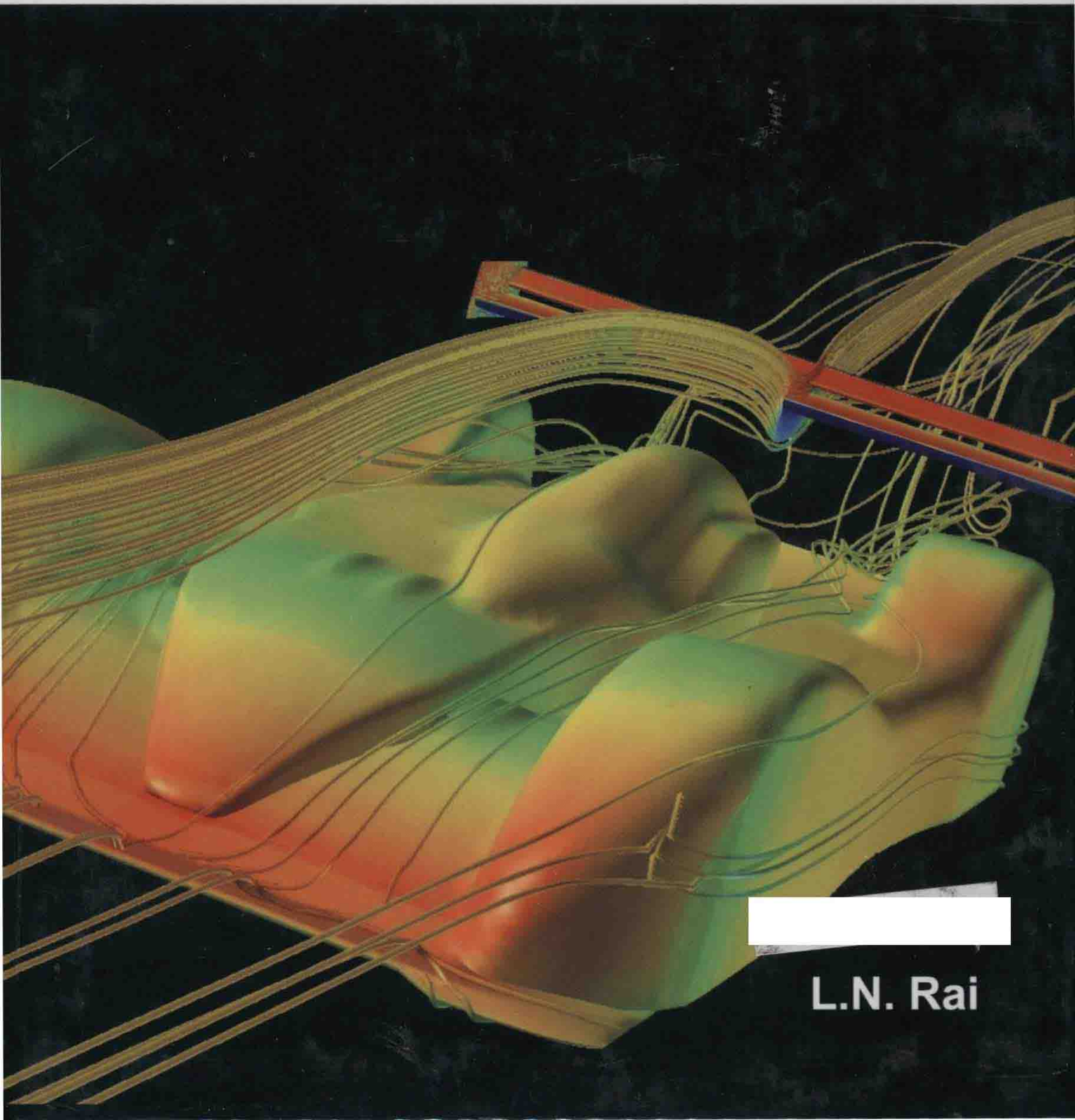
ONCEPTS IN

Engineering Physics



L.N. Rai

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Preface

Unlike traditional engineering disciplines, engineering science/physics is not necessarily confined to a particular branch of science or physics. Instead, engineering science/physics is meant to provide a more thorough grounding in applied physics for a selected speciality such as optics, quantum physics, materials science, applied mechanics, nanotechnology, microfabrication, mechanical engineering, electrical engineering, biophysics, control theory, aerodynamics, energy, solid-state physics, etc. It is the discipline devoted to creating and optimizing engineering solutions through enhanced understanding and integrated application of mathematical, scientific, statistical, and engineering principles. The discipline is also meant for cross-functionality and bridges the gap between theoretical science and practical engineering with emphasis in research and development, design, and analysis. Engineering physics or engineering science degrees are respected academic degrees awarded in many countries. It is notable that in many languages the term for "engineering physics" would be directly translated into English as "technical physics". In some countries, both what would be translated as "engineering physics" and what would be translated as "technical physics" are disciplines leading to academic degrees, with the former specializes in nuclear power research, and the latter closer to engineering physics. In some institutions, engineering (or applied) physics major is a discipline or specialization within the scope of engineering science, or applied science.

