AFOSR-Supported Nobel Prize Laureates

The Air Force Office of Scientific Research has created a strong legacy of Nobel Prize winning research.

One of the most highly coveted and recognized awards, the Nobel Prize recognizes those who contribute significant achievements in the areas of physics, chemistry, physiology or medicine, literature, peace, and economic sciences (the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel). The Nobel Foundation was established in 1900, and in 1901 the Nobel Prize became the first international award to be given on an annual basis. Established as outlined in his last will and testament, Dr. Alfred Nobel stated, "…the whole of my remaining realizable estate shall be dealt with in the following way…annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit to mankind." For one hundred years, Nobel laureates have been the recognized leaders in their respective fields, accomplishing research at the very edge of the frontiers of science.

During the past 56 years, since its establishment in 1951, the Air Force Office of Scientific Research (AFOSR) has sponsored 56 Nobel Prize laureates. On average, these laureates received AFOSR funding sixteen years prior to winning their Nobel awards. The accomplishments of these laureates demonstrate the astute ability of AFOSR program managers to choose world-class researchers to readily address Air Force requirements and advance Air Force programs. The following descriptions of the work performed by AFOSR-funded Nobel recipients recognize the remarkable scientific contributions that have contributed to the significant United States Air Force advantage on the battlefield. AFOSR has funded 29 laureates in Physics, 19 in Chemistry, six in Physiology or Medicine, and two in Economics.

AFOSR-Supported Nobel Prize Laureates

	Award Year	AFOSR Support Began	Award Type	Name
1.	1955	1954	Physics	Polykarp Kusch
2.	1955	1954	Physics	Willis E. Lamb
3.	1956	1953	Physics	John Bardeen*
4.	1960	1952	Chemistry	Willard Libby
5.	1961	1953	Physics	Robert Hofstadter
6.	1963	1958	Physics	Eugene P. Wigner
7.	1964	1953	Physics	Charles H. Townes
8.	1966	1952	Chemistry	Robert S. Mulliken
9.	1967	1953	Physics	Hans Albrecht Bethe
10.	1967	1959	Medicine	Ragnar Granit
11.	1967	1962	Chemistry	George Porter
12.	1968	1966	Chemistry	Lars Onsager
13.	1969	1958	Physics	Murray Gell-Mann
14.	1970	1959	Medicine	Ulf Von Euler
15.	1972	1953	Physics	John Bardeen*
16.	1973	1961	Medicine	Nikolaas Tinbergen
17.	1973	1968	Physics	Brian D. Josephson
18.	1974	1961	Chemistry	Paul J. Flory
19.	1976	1959	Chemistry	William N. Lipscomb
20.	1977	1968	Physics	Philip W. Anderson
21.	1977	1964	Physics	John H. Van Vleck
22.	1977	1954	Chemistry	Ilya Prigogine
23.	1979	1958	Physics	Sheldon L. Glashow
24.	1979	1962	Physics	Abdus Salam
25.	1979	1958	Physics	Steven Weinberg
26.	1980	1959	Chemistry	Walter Gilbert
27.	1981	1975	Physics	Nicolaas Bloembergen
28.	1981	1956	Physics	Kai M. Siegbahn
29.	1981	1959	Phys/Med	David H. Hubel
30.	1981	1959	Phys/Med	Thorsten N. Wiesel
31.	1981	1962	Chemistry	Kenichi Fukui
32.	1981	1981	Physics	Arthur Schawlow
33.	1983	1961	Physics	S. Chandrasekhar

	Award Year	AFOSR Support Began	Award Type	Name
34.	1983	1961	Physics	William A. Fowler
35.	1986	1981	Chemistry	John C. Polanyi
36.	1986	1979	Chemistry	Dudley R. Herschbach
37.	1987	1962	Chemistry	Donald J. Cram
38.	1988	1970	Physics	Melvin Schwartz
39.	1990	1968	Chemistry	Elias J. Corey
40.	1990	1961	Physics	Jerome I. Friedman
41.	1990	1961	Physics	Henry W. Kendall
42.	1992	1962	Chemistry	Rudolph A. Marcus
43.	1995	1995	Chemistry	Mario Molina
44.	1997	1988	Physics	Steven Chu
45.	1998	1985	Physics	Daniel C. Tsui
46.	1999	1986	Chemistry	Ahmed Zewail
47.	2000	1988	Chemistry	Alan J. Heeger
48.	2000	1995	Physics	Herbert Kroemer
49.	2000	1984	Medicine	Paul Greengard
50.	2000	1958	Physics	Jack S. Kilby
51.	2002	1975	Chemistry	John B. Fenn
52.	2002	1977	Economics	Daniel Kahneman
53.	2005	1991	Physics	John L. Hall
54.	2005	1987	Chemistry	Robert H. Grubbs
55.	2005	1962	Physics	Roy J. Glauber
56.	2005	1960	Economics	Thomas C. Schelling
57.	2006	1985	Physics	George F. Smoot

***Note: John Bardeen awarded Physics Nobel in 1956 and 1972.**

Nobel Laureates supported after they received the award (4).

	Award Year	AFOSR Support Began	Award Type	Name
1.	1982	1984	Physics	Kenneth Wilson
2.	1989	1991	Physics	Hans G. Dehmelt
3.	1994	1995	Chemistry	George A. Olah
4.	1996	2003	Chemistry	Richard Smalley

(List current as of December 2007)

<u>Polykarp Kusch</u> (Columbia University, New York, NY)
<u>Willis Lamb</u> (Stanford University, Stanford, CA)
PHYSICS: 1955

In the area of Physics, many breakthroughs have occurred with the aid of AFOSR funding. In 1955, Kusch and Lamb shared the prize for "***precision determination of the magnetic moment of the electron***" and "***discoveries concerning the fine structure of the hydrogen spectrum,***" respectively.

Prior to his laureate, Kusch studied the effects of magnetic fields on beams of atoms with Nobel Laureate Dr. Isidor Rabi, who had a profound influence on Kusch's research. Through diligence and effort, Kusch demonstrated that magnetic properties of electrons were not consistent with existing theories. He accurately measured the magnetic moment of the electron and its behavior in hydrogen and numerous atomic, molecular, and nuclear properties by radio-frequency beam techniques.

Lamb joined the faculty of Colombia University in 1938, and worked in the radiation laboratory alongside Kusch. In 1947, Lamb applied new techniques to measuring the hyperfine structure of lines appearing in the spectrum of light and found their positions to be slightly different from theoretical predictions. He later devised microwave techniques for examining the spectral lines of helium. The varied scope of Lamb's research ranged from such diverse areas as the fluctuation in cosmic ray showers and order-disorder problems, to the ejection of electrons by metastable atoms.

The research by these two winners resulted in the development of techniques for microwave interaction with atoms and atomic beams, now used in many technological applications.

One important application to the Air Force and increasingly within civilian economy is the cesium beam atomic clock, an essential part of the Global Positioning System (GPS). Without the incredibly accurate time-keeping capabilities of atomic clocks, the GPS would not be possible.

AFOSR Funding Began: 1954

<u>John Bardeen</u> (University of Illinois, Urbana, IL)

PHYSICS: 1956

Dr. John Bardeen was the first scientist to win two Nobel prizes in the same category. He won his first Nobel physics prize in 1956 for "***co-invention of the transistor***," a tiny electronic device capable of performing most of the functions of a vacuum tube. In 1972, he shared the prize with two others for their **"*theory of superconductivity, usually called the BCS-theory***," an abbreviation formed by the first letter of each of the winner's surnames.

While Bardeen developed the transistor at Bell Labs in the late 1940s, it was in 1953 that AFOSR funded Bardeen and others in the refinement of integrated circuit technology for Air Force applications   Air Force systems in use today would be far more bulky, heavier and antiquated if not for Bardeen's discovery.

Dr. Bardeen's second award was for the "development of a theory to explain superconductivity," the disappearance of electrical resistance in certain metals and alloys at temperatures near absolute zero. His work has benefited the medical field with applications to magnetic resonance imaging (MRI), and the electronic field with the development of sensors, transducers, magnets and particle accelerators.

