graduate Laboratory Fellow (1978-1980)

Undergraduate Summer Student Fellow (1974)

California Institute of Technology

Undergraduate Teaching Assistant, Physics Department (1974-1975)

Undergraduate Research Assistant, Department of Geology and Geophysics (1972-1975)

**iii) Honors**

Fellow, American Physical Society (elected 1994)

Outstanding Referee Award, American Physical Society (2009)

Graduate Laboratory Fellowship, Argonne National Laboratory (1978 – 1980)

Outstanding Teacher Award, University of Missouri–Rolla, 1987, 1988, 1990, 1991

Faculty Excellence Award, University of Missouri-Rolla, 1987, 1988, 1989, 1990, 1991, 1992 (only Assistant Professor to receive this award in 1987, 1988)

Certificate of Recognition for Contributions to Students, University of Nebraska Parents Association, 1995, 1999, 2004, 2007, 2010, 2012

**iv) 10 Most Significant Publications**

J.W.Maseberg, K. Bartschat, and T. J. Gay, “Threshold Alignment Reversal and Circularly-Polarized Fluorescence in Rotationally-Resolved H2,” Phys. Rev. Lett. **111**, 253201 (2013).

T.J. Gay, “Physics and Technology of Polarized Electron Scattering From Atoms and Molecules,” Adv.At.Mol.Phys. **57**, 157 (2009).

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1. **Synergistic Activities**

*Broadening the Participation of Underrepresented Groups in Physics*

Since its inception, Professor Gay's group has benefited from the participation of 28 students from groups that are underrepresented in physics: 24 women, 2 Hispanics, and 2 Native Americans.

*Football Physics – Telling the Public Why Physics is Relevant to Something They Care About*

From 1999-2004, Professor Gay presented one-minute "mini-lectures" on the connection between (American) football and physics at each of the University of Nebraska's home football games. These lectures are shown on the two Jumbotrons located in the stadium. The attendance at these games is ~8x104 so this is (with the possible exception of astronaut David Scott dropping a feather on the moon) the largest physics class ever held. The news media, including *The New York Times*, *USA Today*, *The Wall Street Journal*, *People* Magazine, *ESPN II*, *CNN*, and *ABC World News Tonight*, have run stories on this series. Professor Gay has also developed a similar series for the National Football League, which aired from 2002-2005 on their *Blast!* TV show, shown in 190 foreign countries. He has also written a book, *The Physics of Football*, published by Harper-Collins.

*Service to the Physics Community*

Professor Gay has served as Chair and Secretary/Treasurer of the Division of Atomic, Molecular, and Optical Physics (DAMOP) of the American Physical Society, and a two-time member of the Committee on Atomic, Molecular, and Optical Physics (CAMOS) of the National Research Council. He currently Chairs three committees for the American Physical Society: the Allis Prize Committee, the Committee on Meetings, and the April Meeting Task Force.

## Letters of support

