History *of* Physics
NEWSLETTER
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The Laser: Its History and Impact on Precision Measurements

(joint session with the FIAP) at the 2010 "April" meeting, Washington D.C.

By Daniel Kleppner, Forum Chair

At the "April" 2010 meeting (held in February to be joint with the American Association of Physics Teachers),the FHP and the Forum on Industrial and Applied Physics sponsored "The Laser: Its History and Impact on Precision Measurement" (Session X4). The speakers were Joseph Giordmaine, Frederico Capasso, and John Hall. Dr. Giordmaine, completed his Ph.D. with Charles Townes at Columbia University, on the use of the maser amplifier in planetary astronomy. Later at Bell Labs he worked with ruby lasers, harmonic generation, and nonlinear optics, and is now retired vice president of physical science research at NEC Labs. Dr. Capasso pioneered band structure engineering through molecular beam epitaxy, resulting in electronic and photonic devices dominated by mesoscopic scale quantum effects, including the quantum cascade laser. Dr. Hall, currently a NIST Senior Fellow Emeritus and Fellow at the Joint Institute for Laboratory Astrophysics (JILA), won the 2005 Nobel Prize in physics (with Theodor W. Hnsh) for his work on laser-based precision spectroscopy and the optical comb technique.

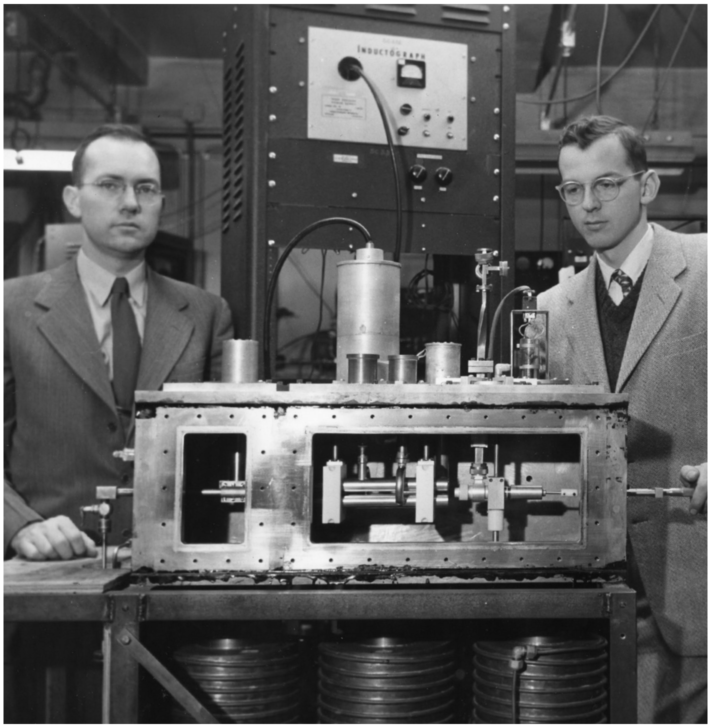

Fig. 1. Charles Townes (left) and J. P. Gordon standing with the second ammonia beam maser at Columbia University, 1955. AIP Emilio Segre Visual Archives, Physics Today Collection.

Joseph Giordmaine traced the pioneering advances made in the laser during the years 1960-1964, in his talk "The Laser: Historical Perspectives and Impact on Precision Measurements." The seminal concept, stimulated emission, introduced by Albert Einstein in 1917, took nearly forty years to bear fruit. In the mid 1920s, media with an inverted population had been considered by Hendrik A. Kramers, John H. Van Vleck, and Richard C. Tolman, and in the 1930s Hans Kopfermann and Ernst A. Lautenberg saw effects of population inversion on dispersion. Valentin A. Fabrikant in 1939 searched for negative absorption (viz., amplification, excessive stimulated radiation compared to absorbed radiation). Willis Lamb and Ernest Rutherford, Edward M. Purcell, and Joseph Weber all considered implications of negative absorption. However, nobody visualized applications for negative absorption and the matter was not pursued.

The crucial idea, using an inverted population to sustain oscillations, was conceived by Charles H. Townes (Fig. 1). In a famous incident while he was sitting alone early on a bench in Franklin Park, Washington, Townes suddenly realized that if excited atoms were surrounded by a cavity,

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In This Issue

News of the Forum: 2011 Abraham Pais Prize for History of Physics

Silvan Schweber
Brandeis University, Emeritus

Citation: *"For his sophisticated, technically masterful historical studies of the emergence of quantum field theory and quantum electrodynamics, and broadly insightful biographical writing on several of the most influential physicists of the 20th century: Einstein, Oppenheimer, and Bethe."*

Silvan (Sam) Schweber was born in Strasbourg, France in 1928. He came to the United States in July 1942. He attended the City College of NY and graduated as a chemistry and physics major in 1947. He thereafter obtained a MS in Physics from the University of Pennsylvania in 1949 and a PhD from Princeton University in 1952 working with Professor Arthur Wightman. From 1952 to 1954 he was an NSF post doctoral fellow at Cornell University. In 1955 he accepted a faculty appointment at Brandeis University.

Dr. Schweber is the author with Hans Bethe and Fred de Hoffman of Volume I of Mesons and Fields (1955) and of an Introduction to Relativistic Quantum Field Theory (1961). In the mid-1970s his research interests shifted to the history of science. He has written extensively on Charles Darwin and 19th century evolutionary theories, and since the mid 1980s on the history of physics during the 20thcentury. He is the author of QED and the Men Who Made It, Bethe and Oppenheimer and the Moral Responsibility of Scientists, and of Einstein and Oppenheimer: The Meaning of Genius. He has just finished Volume 1 of Faith in Reason, a biography of Hans Bethe. He helped establish the Dibner Institute for the History of Science and Technology at MIT in 1988 and was its first director. In 2005 he retired from Brandeis University as the Koret Professor of the History of Ideas and Professor of Physics, emeritus. Since 1981 he has been a Faculty Associate in the Department of the History of Science at Harvard. He is a fellow of the APS, the American Association for the Advancement of Science and of the American Academy of Arts and Sciences.

Dr. Schweber will present the 2011 Pais Prize Lecture, entitled "Shelter Island 1947 Revisited," in the "Solvay at 100" session of the April meeting (Anaheim, CA, April 30). We congratulate Dr. Schweber as the recipient of the 2011 Pais Prize. ■

Laser History

Continued from cover

the radiated energy could build up a field that would sustain the emission. His molecular oscillator consisted of nothing more than a state-selected beam of molecules passing through a microwave resonator. In 1954, maser oscillation was demonstrated in his group by Jim Gordon and Herb Zeiger (the term "maser" was coined that year by Townes). Shortly after, Nikolay Basov and Alexander Prokhorov demonstrated maser operation at the Lebedev Institute. In the summer of 1956, Nicolaas Bloembergen introduced the concept of a 3-level solid state maser, opening the way to the creation of practical maser amplifiers. After extended success with ammonia masers at various laboratories, a ruby maser was constructed at Columbia. In 1964 Arno A. Penzias and Robert W. Wilson used a ruby maser amplifier in their discovery of the cosmic background radiation.

During the summer of 1957 Townes started working with Arthur Schawlow at Bell Labs on the theory and details of an optical maser. That September he had Giordmaine, then a graduate student, witness a notebook entry laying out the general principles. Their proposal, using a potassium

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History*of* Physics
NEWSLETTER

The Forum on History of Physics of the American Physical Society publishes this Newsletter semiannually. Nonmembers who wish to receive the Newsletter should make a donation to the Forum of $5 per year (+ $3 additional for airmail). Each 3-year volume consists of six issues.

The articles in this issue represent the views of their authors and are not necessarily those of the Forum or APS.

Editor
Dwight E. Neuenschwander
Department of Physics
Southern Nazarene University
Bethany, OK 73008
dneuensc@snu.edu
(405) 491-6361

Associate Editor
Don Lemons
Department of Physics
Bethel College
North Newton, KS 67117
dlemons@bethelks.edu

Editors' Corner

The philosopher of scence Imre Lakatos argued that revisionist accounts of science were acceptable, provided they were supplemented with footnotes to preserve historical facts. In an imagined dialogue between Lakatos andPaul Feyerabend, their editor had Lakatos uttering these lines:

> *"…I might agree that methods in science (and mathematics) change and can be expected to change. The important thing is to try and ensure that such methodological changes are for the better. However, we can take charge of this only if we succeed in rationally reconstructing change in standards as we reconstruct change in scientific theories. From this point of view my 'Changing Logic' [a book Lakatos planned but never finished] aims at grasping the 'unfolding of reason' and presenting it 'cut and dry,' after its process of formation has been completed.*
>
> *"…And my exhortation towards a rational reconstruction of individual historical cases should be taken as a historicographical programme, an encouragement towards defining the reasons and strategies which have produced new ideas. There is, therefore, nothing wrong in appraising past beliefs according to a given norm or theory of rationality….[W]e should try to analyse and evaluate the case we are faced with in the light of our methodological standards.*[original emphasis] [1]

The author of a philosophy of science textbook explains:

> *"Lakatos had some views about the relation between the history of science and the philosophy of science that are spectacularly strange. Lakatos argued that historical case studies should be used to assess philosophical views of science. Fine, so far. But he also said that we should write 'rational reconstructions' of the historical episodes, in which scientists' decisions are made to look as rational as possible. We should then separately (or in footnotes) point out places where the rational reconstruction is not an accurate description of what actually went on. So it is OK to deliberately misrepresent what happened in the past, so long as the footnotes set things straight. What matters most is that in the main discussion we are able to spin a story in which the scientific decisions came out looking rational."*[2]

Such practices, I suppose, make historians of physics reach for their swords. We all know countless instances where textbooks present revisionist versions of the origins of physics paradigms – while neglecting to add the historical footnotes. Rather than presenting the messy but authentic stories about what actually happened, we know how easy it is, with our advantage of hindsight, to introduce special relativity or quantum mechanics by describing how they could have been neatly cut from whole cloth in their present forms, made to appear complete and whole in a kind of spontaneous creation.