AFOSR Funding Began: 1953

Willard Libby (University of California, Los Angeles, CA)

CHEMISTRY: 1960

Willard F. Libby won the 1960 Nobel Chemistry Prize for his ***"method to use carbon-14 for age determination in archaeology, genealogy, geophysics, and other branches of science."***

Libby studied radioactive isotope carbon-14 since its discovery in 1941and is best known for his radiocarbon dating techniques. He first showed that C-14 is present in small amounts of $C0_2$ in our atmosphere and is absorbed by all life forms in regular amounts up to a point, after which no more is taken in. Using this knowledge, Libby postulated, together with the known half-life rate of 5730 years and the calculated amount of the isotope present in the object, one could calculate an approximate age for ancient materials. In 1947, Libby and his students at the Institute for Nuclear Studies developed the method of C14 dating using a highly sensitive Geiger counter. Since C14 decays at a measurable rate upon the death of an organism, Libby was able to determine the age of organic artifacts by measuring the amount of remaining C14. The tests proved reliable for objects up to 70,000 years.

Mr. Libby's dating technique is extremely valuable to earth scientists, anthropologists and especially archaeologists, virtually eliminating the educated guesses about the ages of various artifacts based on evidence found at the site. Now that samples from around the world can be tested, a new chronology has emerged that knits together archaeological findings from around the world. His Nobel Prize citation read: "Seldom has such a single discovery in chemistry had such an impact on the thinking of so many fields of human endeavor. Seldom has a single discovery generated such wide public interest."

AFOSR funding for Libby covered a wide range of requirements: radioactive isotopes, optical transparency, high-pressure chemistry, electron tunneling, pollution control catalysts, and industrial chemistry in space were but a few of Libby's research efforts.

AFOSR Funding Began: 1954

Robert Hofstadter **(Stanford University, Stanford, CA)**

PHYSICS: 1961

Robert Hofstadter won the 1961 Physics Nobel for his ***"pioneering studies of electron scattering in atomic nuclei and for his thereby achieved discoveries concerning the structure of the nucleons."***

Hofstadter used a linear electron accelerator to measure and explore the constituents of atomic nuclei. At the time, protons, neutrons, and electrons were all thought to be particles without structure; but Hofstadter discovered that protons and neutrons have a definite size and form. He was able to determine the precise size of the proton and neutron and provide the first reasonably consistent picture of the structure of the atomic nucleus. He also made substantial contributions to gamma ray spectroscopy, leading to the use of radioactive tracers to locate tumors and other disorders. During World War II he worked as a physicist at the National Bureau of Standards, where he helped develop the proximity fuse, an antiaircraft weapon.

His work on X-Ray detection in semiconductors and scintillators contributed to US strategic systems in two ways. Semiconductor and scintillation detectors are used in flash x-ray machine work that is part of nuclear hardening of strategic systems including Peacekeeper Missile and Minuteman. They are also used in circuitry that protects on-board computer systems in such missiles from disruption by nuclear radiation.

AFOSR Funding Began: 1953

<u>Eugene Wigner</u> (Princeton University, Princeton, NJ)

PHYSICS: 1963

Noble Laureate in 1963 for Physics, Dr. Eugene Wigner received his prize for his "***contributions to the theory of the atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles***."

Wigner's work helped to disclose the structure of the atomic nucleus and extended quantum mechanics theory relations to the nature of the proton and neutron.

In 1939, Wigner was one of five scientists who informed President Franklin D. Roosevelt about the possible military use of atomic energy.

Known as the "Father of Nuclear Engineering," Wigner's work contributed to the development of the atomic bomb and the design of commercial nuclear reactors. He designed the first fast neutron breeder reactor.

Under AFOSR contract, Wigner explored a wide range of topics. He discussed the usefulness of mathematics as a tool for the formation of the laws of physics; explored various aspects of the future of nuclear energy; and also reviewed the standard theory of measurements in quantum mechanics.

AFOSR Funding Began: 1958

<u>Charles Townes</u> (Massachusetts Institute of Technology, Cambridge, MA)

PHYSICS: 1964

Beginning in 1953, AFOSR helped to sponsor the research of Dr. Charles Townes, who went on to win the 1964 prize in Physics for his "***fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle***."

Townes is credited for inventing the maser, a device that amplifies electromagnetic waves. This technology provided the means for sensitive reception of communications and for precise navigation. The maser also provided the basis for its successor, the laser. AFOSR helped to fund the early maser and follow-on laser work of Dr. Townes. The result of this revolutionary research transformed communications, navigation, astronomy, radar, atomic clocks, surgery and many industrial applications. His discoveries have had wide-ranging impact not only on the Air Force, but our entire society.

AFOSR Funding Began: **1953**

<u>Robert Mulliken</u> (University of Chicago, Chicago, IL)

CHEMISTRY: 1966

Winning the Noble prize in Chemistry in 1966, Dr. Robert Mulliken's research was recognized for "***fundamental work concerning chemical bonds and the electronic structure of molecules by the molecular orbital method***."

His early work concentrated on isotopes and on diatomic band spectra, followed by theoretical work to systematize the electronic state of molecules. Later work by Dr. Mulliken involved extensive research of the structure and spectra of molecular complexes and also extending and progressing the structure and spectra of hydrogen, helium, nitrogen and other small molecules.

A pioneer, Mulliken significantly contributed to the development of methods now used in computational chemistry. His work led to the advancement of computer codes with real predictive capabilities that are now used widely throughout the Department of Defense.

Mulliken's relationship with AFOSR dates back to 1952 and ensuing years, when Mulliken's research group obtained computationally practicable expressions for two-center integrals and went on to simplify the time consuming effort of programming the formulas for molecular integrals.

The methods developed by Mulliken enable calculations of many molecular properties to guide the process of synthesizing new compounds, such as fuels and propellants, and are also used to develop sensors that can help with the defense against chemical and biological attacks.

AFOSR Funding Began: **1952**

Hans Bethe (Cornell University, Ithaca, NY)

PHYSICS: 1967

Hans Bethe received the Nobel prize in Physics in 1967 for his "***contributions to the theory of nuclear reactions, especially his discoveries concerning the energy production in stars***."

Bethe suggested that the production of energy by the sun and other stars occurs through thermonuclear fusion, a series of nuclear reactions by which hydrogen is converted into helium.

Bethe provided great insight into the fundamentals of heavy ions and their interaction with matter. His work led directly to a capability to accurately predict energy deposition of heavy ions in any kind of material.

With the advent of Air Force space satellites and the discovery of the intense radiation belts surrounding the earth, radiation vulnerability of these satellites became a serious problem for the Air Force. Dr Bethe's work applies directly to the interactions of these radiations and his prize-winning work is used to assess survivability from radiation for every Air Force satellite in orbit today.

AFOSR Funding Began: **1953**

Ragnar Granit (The Karolinska Institute, Stockholm, Sweden)
PHYSIOLOGY/MEDICINE: 1967

Ragnar Granit was co-winner of the Nobel prize for Physiology and Medicine in 1967 for his ***"discoveries concerning the primary physiological and chemical visual processes in the eye."***

As a neurophysiologist, Dr. Granit studied nerve impulses to understand how the eye works with the brain to create vision. Granit worked on a method to use microscopic electrodes to measure the stimuli of the optic nerves of the retina, the part of the eye that sends the image gathered by the lens to the brain. He realized that when light is received by the retina the light has both an excitatory and inhibitory effect on the optic nerves and that this combination of effects creates contrast in the image received by the brain. In 1933 he helped to develop the electroretinogram (ERG), a device used to measure the activity of the retina. He used it for vision research in general, but especially for color vision research.

In the mid-1940s, Granit turned his attention to the study of the length and tension meters in the muscles known as muscle spindles and tendon organs. Granit's work in this area did much to explain the physiology of muscle control and excitation. Granit co-authored two reports in this field under AFOSR auspices.

Dr. Granit's research on the electrical properties of neurons led to discoveries relating to the electrical signals of brain nerve cells. Those findings were used to assess cognitive workloads under a variety of conditions that affect an individual's performance. In addition, engineers are using his methods for determining functional properties for networks of nerve cells to develop more effective designs for analog computers and non-linear dynamic control systems.

