HISTORY OF NOBEL LAUREATES IN PHYSICS

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Contents

Summary

This chapter aims to give an overview of the history of the Nobel Prize in physics and the work performed by each one of the laureates. Their work is described briefly, as it would be a formidable task to engage in the thorough exploration of the physical concepts behind each one of the acknowledged works. This chapter is divided into six general areas of knowledge in physics: atomic and particle physics, quantum mechanics, condensed matter, astrophysics, thermodynamics and statistical mechanics, and development of experimental methods and technology. The order in which the laureates are presented in each section is mostly chronological, except where main sub-areas could be clearly identified and their separate treatment made the description more coherent.

1. Introduction

Born in 1833 in Stockholm, Sweden, Alfred Nobel was an inventor and entrepreneur who formulated dynamite and established numerous companies all over the world. On November 27th 1895, Nobel signed his last will providing for the establishment of the Nobel Prize. In his will he stated that part of his estate was to be invested and the interest thereby generated would be annually distributed as prizes to those who had contributed most to the benefit of mankind. He divided the total prize into five equal parts recognizing the most important discoveries in the fields of physics, chemistry, physiology and medicine, literature, and the promotion of peace. Nobel also stated that in awarding the prizes, no consideration should be given to nationality, but that the most worthy should receive the prize. The prizes for physics and chemistry were to be awarded by the Swedish Academy of Sciences. Alfred Nobel died of cerebral hemorrhage in his home in San Remo, Italy on December 10, 1896. The provisions of his will as well as the way it was to be executed attracted much attention and generated skepticism. Many obstacles had to be overcome and it took years of negotiations to establish the Nobel Foundation which was to execute Nobel's will and preserve the original concepts expressed within. On June 29, 1900, the Statutes of the Nobel Foundation and the regulations for the awarding of the prizes were finally promulgated by the King Oscar II. The awarding of the first Nobel Prizes in 1901 marked the beginning of a tradition that honors the discoveries and developments of the most eminent scientists in the different areas stipulated by Alfred Nobel. It must be noted that in some years (1916, 1931, 1940-1942) the Nobel Prize in physics was not awarded due to the political turmoil that prevailed in the world.

2. Atomic and Particle Physics

The history of the Nobel Prize in physics started in 1901 when **Wilhelm Conrad Röntgen** received the award for the discovery of a new form of energy. This energy was similar to light in that it traveled in a straight line, but it was invisible and passed through matter that was opaque to light. These rays were named **Röntgen** rays by his contemporaries, but are more familiar to us by the name **Röntgen** himself gave to them: X-rays. Although many properties of X-rays were investigated by **Röntgen** and others, at the time of the awarding of the prize, their origin was unknown. When electricity is discharged through a tube of gas at very low pressure, a stream of electrons, then called cathode rays, is produced (see the prize given in 1905). **Röntgen** first discovered the X-rays when he allowed the cathode rays to strike an object. The discovery of X-rays itself was an amazing advance in physics, but the real impact of **Röntgen**'s discovery came from the application of X-rays in medicine. It was quickly discovered that certain materials, such as skin and muscle, allowed X-rays to pass through them, while others, such as bone or metal, did not. With this new tool, surgeons were now able to survey a foreign object or a broken bone before operating on a patient. Today, X-rays remain one of the most common internal imaging tools available to doctors.

The second Nobel Prize switched focus from X-rays to visible light. The subject matter was important not only to electromagnetic theory to help support the electron description of electricity, but also had great consequences in the realm of atomic and molecular physics. The theoretical work for the Nobel Prize was performed by **Hendrik Antoon Lorentz**. Expanding on the famous work done by Maxwell, **Lorentz** improved on the theory of electricity and magnetism by investigating the consequences of the theorized particle form of electricity. Using the hypothesized electron as his model, he predicted many interesting effects that should arise from this theory, most notably, effects of magnetic fields on the polarization of light, and the splitting of spectral lines in a magnetic field. Through a series of experiments, **Pieter Zeeman** later demonstrated the effects that **Lorentz**'s theory predicted. For this work, the academy awarded **Lorentz** and **Zeeman** the Nobel Prize in physics in 1902.