Of course, arranging a network of physics concepts into a pattern of logical coherence is necessary for genuine understanding. Thus on the first day of electrodynamics class we are justified in asserting that "Electrostatics consists essentially of Coulomb's law along with the superposition principle." In so saying we are emphasizing the discipline's logical structure. But although the mastery of a paradigm's logic is essential, to stop there deprives the appreciator of a richer experience. Every physics concept, like every person, object, or community, has a story. In the adventure of seeking knowledge, if we nail the paradigm's logic but neglect its story, how deeply can we claim to know it? Samuel Crothers illustrated the point in another context:

> *"Your friends say, 'I want you to know Mr. Stifflekin,' and you say that you are happy to know him. But does either of you know the enigma that goes under the name of Stifflekin?... To really know him you must not only know what he is but what he used to be; what he used to think he was; what he used to think he ought to be and might be if he worked hard enough. You must know what he might have been if certain things had happened otherwise, and you must know what might have happened otherwise if he had been otherwise. All these complexities are a part of his own dim apprehension of himself. They are what make him so much more interesting to himself than he is to anyone else."*[3]

Imre Lakatos's good friend, Paul "Anything Goes" Feyerabend, wrote in Against Method:

> *"The history of science, after all, does not just consist of facts and conclusions drawn from facts. It also contains ideas, interpretations of facts, problems created by conflicting interpretations, mistakes, and so on…. This being the case, the history of science will be as complex, chaotic, full of mistakes, and entertaining as the ideas it contains, and these ideas in turn will be as complex, chaotic, full of mistakes, and entertaining as are the minds of those who invented them. Conversely, a little brainwashing will go a long way in making the history of science duller, simpler, more uniform, more 'objective' and more easily accessible to treatment by strict and unchangeable rules."*[4]

Students of science are "brainwashed" in different ways at different ages. Around the time of middle school, they are brainwashed though a checklist "Scientific Method" that presents science as catechism, with rigid rules to be memorized for a quiz. A few years later in university physics courses it is oh-so-easy to brainwash them again with smooth "rational reconstructions" of science history.

While a personal logical reconstruction in each learner's mind forms a creative task whose completion is essential to content mastery, teaching only such pre-edited reconstructions creates an impression of how science is done that is as misleading as the sixth-grade checklist. (One wonders if such experiences were the stimuli that led the logical positivists astray, with their rigid rules about how science was supposed to be done).

A contribution to my own education that has come with my role as editor of this newsletter, is seeing first-hand the passion of physics historians who work hard to capture the events and personalities behind the textbook recitations. The stories they uncover restore the paradigms to shimmering life. I have found that sharing the history—not as mere footnotes, but as an integral part of the story—makes the physics itself more interesting to students, as it does for me. With the story comes authentic interest; with genuine interest comes the motivation to recreate in one's own mind the logical structure. Both the logical awareness and the historical appreciation are thereby enhanced. ■

—Dwight E. (Ed) Neuenschwander, Editor

[1] *Imre Lakatos and Paul Feyerabend, For and Against Method, Matteo Motterlini, Ed. (University of Chicago Press, Chicago, IL, 1999), pp. 15-16. This passage comes from an introductory fictitious dialog between Lakatos and Feyerabend, written by Motterlini, summarizing their correspondence, arguments, and ideas.*

[2] *Peter Godfrey-Smith, Theory and Reality (University of Chicago Press, Chicago, IL, 2003), pp. 103-104.*

[3] *Samuel M. Crothers, "Every Man's Natural Desire to be Somebody Else," originally published in Dame School of Experience (Houghton-Mifflin Co., Boston MA); appearing in my high school reader Exploring Life through Literature (Scott, Foresman and Co., Chicago, IL, 1964), pp. 413-420.*

[4] *Paul Feyerabend, Against Method (Verso, New York, NY, 2010), p. 3.*

Upcoming FHP-Sponsored Sessions

March Meeting 2011: March 21-25, 2011 Dallas, Texas

http://www.aps.org/meetings/march/index.cfm for March meeting details

The History of Superconductivity from its Discovery by Kammerlingh Onnes in 1911
Monday March 21st, 11:15 – 14:15
Chair: Martin Blume

Dirk van Delft, *Leiden University, Netherlands:* "Heike Kamerlingh Onnes and the Road to Superconductivity"

Brian Schwartz, *CUNY-Graduate Center:* "The Meissner Effect in the History of Superconductivity

Leon Cooper, *Brown University:* "The BCS Theory After Fifty Years" (Talk recorded at Brown University on December 10th 2010)

John Rowell, *Arizona State University:* "Giaever, Nb3Sn, and Josephson"

Paul C. W. Chu, *University of Houston:* "The Arrival of High Temperature Superconductors"

J. H. Van Vleck: Quantum Theory and Magnetism
Tuesday March 22nd, 14:30 – 17:30,
Chair: Chun Lin

Michel Janssen, *University of Minnesota-Minneapolis:* "Van Vleck from Spectroscopy to Susceptibilities: Kuhn Losses Regained"

David Huber, *University of Wisconsin-Madison:* "Van Vleck at Wisconsin: 1928–1934"

Nicolaas Bloembergen, *University of Arizona:* "My interactions with J. H. Van Vleck as a Student and Colleague at Harvard"

Charles Slichter, *University of Illinois-Urbana:* "Van Vleck and Magnetic Resonance"

Horst Meyer, *Duke University:* "Van Vleck and the Magnetic Susceptibilities of Gaseous Molecules"

Migrations of Physicists (Jointly Sponsored by the Forum on International Physics)
Thursday March 24th, 14:30-17:30,
Chair: Noemie Koller

Katepalli Sreenivasan, *New York University, & Past Director, ICTP, Trieste:* "Migrations and the International Center for Theoretical Physics—A Personal and Professional View"

Alan Beyerchen, *Ohio State University:* "Physicists' Forced Migrations under Hitler"

Dieter Hoffmann, *Max Planck Institute for the History of Science, Berlin:* "Scientific Migration in Central Europe in the Context of the Cold War"

Alexei Kojevnikov, *University of British Columbia, Vancouver:* "Russian, Soviet, and Post-Soviet Scientific Migration: History and Patterns"

Zuoyue Wang, *California State Polytechnic University-Pomona:* "Chinese/American Physicists: a Trans-National History"

April Meeting 2011: April 30-May 3, 2011, Anaheim, California

http://www.aps.org/meetings/april/index.cfm for April meeting details

Solvay at 100 (jointly with the Division of Particles and Fields)
Saturday, 30 April, 10:45
Chair: Daniel Kleppner

Richard Staley, *University of Wisconsin:* "Solvay 1911"

Antony Valentini, *Perimeter Institute:* "Solvay 1927"

Sylvan Schweber, *Brandeis and Harvard, Pais Prize Lecture*: "Shelter Island 1947 Revisited"

Centennial of the Nuclear Atom
Saturday, 30 April, 13:30
Chair: TBD

John Heilbron, *UC Berkeley*: "The Rutherford Model and the Group at Manchester that Developed It"

Suman Seth, *Cornell*: "Atomic Models, Sommerfeld, and Heisenberg"

Jerome Friedman, *MIT*: "Looking Back at Rutherford: Scattering in Modern Physics"

Accelerators for Sub-Atomic Physics (jointly with Division of Physics of Beams)
Saturday, 30 April, 15:30.
Chair: Gregory Loew

Michael Craddock, *UBC/TRIUMF*: "Cyclotrons: From Science to Human Health"

Thomas Wangler, *LANL*: "Linear Accelerators: from Radio Frequency to Microwave Superconductivity"

Lyndon Evans, *CERN*: "Proton-Anti-Proton Colliders"

Centennial of Superconductivity
Sunday 1 May 2011, 13:30
Chair: Martin Blume

Peter Pesic, *St. John's College, Santa Fe*: "Superconductivity: Anatomy of a Discovery"