AFOSR Funding Began: **1958**

<u>George Porter</u> (Royal Institution of Great Britain, London, England)
CHEMISTRY: 1967

George Porter shared the 1967 Nobel Prize in Chemistry **"*for studies of extremely fast chemical reactions, effected by disturbing the equilibrium by means of very short pulses of energy*."**

As Porter observed, one of the principal activities of a scientist was extending the very limited senses of man, enabling him to observe phenomena beyond his normal experience. Microscopes and microbalances allow the observation of things which man cannot perceive through his own senses. In the dimension of time, man's perception is limited to about one-twentieth of a second, the response time of the eye. However, most fundamental chemical reactions occur in the range of milliseconds or less, making it necessary to observe reactions in microtime. It was in the field of making these observations and interpreting the resulting data that Porter made lasting contributions to science by the method of flash photolysis. Employing this process, Porter was able to yield information concerning the mechanism and kinetics of the photochemical reactions that occurred.

Porter's early relationship with the U.S. Air Force concerned research on low-level excitation and energy transfer of gases. His later work with AFOSR dealt with energy storage and transfer on the molecular level to provide understanding of processes related to Air Force needs in solar energy conversion devices, photographic imaging, flash blindness protection, and radiation damage control in biological systems.

AFOSR Funding Began: 1962

Lars Onsager (Yale University, New haven, CT)

CHEMISTRY: 1968

Lars Onsager won the 1968 Nobel Chemistry prize ***"for the discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes."***

One could have expected that the importance of his "reciprocal relations in irreversible processes" would have been immediately obvious to the scientific community. Instead it turned out that Onsager was far ahead of his time. After publication it attracted almost no attention for more than a third of a century. It was only after WWII that the concept became more widely known and eventually played a dominant role in the rapid development of irreversible thermodynamics, with numerous applications not only in physics and chemistry but also in biology and technology. The great importance of irreversible thermodynamics becomes apparent if we realize that almost all common processes are irreversible and cannot by themselves go backwards. Examples are conduction of heat from a hot to a cold body and mixing or diffusion. When a cold lump of sugar is dissolved in a cup of hot tea these processes take place simultaneously.

Onsager's great contribution was that he could prove that if the equations governing the flows are written in an appropriate form, then there exist certain simple connections between the coefficients in these equations. These connections - the reciprocal relations - make possible a complete theoretical description of irreversible processes. Earlier attempts to treat such processes by means of classical thermodynamics gave little success.

Onsager's research for AFOSR dealt with low-temperature physics.

AFOSR Funding Began: 1966

Murray Gell-Mann (California Institute of Technology, Pasadena, CA)
PHYSICS: 1969

Murray Gell-Mann won the Nobel prize in 1969 for his ***"contributions and discoveries concerning the classification of elementary particles and their interactions."***

As a theoretical physicist Gell-Mann is known for his classification of subatomic particles and his proposal for the existence of quarks. His research in particle physics concerned the interactions between protons and neutrons. On the basis of a proposed property called "strangeness," conserved by particles involved in strong and electromagnetic interactions, Gell-Mann grouped related particles into multiplets, or families. In 1963 he and a colleague George Zweig advanced the "quark" theory. They hypothesized that quarks, particles carrying fractional electric charges, are the smallest particles of matter. Dr Gell-Mann's "eightfold way" theory brought order to the chaos created by the discovery of some 100 particles in the atom's nucleus. He found that all of these particles, including the neutron and proton, are composed of fundamental building blocks-quarks-that are permanently confined by forces coming from the exchange of "gluons." He called the quantum field theory of quarks and gluons, "quantum chromodynamics," which seems to account for all the nuclear particles and their strong interactions.

AFOSR Funding Began: **1958**

Ulf von Euler (The Karolinska Institute, Stockholm, Sweden)
PHYSIOLOGY/MEDICINE: 1970

Armed, in part, with funding from AFOSR, Dr. Ulf von Euler made important discoveries in the areas of physiology and medicine. He shared the Nobel Prize with two others in 1970 for "***discoveries concerning the humoral transmitters in the nerve terminals and the mechanism for their storage, release and inactivation***."

Von Euler is credited for discovering that neural transmitters are stored and released from nerve cell granules, which controls the body's response to stress or exertion. His findings stimulated a tremendous amount of research regarding the affect neurochemical influences have on the brain, heart and other body systems. The subsequent work produced major advances in the way those with mental illness, heart disease and other neurogenic conditions are treated.

Dr. von Euler's work is used by the Air Force to learn more about a person's neural control as they go about their normal daily routine as well as during periods of sleep. This research is used to help determine the effectiveness of an individual during sustained operations.

AFOSR Funding Began: 1960

John Bardeen (University of Illinois, Urbana, IL)
PHYSICS: 1972

Dr. John Bardeen was the first scientist to win two Nobel prizes in the same category -- Physics. He won his first prize in 1956 for "***co-invention of the transistor***," a tiny electronic device capable of performing most of the functions of a vacuum tube. In 1972, he shared the prize with two others for their **"*theory of superconductivity, usually called the BCS-theory***," an abbreviation formed by the first letter of each of the winner's surnames.

While Bardeen developed the transistor at Bell Labs in the late 1940s, it was in 1953 that AFOSR funded Bardeen and others in the refinement of integrated circuit technology for Air Force applications Air Force systems in use today would be far more bulky, heavier and antiquated if not for Bardeen's discovery.

Dr. Bardeen's second award was for the "development of a theory to explain superconductivity," the disappearance of electrical resistance in certain metals and alloys at temperatures near absolute zero. His work has benefited the medical field with applications to magnetic resonance imaging (MRI), and the electronic field with the development of sensors, transducers, magnets and particle accelerators.

AFOSR Funding Began: 1953

<u>Nikolass Tinbergen</u> (University of Oxford, Oxford, United Kingdom)
PHYSIOLOGY/MEDICINE: 1973

Dr. Nikolaas Tinbergen shared the Nobel prize for Physiology & Medicine with two others in 1973 for their ***"discoveries concerning organization and elicitation of individual and social behavior pattems."*** It was the first time the Nobel Committee recognized research in sociobiology or ethology.

As a zoologist, Dr Tinbergen's experimental work demonstrated how complex patterns of animal behavior depended on both slowly changing inherited behavioral patterns and more rapid-paced changes due to learning. His findings stimulated considerable scientific work in such diverse fields as animal communication and human language learning, mate selection, evolutionary theory and, most important to the Air Force, theories of cooperative behavior. These theories help explain and predict ways that large numbers of simple systems can produce very complex goal-directed behaviors with minimal communication between them.

The path of Tinbergen's work passed through cybernetics in the 1960s, learning automata in the 1970s, neural networks and "animats" in the 1980s, to modern control theory. The rules that determine properties of cooperating microsatellites, micro-air vehicles, and ground-based "nano-bots" may be found to share much in common with the rules that determine goal-seeking behaviors found in ant colonies.

AFOSR Funding Began: 1961

<u>Brian Josephson</u> (Cambridge University, Cambridge, United Kngdom)
PHYSICS: 1973

Nobel Laureate in Physics, Dr. Brian Josephson, won the 1973 prize for his "***theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena that are generally known as the Josephson effects***."

He invented a superconductivity device that bears his name - the Josephson Junction - which is used in digital electronic applications. This device provides the basis for the world's most sensitive magnetometers and the fastest, lowest power electronic switching elements.

Josephson was responsible for developing the theory now known universally as the Josephson effects in superconductors, which is used to make the world's fastest, high-resolution electronic circuitry, currently used in Air Force electronic countermeasures systems.

AFOSR Funding Began: 1968

Paul Flory (Stanford University, Stanford, CA)

CHEMISTRY: 1974

Dr. Paul John Flory, won the Nobel prize for Chemistry in 1974 for his "***fundamental achievements, both theoretical and experimental, in the physical chemistry of the macromolecules***."

Dr. Flory's first research focused mostly on photochemistry and spectroscopy, which enables scientists to determine the composition of molecules by analyzing the light they emit when heated. Later, Flory began researching the physical chemistry of polymers. He studied their properties in solution and in bulk and his research revealed the connections between the chemical structures of the individual polymer molecules and their physical properties. Considered by many to be the "founder of polymer science," Flory's work with nylon and synthetic rubber proved to be of great commercial importance.