In many universities, engineering science programs may be offered at the levels of B.Tech, B.Sc., M.Sc. and Ph.D. Usually, a core of basic and advanced courses in mathematics, physics, chemistry, and biology forms the foundation of the curriculum, while typical elective areas may include fluid dynamics, quantum physics, economics, plasma physics, relativity, solid mechanics, operations research, information technology and engineering, dynamical systems, bioengineering, environmental engineering, computational engineering, engineering mathematics and statistics, solid-state devices, materials science, electromagnetism, nanoscience, nanotechnology, energy, and optics. While typical undergraduate engineering programs generally focus on the application of established methods to the design and analysis of engineering solutions, undergraduate program in engineering science focuses on the creation and use of more advanced experimental or computational techniques where standard approaches are inadequate (i.e., development of engineering solutions to contemporary problems in the physical and life sciences by applying fundamental principles). Applied mechanics, as its name suggests, bridges the gap between physical theory and its application to technology. As such, applied mechanics is used in many fields of engineering, especially mechanical engineering. In this context, it is commonly referred to as engineering mechanics. Much of modern engineering mechanics is based on Isaac Newton's laws of motion while the modern practice of their application can be traced back to Stephen Timoshenko, who is said to be the father of modern engineering mechanics. Within the theoretical sciences, applied mechanics is useful in formulating new ideas and theories, discovering and interpreting phenomena, and developing experimental and computational tools. In the application of the natural sciences, mechanics was said to be complemented by thermodynamics by physical chemists Gilbert N. Lewis and Merle Randall, the study of heat and more generally energy, and electromechanics, the study of electricity and magnetism.

The publication is timely in view of the impressive development of the methods and techniques with their application to understanding the subject.

—Editor

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Nuclear Physics

The Atom

An atom consists of a positive charged atomic nucleus where you can find protons and neutrons and it consists of a negative charged atomic shell with electrons. In every atom the number of the electrons is equal to the number of the protons so it is neutral.

The number of the protons decides which chemical element the atom is. The first element in the "Periodic table of the elements" is hydrogen. The elements in the "Periodic table of the elements" are sorted by the number of the protons.

The atomic nucleus of a hydrogen atom consists of only one proton. But there are a few isotops of every element. Isotops are atoms with the same number of protons, but another number of neutrons.

The different isotops of one element do not differ in their chemical properties. There are for example three isotops of hydrogen. The first isotop is the one I wrote about.

The second isotop of hydrogen is deutrium with one proton and one neutron in his atomic nucleus and the third isotop is tritium which has got one proton and two neutrons in his atomic nucleus. In the atomic nucleus of a tritiumatom there is no balance between the protons and the neutrons so it is instable and decays.

The particle which is emited from this decay is radioaktiv and it is charged. You can make ions of atoms. We can say that an ion is an atom which has got less or more electrons than protons. An ion is not neutral an so it is radioactif.

Radioactivity

Radioactivity means that atoms decays. The reason for this decays is that they are instable. A atomic nucleus is instable when he is to heavy or when a balance is missing between the protons and the neutrons. Every atom which has got a higher number of nucleons (protons and neutrons togehter) than 210 is instable. There are three types of decays: alpha decay, beta decay and gamma decay. Because it is impossible today to say which atomic nucleus will be the next who decays there statistics. We can say how many atomic nucleus will decay in a certain time.

This is the principle for half lifes. After one half life a half of the atomic nucleus of a certain material decayed. Plutonium-239 for example has got a half life 24,000 years, radium-228 has got a half life of 6.7 years, thorium-232 has got a half life of 14,000,000,000 years and polonium-212 has got a half life 0.0000003 seconds. There are many physical properties, but I will talk about the activity now. The activity is the number of decays devided by a certain time. The unit of the activity is becquerel. 1 becquerel is one decay per second. So 20 becquerels are 20 decays per second. To prove these decays there is a geiger counter. It consists of a closed tube which is often filled with argon. At the end of the tube there is a wire, which is not allowed to touch the other end of the tube or the walls. The wire is charged positive and the walls are charged negative. A radioactive particle which flows into the tube ionizes one or a few gas atoms. The out-pushed electrons go to the wire. The consequence is a voltage surge. This voltage surge is shown on an output device as a decay. On the photo there shown a geiger counter.