David C. Larbalestier , *National High Magnetic Field Laboratory and Florida State University*: "Applications of Superconductivity"

Anthony Zee, *Kavli Institute of Theoretical Physics, University of California at Santa Barbara:* "Superconductivity Beyond Superconductors"

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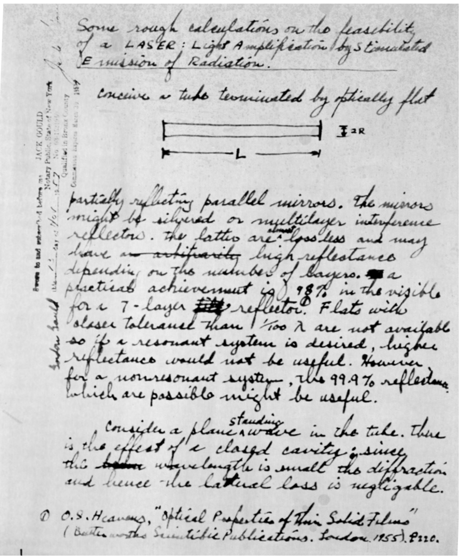

Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

Conceive a tube terminated by optically flat

partially reflecting parallel mirrors. The mirrors might be silvered or multilayer interference reflectors. The latter are almost lossless and may have ~~an arbitrarily~~ high reflectance depending on the number of layers.① a practical achievement is 98% in the visible for a 7-layer reflector. Flats with closer tolerance than 1/100 λ are not available so if a resonant system is desired, higher reflectance would not be useful. However for a nonresonant system, the 99.9% reflectance which are possible might be useful.

Consider a plane standing wave in the tube. There is the effect of a closed cavity; since the wavelength is small the diffraction and hence the lateral loss is negligible.

① O.S. Heavens, "Optical Properties of Thin Solid Films" (Butterworths Scientific Publications. London 1955). P220.

Sworn to and subscribed before me this 13 day of Nov 1957
JACK GOULD
Notary Public, State of New York
Qualified in Bronx County

Gordon Gould

Fig. 2. First page of Gordon Gould's 1957 lab notebook where he defines the term 'laser'. AIP Emilio Segre Visual Archives, Hecht Collection.

Fig. 3. Gordon Gould, circa 1985. AIP Emilio Segre Visual Archives, Hecht Collection.

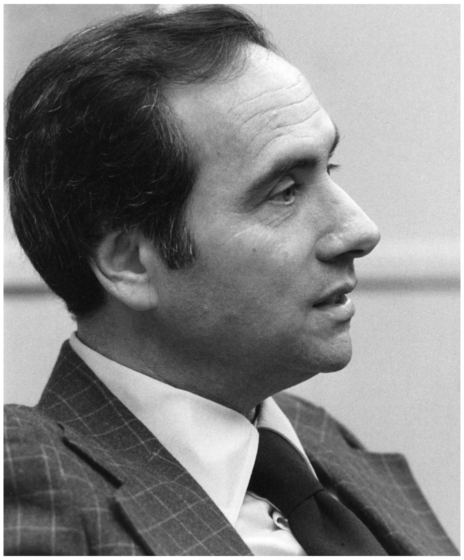

Fig. 4. Theodore Maiman. AIP Emilio Segre Visual Archives.

medium, incorporated a key idea: an optical cavity without side walls consisting of two parallel mirrors. These ideas were shared with Gordon Gould who coined the acronym "LASER" for "light amplification by stimulated emission of radiation" (Figs. 2, 3). Later, Gould secured patent rights on many of the key ideas. With the publication of the Schawlow-Townes paper, many laboratories set out to create a laser. Theodore Maiman (Fig. 4), at Hughes Research Laboratories (now HRL Laboratories), chose to work with ruby. This seemed like an unpromising source because calculations indicated that the quantum efficiency for pumping would be too low to be practical. Maiman carried out his own calculations and decided that his scheme should work. However, pumping required tens of kilowatts of optical power, whereas other schemes required milliwatts of power. Using a commercial flash lamp to pump the ruby, Maiman successfully demonstrated laser action (Figs. 5-7). His breakthrough was a complete surprise to the community. His letter was rejected by *Physical Review Letters* because the title included the term "maser", a topic that had had been embargoed by the editors.

Continuous wave operation of a laser was achieved by the He-Ne laser by Ali Javan and W.R. Bennett at Bell Labs and reported on Dec. 31, 1960. Soon after, the output of two lasers was mixed, demonstrating optical frequency stability of better than 1 MHz over a period of 100 seconds. The number of active laser groups grew from 50 in 1960 to 500 in 1962. Most publications came from industrial labs where there was more activity in engineering departments, than in physics departments. Numerous basic problems were attacked, for instance the nature of open resonators by A.Gardner Fox and Tingye Li, the theory of unstable resonators by Herwig Kogelnik, and the question of whether semiclassical theory was adequate to describe the laser field. Quantum optics problems became amenable with Roy A. Glauber's work in 1962, for which he received the Nobel Prize in 2005. Among the discoveries that quickly followed was saturation-narrowing of a spectral line, later called the Lamb dip. In 1961 nonlinear optics was launched by Peter Franken who demonstrated frequency doubling in a solid. Shortly after, two-photon absorption was observed. In the spring of 1961, Giordmaine, guided by Franken's findings, discovered the significance of phase matching. Another discovery in that period was the power of Q-switching by Bob Hellwarth. The discovery immediately led to the discovery of Raman scattering and had a tremendous impact on nonlinear optics.

Giordmaine noted that although the rate of discoveries in lasers and optics in the period 1960-64 was enormous, applications were slow to come. A ruby laser had been used to treat a retinal tumor, but the revolution in technology due to lasers lay in the future.

Federico Capasso, in his talk "Freedom from Band-Gap Slavery: From Diode Lasers to Quantum Cascade Lasers" described the history of semiconductor lasers as a story of the convergence of different fields in highly interdisciplinary laboratories, primarily industrial and Government labs. Bell Labs, General Electric, IBM, Lincoln Labs and the Ioffe Institute all played prominent roles. The convergent fields include materials research, particularly thin-film growth technologies, solid-state physics, solid–state electronics, and band structure engineering. In the past solid-state physics was deprecated by Pauli and other notable physicists,

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The 50th Anniversary of the Production of Superfluidity of He^3

FHP Session at the APS 2010 March Meeting

By George Zimmerman

Quick notes on liquid helium and superfluidity: *As the lightest noble gas, helium has to be cooled to 4.2K before it liquefies. Cooled further to 2.17K, liquid* He^4 *becomes a "superfluid," a liquid Bose-Einstein condensation. This results in unusual macroscopic behaviors such as flow with no viscosity and persistent vortex formation with quantized circulations. Above about 2.6 milliKelvins (mK),* He^3 *does not exhibit superfluidity because* He^3 *atoms are fermions. However, below 2.6 mK,* He^3 *atoms can form Cooper pairs, i.e., integer-spin and l = 1 (orbital angular momentum) composites, and exhibit superfluidity. This superfluid is more complicated than the* He^4 *superfluid because of the spin-orbit coupling within the pairs. At high pressure, near the solidification boundary, the superfluid forms a spin-up or spin-down phase, the A-phase. At lower pressures and temperature it exists in a spin-up, spin-down, and spin-zero phase, the B-phase. This leads to textures akin to those of liquid crystals.[1] Also see Figure 1.[2]*

Fig. 1. Capacity audience at Session X8, March 2010 meeting, "The 50th Anniversary of the Prediction of Superfluidity of He3." Photo courtesy of George Zimmerman.

Session X8 of the March 2010 meeting celebrated two publications which, only three years after the publication of the BCS theory of superconductors,[3] predicted the occurrence of superfluidity in He^3. Those papers were:

- "Level Structure of Nuclear Matter and Liquid He^3" by K. A. Brueckner and Toshio Soda (University of California-La Jolla), Philip W. Anderson (Bell Telephone Laboratories-Murray Hill, NJ), and Pierre Morel (French Embassy in New York City), submitted to *The Physical Review* on 15 January 1960;[4]
- "Possible Phase Transition in Liquid He^3" by V. J. Emery (UC-Berkeley) and A. M. Sessler (Lawrence Radiation Laboratory, UC-Berkeley), submitted on 8 February of the same year to the same journal.[5]

Although the initial estimates of the liquid He^3 superfluid transition temperature were somewhat high, they were just within the reach of contemporary experimental techniques, so these publications inspired a large number of experiments. The experimental discovery of the liquid He^3 superfluid phases came twelve years later in 1972 by David Lee, Bob Richardson and Doug Osheroff,[6] for which they received the 1996 Nobel Prize in Physics.