Dr. Flory developed the framework to understand the physics and viscoelasticity behavior of polymers. This framework led to the development of advanced resins used in organic-matrix, carbon-fiber reinforced composites currently used in the wings and fuselages of many Air Force aircraft, including the F-16, B-2, F-22 and Joint Strike Fighter (JSF).

AFOSR Funding Began: 1961

William Lipscomb **(Harvard University, Cambridge, MA)**

CHEMISTRY: 1976

William N. Lipscomb put his AFOSR funding to optimal use when he earned the Nobel prize for Chemistry in 1976 for his ***"studies on the structure of boranes illuminating problems of chemical bonding."***

Boranes are compounds of boron and hydrogen. By developing x-ray techniques that later proved useful in many chemical applications, Lipscomb and his associates were able to map the molecular structures of numerous boranes and their derivatives. The stability of boranes could not be explained by traditional concepts of electron bonding -- in which each pair of atoms is linked by a pair of electrons -- because boranes lacked sufficient electrons. Lipscomb showed how three atoms could share a pair of electrons. In 1961, the work of Dr. Lipscomb was featured in *AFOSR Chemistry Program Review* to illustrate some of his innovative crystallographic work.

Since the early 1960s his research also focused on the relationship between three-dimensional structures of enzymes and how they catalyze reactions. He is noted for his famous quotation: "The creative process, first of all, requires a good nine hours of sleep a night. Second, it must not be pushed by the need to produce practical applications. "

AFOSR Funding Began: **1959**

Philip Anderson (Bell Laboratories, Murray Hill, NJ)
John Van Vleck (Harvard University, Cambridge, MA)
PHYSICS: 1977

Philip W. Anderson, John H. Van Vleck, and Nevill Mott, won the Nobel Prize in 1977 for their contribution to the *"**fundamental theoretical investigations of the electronic structure of magnetic and disordered systems**."*

Anderson is one of the leading theorists on superconductivity and won his part of the prize for developments in advanced electronic circuitry. He showed conditions under which an electron in a disordered or imperfect system can either move through the system as a whole or stay in a specific position -- becoming a localized electron. This development provided a better understanding of electrical conduction in magnetic materials. His research in solid-state physics made possible the development of inexpensive electronic switching and memory devices in computers. Anderson also has done work on pulsar glitches with David Pines. He is credited with developing concept of the "Higgs" boson in 1962.

Dr. Van Vleck was recognized for his contributions to the understanding of the behavior of electrons in magnetic, noncrystalline solid materials. Early during the 1930s, Van Vleck developed the first fully articulated quantum mechanical theory of magnetism. Later he was a chief architect of the ligand field theory of molecular bonding. The research performed in solid-state physics by these Nobel laureates made possible the development of inexpensive electronic switching and memory devices in computers, which are widely used in industry and in military systems. Van Vleck also contributed to a variety of studies, most notably, on the spectra of free molecules and paramagnetic relaxation.

AFOSR Funding Began: 1964 (Van Fleck); 1968 (Anderson)

Ilya Prigogine (Universite Libre de Bruxelles, Brussells, Belgium; and University of Texas, Austin, TX)
CHEMISTRY: 1977

Dr. Ilya Prigogine won the Nobel prize for Chemistry in 1977 for his *"**contributions to non- equilibrium thermodynamics, particularly the theory of dissipative structures**."*

Prigogine focused most of his work on better understanding the role of time in biology and in the physical sciences. He has contributed significantly to the understanding of irreversible processes, particularly in systems far from equilibrium. He initiated the application of thermodynamics to irreversible processes in both living and inanimate systems. Prigogine's contributions have come largely in *irreversibility*, or, as he calls it, "the arrow of time."

His concept of dissipative structures describes the workings of open systems -- systems in which there is an exchange of matter and energy with the outside environment. His theory has been widely adopted by the U.S. Department of Transportation to predict traffic-flow patterns. In biology, the theory has proved useful in understanding a number of phenomena, including the glycolytic, or sugar, cycle, a metabolic process by which living cells extract energy from food.

As a leader in the field of nonlinear statistical mechanics, his work contributed to the ability to analyze processes in complex systems. The contribution of his work to DoD is in understanding the atmospheric processes that are governed by complex interrelated phenomena.

AFOSR Funding Began: 1953

Sheldon Glashow (Harvard University, Cambridge, MA)

Steven Weinberg (Harvard University, Cambridge, MA)

Abdus Salam (International Centre for Theoretical Physics, Trieste, Italy, and Imperial College of Science and Technology, London, United Kingdom)

PHYSICS: 1979

AFOSR funded physicists Sheldon L. Glashow, Abdus Salam, and Steven Weinberg won the Nobel Prize for Physics in 1979 for their "***contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including inter alia the prediction of the weak neutral current*** ."

Four forces were believed to drive the laws of physics: gravity, electromagnetism, the strong force (which holds an atom's nucleus together), and the weak force (which breaks an atom apart, as in radioactivity). Independent works by Drs. Glashow, Salam and Weinberg resulted in the unification of the weak and electromagnetic forces.

Glashow's research involved many aspects of particle theory, cosmology, and classical mechanics. He received the award for his pioneering work on the electroweak theory. This theory, completed in the 1970s, discusses the relationship between two of the four fundamental forces of nature, electromagnetic force and weak force. Through these forces, subatomic particles interact with each other. The electromagnetic force holds molecules together and keeps electrons in orbit around an atomic nucleus. The weak force causes radioactive decay in the nucleus. Glashow also predicted the existence of the charm quark, one of the quarks that make up elementary particles.

Dr. Salam is also famous for his contributions to the electroweak theory. Additional electroweak theory research was conducted by Steven Weinberg, who, around 1967, theorized that the electromagnetic and the weak forces are the same at extremely high energy levels. The validity of the theory was ascertained in the following years through experiments carried out at the superprotosynchrotron facility at CERN in Geneva, which led to the discovery of the W and Z particles. Salam's electroweak theory is still the core of the 'standard model' of high-energy physics. Their work represented one giant step closer to physicists' long-dreamed of goal of finding a single elegant equation to explain all the matter and forces in nature.

The work of these three nuclear physicists on isotopic spin provides some of the basic understanding that AFOSR is building upon in studies of spin isomers, which have significant ability to store large amounts of energy. This AFOSR funded work is regarded as revolutionary. If developments are successful, weapons systems of unprecedented capability will emerge along with numerous applications in space and industry.

AFOSR Funding Began: **1958 (Glashow); 1958 (Weinberg); 1962 (Salam)**

<u>Nicolaas Bloembergen</u> (Harvard University, Cambridge, MA)
<u>Arthur Schawlow</u> (Stanford University, Stanford, CA)
<u>Kai Siegbahn</u> (Uppsala University, Uppsala, Sweden)
PHYSICS: 1981

AFOSR-funded Nicolaas Bloembergen and Arthur Schawlow were co-recipients of the 1981 Physics Nobel for their ***"contribution to the development of laser spectroscopy."*** AFOSR also funded Kai M. Siegbahn whose Nobel prize was awarded ***"for his contribution to the development of high-resolution electron spectroscopy."***

Bloembergen's contributions to non-linear optics and spectroscopy advanced both nonlinear theory and development of instrumentation. The resulting impact during the last 20 years has been significant across science and engineering disciplines. For example, his findings for "four wave mixing" are being extended to develop advanced technology for non-contact NDE (non-destructive evaluation) of airframes which greatly benefits the Air Force and DoD. Recently a laser ultrasonic system was developed that is capable of detecting damage in aging airframe structures and engine components without having physical contact with them.

In the 1950s, Arthur Schawlow collaborated with Nobel Laureate Charles Townes on maser and laser theory and design. They sought ways to extend the maser principle to amplify electromagnetic waves into shorter wavelengths of infrared and visible light. Schawlow's solution was to build a cavity consisting of a synthetic ruby that would serve as a resonator for light waves. His work was important toward development of techniques for "pumping" energy into materials suc as ruby and carbon dioxide. When such materials have been pumped, they can be induced to "lase," to emit that extra energy as a beam of coherent light.