New sources of radiation were the subject of the physics Nobel Prize in 1903. For the third year in a row, the number of recipients was increased by one, as three persons shared that year's prize. The discovery of **Henri Becquerel** is one of many great examples of serendipity's important role in science. After **Röntgen** discovered the X-rays, there was a great effort to determine other sources of this new energy aside from the cathode ray method. **Becquerel** hypothesized that shining visible light on different samples might cause the samples to emit X-rays in an analogous fashion to samples irradiated with cathode rays. He found in this study that certain materials, in particular uranium salts, emitted rays similar to the ones that **Röntgen** observed after being illuminated by visible light. The surprising discovery was that upon closer examination, **Becquerel** found that these materials emitted X-rays regardless of whether they had been illuminated or not. This phenomenon was termed 'spontaneous radiation'. The prize was also shared by **Pierre** and **Marie Curie**, who spearheaded the research of this new radiation. The **Curies** found many more substances that possessed the property of spontaneous radioactivity, including the highly reactive element radium. These new substances were used to determine the properties of this new radiation. They found that this radiation seemed to consist of more than one type of radiation. Some, like cathode rays could be deflected by a magnetic or electric field, while others, like X-rays could not. As often happens in science, new discoveries led to new questions.

The Nobel Prize in physics is not always awarded for research performed in a chronological order; often many years pass before the importance of a scientist's work is realized, as was the case in the 1905 prize. **Phillip Lenard** was awarded the prize for his development of the cathode ray method, which was necessary for the realization of the work of **Röntgen**, **Becquerel**, and the **Curies**. When Lenard began his work in 1893, cathode rays, discovered by Hittorf in 1869, suffered a major constraint: they had only been witnessed inside of the glass tube in which they were produced. **Lenard** discovered that by placing a thin metal plate at one end of the glass tube, the rays could pass through into the air outside the tube. This not only allowed new physics to be investigated, but more than twenty years later, as **Lenard** was awarded the prize, physicists were beginning to understand the underlying mechanisms for the method he had helped to develop. The electron theory, the theory of a small negative charge, began to explain a phenomenon first witnessed some thirty years earlier.

In the following year, 1906, **J.J Thomson** was awarded the Nobel Prize for investigating the particles that composed the cathode rays: electrons. In addition, he was able to study the smallest positively charged particles, *i.e.* protons. **Thomson** managed to measure the unit charge and masses of both of these particles by condensing ions with steam. He found that the electron was some 1000 times lighter than the lightest atom, hydrogen, but that the proton had roughly the same mass as the hydrogen atom. This led him to theorize that the positively charged particles were merely atoms that had lost their electrons. This suggested that electrons were the charge carriers in materials. In addition to this important work, from similar experiments **Thomson** also made great advances in thermodynamics by determining the number of atoms in a cubic centimeter of gas at a certain temperature and pressure.

In 1914, X-rays, the mysterious radiation first discovered by **Röntgen** in 1896, had finally been explained. Until 1914 there had been two competing theories, which had to explain the lack of effect a magnetic or electric field had on the X-rays, and the failure of any attempts to refract, reflect, or diffract them. The first theory postulated that X-rays were actually two particles together of equal and opposite charge, neutralizing one another. The other hypothesized that X-rays were a form of light with a wavelength small enough that it had impeded all previous efforts of diffraction. We now know that the latter is the correct interpretation, but the difficulty in proving this was in finding a grating small enough to diffract the X-rays, which have wavelengths of ~ 1 angstrom. **Max von Laue** achieved this by realizing that the wavelength of the X-rays, calculated by **W. Wein** earlier, should be on the order of the distance between molecules of a solid body. **Von Laue** had the idea of using a solid body with regularly-arranged molecules (a crystal) as his diffraction grating. In order to perform the experiments and interpret his results he had to further develop the theory of crystals too. This he did, and the discovery of the diffraction of X-rays led to the correct explanation of their nature. For such remarkable insight and his contributions in the field, **Max von Laue** was awarded the Nobel Prize in physics in 1914.