The session included five talks. Two were presented by a co- author of each of the 1960 papers, Phil Anderson and Andy Sessler. Another speaker was David Lee, one of the experimental discoverers of liquid He^3 superfluidity. The two other speakers were Joe Serene, who was a theory graduate student at the time of the experimental discovery, and Tony Leggett, who contributed greatly to the understanding of the experimental properties of the superfluid. Despite the fact that the session was scheduled for the afternoon of the second-to-last day of the meeting, the 400-seat hall was packed to capacity (Fig. 1), with many in the audience obliged to stand or sit in the aisles.

The first speaker was Phil Anderson (Fig. 2), whose talk was entitled "Superconductivity with Very Repulsive Interactions: He^3, Pierre Morel, and Me." He described some of the early ideas about He^3, and stated that 1960 was the right time for the prediction to emerge because He^3 was becoming available and physicists were starting to think about it. As is evident from the title of the 1960 paper he co-authored, because liquid helium is composed of Fermi particles it was thought to be a model substance for nuclear matter. Brueckner and Soda were nuclear theorists who apparently got the idea of working on He^3 by visiting the Bell Laboratories where Anderson and his first graduate student, Morel, were located. Anderson mentioned previous ideas about the superfluidity of liquid He^3 that were held by Lev Pitaevski in Russia, who may have ascribed their origin to Lev Landau. Because their ideas were published in Russian journals which were not generally read by American physicists, Pitaevski and Landau had little influence on the two 1960 *Physical Review* papers. Anderson also mentioned John Fisher, of GE labs, whom he visited in January 1959. At that time Fisher suggested the idea of working on liquid He^3. The Brueckner *et. al*. paper predicted a superfluid phase with l = 2 and a transition temperature of 0.1K. After considering spin fluctuations, Anderson and Morel reduced the prediction of the transition temperature in subsequent papers to 0.02K. The rest of Anderson's talk was devoted to the technicalities and predictions of the nature of the superfluid phase of He^3, as worked out in subsequent papers with Morel and other authors.

The second speaker was Andy Sessler (Fig. 3) whose talk was entitled "Early Thoughts on the Superfluidity of He^3." He started by pointing to a paper written by L. N. Cooper, R. L.

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Fig. 2. Phil Anderson about to present "Superconductivity with Very Repulsive Interactions: He3, Pierre Morel, and Me." Photo courtesy of George Zimmerman.

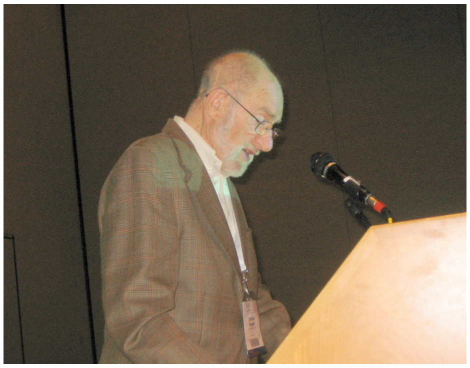

Fig. 3. Andy Sessler presenting "Early Thoughts on the Superfluidity of He^3." Photo courtesy of George Zimmerman.

Fig. 4. Joe Serene presenting "Historically Related Puzzles in He3: Spin Fluctuations, the Specific Heat, and the Superfluid Phase Diagram." Photo courtesy of George Zimmerman.

Mills, and A. M. Sessler a year before the publication of the Emery-Sessler paper.[7] The paper was written at a time when Sessler, Cooper, and Mills were at Ohio State University, where low-temperature experiments were being conducted by J.G. Daunt, D.F. Brewer and D.O. Edwards. Their joint 1959 paper did not find superfluidity. Sessler attributed this to the omission of the consideration of the nonzero angular momentum states, and to the concentration on the beautiful mathematical formulation by Mills. Sessler had previously met Cooper and Mills at Columbia University, where Sessler was between 1949 and 1953. (Parenthetically, Sessler mentioned a conversation he had with I.I. Rabi at Columbia, who allegedly remarked that the physics research carried on there was, in his opinion, not first rate! As it turned out, about ten of the researchers who were there at the time subsequently received the Nobel Prize and many others went on to distinguished careers.) Sessler and Emery met during a sabbatical at the Lawrence Berkeley Laboratory. Sessler noted that the two 1960 papers, in whose honor the session was held, did not mention each other as a reference; they were quite independent. He concluded his talk by showing some pictures of his associates, and mentioned a subsequent paper in which the dynamics of anisotropic superfluid He^3 were worked out prior to its experimental discovery.

The third speaker was Joe Serene (Fig. 4) who presented "Historically Related Puzzles in He^3: Spin Fluctuations, the Specific Heat, and the Superfluid Phase Diagram". At the time of the experimental discovery of the superfluidity in He^3 in 1972, Serene was a graduate student of Vinay Ambegaokar at Cornell University. In the talk Serene concentrated on the time of intense competition between the theoretical groups at Cornell University and Bell Laboratories. He discussed the consequences of odd versus even angular momentum pairing and the influence of spin fluctuations on the magnetic susceptibility and specific heat of He^3. He described the superfluid phases of He^3, the A-1 and A-2 phases which are best described by the Anderson-Brinkman-Morel model, and the B or Balian-Werthamer phase.[8,9] Serene had gone to a conference where he met W. Brinkman. They discovered that they were working on similar ideas using similar methods. That discovery resulted in Serene's being invited to Bell Laboratories, and collaboration ensued between him and the Bell Labs theory group.

The fourth speaker was David Lee (Fig. 5) whose talk "Early Days of Superfluid He^3: An Experimenter's View" began with a description of how He^3 was obtained. He then reviewed some of the experimental results of measurements made on liquid He^3, including parameters in the Landau theory of Fermi liquids. In the theoretical predictions the transition temperature to superfluid phases depended on the Landau parameters which were obtained from the calculated and measured interaction of He^3 atoms in the liquid. The initial 1960 prediction put the transition temperature at or just below the experimentally achievable temperatures of the time. The techniques of adiabatic demagnetization, and the subsequent addition of a first stage of a He^3 refrigerator, could cool He^3 down to several tens of milliKelvins. When some experimental groups started looking for the transition without finding it, they measured the Landau parameters by looking at the specific heat, spin diffusion, viscosity, magnetic susceptibility, and thermal conductivity. Those groups were at Cornell University (David M. Lee *et. al.*), Ohio State University (John G. Daunt *et. al.*) , Yale University (Henry A. Fairbank *et. al.*), as well as the University of Illinois and later University of California at San Diego (John C. Wheatley *et. al.*). There was intense competition among these groups, and all their measurements pointed to the behavior of He^3 as a Landau-Fermi liquid, including the measurement of "Zero Sound" by the Wheatley group. Lee specifically mentioned the magnetic susceptibility measurements by William M. Fairbank and G.K. Walters as the early evidence of Landau-Fermi liquid behavior.

Lee then went on to describe the

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Sam Goudsmit: Physics, Editor, and More

FHP Session at the APS 2010 March Meeting

By George Zimmerman

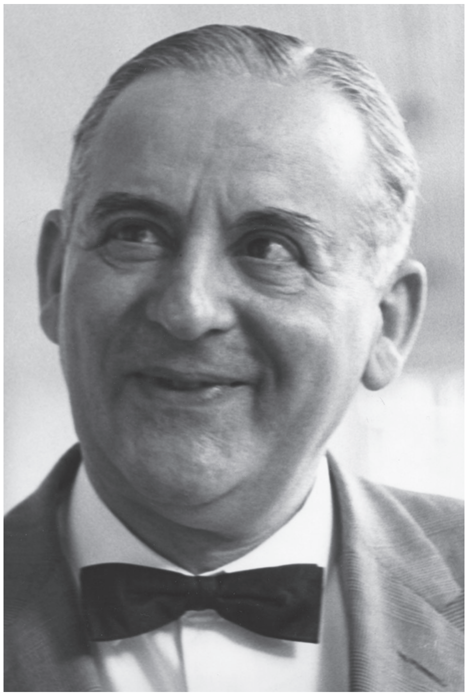

Fig. 1. Samuel Goudsmit. Photograph by Heka Davis, courtesy AIP Emilio Segre Visual Archives.

Fig. 2. Samuel Goudsmit's father and daughter Esther, 1935. Credit: Photograph by Samuel Goudsmit, courtesy AIP Emilio Segre Visual Archives, Goudsmit Collection.

Fig. 3. Esther Goudsmit, daughter of Sam Goudsmit, presenting her talk entitled "Samuel Goudsmit – Early Influences" at the APS March Meeting in Portland, Oregon, at the Convention Center, 15 March 15 2010. Photo by George Zimmerman.

Fig. 4. Jonathan Logan presenting "A Keen Eye for Clues." Photo by George Zimmerman.

On Monday, 15 March at the APS March meeting for 2010, following the Pais Prize lecture, "Henry Cavendish and John Michell: Weighing the Stars" by Russell McCormmach, the session changed gears to become a celebration of the life and work of Samuel Goudsmit (Fig. 1). That part of the session, called "Sam Goudsmit: Physics, Editor, and More" featured talks by Goudsmit's daughter, Esther Goudsmit, and four others who covered different aspects of his life.