The award to Kal Siegbahn was for his work in electron spectroscopy, or the analysis of electrons expelled from atomic systems. Before his work, electron spectroscopy was limited. When a substance was excited with radiation, the energy of the electrons emitted could not be analyzed in their entirety. In 1954, Siegbahn developed a type of spectrometer that provided a more accurate analysis of the electron's energy and electromagnetic spectrum. This work contributed to the development of high-tech polymer materials used in a wide variety of applications to include the aerospace industry.

AFOSR Funding Began: 1956 (Siegbahn); 1975 (Bloembergen); 1981 (Schawlow)

Kenichi Fukui (Kyoto University, Kyoto, Japan)
CHEMISTRY: 1981

Dr. Kenichi Fukui used his AFOSR funding to team with Roald Hoffman to win the Nobel Prize for Chemistry in 1981 ***"for their theories, developed independently, concerning the course of chemical reactions."***

Fukui did experimental work in organic chemistry (the chemistry of compounds containing carbon), including fossil fuels -- oil, gas, and coal.
In 1952, he discovered that one could understand chemical reactions in terms of the density of electron clouds around reacting atoms. Fukui developed the theory that during chemical reactions molecules share loosely bonded electrons, which occupy so-called frontier orbitals. Fukui found that a good guide as to whether particular atoms would combine to form a particular compound was to consider the densities of the electron clouds in the atoms. This theory advanced the understanding of the mechanism of chemical reactions, especially in the production of organic compounds.

From 1970, Fukui and his group of theoreticians extended his insight to an understanding of the path of chemical reactions and on the geometric shapes of reacting molecules. His ideas were the basis for other discoveries and helped pharmaceutical companies develop new drugs.

AFOSR Funding Began: 1962

<u>David Hubel</u> (Harvard Medical School, Boston, MA)
<u>Thorsten Wiesel</u> (Harvard Medical School, Boston, MA)
PHYSIOLOGY/MEDICINE: 1981

AFOSR-funded scientists Drs. David H. Hubel and Thorsten N. Wiesel won a Nobel prize for Physiology and Medicine in 1981 for their "***discoveries concerning information processing in the visual system***."

In 1958 Hubel and Wiesel decided to study the mechanisms of the brain's visual system. In experiments with cats and monkeys, they used tiny conductors inserted into the brain to record how various visual stimuli activate different cells at different locations within the visual cortex. They also injected radioactively labeled amino acids into the retina under specific conditions of stimulation. The researchers were then able to trace the exact path of the amino acids, thereby uncovering a route of transmission for nerve impulses under specific conditions. Some years later, Wiesel and Hubel demonstrated that the brain's ability to see is formed through use of the eyes in the first few weeks after birth. This prompted doctors to immediately correct congenital cataracts or crossed eyes.

Their primary discoveries in vision suggested both the elementary units of visual analysis and a logic by which the brain could conjoin these units to represent visual scenes. Computer algorithms that incorporate similar analysis and logic are now a mainstay of automatic systems for image recognition and speech recognition. Many in today's military benefit from their discovery of motion-sensitive cortical cells, which led to the study of how humans detect and track moving targets.

AFOSR Funding Began: **1959**

<u>Subramanyan Chandrasekhar</u> (University of Chicago, Chicago, IL)
<u>William Fowler</u> (California Institute of Technology, Pasadena, CA)
PHYSICS: 1983

Subramanyan Chandrasekhar and William A. Fowler, both funded by AFOSR, were co-recipients of the Nobel Prize for Physics in 1981. Chandrasekhar won for his "***theoretical studies of the physical processes important to the structure and evolution of the stars***." Fowler was honored for his "***theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe***."

Chandrasekhar developed many theories that changed the way people look at the universe. His initial research involved stellar evolution and the theory of white dwarfs. At the time, astronomers were beginning to notice that stars vary in size and temperature, which indicated what phase a star was in its life. The common belief stated that stars in their final stages would become white dwarfs because they would eventually cool. Chandrasekhar deduced that not all stars could become white dwarfs. He discovered that only stars with a mass up to 1.44 times that of the sun could become a white dwarf. In a massive star, equilibrium between gas pressures and gravity cannot occur. Thus, the star would not be able to collapse on itself and become a white dwarf. This boundary for stars is known as the Chandrasekhar limit.

His work on astrophysics and stellar dynamics was seminal in the development of models of nucleosynthesis and thermonuclear reactions. Such knowledge was critical in the development of the U.S. thermonuclear arsenal. In addition, his work led to models for the solar interior, which permitted development of a capability to perform space weather forecasting.

Fowler studied how chemical elements are formed in nuclear reactions, especially in the formation of stars. He also studied the radio emissions of quasars and the functioning of subatomic particles such as neutrinos. For decades he investigated the nuclear reactions believed to occur in stellar interiors.

Fowler was primarily concerned with studies of fusion reactions -- how the nuclei of lighter chemical elements fuse to create the heavier ones in a process known as nucleosynthesis. In 1957, in the seminal paper "Synthesis of the Elements in the Stars," Fowler showed that all of the elements from carbon to uranium could be produced by nuclear processes in stars, starting only with the hydrogen and helium produced in the Big Bang. This work put Fowler and his collaborators at the forefront of some of the most central issues in modern physics and cosmology: the formation of the chemical elements inside stars; the Big Bang origin of the universe; and the current "dark matter" debate over what makes up most of the universe.

AFOSR Funding Began: 1960 (Chandrasekhar); 1960 (Fowler)

Dudley Herschbach (Harvard University, Cambridge, MA)
John Polanyi (University of Toronto, Toronto, Canada)
CHEMISTRY: 1986

AFOSR-funded Dudley R. Herschbach and John C. Polanyi were co-recipients of the Nobel Prize for Chemistry in 1981 for their "***contributions concerning the dynamics of chemical elementary processes***. "

Their work opened a new area of research in chemistry -- reaction dynamics -- that has provided a much more detailed understanding of how chemical reactions take place.

Dr. Herschbach shared the prize for helping to apply the technology and theory of physics to chemistry. He invented the "crossed molecular beam technique," which allows for the detailed analysis of chemical reactions through the use of supersonic molecular beams. Polanyi was cited for developing "the method of infrared chemiluminescence, in which the extremely weak infrared emission from a newly formed molecule is measured and analyzed. He used this method to elucidate the detailed energy disposal during chemical reactions. Because he understood the source of this light emission he was able to propose vibrational and chemical lasers, the most powerful sources of infrared radiation ever developed.

The works of Herschbach and Polanyi provided the fundamental understanding about the details of how reactions occur at the atomic and molecular levels. Their pioneering work was pivotal in the development of the first chemical lasers that will form the basis for future DoD defensive laser weapons, such as the airborne and space-based lasers.

Their work on reaction dynamics and molecular structure contributed to the development and validation of theoretical models of quantum chemistry. These models are now routinely used in the DoD to guide the synthesis of new compounds, such as energetic materials, and to predict the energy release in reactions, which are applied for use in modeling rocket plumes and signatures.

AFOSR Funding Began: 1979 (Herschbach); 1981 (Polanyi)

<u>Donald Cram</u> (University of California, Los Angeles, CA)
CHEMISTRY: 1987)

Donald J. Cram was co-recipient of the 1987 Nobel Prize for Chemistry for "***development and use of molecules with structure-specific interactions of high selectivity***."

Cram is best known for his role in developing what is now known as host-guest chemistry. The work involves creating synthetic host molecules that mimic some of the actions enzymes perform in cells. Over a 30-year period, Cram and his colleagues designed and prepared more than 1,000 hosts, each with its own chemical and physical properties that would attract and bind specific guest molecules. He succeeded in synthesizing molecules that are able to behave like the molecules of living things, in that they "recognize" and attach themselves to specific atoms.

The molecules Cram produced have many practical applications. They are used to control chemical reactions. They also are used in medicines, delivering active ingredients in controlled dosages long after the medicine has been taken.