Charles Glover Barkla won the Nobel Prize three years later for further work on X-ray radiation. It was well known by this time that when a material is subjected to X-rays, it produced secondary radiation. **Barkla** found that this secondary emission actually consisted of two types of radiation. The first kind had the same energy as the incident radiation and was subsequently determined by **Barkla** to be rays scattered from the incident beam. He found that by measuring the spatial distribution of this radiation, he could approximate the number of electrons in an atom. He also found that the second kind of X-rays were completely independent of the nature of the incident radiation, and their energy was determined by the elements present in the irradiated substance. **Barkla** then found that each element has not only one characteristic radiation, but a characteristic spectrum. These results allowed researchers to determine that the charge of the nucleus of the atom determined its place in the periodic table and not the atomic weight, which had been assumed until then.

The discrete spectrum of atoms was the subject of the 1919 Nobel Prize. **Johannes Stark** studied the properties of positive ions moving in gas at very high velocities. Due to the large velocities, light is emitted as these ions collide with the molecules in the gas. The work of Doppler had shown that as a light source moves towards an observer, there is a shift in the perceived wavelength of the light, due to the compression of the waves as the source moves. **Stark** realized that the same effect should be seen in the fast moving particles he was studying. His observations of this effect marked the first time that a Doppler shift in light was seen coming from a terrestrial source. While studying this effect, **Stark** also noticed a broadening of the spectral lines of atoms. This broadening, he realized, was due to the atoms being in a very large electrical field, much like the effect found in magnetic fields discovered by **Zeeman** (Nobel Prize 1902).

One of the most important advances in atomic physics was made in 1922. The award of the Nobel Prize to **Niels Bohr** in this year marked the transition of particle and atomic studies from classical physics, to what is known today as quantum physics. The physicists Balmer and Rydberg had succeeded in determining the spectra of glowing glasses, but no one knew the physical process that produced these lines. Furthermore, the predictions for solids and liquids did not agree with experiment. To predict these spectra, an accurate model of the atom needed to be found. Rutherford had put forth the idea of an atom which had a positive nucleus with electrons orbiting around it, much like the earth orbits the sun. The problem with this model was that the classical theory of electricity predicted that orbiting electrons should emit radiation and constantly lose energy. They should consequently orbit in smaller and smaller orbits and eventually crash into the nucleus when enough energy was lost. But, this would produce a continuous spectrum from the glowing gasses, not the spectral lines that were observed. This offered two options: either the atomistic model was incorrect, or the classical theory of electricity was wrong. **Bohr** postulated that the classical theory did not hold in the atom. He assumed that the electrons did not emit light when they moved in circular orbits around the nucleus, but only emitted light when they jumped from one orbital to another, like a train jumping from one track to another. **Bohr** succeeded in generating the correct results with his model for the spectra and also found the value of an important constant called the Rydberg constant, which agreed to within 1% of the experimental value. **Bohr**'s proposed theory of quantized energy levels in the atom proved to be correct.

The next year **Robert A. Millikan** won the award for his work on the determination of the fundamental charge through experiments with oil droplets. **Millikan** found that by measuring the movement of very small oil droplets in an electric field, he could measure the value of the electrical charge to great accuracy. His setup involved two plates, one slightly above the other, which could be shorted or set at a specific potential. In the top plate there was a small hole through which **Millikan** could spray tiny oil droplets, with a radius on the order of one thousandth of a millimeter. These drops would become charged in the spraying process and get trapped by the voltage between the plates. The voltage would cause the droplet to rise slightly over time. The air was ionized by radium that could be screened off. As the droplets rose, they would acquire these ions, changing the speed at which the oil droplet rose. The change in this speed was found to always be the same value or a multiple of that value, meaning that the drop had caught one or more units of electrical charge. Through this method, **Millikan** measured the electrical charge, one of the most fundamental constants in nature.