The first speaker was Esther Goudsmit of Oakland University in Rochester, Michigan (Fig. 2, 3). Her talk was entitled "Samuel Goudsmit—Early Influences." She was followed by Jonothan Logan (EPG Research Foundation, NY, Fig. 4) with "A Keen Eye for Clues," then Benjamin Bederson (New York University, Fig. 5) who presented "Sam Goudsmit—His Physics and His Statesmanship;" and Peter M. Levy (New York University, Fig. 6) who spoke on "Electron Spin from Goudsmit and Uhlenbeck to Spintronics." Martin Blume (APS) was invited to present the final talk of the session. However, he was unable to reach the meeting because of a serious snowstorm. At literally the last minute, Daniel Kleppner (MIT) assembled a substitute talk called "Sam, Brookhaven, and the *Physical Review*" (Fig. 7).

Samuel Abraham Goudsmit was born on 11 July 1902 in The Hague, Netherlands. Esther Goudsmit described how he was the first member of his large extended family to be educated beyond high school. Educated in Amsterdam and Leiden, in 1927 Goudsmit earned the PhD in physics at the University of Leiden (Fig. 8). While there, in 1925 he and George Uhlenbeck, both students of Paul Ehernfest, postulated electron spin to explain the atomic spectra of gases.[1]

Logan described Goudsmit as a pioneering atomic theorist who specialized in the "exacting, quantitative art of interpreting line spectra." In addition to co-discovering electron spin, Goudsmit also "contributed key studies of nuclear moments, neutron scattering, and the statistics of experimental measurement." These contributions include two books on atomic spectra: In 1930 *The Structure of Line Spectra* that Goudsmit co-authored with Linus Pauling, and *Atomic Energy States* in 1932 with Robert F. Bacher. After completing his degree in Holland, Goudsmit continued his career at the University of Michigan. He held a position there from 1927 through 1946, although he spent part of WWII at the Massachusetts Institute of Technology working on radar.

Esther Goudsmit's talk focused on her father's "significant and diverse contributions in several realms including not only physics but also teaching, Egyptology, and scientific intelligence." This theme was echoed by Logan who

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Fig. 5. Benjamin Benderson presenting "Sam Goudsmit – His Physics and His Statemanship." Photo by George Zimmerman.

Fig. 6. Peter Levy presenting "Electron Spin from Goudsmit and Uhlenbeck to Spintronics." Photo by George Zimmerman.

Fig. 7. Daniel Kleppner presenting "Sam, Brookhaven, and the Physical Review." Photo by George Zimmerman.

Fig. 8. L-R: Oskar Klein, George Uhlenbeck, Samuel Goudsmit, University of Leiden, summer 1926. Credit: AIP Emilio Segre Visual Archives.

Fig. 9. Goudsmit driving a jeep in Stadtilm, Germany, 16 April 1945, on the Alsos Mission (with Lt. Toepel). Credit: AIP Emilio Segre Visual Archives

Fig. 10. Equipment 'Haigerloch pile being dismantled as part of the Alsos mission, Haigerloch, Germany (date unknown). Credit: AIP Emilio Segre Visual Archives, Goudsmit Collection.

described how Goudsmit was "drawn to a wider world of inquiry—to museums and archeological sites in Cairo as a respected amateur Egyptologist; to the MIT Radiation Lab early in WWII; and to the briefing rooms of British pilots, analyzing the effectiveness of radar; and across wartime Europe by jeep…"

As a respected Egyptologist, Goudsmit published numerous articles on Egyptian archeology.[2] The Kelsey Museum of Archaeology at the University of Michigan-Ann Arbor houses the Samuel A. Goudsmit Collection of Egyptian Antiquities.[3] The Goudsmit Collection includes cuneiform tablets. Such tablets range in dates from about 2300 BCE to roughly 240 BCE.[4]

Bederson discussed details of Goudsmit's scientific career, which began in 1921 with the publication of a paper on atomic spectroscopic doublets, when Goudsmit was 19 years old. This work was a precursor of the Uhlenbeck and Goudsmit spin paper of 1925.[1] In 1926 he was already tackling nuclear spins, whose values could be inferred from precision spectroscopic measurements. Soon thereafter Goudsmit expanded such analyses to determining nuclear magnetic moments, eventually moving on to nuclear diffraction and interference. While at the Radiation Lab at MIT, before his appointment to *Alsos*, Goudsmit worked on the critical problem of short wavelength radar sources and their use in the Battle of Britain.

Goudsmit was appointed head of the Alsos mission (a part of the Manhattan Project) whose aim was to collect evidence as the Allies swept across Germany, to assess the progress and effectiveness of the Nazi atomic bomb project (Figs. 9, 10, 11). Typically Goudsmit's team would visit German project sites with Allied troops, although sometimes Aslos preceded the troops. As Goudsmit described in the 1947 book Alsos, the Axis powers had never come close to building a nuclear bomb. Bederson noted, "Partly because of his service as scientific leader of the Alsos project at the end of WWII he became a leading statesman of science."

After the war Goudsmit was briefly a professor at Northwestern University. In 1948 he went to Brookhaven National Laboratory, where he remained until 1970 (Fig. 12), serving as chair of the department during 1952-1960. During that time Goudsmit became Editor-in-Chief of *Physical Review* where, as Logan expressed it, Goudsmit also "created the ambitious new journal, *Physical Review Letters*." Kleppner described Goudsmit's original vision for *Physical Review Letters*, his ongoing fight for clarity, and his war against neologisms, acronyms, and other stylistic barbarities. Kleppner quoted some of Goudsmit's cautions about good manners, and described his failing battle for brevity, that terminated only when the page length had crept from one to four.

Goudsmit also reached out to the general public on behalf of science literacy. For instance, in 1966 he and Robert Clairborne authored the volume *Time* for the Time-Life Science Library Series.

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Superfluidity of He^3

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Fig. 5. David Lee presenting "Early Days of Superfluid He^3." Photo courtesy of George Zimmerman.

breakthroughs for achieving temperatures sufficiently low to make possible the discovery of the various superfluid phases. These were the discovery of the separation of He^3-He^4 mixtures into a He^3-rich phase, and a phase having a mixture of He^3 and He^4 at zero temperature. That enabled the development the dilution refrigerator at the Leiden Laboratory in the Netherlands and by Henry Hall in the U.K. The design was perfected by Wheatley at UCSD. The dilution refrigerator could reach temperatures of five to ten mK which was used as a first stage in the cooling procedure. The other development was the measurement of the He^3 liquid-solid coexistence curve which showed a minimum at about 0.3K on the pressure-temperature diagram with a negative slope below that temperature. According to the Clausius-Clapeyron equation, this indicated that the substance could be cooled by compression, which led to the adiabatic cooling technique first suggested by Isaak Pomaranchuk and demonstrated by Yu D. Anufriev in the USSR. Thus the transition was initially discovered.

By 1971, before the He^3 superfluid transition was discovered, most of the low temperature He^3 research had become directed towards the exploration of solid He^3 and He^3-He^4 mixtures. Indeed, when graduate student Willy Gully fixed a helium leak on a Cornell apparatus, which enabled adiabatic compression, and Doug Osheroff observed a kink in the pressure versus time curve during a continuous adiabatic compression, the superfluid liquid He^3 phases were observed. Since the compression cell contained both liquid and solid He^3, the kink anomaly was initially thought to be due to the solid which was expected to undergo a transition to an ordered state (the solid magnetic ordering was discovered several years later, at pressures above 30 atm). The confirmation that the kinks were due to the He^3 liquid came within a few months with the measurement of the nuclear magnetic resonance at Cornell, after several suggestions by John Goodkind of UCSD and Viktor Vvdenskii of the Kapitza Institute in Moscow. The capacitive pressure gauge in the experimental cell was developed by G.C. Straty and E.D. Adams of the University of Florida.[10] By applying a magnetic field gradient at the cell while observing the NMR signal, one could tell where the solid and liquid portions were, perhaps one of the first applications of the MRI technique now used in medicine.

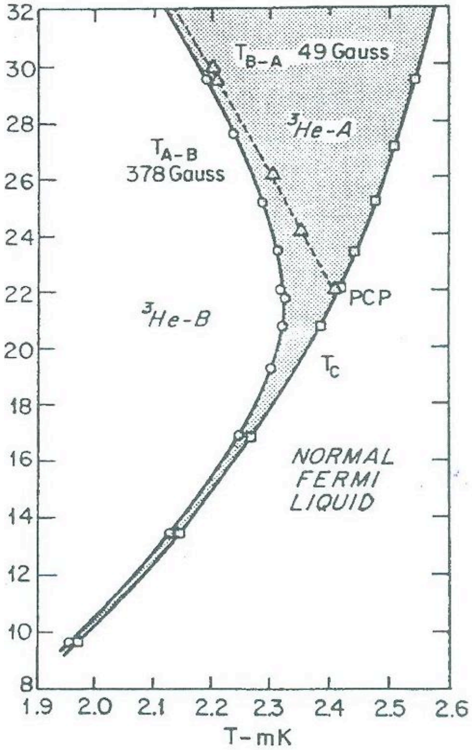

Fig. 6. Phase diagram of liquid He3 in a field of 378 G. The polycritical point (PCP) occurs at about 22 bars. From D.N. Paulson, J.C. Wheatley, and D.M. Lee, Phys. Rev. Lett. 32 (1974), 1098; repeated in J.C. Wheatley, Reviews of Modern Physics 47 (1975), 417 and D. Lee, Reviews of Modern Physics 69 (1996), 657.

