Introduction to Nuclear and Particle Physics

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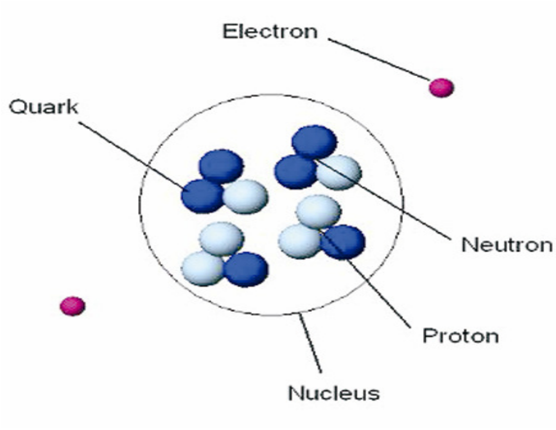
Abstract
In this presentation we will have and Introduction to Nuclear and Particle Physics and their applications in different areas.

Introduction

Protons, electrons, neutrons, neutrinos and even quarks are often featured in news of scientific discoveries. All of these, and a whole "zoo" of others, are tiny sub-atomic particles too small to be seen even in microscopes. While molecules and atoms are the basic elements of familiar substances that we can see and feel, we have to "look" within atoms in order to learn about the "elementary" subatomic particles and to understand the nature of our Universe. The science of this study is called Particle Physics, Elementary Particle Physics or sometimes High Energy Physics (HEP).

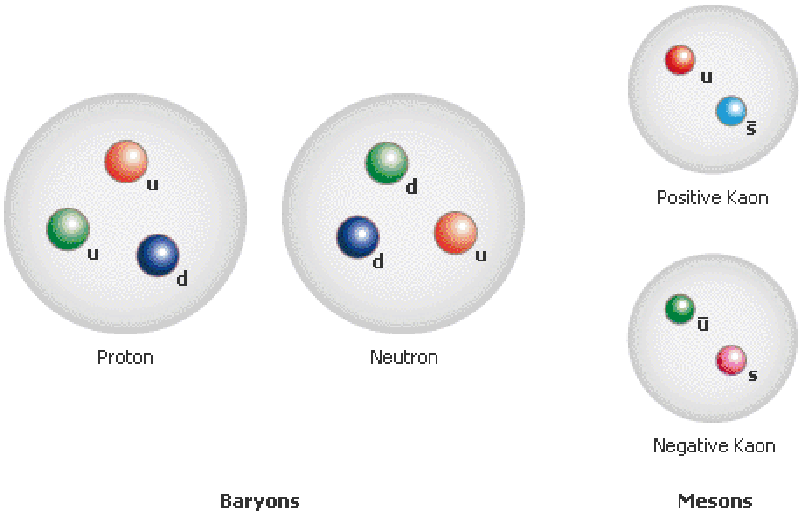


Inside an Atom: The central nucleus contains protons and neutrons which in turn contain quarks. Electron clouds surround the nucleus of an atom

Atoms were postulated long ago by the Greek philosopher Democritus, and until the beginning of the 20th century, atoms were thought to be the fundamental indivisible building blocks of all forms of matter. Protons, neutrons and electrons came to be regarded as the fundamental particles of nature when we learned in the 1900's through the experiments of Rutherford and others that atoms consist of mostly empty space with electrons surrounding a dense central nucleus made up of protons and neutrons.
The science of particle physics surged forward with the invention of particle accelerators that could accelerate protons or electrons to high energies and smash them into nuclei to the surprise of scientists, a whole host of new particles were produced in these collisions. By the early 1960s, as accelerators reached higher energies, a hundred or more types of particles were found. Could all of these then be the new fundamental particles? Confusion reigned until

it became clear late in the last century, through a long series of experiments and theoretical studies, that there existed a very simple scheme of two basic sets of particles**:** the quarks and leptons (among the leptons are electrons and neutrinos), and a set of fundamental forces that allow these to interact with each other. By the way, these "forces" themselves can be regarded as being transmitted through the exchange of particles called gauge bosons. An example of these is the photon, the quantum of light and the transmitter of the electromagnetic force we experience every day.

Together these fundamental particles form various combinations that are observed today as protons, neutrons and the zoo of particles seen in accelerator experiments. (We should state here that all these sets of particles also include their anti-particles, or in plain language what might roughly be called their complementary opposites. These make up matter and anti-matter.)

