Lecture 1. Physics of Elementary particles

In particle physics, an elementary particle or fundamental particle is a particle whose substructure is unknown; thus, it is unknown whether it is composed of other particles.[1] Known elementary particles include the fundamental fermions (quarks, leptons, antiquarks, and antileptons), which generally are "matter particles" and "antimatter particles", as well as the fundamental bosons (gauge bosons and the Higgs boson), which generally are "force particles" that mediate interactions among fermions.[1] A particle containing two or more elementary particles is a composite particle.

Everyday matter is composed of atoms, once presumed to be matter's elementary particles—atom meaning "unable to cut" in Greek—although the atom's existence remained controversial until about 1910, as some leading physicists regarded molecules as mathematical illusions, and matter as ultimately composed of energy.[1][2] Soon, subatomic constituents of the atom were identified. As the 1930s opened, the electron and the proton had been observed, along with the photon, the particle of electromagnetic radiation.[1] At that time, the recent advent of quantum mechanics was radically altering the conception of particles, as a single particle could seemingly span a field as would a wave, a paradox still eluding satisfactory explanation.[3][4][5]

Via quantum theory, protons and neutrons were found to contain quarks—up quarks and down quarks—now considered elementary particles.[1] And within a molecule, the electron's three degrees of freedom (charge, spin, orbital) can separate via the wave function into three quasi particles (holon, spinon, orbiton).[6] Yet a free electron—which is not orbiting an atomic nucleus and lacks orbital motion—appears unsplittable and remains regarded as an elementary particle.[6]

Around 1980, an elementary particle's status as indeed elementary—an ultimate constituent of substance—was mostly discarded for a more practical outlook,[1] embodied in particle physics' Standard Model, what's known as science's most experimentally successful theory.[5][7] Many elaborations upon and theories beyond the Standard Model, including the popular supersymmetry, double the number of elementary particles by hypothesizing that each known particle associates with a "shadow" partner far more massive,[8][9] although all such superpartners remain undiscovered.[7][10] Meanwhile, an elementary boson mediating gravitation—the graviton—remains hypothetical.

Lecture 2. Discovering of Nucleon (proton and neuteron)

In chemistry and physics, a nucleon is either a proton or a neutron, considered in its role as a component of an atomic nucleus. The number of nucleons in a nucleus defines an isotope's mass number (nucleon number).

Until the 1960s, nucleons were thought to be elementary particles, not made up of smaller parts. Now they are known to be composite particles, made of three quarks bound together by the so-called strong interaction. The interaction between two or more nucleons is called internucleon interactions or nuclear force, which is also ultimately caused by the strong interaction. (Before the discovery of quarks, the term "strong interaction" referred to just internucleon interactions.)

Nucleons sit at the boundary where particle physics and nuclear physics overlap. Particle physics, particularly quantum chromodynamics, provides the fundamental equations that explain the properties of quarks and of the strong interaction. These equations explain quantitatively how quarks can bind together into protons and neutrons (and all the other hadrons). However, when multiple nucleons are assembled into an atomic nucleus (nuclide), these fundamental equations become too difficult to solve directly (see lattice QCD). Instead, nuclides are studied within nuclear physics, which studies nucleons and their interactions by approximations and models, such as the nuclear shell model. These models can successfully explain nuclide properties, for example, whether or not a certain nuclide undergoes radioactive decay.

The proton and neutron are both baryons and both fermions. One carries a positive net charge and the other carries a zero net charge; the proton's mass is only 0.1% less than the neutron's. Thus, they can be viewed as two states of the same nucleon, and together form an isospin doublet ($I = \frac{1}{2}$). In isospin space, neutrons can be transformed into protons via SU(2) symmetries, and vice versa. These nucleons are acted upon equally by the strong interaction, which is invariant under rotation in isospin space. According to the Noether theorem, isospin is conserved with respect to the strong interaction.

Lecture 3. Introduction to Nuclear Reactor.

Some heavy elements, such as uranium-235, can be induced to fission by adding a neutron to their nuclei. When fission occurs, the resultant lighter elements do not require as many neutrons in their nuclei to maintain a stable configuration and, on average, between two and three surplus neutrons are released. These neutrons can cause further fissioning of other U-235 nuclei and so establish a chain reaction. Such a reaction can be allowed to diverge, as in an atomic bomb, or be controlled, as in a nuclear reactor. Under steady state conditions, just one neutron on average from each fission should go on to produce another fission event. When fission occurs, the release of energy drives the lighter elements or fission products and the surplus neutrons away from one another at high velocity. Most of the energy is thus transformed into kinetic energy carried by the fission products. As heavy strongly charged particles, they do not travel any significant distance and dissipate their kinetic energy in the fuel by interaction with other atoms, thus increasing the temperature of the fuel. The high energy fast neutrons, being uncharged, readily pass through the fuel and other reactor materials.