Fig. 7. Tony Leggett presenting "Superfluid He^3: Understanding the Experiments." Photo courtesy of George Zimmerman.

Subsequent measurements were made in short order by the Cornell group and the UCSD group that mapped out the phase diagram. Two phases of superfluid He^3 liquid were determined (Fig. 6). The initially- seen A-phase occurs at high pressure and corresponds to the parallel spin triplet phase described by the Anderson-Brinkman-Morel model with $S_z = 1, -1$. The B-phase is identified with the Balian-Werthamer model where $S_z = 1, 0, -1$. Two other phenomena were discovered during the NMR measurements. One was a frequency shift in the superfluid which corresponded to an internal magnetic field of about 30G, and the other was the 104 degree angle which confirmed that the B-phase conformed to the Balian-Werthamer model.

Lee's talk ended with the mention of measurements made by the many low-temperature groups in the US, Great Britain, Finland, the Netherlands, Denmark and elsewhere, which followed up on the experimental discovery and the rich physical patterns discovered in superfluid He^3. Many members of those groups mentioned, or their collaborators, were in the audience.

The fifth speaker, Tony Leggett (Fig. 7), concluded the session with his talk entitled "Superfluid He^3: Understanding the Experiments." He reviewed the couple of years following the experimental discovery of the He^3 superfluid transition. There were many

Superfluidity of He^3

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Fig. 8. Leggett in post-presentation discussions. Photo courtesy of George Zimmerman.

questions to be resolved and experimental phenomena to be explained. One of the questions concerned the orbital pairing of the transition, which was determined to be the $l = 1$ state, although initially the $l = 2$ state was predicted. Other questions were about the nature of the A-phase which existed at high pressures and high temperatures (below 2.6 mK) and the B-phase which existed at lower temperatures and pressures down to saturated vapor where the transition occurs at about one mK. It was determined that both have an orbital state of $l = 1$, that the A-phase corresponds to the Anderson-Brinkman-Morel model with the spin pairing of $S_z = 1$ and $S_z = -1$, while the B-phase corresponds to the Balian-Werthamer model with $S_z = 1,0,-1$. The Balian-Werthamer phase was supposed to be more stable and thus why the A-phase existed at all was puzzling. This was explained by Anderson and Brinkman as being caused by fluctuations when the substance became a superfluid. Another puzzle was the NMR frequency shift in the A-phase which amounted to a 30 Gauss magnetic field. That field was much greater than the field due to the individual He^3 spins. That puzzle was explained by Leggett as being due to the spin-orbit coupling in that phase.

Since there was no question time during the talks, audience members met individually with the speakers after the talks were over (Fig. 8).

[1] Richard E. Packard, "Liquid Helium," *Macmillan Encyclopedia of Physics*, Vol. 2, 879-881 (Macmillan Reference, New York, NY, 1996).

[2] Paulson, D.N., H. Kojima, and J.C. Wheatley, *Phys. Rev. Lett.* **32**, 1098 (1974)

[3] J. Bardeen, L.N Cooper, J. R. Schriefer, *Phys. Rev.* **108**, 1175 (1957). The electron paring of the BCS theory that explained superconductivity also applies to He^3. When the Cooper pairs form in with helium-3 below ~0.002K, the fluid has zero viscosity and zero thermal resistivity, analogous to the zero resistance of a superconductor.

[4] K.A. Brueckner, Toshio Soda, Philip W. Anderson, and Pierre Morel, *Phys. Rev.* **118**, 1442–1446 (1960)

[5] V. J. Emery and A. M. Sessler, *Phys. Rev.* **119**, 43 (1960)

[6] D.D. Osheroff, R.C. Richardson, and D.M. Lee, "Evidence for a New Phase of Solid He^3", *Phys. Rev. Lett.* **28**, 885–888 (1972).

[7] L.N. Cooper, R.L. Mills, and A.M. Sessler, "Possible Superfluidity of a System of Strongly Interacting Fermions," *Phys. Rev.* **114**, 1377–1382 (1959)

[8] P. W. Anderson and P. Morel, *Phys. Rev.* **123**, 1911 (1961).

[9] R. Balian and N. R. Werthamer, *Phys. Rev.* **131**, 1553 (1963).

[10] G.C. Straty and E.D. Adams, *Review of Scientific Instruments* **40** (11), 1393-1397 (1969). ■

For further references please consult these review articles: From Rev. Mod. Phys. **69** *(1997) see Robert C. Richardson, "The Pomeranchuk effect," 683–690; David. M. Lee, "The extraordinary phases of liquid He^3," 645–666; Douglas D. Osheroff, "Superfluidity in He^3: Discovery and understanding," 667–682. From Rev. Mod. Phys.* **47** *(1975) see Anthony J. Leggett, "A theoretical description of the new phases of liquid He^3," 331–414; John C. Wheatley, "Experimental properties of superfluid He^3," 415–470.*

Sam Goudsmit

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Fig. 11. Alsos Intelligence officers have located the hidden hoard of German uranium cubes in Haigerloch, southern Germany (date unknown). Samuel Goudsmit is third from left. Credit: Photo by Samuel Goudsmit, courtesy AIP Emilio Segre Visual Archives, Goudsmit Collection.

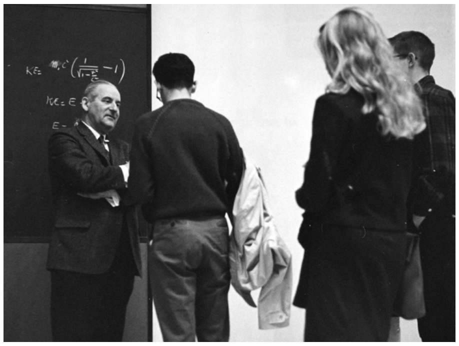

Fig. 12. Light and Quanta lectures, Christmas at Rockefeller Institute, 1963. Credit: AIP Emilio Segre Visual Archives, Goudsmit Collection.

Logan, who was Goudsmit's assistant at *Physical Review* 40 years ago, saw a common element in Goudsmit's diversity of interests: his "abiding delight in solving puzzles of every kind, coupled with a detective's keen eye for clues."

Peter Levy described how electron spin "was adopted in a very different setting a decade later to explain the unusual physical and electrical transport properties of ferromagnetic metals." That work led by 1988 to the control of currents through the spin of the electron, or "spintronics." Levy traced the origins of the field back to Neville Mott's work of the 1930s, using electron spin in a two-current models of conduction in the 3d transition-metal

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Laser History on Precision Measurements

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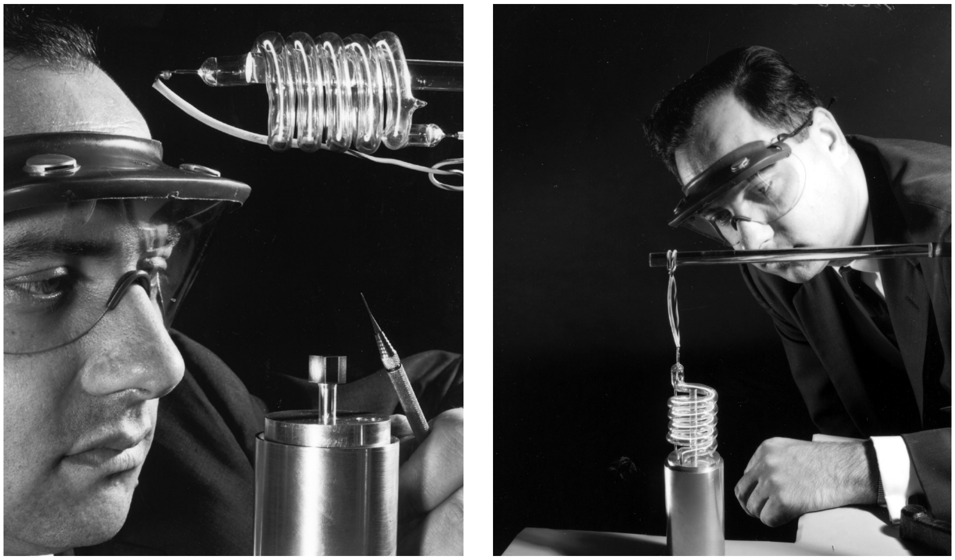

Figs. 5, 6. Theodore Maiman with his first ruby laser, 1960. Photo courtesy of HRL Laboratories; used by permission.