AFOSR Funding Began: 1962

Melvin Schwartz: (Stanford University, Stanford, CA, and Digital Pathways International, Inc., Mountain View, CA)

PHYSICS: 1988

Melvin Schwartz, Leon Lederman, and Jack Steinberger, shared the 1988 Nobel Prize in Physics, ***"for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino."***

The work carried out in concert by Schwartz, Lederman, and Steinberger during the 1960s came out of discussions at Columbia University regarding a need to find a feasible method of studying the effect of weak forces at high energy levels. It was Melvin Schwartz who suggested employing a beam of neutrinos for this purpose and work commenced to design a complimentary detector for measuring neutrino reactions. The team was successful in building a sophisticated detector which excluded unwanted particles from the neutrino beam. This first successful neutrino beam experiment has been used extensively for investigating the weak force and the quark structure of matter, as well as the neutrino itself.

In the 1970s Dr. Schwartz went on to investigate state of the art approaches to the secure management of data communications. It was in this area that AFOSR issued several contracts to Dr. Schwartz to explore ways to ensure the integrity, viability, and increased capacity of Air Force telecommunications systems.

AFOSR Funding Began: 1970

Elias J. Corey (Harvard University, Cambridge, MA)
CHEMISTRY: 1990

Elias Corey received the 1990 Nobel Prize in Chemistry, ***"for his development of the theory and methodology of organic synthesis."*** Thought by many to be one of the greatest living chemists, Cory is most famous for his seminal and overarching discoveries and development of theory in the field of organic synthesis—the construction of organic molecules via chemical processes. Corey's Nobel Prize recognized his formal approach to synthesis design, based on retrosynthetic analysis, whereby the research is planned backwards from the product, using standardized rules and procedures. Corey's retrosynthetic analysis begins with the planned structure of the hoped for molecule and an ensuing analysis of which bonds must be broken in turn—simplifying the structure in a formalized retrograde approach. Corey has developed several new synthetic reagents as well as numerous reactions which have become commonplace in the field.

Corey's frontier-breaking work has been fundamental to the direct or inferential advancement and facilitation of numerous Air Force requirements in flight medicine.

AFOSR Funding Began: 1968

Jerome Friedman (Massachusetts Institute of Technology, Cambridge, MA)
Henry Kendall (Massachusetts Institute of Technology, Cambridge, MA)
PHYSICS: 1990

Jerome Friedman, Henry Kendall, and Richard Taylor (Stanford University), received the 1990 Nobel Prize in Physics, ***for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics."*** This award recognized a significant breakthrough in our understanding of the basic structure of matter.

In 1963, Friedman and Kendall joined forces with Taylor and others to conduct experiments at the Stanford Linear Accelerator Center. This MIT/SLAC collaboration resulted in a series of measurements of inelastic electron scattering from the proton and the neutron which provided the first direct evidence of the internal quark sub-structure of the nucleon. The accelerator experiments proved that quarks formed the fundamental building blocks of protons and neutrons, and that there is a glue which binds the quarks together—gluons. These discoveries begot a new era in the history of physics.

Among other contributions, AFOSR funding for Friedman and Kendall resulted in enhanced nuclear instrumentation and particle accelerator advances at the Air Force Cambridge Research Laboratory.

AFOSR Funding Began: 1961 (Friedman); 1961 (Kendall)

Rudolph A. Marcus (California Institute of Technology, Pasadena, CA)
CHEMISTRY: 1992

Rudolph Marcus was the recipient of the 1992 Nobel Prize in Chemistry ***"for his contributions to the theory of electron transfer reactions in chemical systems.***"

Marcus is best known for his exceptional theoretical work on electron transfer and the fact that his efforts in this area have resulted in basic chemical theory of great practical consequence in the field. The Marcus Theory describes and makes predictions concerning photochemical production of fuel, chemiluminescence (cold light), the conductivity of electrically conducting polymers, corrosion, and many other chemical reactions. It was in the early 1960s that AFOSR funded Dr. Marcus when he was engaged in the research and publication of a series of papers on electron transfer reactions. His work led directly to the solution of the problem of greatly varying reaction rates.

AFOSR Funding Began: 1962

<u>Mario Molina</u> (Massachusetts Institute of Technology, Cambridge, MA)

CHEMISTRY: 1995

Mario Molina, Paul Crutzen and Sherwood Rowland won the 1995 Chemistry prize for their ***"work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone."*** It was the first time a Nobel had been awarded to a Mexican American, and also the first time the Nobel Committee had recognized leaders in environmental science. These three chemists have all made pioneering contributions to explaining how ozone is formed and decomposes through chemical processes in the atmosphere.

Molina presenting the first definitive demonstration that human actions can harm the environment on a global scale. In 1974, Molina hypothesized that chlorofluorocarbons, or CFCs, then a widely used ingredient of aerosol cans, air conditioners, and refrigerators, were depleting the ozone layer. Stratospheric ozone protects the planet from the sun's harmful ultraviolet rays. Without it, plant and animal life as we know it could not exist on the planet, at least on land.

Molina's initial work was greeted with skepticism, but by 1979 he had proven his theory, and alarmed by news of an "Achilles heel" in the atmosphere, the public demanded action. Manufacturers looked for alternatives to CFCs. This flurry of action, including a ban on CFCs as propellants in spray cans in the US, took place despite the fact that no one had observed any loss of stratospheric ozone. The discovery of the hole in the ozone layer above Antarctica in 1980 increased the sense of urgency that CFCs should be widely banned.

In 1987, an international accord known as the Montreal Protocol was signed to phase out the use of CFCs in developed and developing countries. Molina went on to prove the connection between CFCs and the Antarctic ozone hole by proposing a new series of chemical reactions that was confirmed in 1991.

Dr. Molina was funded by AFOSR as part of an effort to assess the impact of Air Force space launch operations on the environment. Molina investigated the potential catalytic activity of aluminum oxide particulates exhausted from solid rocket motors on atmospheric processes, including ozone depletion.

AFOSR Funding Began: 1995

<u>Steven Chu</u> (Stanford University, Stanford, CA)

PHYSICS: 1997

Dr. Steven Chu shared the Nobel Prize for Physics in 1997 with two others for "***development of methods to cool and trap atoms with laser light***."

Dr. Chu's method of cooling and trapping atoms with laser lights provides the foundation for atom interferometers, atom lasers and more precise frequency standards, such as the basis for atomic clocks. These clocks, used in space and earth navigation to pinpoint a position, are expected to result in a 1000-fold increase in accuracy.

Physics is not the only area the improved time standard has generated a positive ripple effect. Other branches of science have been influenced by Dr. Chu's discoveries. They include: a new way of understanding polymer behavior (coatings, friction, injection molding); direct studies of biological interactions (DNA behavior, bacterial interactions); insight into novel forms of matter (Bose-Einstein condensation, atom interferometer); and a legacy of graduate students to enrich the U.S. talent pool.

The Air Force benefit is significant thanks to Dr. Chu's work. Navigation and control systems, smaller electronic circuits with greater density, and covert and encrypted communications will witness marked improvements.

AFOSR Funding Began: 1988

<u>Daniel Tsui</u> (Princeton University, Princeton, NJ)

PHYSICS: 1998

Dr. Daniel Tsui shared the Nobel Prize for Physics in 1998 for the "***discovery of a new form of quantum fluid with fractionally charged excitations***."

Dr. Tsui developed his award-winning idea during a long and productive career with Bell Labs. He then joined Princeton University where he used AFOSR sponsorship to forward extensions of that work. Tsui's efforts led to miniaturized, high-performance millimeter wave components that are used extensively in surveillance and communications systems.

Tsui made refined studies of the quantum Hall effect using inversion layers in materials of ultra-high purity. Plateaus appeared in the Hall effect not only for magnetic fields corresponding to the filling of orbits with one, two, three, etc, electron charges, but also for fields corresponding to fractional charges. This could be understood only in terms of a new kind of quantum fluid, where the motion of independent electrons of charge e is replaced by excitations in a multi-particle system which behave (in a strong magnetic field) as if charges of

The smaller, faster components expected to be developed from Dr. Tsui's breakthrough will play a key role in helping the Air Force to achieve its goal of reducing the weight and volume of electronic circuits by 75 to 80 percent early this century.

AFOSR Funding Began: 1985

<u>Ahmed Zewail</u> (California Institute of Technology, Pasadena, CA)
CHEMISTRY: 1999)

Dr. Ahmed Zewail took home the Nobel Prize for Chemistry in 1999 for his "***studies of the transition states of chemical reactions using femtosecond spectrocopy***."