In 1924, **Manne Siegbahn** won the Nobel Prize in physics for his work with X-rays. He extended much of the work that **Barkla** had done on characteristic radiation of the elements. While **Barkla** had found the so-called *k* and *l* series, **Seigbahn** not only found new lines in these spectrum series, but he also discovered the new *m* and *n* series. He also improved the quality of the measurements of these lines, allowing the measurement of the wavelengths of these lines with one thousand times better accuracy.

James Franck and **Gustav Hertz** won the award in 1925 for their work on the collision of electrons with atoms. By 1925, **Bohr**'s model of the atom, with its quantized energy states had caused a revolution in physics. A problem still remained in that although many aspects of **Bohr**'s theory agreed wonderfully with experiments, **Bohr**'s major assumption, that an atom can exist in different states each characterized by a given energy level, was unproven. **Franck** and **Hertz**, through their work on the collision of electrons with atoms, and the collision of atoms, ions, and molecules with one another, allowed **Bohr**'s basic assumption to be experimentally proven. In addition, the work itself was a great advancement in the physics of colliding particles.

Barkla had found that atoms bombarded with X-rays emitted two kinds of radiation, one of which was considered to be X-rays scattered from the atom. The other was a characteristic radiation of the atom, the discovery of which garnered him the Nobel Prize. **Arthur Holly Compton** was more interested in the first type of radiation. **Barkla** had found that the radiation that was scattered, or at least some of it, was more easily absorbed than the original radiation, *i.e.* it had lower energy. **Compton** found that this scattering actually consisted of two energies; one was the same as the source radiation, and another of slightly smaller energy. He also found that the energy of this secondary scattered radiation varied as a function of the angle at which it scattered. **Compton**'s proposed a theory which explained this angular dependence, by assuming that the angle in which the radiation travels after scattering is directly related to the amount of recoil the scattering atom is given. This recoil converts some of the energy from the X-rays into kinetic energy, therefore decreasing the energy of the scattered X-ray. The observation and explanation both were found to be accurate and extremely vital to many areas of physics and won **Compton** the Nobel Prize in physics in 1927.

In 1935, the theory of the atom was still not complete. Scientists had determined that an atom generally consisted of a massive, positively-charged nucleus, which was assumed to be made up of a number of protons, surrounded by light orbiting electrons. The quandary was that the weight of different atoms could not be reconciled with the fact that atoms are neutral. The simplest atom would consist of equal numbers of protons and electrons, therefore satisfying the neutrality requirement. However, this did not yield the correct atomic weight for certain atoms. Schemes of varying numbers of protons and electrons in different parts of the atom tried to solve this contradiction, but none agreed with experiment. **James Chadwick** solved the problem by discovering a particle that could change the mass without changing the charge: the neutron. This new particle had approximately the same mass as the proton, but had no charge. The neutron had been theorized previously, but numerous attempts to find it had proven fruitless. By studying the collisions between radiation from beryllium and the nuclei of atoms, **Chadwick** was able to prove the existence of the neutron and finally complete the puzzle of the composition of the atom, work for which he received the Nobel Prize in physics for 1935.

Neutrons were also central to the physics Nobel Prize in 1938, awarded to **Enrico Fermi**. **Becquerel** had found many years before that certain elements, like uranium, spontaneously gave off radiation. Some of this radiation was in the form of a helium atom nucleus. As the uranium gave off this radiation, it decayed into another element which in turn decayed into yet another and so on until a stable element was reached, in this case lead. It was found that one can make an element unstable, and therefore more likely to decay, by bombarding it with projectile particles. Many had used this process with helium and hydrogen nuclei to split atoms, but only atoms of atomic number 20 or lower could be split by this method. **Fermi** had the idea of using neutrons to split larger atoms. Using this method, **Fermi** was able to split elements of larger atomic numbers than had been previously split. An additional discovery was that when using this process, the neutron is absorbed and electrons emitted, resulting in the creation of an atom of higher atomic number. Utilizing this method, **Fermi** created elements numbered 93 and 94, the first synthetic elements.