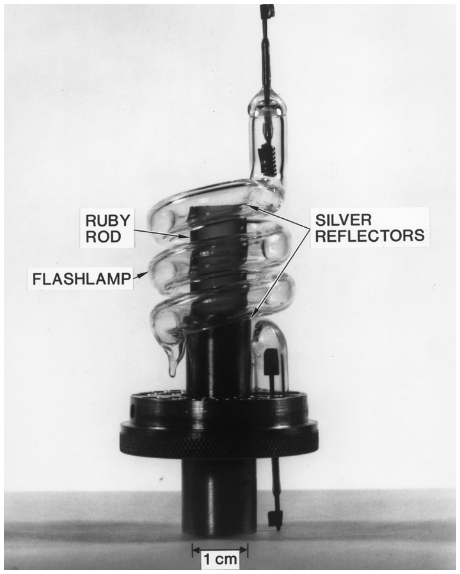

Fig. 7. Structure of the first ruby laser by Theodore Maiman, Hughes Research, 1960. Photo courtesy of HRL Laboratories; used by permission.

but in fact bandgap engineering now permits the design of materials with desired properties using the tools of quantum theory.

Semiconductor lasers were created in 1962 at GE by Robert N. Hall (Fig. 8) and Nick Holonyak, at IBM by Marshall I. Nathan and at MIT-Lincoln by Robert Rediker. At the time Capasso was finishing his Ph.D. research under F. De Martini. His advisor recommended that he leave non-linear optics and lasers because the field was saturated. So Capasso went to work on fiber optics, then to Bell Labs where he worked on transport. Ten years later he grew interested in the possibility of laser action between quantum well states pumped by quantum tunneling. He worked on this intermittently for seven years, somewhat hiding the research for fear of losing his job. At one point a higher-up ordered him to stop, but fortunately a higher higher-up gave him the OK keep going. In January 1994, Capasso demonstrated pulsed low-power laser radiation from a quantum well device, though it could operate only at 90K. The significance of his discovery was that the quantum wells could be tailored to be resonant, and could be cascaded using multi layer films, building up the power and using each electron over and over. Today, continuous wave high power quantum well lasers operate at room temperature.

Quantum cascade lasers operate from the mid infrared region (3-25 mm), including the important atmospheric transparency windows of 3-5 mm and 8-12 mm. They can produce radiation by difference-frequency mixing modes in the THz region, (60-300 mm). In some cases outputs of watts and efficiencies approaching 50% are achieved. Wide tuning ranges can also be achieved, making these lasers ideal for spectroscopy and population pumping in chemical physics. In addition to telecommunications, applications include atmospheric and tropospheric sensing of greenhouse and trace gases, medical imaging, biomedicine, and security. Development continues with one of the goals being beam engineering—the generation of laser beams with arbitrary wave fronts.

In his talk "Developing Stabilized Lasers, Measuring their Frequencies, Demoting the Metre, Inventing the Comb, and Further Consequences," **John L. "Jan" Hall** recalled incidents from a career devoted to applying lasers to precision measurements. The field of precision laser measurements was launched with the demonstration of a continuous wave laser by A. Javan and W.R. Bennett at Bell Labs at the end of 1961. Laser physics essentially bifurcated at that point. One stream pursued high power, short times, and nonlinear effects; the other avoided nonlinear effects as much as possible in order to pursue the ultimate in time and power stability. Hall suggested that with the creation of the frequency comb those streams have now rejoined. He traced his obsession with precision measurements to hearing a talk by Javan in which he played a recording of an audio signal generated by mixing the light from two separate lasers. Hall pursued his obsession at the Joint Institute for Laboratory Astrophysics, now JILA, which provided an ideal environment for pursuing this new field. JILA had excellent facilities and, most importantly, excellent collaborators. Alan White demonstrated how to stabilize a HeNe laser using Zeeman lines for the discriminator, and then Hall and R.L. Barger showed how to stabilize a laser on the Lamb dip. Using a Fabry-Perot interferometer they could then compare a wavelength with the legal krypton standard to 4 parts in 109 in a few minutes. They discovered a narrow line in methane that was well suited to laser metrology and developed a method for locking a laser to the line using an external absorption cell. These techniques became standard practice.

Laser History

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Fig. 8. L-R: Gunther E. Fenner, Robert N. Hall and Jack D. Kingsley, November 1, 1962. Kingsley holds a refrigerated container in which the laser operates at liquid-air temperatures. In the background another laser operates within a container chilled by liquid helium. The oscilloscope makes it possible to observe the shape of pulses produced by the laser. Photo courtesy General Electric Research Laboratories (used by permission), and the AIP Emilio Segre Visual Archives, Hecht Collection.

Peter Bender, Jim Faller and Hall undertook a speed-of-light measurement based on standing waves of two neon lines, whose difference frequency could be measured directly. The experiment was carried out in Poorman's Relief Gold mine in Colorado using a 30 m evacuated baseline. One of the surprises was a systematic shift in the baseline arising from Earth tide. At about that time Javan published a proposal for measuring the frequency of a laser by using the nonlinearity of a point contact diode to generate high harmonics, starting from an atomic clock. The idea was to span the frequency range from microwave to optical by a series of steps in which a laser would be stabilized to the harmonic of a lower frequency standard, and used to generate the next step in the chain. In 1972 Ken Evenson and colleagues used the method to measure the frequency of a 9.3 micron line of CO_2 using three lasers. This dinosaur method was eventually implemented at the Physikalisch-Technische Bundesanstalt (PTB), using 24 phase-locked loops. A collaboration at JILA in which Evenson played a principal role made a series of frequency vs. wavelength measurements and obtained a value for *c* that was limited only by the precision with which wavelengths could be compared. This effectively rendered obsolete the use of wavelength as a standard for length. In 1983 the speed of light was *defined*, and the meter was redefined in terms of the distance light travels in a second. By then the artifact meter bar at Bureau International des Poids et Mesures in Sevres, France, had long been obsolete, but this redefinition was not a matter of incremental precision but of fundamental meaning: length, as a primary standard, was now obsolete.

The invention of the frequency chain by the Munich and JILA groups totally changed the landscape for optical frequency metrology. The discovery of the coherence of sidebands in pulsed lasers, and methods for broadening the spectra to span an octave or more, provided an optical "gear chain" that could link frequencies from the microwave to the optical. With this, optical clocks became a realistic possibility. The comparison of an ion-based optical clock at NIST (Boulder) with an atom-based optical clock at JILA, several km away using a fiber-optic line, with an accuracy of about two parts in 10^{16}, marked the beginning of a new era in frequency metrology and a new field of physics based on the control of the phase of optical fields.

Hall has turned JILA leadership into this new era over to his protégé Jun Ye. Meanwhile, he is devoting himself to what he regards as the most critical national need: education. With his wife Lindy he has established Sci-Teks Discovery Program for Kids. For details, see *http://sci- teksdiscoveryprogramforkids.org/* . ■

For further reading and references see "Bright Idea: The First Lasers," an on-line exhibit of the Center for History of Physics, Niels Bohr Archive, American Institute of Physics: http://aip.org/history/exhibits/laser/ , and an article adapted from it (with permission), "Bright Ideas: From Concept to Hardware in the First Lasers," Radiations ***16****, 12-16 (Spring 2010) which is also available online at http://www.sigmapisigma.org/radiations/2010/bright_ideas.pdf.*

Upcoming Sessions

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Working with Luis Alvarez (1011-1988)
Tuesday 3 May 2011, 10:45.
Chair: TBD

Richard Muller, *UC Berkeley*: "Working with Luie as a Graduate Student"

Arthur H. Rosenfeld, *UC Berkeley*: "Working with Luie on Bubble Chambers"

Moishe Pripstein, *NSF*: "Life after Luie" ■

New Books *of* Note

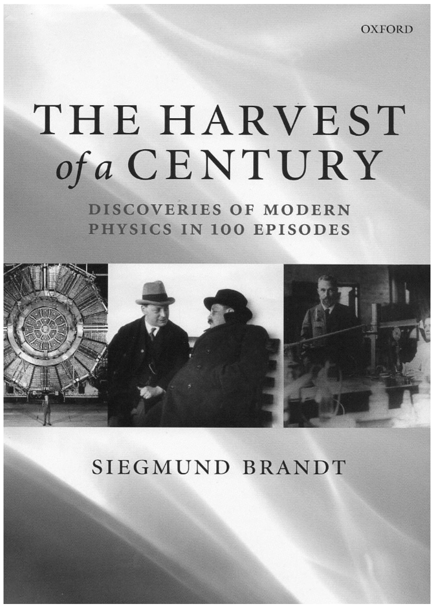
The Harvest of a Century:
Discoveries in Modern Physics in 100 Episodes

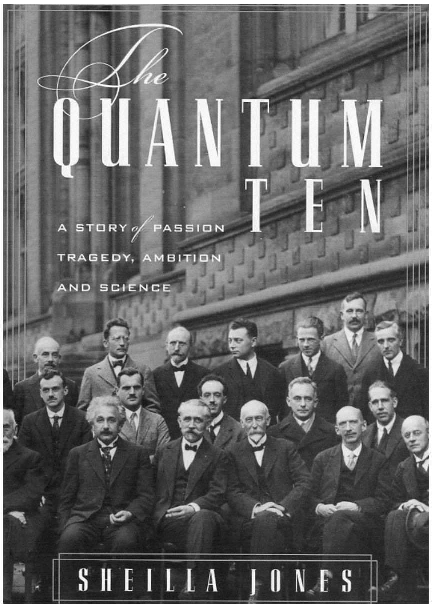
*By **Siegmund Brandt,** Oxford University Press, 2009, illustrated, 512 pp., $70.00*

The Quantum Ten:
A Story of Passion, Tragedy, Ambition and Science

*By **Shiella Jones**, Oxford University Press, 2008, 323 pp., photographs, $24.95*

Reviewed by Michael Riordan





Here are two interesting books that have been largely overlooked by the review media — at least those that I pay attention to. Both published by Oxford University Press, they make worthwhile contributions to the literature on 20th century physics, and therefore merit the consideration of Forum members.