When we talk about the alpha decay then it means that a twice positive charged heliumion (helium atomic nucleus) is emited from the atomic nucleus. Then we find two protons ans two neutrons less in this atomic nucleus, so it is lighter. The alpha radiation is the most dangerous of the three types of radiation, but a sheet of paper is enough to protect oneself. The skin protects us also from alpha radiation.

There are two types of the beta decay. The one is the beta minus decay and the other is the beta plus decay. When we talk about the beta minus decay a neutron decays into a proton, an electron and an antineutrino. The electron and the antineutrino are emited. The radioactive particle is the electron. The number of nucleons do not change, but we have got one proton more than before the decay. 2 or 3 cm of wood are enough to protect oneself.

When we talk about the beta plus decay a proton decays into a neutron, a positron (the antiparticle of the electron) and a neutrino. The positron and the neutrino are emited. The radioactive particle is the positron. When we talk about the gamma decay high-energy electromagnetic waves are emited from the atomic nucleus. This waves are photons, which have got a higher frequency and less wave long than light. A gamma decay can happen after an alpha decay or a beta decay, because the atomic nucleus is very energitif. You need a big wall of lead to protect yourself from gamma radiation.

The Applications of Radioactivity

Everyone knows that strong radiation is not good fot the health, but we use radioactive materials for nuclear power plants ans nuclear weapons for example. But there are good sides for radioactivity, too. There for example nuclear medicine. An X-ray instrument sends X-Rays thought our body onto a photo plate.

Where the photo plate becomes black the X-rays goes thought our body, there where the photo plate stays transparent the X-rays do not pass our body. Another positive aspect is the radiotherapy. It is used to destroy cancer. In old clocks which have illuminated you can find radium and thorium which were used to bring the zinc sulfite to illuminate. The glowing trunk for camping lamps contained thorium.

The energy source for the batteries for cardiac pacemaker is plutonium-238. There is not any nuclear fission in those batteries, because the energy source is the natural nuclear decay. Radionuclide batteries are also used for space probes like Voyager I, Voyager II and Cassini who are very long in space and so they need radionuclide batteries who are an energy source for a long time.

Nuclear Reactions and their Applications

There are many nuclear reactions, but I will only discribe the nuclear fission and the nuclear fusion. For a nuclear fission in a nuclear power plant or for an explosion of a nuclear bomb you need plutonium-239 or uranium-235 as a split material.

To make a nuclear fission it is necessary to bombard the split material with thermal neutrons. After the fission there are two new atoms and two or three free neutrons. This free neutrons make a fission of other atoms and so it is a nuclear chain reaction.

The animation of a nuclear fission:

In a nuclear bomb there is a globe made of plutonium-239 or uranium-235. In this globe there is a neutron source which only effective when the TNT (trinitrotoluene) exploses. Because of the compression of the explosion the critical mass of the split material is overstepped. There are nuclear bomb which are build otherwise, but the princip is always the same.

This both materials are very expensive, because on earth we find very little plutonium so it means that we must produce plutonium. To produce plutonium it is necessary to bombard the natural and very cheap uranium-238 with neutrons to make uranium-239. Uranium-239 decays to neptunium-239 and neptunium-239 decays after a certain time to plutonium-239. You can find uranium-235 in nature, but only in uranium-238. To split this uranium-235 from uranium-238 is very expensive, because their chemical properties are the same so it is not possible to split them in a chemical way. A nuclear bomb like this can have an explosion force of 20 kilotons (20000 tons). This means that an explosion of such a bomb is as effective as the explosion of 20 kilotons of TNT.

Hydrogen bombs can reach an explosion force of 20 megatons (20 million tons). This bombs are also knows as three-phase fuzes. The fission like in a nuclear bomb is only the first phase. In the second phase there is a fusion between deutrium and tritium. The temperatur in the second phase behave 200 to 300 million degrees celsius (much hoter than the core of the sun). The third phase is the fission of uranium-238 which is of the outer side of the bomb. Under this conditions the fission of uranium-238 is possible.

The princip of power plants is the same like in nuclear bombs, but without using TNT. The reason why nuclear power plants do not exploses is that there are control rods to control the number of the neutrons in the reactor. This is a controlled nuclear chain reaction in the opposite of an uncontrolled nuclear chain reaction in nuclear bombs. The nuclear power plants in the future will be fusion reactors which do not crack heavy atomic nucleus, but fuses light atomic nucleus. Fusion are today possible but energy which you need for a fusion is higher than the energy you get and this is not the sense of nuclear fusions. With fusions the last elements of the "Periodic table of the elements" have been created, because their are not on earth.