Lecture 4. Mechanism of nuclear power reactors

Mechanism of Nuclear Power Generation

In nuclear power plants, uranium fuel undergoes nuclear fission and generates an enormous amount of heat. The heat makes high-temperature and high-pressure steam that rotates turbines to generate electricity.

Light Water Reactor (LWR)

LWRs use light water (normal water) as coolant and moderator. Coolant removes heat produced during nuclear fission from a reactor core. Moderator reduces the speed of neutrons produced in nuclear fission to facilitate further fission reaction and sustain a chain reaction.

There are two types of LWRs - a boiling water reactor (BWR) and a pressurized water reactor (PWR). Each type is adopted in almost equal numbers in Japan.

Lecture 5. Mechanism of reactors: Cooling and reactivity control.

Control rods are usually used in control rod assemblies (typically 20 rods for a commercial PWR assembly) and inserted into guide tubes within a fuel element. A control rod is removed from or inserted into the central core of a nuclear reactor in order to increase or decrease the neutron flux, which describes the number of neutrons that split further uraniumatoms. This in turn affects the thermal power, the amount of steam produced and hence the electricity generated.

Control rods often stand vertically within the core. In PWRs they are inserted from above, with the control rod drive mechanisms mounted on the reactor pressure vessel head. In BWRs, due to the necessity of a steam dryer above the core, this design requires insertion of the control rods from beneath. The control rods are partially removed from the core to allow a chain reaction to occur. The number of control rods inserted and the distance to which they are inserted can be varied to control activity. Typical shutdown time for modern reactors such as the European Pressurized Reactor or Advanced CANDU reactor is 2 seconds for 90% reduction, limited by decay heat.

Lecture 6. Classification by type of nuclear reaction

A nuclear reaction is considered to be the process in which two nuclear particles (two nuclei or a nucleus and a nucleon) interact to produce two or more nuclear particles or ɣ-rays (gamma rays). Thus, a nuclear reaction must cause a transformation of at least one nuclide to another. Sometimes if a nucleus interacts with another nucleus or particle without changing the nature of any nuclide, the process is referred to a nuclear scattering, rather than a nuclear reaction. Perhaps the most notable nuclear reactions are the nuclear fusion reactions of light elements that power the energy production of stars and the Sun. Natural nuclear reactions occur also in the interaction between cosmic rays and matter.

The most notable man-controlled nuclear reaction is the fission reaction which occurs in nuclear reactors. Nuclear reactors are devices to initiate and control a nuclear chain reaction, but there are not only manmade devices. The world's first nuclear reactor operated about two billion years ago. The natural nuclear reactor formed at Oklo in Gabon, Africa, when a uranium-rich mineral deposit became flooded with groundwater that acted as a neutron moderator, and a nuclear chain reaction started. These fission reactions were sustained for hundreds of thousands of years, until a chain reaction could no longer be supported. This was confirmed by existence of isotopes of the fission-product gas xenon and by different ratio of U-235/U-238 (enrichment of natural uranium).

Lecture 7. Current technologies

TVA Watts Bar Nuclear Power Plant | Photo courtesy of Tennessee Valley Authority

Nuclear power has reliably and economically contributed almost 20% of electrical generation in the United States over the past two decades. It remains the single largest contributor (more than 70%) of non-greenhouse-gas-emitting electric power generation in the United States.

Small Modular Reactor Technologies

Small modular reactors can also be made in factories and transported to sites where they would be ready to "plug and play" upon arrival, reducing both capital costs and construction times. The smaller size also makes these reactors ideal for small electric grids and for locations that cannot support large reactors, offering utilities the flexibility to scale production as demand changes.

Light Water Reactor Technologies

The existing U.S. nuclear fleet has a remarkable safety and performance record. Extending the operating lifetimes of current plants beyond 60 years and, where possible, making further improvements in their productivity will generate early benefits from research, development, and demonstration investments in nuclear power.

Advanced Reactor Technologies

As a result of ARC research, nuclear energy will continue to provide clean, affordable, and secure energy while supporting the administration's greenhouse gas reduction goals by introducing advanced designs into new energy and industrial markets. DOE will pursue RD&D on both advanced thermal and fast neutron spectrum systems.