Of the two, The Harvest of a Century is more to my liking, a compendium of what the author considers the most significant advances in physics during the past century. Siegmund Brandt is Professor Emeritus of Physics at the University of Siegen. He specialized in experimental particle physics, doing his research at DESY and CERN. From the thoroughness and detailed nature of the book, he has obviously devoted substantial time and effort to studying the history of 20th century physics.

Each of the "episodes," which begin in 1895 with Röntgen's discovery of X-rays, are described in four to six pages of text plus period photos and illustrations from the relevant physics literature. Most of them have a good mixture of theory and experiment, giving readers an idea of the interactions that occurred in arriving at a result and interpreting its meaning. More detailed derivations with equations are set off in sidebars, allowing readers so inclined to bypass this material or return to it later. Everything is thoroughly referenced, both to the primary literature where the original papers were published and to some (but not all) of the relevant historical interpretations. Brandt has done his homework.

He emphasizes the experimental side of the discipline, as one might expect, given his professional focus. I, for one, have no problem with this, but others might quibble. (And I was happy to see that no episode on string "theory" was included on his list!) Overall, the treatment is presented at a level that graduate students in physics can benefit from the book. However, I cannot recommend it to undergraduate students in my courses on the history of 20th century physics, because Brandt assumes a deeper understanding of physics than all but the best of them have.

In any collection like this, there will inevitably be pivotal discoveries and contributions that other scientists feel have been omitted or given short shrift. For instance, the MIT-SLAC deep-inelastic electron scattering experiments, in which I was involved, are one such lacuna. They gave the first solid evidence for the existence of quarks inside nucleons. Surely these experiments should rate at least as high as the 1973 discovery of weak neutral currents at CERN or the 1979 discovery of gluon jets at DESY, both of which warrant entire episodes. Perhaps this omission may be due to Brandt's pro-European bias; or perhaps he is just more familiar with experiments that occurred east of the Atlantic.

Another omission is the revolutionary 1998 discovery of the accelerating universe and its possible interpretation in terms of some variety of dark energy, such as Einstein's cosmological constant. Perhaps Brandt deliberately overlooked recent astrophysics and cosmology, for the 1991 COBE discovery of fluctuations in the cosmic background radiation is also absent from his list. If so, these are unfortunate omissions.

The Harvest of a Century offers what professional science historians would call an "internalist" account of the history of physics — whose dynamics are determined entirely by the give-and-take of theorists and experimenters following only the internal logic of the field. Almost totally absent from these pages is the role of personal philosophy and individual choice, as well as the impact of

New Books of Note

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external economic, social, and political forces on how the history of modern physics ultimately unfolded.

* * *

The opposite is true of The Quantum Ten. In this popular book aimed at a general audience, Sheilla Jones paints a lurid portrait of ten theoretical physicists whose ideas and writings of the 1920s, particularly the core years 1925–1927, led to a successful theory of quantum mechanics — a true scientific revolution in the Kuhnian sense. This is exceedingly well-worn terrain, particularly recently, and thus a difficult arena in which to say anything really new. But Jones succeeds, I believe, by weaving a narrative focused not upon a single physicist (e.g., Bohr or Heisenberg) but on the web of interactions that occurred among an entire group of remarkable iconoclasts. Their activities do not occur in a social or political vacuum but against the turbulent backdrop of Weimar Germany with its dark, looming cloud of intensifying Nazi anti-intellectualism.

The central characters in Jones's taut drama are (none too surprisingly) "Albert Einstein, the lone wolf; Niels Bohr, the obsessive but gentlemanly father figure; Max Born, the anxious hypochondriac; Werner Heisenberg, the intensely ambitious one; Wolfgang Pauli, the sharp-tongued critic with a dark side; Paul Dirac, the silent Englishman; Erwin Schrödinger, the enthusiastic womanizer; Prince Louis de Broglie, the French aristocrat; Pascual Jordan, the ardent Aryan nationalist . . . ; and Paul Ehrenfest, who was witness to it all" and increasingly depressed that his contributions did not measure up to the others'. Jones in large part mines the work of prominent historians — e.g., Abraham Pais on Einstein and Bohr, David Cassidy on Heisenberg, and Martin Klein on Ehrenfest — but she occasionally delves into original documents, particularly letters between the principals. All of this is fortunately well documented in the references.

But Jones takes greater freedom than most in her interpretations of events, comments and writings, ascribing more to personal and external influences than would most professional historians of science. In some cases, in fact, she gets downright gossipy—as her subtitle adumbrates — especially when it comes to the theorists' interactions with their wives and lovers. The trysting Schrödinger is a favorite subject in this regard.

The favorite venue is Brussels, where the periodic Solvay Conferences on quantum theory occurred, beginning in 1911 with one on the quantum theory of radiation. An entire chapter and more is devoted to the climactic Fifth Solvay Conference in 1927 — to which all ten principals except the Nazi-leaning Jordan were invited — where the interpretation of the new quantum mechanics was vociferously debated and Bohr and Heisenberg's Copenhagen interpretation supposedly won out. Here Jones leans heavily on the recent Quantum Theory at the Crossroads, by Guido Bacciagaluppi and Antony Valentini (Cambridge, 2009; reviewed in these pages, Spring 2010), which challenges the commonly accepted notion that Bohr and Heisenberg emerged from Brussels victorious. It apparently took a lot longer, claims Jones, ultimately aided by the exhausted resignation of principal opponents de Broglie and Schrödinger.

For both books, I am grateful that Oxford has kept its prices down to levels where ordinary physicists can afford them. Interested but impecunious readers do not have to wait until the local physics library elects to pay a princely sum to put these books on its history of physics shelves. In this regard, The Harvest of a Century will go up on my own bookshelves to serve as a convenient, authoritative reference whenever I need to review in some detail the major advances in 20th century physics. ■

Michael Riordan is Adjunct Professor of Physics at the University of California, Santa Cruz. Formerly Editor of the History of Physics Newsletter, he now serves as its Book Review Editor. He is author of The Hunting of the Quark and coauthor of Crystal Fire.

Sam Goudsmit

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Fig. 13. Presentation of the National Medal of Science Award at the White House. George Uhlenbeck is at the right end of the line (about to shake hands with President Carter). Fourth from his right is Samuel Goudsmit. November 22, 1977 Credit: The White House, courtesy AIP Emilio Segre Visual Archives.

ferromagnetic metals. Levy's story continued through contemporary interest focused on spin-dependent transport in oxides and carbon-based materials.

Sam Goudsmit and George Uhlenbeck shared the 1964 Max Planck Medal. Goudsmit was awarded the National Medal of Science in 1976 (Fig. 8). He retired in 1974 and became a member of the faculty at the University of Nevada-Reno. Goudsmit passed away in Reno on 4 December 1978.

[1] G.E. Uhlenbeck and S. Goudsmit, *Naturwissenschaften* **47** (1925) 953.

[2] Goudsmit's publications in Egyptology include articles in *Expedition* (Summer 1972), 13-16; *American Journal of Archaeology* **78** (1974) 78; *Journal of Near Eastern Studies* **40** (1981) 43-46.

[3] Margaret Cool Root, *The Samuel A. Goudsmit Collection of Egyptian Antiquities: A Scientist Views the Past,* Exhibition of the Kelsey Museum of Archaeology, January 30-May 9, 1983, The University of Michigan, Ann Arbor; and an exhibition catalog by the same title, Kelsey Museum of Archeology (1984).

[4] See *http://cdli.ucla.edu/collections/kelsey/kelsey_intro.html.* ■

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Forum on History of Physics
American Physical Society
One Physics Ellipse
College Park, MD 20740