Although the parts that made up the atom, *i.e.* proton, neutron, and electron, were known, the process by which the nucleus of the atom was held together was still unidentified. **Hideki Yukawa** studied this problem and made discoveries that rewarded him with the 1949 Nobel Prize in physics. **Yukawa** used the electromagnetic field as his model for nuclear forces. He found that there was a simple relation between the range of nuclear forces and the mass of the particles associated with them. From known experimental data, **Yukawa** calculated that a particle should exist that had the same charge as the electron, but had 200 times its mass. According to **Yukawa**, these particles, eventually called mesons, should be able to be observed experimentally, but only in very energetic reactions. He knew that they would not be created in ordinary nuclear reactions, but that they should be observed in effects from the very highly energetic reactions of cosmic rays with matter. Studies of these cosmic rays by Anderson, Neddermeyer and others found evidence for these mesons. Later, researchers found that two kinds of mesons existed. All of these studies were guided by the theory of **Yukawa**, whose work led to many important discoveries about the nuclei and the fundamental forces of nature.

The awarding of the Nobel Prize in 1951, reminds us again of the occasional lack of chronology in awarding the prizes. In 1938, the prize was awarded to **Fermi** for being the first to split an atom with an atomic number greater than twenty. Yet, the prize in 1951 was given for the work that first demonstrated the possibility to split an atom at all. At the beginning of 1932, **John Cockcroft** and **Ernest Walton** created one element from another one, for the first time completely under human control. They constructed a device that could produce a voltage of about six hundred thousand volts, and used it to accelerate hydrogen nuclei, which were then impacted upon a layer of lithium. From this event, **Cockcroft** and **Walton** observed helium nuclei being emitted from the lithium. They believed that a hydrogen nucleus collided with the lithium nucleus and split it into two helium nuclei, which then flew off in opposite directions. Their interpretation was later shown to be true. This experiment had more far-reaching effects as well, as it helped to prove **Einstein**'s law relating mass and energy.

The award in 1958 was given to **Pavel A. Cĕrenkov**, for investigating, and to **Ilya M. Frank** and **Igor Y. Tamm**, for explaining the observed phenomenon that when radiation from a radium source is allowed to enter fluids, a weak bluish glow can be observed. For years this effect had been assumed to be the characteristic fluorescence produced from an irradiated substance (prize in 1917). **Cĕrenkov** began investigating this effect as a young graduate student, and he quickly realized this explanation was incorrect because the radiation was independent of the composition of the liquid. Through his investigations, **Cĕrenkov** found that the emitted radiation was polarized along the direction of the incoming radiation, and that high speed electrons coming from the radium were its cause. This was the point when **Frank** and **Tamm** came to a physical and mathematically rigorous explanation. The radiation came from electrons that moved through the liquid at a speed faster than that of light in the medium. This seemed to contradict Einstein's theory that no object can move faster than the speed of light, but the theory refers to the absolute speed as that of light in vacuum. The effect observed in **Cěrenkov's** radiation is analogous to a jet that travels faster than the speed of sound, where breaking the speed of sound creates a sonic boom. When fast electrons are moving through a liquid, blue light is the created effect.

Dirac, through his skills in mathematics and physics, produced many wonderful theories that helped push physics into completely new and exciting directions. One of his theories attempted to explain the particles we see in our universe. It predicted the existence of an 'anti-particle' for every known particle. An antiparticle was defined as a particle identical to the one we observe, but with opposite charge. The first antiparticle to be discovered was the positron, or positive electron, which was observed in 1931 (Nobel Prize of 1936). After this great discovery, a search for the antiproton was initiated. To search for these particles, a large proton accelerator, the Bevatron, was built at the University of California, Berkley. The investment paid off, and with **Emilio Segrè** and **Owen Chamberlain** heading the effort, the antiproton was discovered. For this achievement, they were awarded the Nobel Prize in physics in 1959.