Space Power Systems

For over 50 years the Department of Energy and its predecessor agencies have been deeply involved in space research and exploration. Currently, the Office of Space and Defense Power Systems supplies Radioisotope Power Systems (RPS) to the National Aeronautics and Space Administration (NASA) and national security applications for missions that are beyond the capabilities of fuel cells, solar power and battery power supplies.

Lecture 8. Nuclear fuel cycle

The nuclear fuel cycle, also called nuclear fuel chain, is the progression of nuclear fuel through a series of differing stages. It consists of steps in the front end, which are the preparation of the fuel, steps in the service period in which the fuel is used during reactor operation, and steps in the back end, which are necessary to safely manage, contain, and either reprocess or dispose of spent nuclear fuel. If spent fuel is not reprocessed, the fuel cycle is referred to as an open fuel cycle (or a once-through fuel cycle); if the spent fuel is reprocessed, it is referred to as a closed fuel cycle.

Lecture 9. Energy and mechanisms of nuclear fission.

In nuclear physics and nuclear chemistry, nuclear fission is either a nuclear reaction or a radioactive decay process in which the nucleus of an atom splits into smaller parts (lighter nuclei). The fission process often produces free neutrons and gamma photons, and releases a very large amount of energy even by the energetic standards of radioactive decay.

Nuclear fission of heavy elements was discovered on December 17, 1938 by German Otto Hahn and his assistant Fritz Strassmann, and explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch. Frisch named the process by analogy with biological fission of living cells. It is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments (heating the bulk material where fission takes place). In order for fission to produce energy, the total binding energy of the resulting elements must be less negative (higher energy) than that of the starting element.

Fission is a form of nuclear transmutation because the resulting fragments are not the same element as the original atom. The two nuclei produced are most often of comparable but slightly different sizes, typically with a mass ratio of products of about 3 to 2, for common fissileisotopes.[1][2] Most fissions are binary fissions (producing two charged fragments), but occasionally (2 to 4 times per 1000 events), threepositively charged fragments are produced, in a ternary fission. The smallest of these fragments in ternary processes ranges in size from a proton to an argon nucleus.

Apart from fission induced by a neutron, harnessed and exploited by humans, a natural form of spontaneous radioactive decay (not requiring a neutron) is also referred to as fission, and occurs especially in very high-mass-number isotopes. Spontaneous fission was discovered in 1940 by Flyorov, Petrzhak and Kurchatov[3] in Moscow, when they decided to confirm that, without bombardment by neutrons, the fission rate of uranium was indeed negligible, as predicted by Niels Bohr; it was not.[3]

The unpredictable composition of the products (which vary in a broad probabilistic and somewhat chaotic manner) distinguishes fission from purely quantum-tunneling processes such as proton emission, alpha decay, and cluster decay, which give the same products each time. Nuclear fission produces energy for nuclear power and drives the explosion of nuclear weapons. Both uses are possible because certain substances called nuclear fuels undergo fission when struck by fission neutrons, and in turn emit neutrons when they break apart. This makes possible a self-sustaining nuclear chain reaction that releases energy at a controlled rate in a nuclear reactor or at a very rapid uncontrolled rate in a nuclear weapon.

The amount of free energy contained in nuclear fuel is millions of times the amount of free energy contained in a similar mass of chemical fuel such as gasoline, making nuclear fission a very dense source of energy. The products of nuclear fission, however, are on average far more radioactive than the heavy elements which are normally fissioned as fuel, and remain so for significant amounts of time, giving rise to a nuclear waste problem. Concerns over nuclear waste accumulation and over the destructive potential of nuclear weapons are a counterbalance to the peaceful desire to use fission as an energy source, and give rise to ongoing political debate over nuclear power.

Lecture 10. The power rating of a nuclear power reactor

How much electricity does a nuclear power plant generate?

As of December 1, 2016, there were 99 operating nuclear reactors at 61 nuclear power plants in the United States. The R. E. Ginna Nuclear Power Plant in New York is the smallest nuclear plant in the United States, and it has one reactor with an electricity generating capacity[1] at 508 megawatts (MW). The Palo Verde nuclear power plant in Arizona has three reactors and has the largest combined electricity generating capacity[1] of about 3,937 MW.

The amount of electricity that a power plant generates depends on the amount of time it operates at a specific capacity. For example, if the R. E. Ginna reactor operates at 508 MW capacity for 24 hours, it will generate 12,192 megawatthours (MWh). Most power plants do not operate a full capacity every hour of every day of the year.

Lecture 11. Physics of high energy matter

The Universe is made of matter, not antimatter, and 'CP violation' in particle decays could be the reason. Results from experiments measuring this effect at last confirm the predictions of a 30-year-old theory.