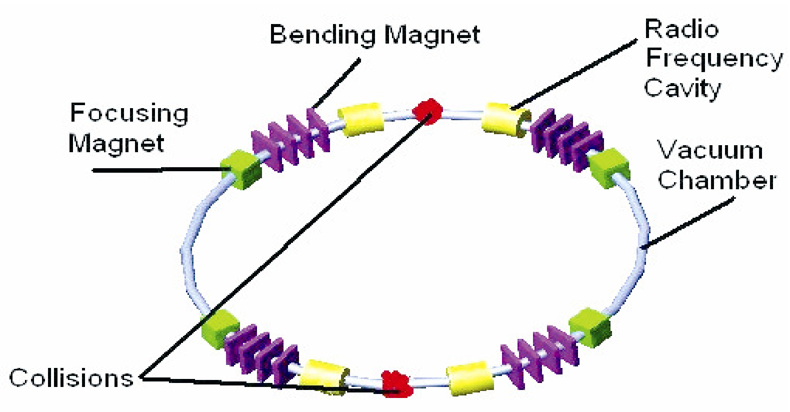


Matter is composed of tiny particles called quarks. Quarks come in six varieties:
up (u), down (d), charm (c), strange (s), top (t), and bottom (b). Quarks also have antimatter counterparts called antiquarks (designated by a line over the letter symbol). Quarks combine to form heavier particles called baryons, and quarks and antiquarks combine to form mesons. Protons and neutrons, particles that form the nuclei of atoms, are examples of baryons. Positive and negative kaons are examples of mesons.

Today, the Standard Model is the theory that describes the role of these fundamental particles and interactions between them. And the role of Particle Physics is to test this model in all conceivable ways, seeking to discover whether something more lies beyond it. Below we will describe this Standard Model and its salient features.[1]

Particle Physics Experiments

Throughout the history of Physics, experimental discoveries and theoretical ideas and explanations have moved forward together, sometimes playing leap-frog, but always drawing inspiration one from the other. Modern versions of Rutherford's table-top experiment on the scattering of alpha particles occupy many square kilometers of land, with massive and costly apparatus in underground tunnels tens of kilometers long. These are the particle accelerators that speed protons, antiprotons, electrons, or positrons to near the speed of light and then make them collide head-on with each other or with stationary targets.



In an accelerator, focusing magnets and bending magnets guide the beam of particles around a ring. (Only a few of the bending magnets are shown here). High frequency microwave (RF) cavities accelerate the beams as they pass through.

The quest has mostly been for higher and higher collision energies. To make a pair of massive new particles and observe them flying apart, one has to generate excess energy over and above the equivalent of the mass (2mX) of the pair : **E**collision **> 2mX c2** . High energy is also needed to probe deeper and deeper to smaller length scales in studying the unknown. This is the equivalent of using X rays of shorter wave-lengths to probe smaller crystal structures. On the other hand, to look for rare phenomena, it is necessary to increase the intensity of particle beams and the collision rates. So accelerators have proceeded along parallel paths of ever higher energies and ever higher intensities.

To observe and interpret the results of collisions, particle detectors have to be developed that can track and analyze the particles that fly apart and disappear in nanoseconds. The detector consists of many different types of complex apparatus and electronics, requiring a cadre of experts in every conceivable technology. Collider experiments use large detectors completely surrounding the "interaction point" where high energy particles and antiparticles collide head-on. Typical are electron-positron colliders, proton-antiproton colliders and massive detectors at the interaction points. Other experiments study the collisions of intense beams with fixed (stationary) solid targets. Typical are several experiments with intense high energy neutrino beams and massive detectors in which neutrinos can interact. Many are studying the conversion of one type of neutrino (the muon-neutrino) into another (e.g., the tau-neutrino). Evidence for this is now pretty definite after decades of research, and precise measurements may pin down the non-zero mass of each neutrino.

Relic neutrinos from the Big Bang populate the Universe, and even a tiny mass can explain some of the Dark Matter. The art and science of particle accelerators and detectors has depended heavily on technology. The technology of solid state devices, superconducting magnets, electronics, computers and exotic materials, all have played leap frog with developments in experimental particle physics, sometimes driving and sometimes being driven by the inventions of particle physicists.

All these very complex detectors are built and operated by large numbers of physicists, in collaborations ranging from 100 to almost 1000 personnel. The collaborations extend across boundaries of countries and continents, in a typical illustration of science extending the hand of cooperation and friendship across national and political barriers.

Looking to the Future

One of the primary goals for the new and upgraded facilities in Fermilab near Chicago (the Tevatron) and CERN in Geneva Switzerland (the Large Hadron Collider or LHC) is to find the Higgs boson, the one missing element of the Standard Model.

Evidence for supersymmetric partners of the known particles is a goal in all experiments, as part of the search for the true particle theory beyond the Standard Model. Beyond that is the need to find anything that can point to a real Grand Unification with the gravitational force.

A different kind of e+ e- collider is being planned internationally the International Linear Collider or **ILC**, a very high energy linear collider, with two opposing linear accelerators tens of kilometers long. The technical challenges are many and this is likely to be the first truly world-wide accelerator collaboration.

Reference:

[1]- Fayyazuddin, Riazuddin, A Modern Introduction to Particle Physics, World Scientific, 2000