In 1963, despite many efforts, the forces that held the nucleus together were still not well understood. The prize that year was given for the contribution that **Eugene Wigner**, **Maria Goeppert Mayer**, and **Hans Jensen** made to further the understanding of this force. **Wigner** had found from experiments that the force between two particles in the nucleus (nucleons) was very weak, except when they were very close together, at which point it became extremely strong. He also investigated so-called symmetry properties in the atom, which had far-reaching consequences. **Mayer** and **Jensen** won the award for their work on a model for the nucleons in a nucleus, which was based on **Bohr**'s atomic model. Improving on **Bohr**'s model, they published a book which applied the model to the large volume of experimental data on atomic nuclei, showing the validity of the model and even predicting new phenomena.

In 1967, **Hans A. Bethe** received the Nobel Prize for his role in unraveling a great mystery of our solar system. A great question of his time pertained how the sun has produced such a large quantity of energy (enough to support all of Earth's life) for the millions of years that it has existed. It was not until **Rutherford** discovered the nucleus and the high-energy reactions that occur within it, that a process energetic enough to account for the energy produced in the sun was found. Working from information about the amount of energy the earth receives and work by Eddington which revealed that the sun was composed mainly of hydrogen and helium, **Bethe** developed his theory of a fusion powered sun which depended on the nuclear process of combining hydrogen atoms to make helium, releasing large amounts of energy. **Bethe** developed his theory even while lacking certain experimental evidence required for parts of the theory. Despite this, his theory agreed very well with future experiments and is now the accepted explanation for energy production in the sun.

By the late 1940s, our understanding of the matter and energy had grown immensely compared to our knowledge in 1901 when the first Nobel Prize was awarded. Scientists now knew that matter consisted mainly of protons, neutrons, and electrons. They also knew of particles, named mesons, with the same charge as an electron but with a mass much larger than the electron, yet still smaller than the proton. The pi-meson, predicted by **Yukawa**, was the first meson to be found and turned out to mediate the interactions of the strong force in the nucleus (Nobel Prize 1949). An amazing new discovery occurred when the British physicists Rochester and Butler found new unstable particles which did not fit within the theory of the time. Some of the particles found were heavier than the proton or neutron and were given the name of baryons. The other particles found at the same time were lighter than the proton or neutron, but heavier than the electron. These were called K-mesons. The newly found particles displayed the unique characteristic of having a very long lifetime, which was not expected as they should interact very actively through the strong force. In 1953, **Murray Gell-Mann** successfully explained this phenomenon. For this explanation, and the theory that evolved from it, **Gell-Mann** won the Nobel Prize award in 1969. His explanation was based on a symmetry law that proposed that elementary particles can only be transformed into other particles through strong or electromagnetic interactions if a characteristic called the hypercharge, introduced by **Gell-Mann**, was conserved. Using this theory, **Gell-Mann** not only explained the previous experiments, but he also predicted two new baryons, which were discovered within the next years. Also, in studying the symmetry theory, **Gell-Mann** found that all particles that act through the strong force can be described by assuming they are composed of only three kinds of particles, which he named quarks, and their corresponding antiparticles. These quarks had not been discovered at the time of the presentation of his Nobel Prize, but were eventually discovered (1990 Nobel Prize).

The 1975 prize was awarded for research that rectified the theory of the nucleus for which the 1963 Nobel Prize in physics was given. In 1963, **Wigner**, **Goeppert-Mayer**, and **Jensen** won the award for their work describing the properties of the nucleus. It was found, however, that their theory did not describe all properties of the nucleus correctly. The most notable disagreement was that there were nuclei that were very far from possessing the spherical symmetry expected. It was suggested by many scientists that could be due to an ellipsoid-shaped nucleus, but there was no explanation for the cause of this. **James Rainwater** first suggested a solution to this problem. He proposed that as a result of the rotation of certain parts of the nucleus, the centrifugal force deformed the nucleus into an ellipsoidal shape. A month after **Rainwater** submitted his theory for publication; **Aage Bohr** independently came upon the same conclusions and eventually developed his ideas into a study that explained everything from the oscillations of the nuclear surface to the movements of individual nucleons. Comparison to data was later done by **Bohr** and **Ben Mottelson**, who found the data in such close agreement with the theory, that there was no doubt as to the theory’s accuracy.