Dr. Zewail's pioneering research showed that it is possible, with rapid laser technique, to see how atoms in a molecule move during a chemical reaction. His insights have helped scientists understand how certain molecules are synthesized, how energy is released in reactions and how the outcome of chemical reactions might be controlled.

Using these ultrafast lasers, Zewail was able to image chemical reactions as bonds form and break in real time, or at a scale of femtoseconds - a millionth of a billionth of a second. Dubbed "femtochemistry," it has allowed scientists to understand how and why certain chemical reactions take place but not others. Zewail's work also helped scientists explain why the speed and yield of reactions depend on temperatures. As a result, scientists the world over are studying processes with femtosecond spectrocopy in gases, in solids, in fluids, on surfaces and in polymers.

The Air Force has benefited from Zewail's prize-winning work, focusing their applications on better understanding and controlling the release of energy in chemical reactions in systems, such as novel rocket propellants and the interactions of aerospace vehicles with their environments.

AFOSR Funding Began: **1986**

Alan Heeger (University of California, Santa Barbara, CA)
CHEMISTRY: 2000

Dr. Alan J. Heeger, along with two other scientists, won the Nobel Prize for Chemistry in 2000 for "***the discovery and development of conductive polymers***."

His research in the late 1970s focused on conductive polymers. He and two associates found that a thin film of polyacetylene, when oxidized with iodine vapor, exhibited an electrical conductivity increase of a billion times; turning an insulator to a conductor.

His discovery led to a new field of carbon-based electronics that had wide applications and benefits for the Air Force. His pioneering work pushed the field of polymer research from primarily addressing structural applications to other potential applications typically addressed by semiconducting materials. Scientists and engineers no longer speculate about "plastic airplanes" and "plastic engines." Today, "plastic electronics" and "plastic lasers" are targets of research supported by all the services and agencies within the Department of Defense.

Dr. Heeger's award winning research will also lead to an Air Force and commercial reality in the near future, as plastic display panels -- like those found in a variety of hand-held devices -- are developed.

AFOSR Funding Began: **1988**

<u>Herbert Kroemer</u> (University of California, Santa Barbara, CA)
PHYSICS: 2000

Dr. Herbert Kroemer, an AFOSR-funded physicist, shared half of his 2000 Nobel Prize for Physics with another physicist - the other half going to AFOSR-funded scientist Professor Jack Kilby - for "***developing semiconductor heterostructures used in high-speed and opto-electronics***."

Kroemer was the first to propose the use of thin layers of semiconducting materials, known as heterostructures -- novel composites of two or more materials -- to develop the heterostructure transistor. Kroemer analyzed theoretically the mobility of electrons and holes in heterostructure junctions. His propositions led to the build up of transistors, later called HEMTs (high electron mobility transistors), which are very important in today's high-speed electronics. The new transistor, relying on these composites, made significant improvements over conventional transistors in current amplification and high-frequency applications.

Kroemer and a colleague, working independently, went on to create the heterostructure laser, an innovation crucial to the development of fiber optic communications.

Dr. Kroemer's revolutionary ideas marked the beginning of the era of modern optoelectronic devices that have affected the way the Air Force and the populace at-large interact, such as through radio link satellites, the Internet, mobile phones, CD players.

AFOSR Funding Began: **1995**

<u>Paul Greengard</u> (Rockefeller University, New York, NY)

PHYSIOLOGY/MEDICINE: 2000

Dr. Paul Greengard, shared the Nobel Prize for medicine in 2000 with two other neuroscientists for their discoveries regarding "***signal transduction in the nervous system."***

Greengard's research, begun more than 30 years ago, demonstrated the means by which chemicals known as neurotransmitters carry signals between nerve cells. These findings have resulted in the understanding of how the brain processes function and in the development of new drugs. He has also demonstrated that many effects -- both therapeutic and toxic -- of several classes of common antipsychotic, hallucinogenic and antidepressant drugs can be explained in terms of distinct neurochemical actions which affect the transmission of nerve signals in the brain. Greengard and his colleagues have developed a general model which provides a rational explanation, at the molecular and cellular levels, of the mechanism by which stimuli -- both electrical and chemical -- produce physiological responses in individual nerve cells.

Under AFOSR sponsorship, Greengard experimented with large nerve cells to understand the molecular activity of synapse transmission. This knowledge has led to a better understanding of the brain's function in perception, cognition and action. In turn, this provides a solid scientific basis for designing equipment and jobs to match human capabilities and limitations.

AFOSR Funding Began: **1984**

Jack Kilby (Texas Instruments, Dallas, TX)

PHYSICS: 2000

Jack Kilby, an AFOSR-funded scientist, received half of the 2000 Nobel Prize for Physics for his part "***in the invention of the integrated circuit,***"-- the other half was shared with AFOSR-funded Dr. Herbert Kroemer and another physicist.

There are few living men whose insights and professional accomplishments have changed the world. Jack Kilby is one of these men. His invention of the monolithic integrated circuit - the microchip – almost 50 years ago at Texas Instruments (TI), laid the conceptual and technical foundation for the entire field of modern microelectronics. It was this breakthrough that made possible the sophisticated high-speed computers and large-capacity semiconductor memories of today's information age.

Kilby also was one of the first people to suggest that semiconductors could be developed for use in Air Force weapon systems. As a result, the first Minuteman II computer was successfully flight tested in May 1964. Early ballistic missile tests with Kilby's integrated circuits largely assured the acceptance of semiconductor technology for other military and commercial uses.

AFOSR Funding Began: **1958**

Daniel Kahneman (Princeton University, Princeton, NJ)

ECONOMICS: 2002

Daniel Kahneman received half of the 2002 Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel 2002 ***"for having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty."***

In Dr. Kahneman's case, AFOSR funding began in 1977 when the Life Sciences Directorate supported his ground-breaking work on human perception, attention, and decision-making. Along with psychologist Amos Twersky, Kahneman studied the determinants of human choice in risky situations. Kahneman and Twersky showed that a person's decisions depend on how the decision problem is framed or described, and this dependence results in decisions that deviate in predictable ways from the rational choice strategy. This research directly supported one of the long-standing goals of the directorate for advancement in model perception and cognition for improved human performance.

AFOSR Funding Began: 1977

John B. Fenn (Virginia Commonwealth University, Richmond, VA)
CHEMISTRY: 2002

Fenn shared one-half of the 2002 Nobel Prize in Chemistry ***"for the development of methods for identification and structure analyses of biological macromolecules" and "for the development of soft desorption ionization methods for mass spectrometric analyses of biological macromolecules."***

Early AFOSR support for Dr. John Fenn concerned molecules seeded in atomic beams. AFOSR continued to support Fenn during the 1980s, while he was at Yale University, with several contracts dealing with molecular collision processes. These studies and other associated systems were then used to study fundamental chemical reaction dynamics, which ultimately resulted in the Nobel Prize for chemistry for Herschbach, Lee and Polanyi, in 1986. The 2002 Nobel Prize in chemistry for Fenn was for his work in electrospray mass spectroscopy that grew out of Fenn's experience and expertise from his earlier molecular research.

AFOSR Funding Began: 1975

John L. Hall (University of Colorado, Boulder, CO)
Roy J. Glauber (Harvard University, Cambridge, MA)
PHYSICS: 2005

Hall shared one-half of the 2005 Nobel Prize in Physics, with Theodor W. Hansch, ***"for their contributions to the development of laser precision spectroscopy, including the optical frequency comb technique."*** Roy Glauber was honored with one-half of the 2005 Nobel Physics Prize for ***"his contribution to the quantum theory of optical coherence."***

Hall and Glauber's scientific career's dealt with the characteristics of light, or more specifically, the properties of light on a macroscopic level (Hall) and on a microscopic level (Glauber). AFOSR funding for Glauber first began in 1962. In 1963 Glauber published a seminal work where he created a model for photodetection and explained the fundamental characteristics of different types of light. The work of Glauber and others in the field of quantum optics led to the formulation that certain states of light could not be described with classical wave theory. Glauber's impact has been so significant in this area that coherent states of light are known as Glauber states. AFOSR supported Glauber's quantum optics research throughout the 1960's and 1970s.