Every elementary particle has an anti- particle, a counterpart with precisely the same mass and the opposite electric charge. It would seem natural that all of the interactions of antiparticles are just the opposite of those of particles. But in 1964, in a Nobel-prize-winning experiment, Cronin and Fitch showed that this is not so1. Their measurement showed up a tiny difference, one part in a million of the strength of the weak interaction. New measurements from the BaBar experiment2 at Stanford, USA, and from the Belle experiment3 at Tsukuba, Japan, seem finally to have established a definite origin for this small difference in the behaviour of particles and antiparticles. The new data are a triumph for a theory proposed 30 years ago. But they are also a disappointment. The results so far do not help us understand the most obvious matter–antimatter asymmetry in nature — the fact that we see matter, but no antimatter, in the Universe at large.

The asymmetry in question is a basic one. It is well established that the laws of physics are the same irrespective of the position, time or orientation of the observer. From this statement, it would seem obvious that the laws of physics would also be the same when reflected in a mirror. But in 1956, following the suggestion of Lee and Yang, it was found that the weak interactions that mediate radioactive decay are completely mirror-asymmetric: nuclear β-decay preferentially produces particles that spin in the left-handed sense and antiparticles that spin in the right-handed sense. The interaction, however, seemed to respect the combined operation of mirror reflection (which turns a left-handed spin into a right-handed one) and interchange of particle and antiparticle. Physicists refer to these two operations as P ('parity') and C ('charge conjugation'), so the combined operation is called CP.

The Cronin–Fitch experiment, however, showed that the CP symmetry could be violated in specific particle decays. But it was not clear how to develop new equations to include this effect. CP violation arises only when particle masses are generated, and the origin of mass in particle physics is even now a mysterious issue, one that the elusive Higgs boson might solve.

Lecture 12. The main installations of material world: accelerator

There are two types of mounting systems for Accelerator catchers, each with multiple variations. Each catcher comes with mounting instructions specific to that catcher. All catchers have a general information sheet that provides catcher care direction and basic instructions. If your catcher comes with a bracket in the box, then you will also receive specific bracket installation instructions.

The two types are as follows:

Bracketless Models

These are for mowers that have an elevated ridge or “lip” above the mower discharge, as shown in the photo below. Note how the pin fits through the hole at the front of the lip, while the hook hangs over it several inches back. If for some reason you have lost the instructions or they are missing, feel free to call and have us email you a PDF copy. We are also happy to provide help over the phone.

Models with brackets
If your mower does not have a lip along the top edge you will need a bracket to install the catcher. There is much variation in the models using brackets. If you do not have your instructions you can call or email Accelerator and we will be happy to email you a copy of the appropriate bracket installation instructions.

Lecture 13. Needed advances In Accelerators science.

Superconducting (SC) accelerating structures made from pure niobium are operated at liquid helium temperatures, slightly below -456°F, and can produce high power electron, proton or ion beams continuously. Thanks to recent advances in SC radiofrequency (SRF) technology, extremely high accelerating voltages generated by highly efficient SC resonators became available. Argonne National Laboratory pioneered and perfected a suite of SC resonators for efficient acceleration of protons and ions from ion source velocities to the speed of light.

The ANL Physics Division is carrying out fundamental research in SRF technology related to high-gradient superconducting resonators suitable for efficient acceleration of high-current proton and ion beams. This type of accelerator is required for transmutation of spent nuclear fuel to much shorter living isotopes. Material science studies which use neutron beams generated by high-intensity SRF-based accelerators are relevant to the development of advanced reactors, nuclear fuel cycle needs and fusion research. For inertial fusion, accelerators could compress and ignite fusion targets by ion beam bombardment and serve as efficient drivers for fusion reactors. High power proton and ion beams are required for the development of new radiation resistant materials for future reactors. High-power accelerator beams can also drive the next generation reactors that burn non-fissile fuel, such as thorium. ANL-developed SC accelerating structures for medium- and high-power CW accelerators are also directly applicable in other areas such as isotope production for science and medicine and cargo interrogation for homeland security.

Lecture 14. Particle beams physics.

A particle beam is a stream of charged or neutral particles, in many cases moving at near the speed of light.
There is a difference between the creation and control of charged particle beams and neutral particle beams, as only the first type can be manipulated to a sufficient extent by devices based on electromagnetism. The manipulation and diagnostics of charged particle beams at high kinetic energies using particle accelerators are main topics of accelerator physics.

Lecture 15. Databases on nuclear reactions.