The results of the development of accelerator physics earned **Burton Richter** and **Samuel C.C. Ting** the Nobel Prize in physics in 1976. From Einstein’s theory of mass and energy equivalence, it can be easily seen that to discover particles with a large mass, one must be able to reach very high energies. This was the impetus for building large devices which could accelerate particles to very high speeds, and therefore high kinetic energy. One such accelerator was at the Stanford Linear Accelerator Center. This instrument was a three kilometer long device whose sole purpose was to accelerate particles to a very high speed using magnets. The particles (both electrons and positrons) are fed into a circular ring where the electron and positron streams go around in opposite directions at very high speeds and are then steered into a collision with one another. A magnetic detector is used to record data from the particles emerging after the collision. Another one of these devices was the proton accelerator at Brookhaven National Laboratory. This experimental setup fired high speed protons at a motionless target area of beryllium. While working at SLAC, **Richter** and his collaborators found a new long-lifetime particle, which was named the psi particle. On the other hand, **Ting** and his team at Brookhaven found a heavy particle, and named it the J particle. In November, 1974, **Richter** and **Ting** met and found that the two particles were one and the same. The particle, eventually called the psi particle, suggested that a fourth quark was needed to describe its structure, adding a new element to the complexity of the current theories.

In addition to the strong and electromagnetic forces, there is also the weak force acting within the nucleus. This force is responsible for the process known as beta decay, the first step in the main reaction that fuels the Sun (1967 prize). Independently, through a series of papers, **Sheldon Glashow, Abdus Salam**, and **Steven Weinberg** developed the first theory that accurately described the weak force. Furthermore, their theory had the unforeseen result of unifying the weak ad electromagnetic forces, and predicted a new type of weak interaction observed only a decade later: the weak neutral current. Another important prediction of the theory was a particle which acted as carrier in the weak interactions, much in the way the photon carries the interaction of the electromagnetic force. Yet, unlike the photon which is massless, this strange new particle, named the weak vector boson, was predicted to have a very large mass, around one hundred times the mass of the proton. For the development of the weak force theory and its consequences, **Glashow**, **Salam** and **Weinberg** were awarded the Nobel Prize in 1979.

In 1983, the particles which carried the weak charge were discovered. Theory had predicted that the weak interaction was communicated through two heavy particles, called W and Z. **Carlo Rubbia** proposed converting an existing accelerator to store protons and antiprotons, which could then be collided to produce these two particles. It happened that coincidentally **Simon Van der Meer** had invented a new method of packing and storing protons and antiprotons. **Rubbia**'s idea and **Van der Meer**'s technical knowledge were combined to create the CERN collider. Although many people worked on this project, due to their integral contributions, **Van der Meer** and **Rubbia** were the scientists to win the Nobel Prize for this work in 1984.

The neutrino was more elusive than any particle previously discovered. Neutrinos very rarely interact with matter; in fact a neutrino could pass through a lead wall a light year thick unhindered. This property of the neutrinos made them very hard to study and delayed their discovery for a long time (Nobel Prize of 1995). The strategy to observe the interactions of neutrinos with matter relies on the production of many neutrinos in hopes that one will interact with the detector. **Leon Lederman**, **Melvin Schwartz**, and **Jack Steinberger** were awarded the Nobel Prize in 1988 for developing a new method for producing the large amounts of neutrinos needed for an experiment. They also developed a suitable detector for their experiments. These improvements greatly increased the abillty of researchers to probe the weak force and discover properties of the neutrino. One such discovery was made by **Steinberger**, when he found that there were two types of neutrinos, one that accompanied the electron and another that accompanied the muon.