John Hall first received funding from AFOSR in 1990 for research of "Stabilized Single-Frequency Operation of Visible Diode Lasers, High-Resolution Spectroscopy, and Microwave-to-Visible Synthesis," which, as with Glauber's research, is directly related to the subsequent Nobel award. Hall's research was supported consistently by AFOSR through the next fifteen years as he refined the development of laser-based precision spectroscopy which ultimately led to ever greater accuracy in defining the quantum structure of matter. A major focus of Hall's career, has been getting the frequency of various kinds of lasers stabilized, or fixed, to a very high degree. In his Nobel Lecture, Hall gratefully acknowledged the support of AFOSR.

Hall and Glauber contributed significantly to scientific research on a very broad scale as they have greatly enhanced the precision of time measurements.

AFOSR Funding Began: 1962 (Glauber); 1990 (Hall)

Robert Grubbs **(California Institute of Technology, Pasadena, CA)**
CHEMISTRY: 2005

Robert Grubbs shared the 2005 Nobel Prize in Chemistry with Yves Chauvin and Richard Schrock, ***"for the development of the metathesis method in organic synthesis."***

The word metathesis is from the Greek words *meta* (meaning change), and *thesis* (meaning position), or more simply, to change places. In the work performed by Grubbs, Chauvin and Schrock, the bonds between carbon atoms of organic molecules are broken and new pairings take place. But what makes this possible are the catalyst molecules which were developed by the three respective chemists. When this process is taken further, different parts of different molecules can be combined to create new molecules with new properties. Building on the previous research of Chauvin (who explained how metathesis works), and Schrock (who created the first useful organic synthesis catalysts), Grubbs achieved a breakthrough in 1992 with the first well-defined catalysts for practical laboratory application. This practical application has found very broad use in the chemical industry with the development of new plastics, herbicides, drugs, and synthetic pheromones, which are produced more efficiently, are simpler to use, and are more environmentally friendly.

AFOSR funded Grubbs through a Multi-University Research Initiative (MURI) from 1987 through 2002 which centered on cyclohexadiene and dihydrocatechol polymerization.

AFOSR Funding Began: 1987

Thomas C. Schelling (University of Maryland, College Park, MD)
ECONOMICS: 2005

Thomas Schelling shared the 2005 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel with Robert Aumann, ***"for having enhanced our understanding of conflict and cooperation through game-theory analysis."***

It was during the 1950s, in the midst of the Cold War, that Thomas Schelling began to apply game theory to the issues of global security and the arms race. In 1964, Dr. Schelling's began receiving AFOSR funding, several years after the publication of his landmark book, *The Strategy of Conflict*. His game-theory research proposed the theory that in a conflict a party can strengthen its position by actually weakening or limiting its options. Dr. Schelling's bold idea prompted new developments in game theory and eventual application in various methods throughout the social sciences. AFOSR funded an effort by Schelling in 1966 which resulted in a major scholarly study entitled, *Strategic Analysis of Extra-Legal Internal Political Conflict*, which was a theoretical study of the strategy employed by groups engaged in extra-legal conflict within states.

As described by the Nobel awards committee: "Notably, his analysis of strategic commitments has explained a wide range of phenomena, from the competitive strategies of firms to the delegation of political decision power," In concluding its award remarks, the committee praised Schelling for, "…having enhanced our understanding of conflict and cooperation through game-theory analysis [and] his advancements have been proved to great relevance for conflict resolution and efforts to avoid war."

AFOSR Funding Began: 1960

George F. Smoot (University of California, Berkeley, CA)
PHYSICS: 2006

George F. Smoot shared the 2006 Nobel Prize in Physics with John C. Mather ***"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation."***

This Nobel award in Physics is based on work which the two laureates did to gain a more precise understanding of the origins of galaxies and stars. The foundation of their work was provided by measurements derived from the COBE (Cosmic Background Explorer) satellite launched by NASA in 1989. The goal was to utilize the COBE measurements to investigate the cosmic microwave background radiation of the universe, which ultimately provided increased support for the Big Bang theory of the origins of the universe, as opposed to the steady state theory. Additionally, the in depth study of the COBE measurements marked the beginning of cosmology as a precise science.

Smoot had the responsibility of measuring the very slight variations in the temperature of the cosmic microwave background radiation left over from the initial big bang origin of the universe. The form of this radiation, and its various temperatures across respective wavelengths, resulted in a specific shape across the entire spectrum whose form is known as blackbody radiation. Smoot's task of calculating the small variations in temperature across the blackbody in various directions is termed anisotropy. AFOSR first funded Smoot's work in 1980 in direct support of anisotropic techniques, which can be applied to space-based surveillance requirements.

AFOSR Funding Began: 1980

<u>Hans Dehmelt</u> (University of Washington, Seattle, WA)

PHYSICS: 1989

Hans G. Dehmelt shared one half of the 1989 Physics prize with Dr. Wolfgang Paul for their ***"development of the ion trap technique."*** They introduced and developed the ion trap technique, which has made it possible to study a single electron or a single ion with extreme precision. The other half of the Physics prize went to Norman Ramsey ***"for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks."*** The work of Dehmelt, Paul and Ramsey contributed significantly to the development of atomic clocks.

The first experiments on trapping atoms and ions were made in the laboratory of Wolfgang Paul in Bonn in the 1950s. Hans Dehmelt and his co-workers developed simultaneously, in Paul's laboratory, another kind of ion trap, the "Penning trap". Dehmelt and his co-workers used ion-trap spectroscopy mainly to study electrons. According to relativistic quantum mechanics, the electronic g-factor-essentially the ratio of magnetic and angular momentums-is exactly equal to two. In the l940s a deviation of about 0.1% from this value was discovered. This deviation was shortly afterwards attributed to effects of quantum electrodynamics (QED), i.e. interaction with the surrounding radiation field. Improved methods were developed which led to more accurate determinations of this anomaly, but the most important development took place in Dehmelt's laboratory. In 1973 he succeeded for the first time in observing a single electron in a trap, and two years later he introduced a method for "cooling" the electron—two inventions which improved accuracy considerably. Dehmelt and his co-workers determined the g-factor anomaly with an accuracy of a few parts in a billion, and this, together with corresponding theoretical calculations, constitutes one of the most critical tests done for QED.

In the 1970s Dehmelt succeeded in observing a single ion in a trap. This opened the way to a new kind of spectroscopy, single-ion spectroscopy, which has been further refined and applied particularly at the National Institute of Standards and Technology (NIST, previously NBS) in Boulder, Colorado.

AFOSR Funding Began: 1991

George Olah (University of Southern Califonia, Los Angeles, CA)
CHEMISTRY: 1994

George A. Olah won the 1994 Chemistry prize for his ***"contribution to carbonation chemistry"*** for work conducted in the early 1960s that isolated the positively charged, electron-deficient fragments of hydrocarbons known as carbocations (or carbonium ions).

Although theoretically recognized for several decades as a common intermediate in many organic reactions, carbocations were unobservable because they were a short-lived, unstable class of compound. Olah was able to successfully disassemble, examine, and then recombine carbocations through the use of superacids and ultra-cold solvents. His breakthrough, announced in 1962, initiated a new branch of organic chemistry and led to the development of innovative carbon-based fuels and higher-octane gasoline.

Olah's discovery completely transformed the scientific study of the elusive carbocations. Since the original discovery a large number of carbocations have been prepared and their properties studied in great detail. Olah has also shown how basic knowledge on superacids and carbocations can be applied to the facile synthesis of new and important organic compounds and that a number of small organic molecules, with widespread use as starting material in many large scale synthesis, can be produced in a simple and inexpensive way using superacids as catalysts. His work has resulted in new methods for the conversion of straight chain hydrocarbons (when used in combustion engines these have very low octane number and they are also difficult to degrade biologically) into branched hydrocarbons that have high octane numbers and are more easily biodegradable.

AFOSR funding for Olah concerned the manipulation of polymer microspheres to exhibit various optical properties such as morphological resonance effect for data memory application.

AFOSR Funding Began: 1995