In 1990, **Jerome I. Friedman**, **Henry Kendall**, and **Richard E. Taylor** were awarded the Nobel Prize in physics for further developing the theory that earned **Gell-Mann** the award in 1969. For many years after the basic structure of the atom had been described, the proton, neutron and electron were thought to be the smallest units of matter. None of them were thought to have any inner structure. **Murray Gell-Mann** found that the description of matter was simpler if one invoked particles, named quarks, which composed protons and neutrons. After this new theory was put forth, researchers sought evidence of the existence of quarks, but none was found. After a time, it was assumed that quarks were merely mathematical quantities that appeared in the equations. Then, in the late 60's and early 70's, researchers at the Massachusetts Institute of Technology (MIT) and researchers at the Stanford Linear Accelerator Center (SLAC), collaborated in a series of experiments probing the properties of protons and neutrons with electrons. The experimenters did not expect to find fantastic results, although their experiment used higher energy electrons than had been used before. They assumed that almost everything to be known about nucleons had been discovered. Yet, the researchers not only observed quarks, but the data obtained could only be described with the introduction of a new type of particle. Later to be called the gluon, this particle was found to be the carrier of the strong force.

Some particles, like the electron, are not affected by the strong force. These particles are called, as a group, leptons. In 1995, the Nobel Prize in physics was awarded for the discovery of two leptons, the neutrino and the tau lepton. **Frank Reines** preceded and therefore did not have the convenience of **Lederman**, **Schwartz**, and **Steinberger**'s method of neutrino production. In spite of this, through a cleverly designed experiment **Reines** was able to persist through low counting speeds, and high background signal to transform the neutrino from a theoretical particle to a measured particle. **Martin L. Perl**, independently found the tau lepton, which became important because it was part of a new family of particles that was theorized, but had not been observed. The theory of all particles, called the Standard Model, relied on the existence of this third family as a central tenet of the model.

Work on the strong force led to the awarding of the 2004 Nobel Prize in physics. The strong force (also called the color force) is the force that dominates interactions between protons and neutrons; it is the force that holds the nucleus of an atom together. **David Gross**, **David Politzer**, and **Frank Wilczek**, in studying this force, found it to have a very unique characteristic. Most forces, such as gravity or the electromagnetic force, get stronger as two interacting particles get closer. In contrast, it was found that the strong force gets weaker as the particles are brought together, and at a close enough distance, the force is so weak that they act as free particles. This effect became known as asymptotic freedom. The discovery of this effect came in a brand new theory of the strong force called Quantum ChromoDynamics, or QCD, which is now an important component of the Standard Model.

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The series of Nobel Lectures provides the complete acceptance speeches and lectures by the laureates.

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Biographical Sketches

Jose M. Moran-Mirabal, was born in 1976 in Berlin, Germany. He is a Mexican citizen and lives with his wife Gabriela and daughter Camila. He received a Bachelor of Science in Engineering Physics in 1999, and a Masters of Science in Biotechnology in 2001 from ITESM, Monterrey, NL, Mexico. He is currently pursuing a Ph.D. degree in Applied Physics at Cornell University in Ithaca, NY, USA. His research focuses on molecular patterning for biological studies using micro and nanofabrication techniques.

Kurt Andresen, son of Erik and Dale Andresen was born in 1980 near his hometown of Beech Creek, Pennsylvania, USA. He graduated from Bald Eagle-Nittany High School in 1998 and spent the next four years earning a B.A. in Physics from Boston University. He is currently a graduate student at Cornell University working towards his PhD in Applied Physics with the never ending support of his better half, Julie. He is currently studying nucleic acid structure through small angle X-ray scattering.

Jesse McMullen was born and raised in Toronto, Canada. He obtained a Bachelor of Applied Science from Queen's University in 2002. Currently, he is pursuing a Ph.D. degree in Applied Physics at Cornell University in Ithaca, NY, USA where he does research in Biophysics. He enjoys many hobbies but does not claim to be a master of any of them. He drives a car called the Red Rocket.