In 1999 a few physicists thought that they have discovered the element 118 but two years later in 2001 they said that it was a mistake, so element 114 is the last know element. In stars there are also fusions. In our sun it is the proton proton cycle which you can find on the website of astronomy and astrophysics. Now I will give an answer why we get energy from this nuclear reactions. We must begin which Einstein's famous formula: $E=mc^2$ (E stands for energy, m stands for mass and c stands for the speed of light in the vacuum). This formula makes it possible transform masse in energy. Atomic nucleus have got different binding energy. The binding energy is the energy which holds the nucleons together. Because of this fact there is in every atomic nucleus a mass defect. A free proton and a free neutrons weighs more than deutrium (heavy hydrgen, consists of one proton and one neutron). Iron has got the highest binding energy and stands in the middle of the "Periodic table of the elements". When somebody goes closer to this middle with fissions or fusions a part will be transformed into energy.

Astronomy and Astrophysics

The Big Bang and the Formation of Matter

The most known theory about the orgin of the universe is the Big Bang. The Big Bang took place 15,000,000,000 years ago. This theory says that something which was as big as an atom and which was very hot explosed. After 10^{-35} there were quarks (particles which forms protons and neutrons). There were also antiquarks and when the quarks and the antiquarks came together they have destroyed each other and they only left energy (often gamma radiation thus photons). The temperature was 10^{27} degrees. One theory says that there was more matter than antimatter, if it was not so now there were not any stars or planets in the universe.

But it is a riddle, because the theory of the Big Bang tells us that the Big Bang was symmetrical and that means that there should be as much matter as anitmatter. Another theory says that at the beginning there was as much matter as anitmatter, but the antimatter had decayed very fast. After 0.0001 seconds mesons, protons and neutrons have been formed. The temperature was 10^{12} degrees.

After 3 minutes protons and neutrons fused to ions and when it was colder this ions caught electrons and so the first atoms were born. But this happend 300,000 years later when the temperature was only 3,000 degrees. The first elements were hydrogen and helium. In all this processes there were much energy. So the matter like we know it today was born. Foremost since the Big Bang there is space and time and during the Big Bang the unified power has been divided in the four fundamental powers (gravity, electromagnetic power, weak power, strong power).

The Unified Field Theory

The unified field theory is for modern physics the most important problem. This theory says that after the Big Bang only one unified power has existed. This GUT-Power (Grand Unified Theory) was divided into four fundamental powers.

Table: The four fundamental powers

power	*range*	*strength*	*appearance*
strong power	10^{-15} m	1	between quarks
electromagnetic power	infinite	10^{-2}	between charged particles
weak power	10^{-15} m	10^{-13}	between leptons (neutrinos, elecrons)
gravity	infinite	10^{-38}	between all particles

Today we try to bring the four powers together. It has been discovered that a symmetry has existed between the electromagnetic power and the weak power which has broken. It is important to know that the W^+-, the W^-- and the Z^0-particles are the exchangeparticles of the weak power. In our universe there is the higgs field, which unifieds with the field of the weak power. With high energy it is possible to destroy the higgs field and the exchangeparticles of the weak power are then free, they behave like photons and do not differ from them. For this discovery S.

Glashow, S. Weinberg and A. Salam got the noble price. In an experiment in the CERN (Conseil Européenne pour la Recherche Nucléaire), in the proton-antiproton-collider this particles were found and so the electricalweak power was proofed. Now phycisists work to find a connection between the electroweak power and the strong power.

Galaxies

The Formation of a Galaxy

After teh Big Bang theory galaxies were formed 1,000,000,000 years ago. There are today different theories about the formation. One of this theories says that stars were formed of much gas, that they have drawed each other because of their gravity and that then galaxies were formed.

Another theory says that there was much gas which has drawed each other. They came closer and closer and some of them formed stars. This stars circled round in the outer regions of the protogalaxy and they brought this protogalaxy to illuminate blue. This protogalaxy was much brighter than our galaxy. After a certain time next stars were formed of the gas in the centre of the protogalaxie and then it was a galaxie.

Types of Galaxies

There different types of galaxies. Our galaxy is the milky way a spiral galaxy. She has got a diameter of 100,000 light years and has got four spiral arms. This form of galaxy is the most beautiful I think, because it is a disk of stars which illuminate the gas of the galaxy. Galaxies like this were formed when the gas cloud they came off has rotated.

This rotation made it impossible for the gas cloud to go together, because of the centrifugal power and so not the whole gas could form stars. This galaxies can consists of a few billiard stars. The half of the stars in our galaxy are multiple stars. The single stars circles around one centre of gravity.

The next big galaxy is the Andromeda galaxy (M 31) which is 2.2 million light-years (1 light year is the distance which the light go thought in one year; 9,460,000,000,000 km) away and she is even bigger than our galaxy. Another type is the dwarf galaxy which contains only a few million of stars. The biggiest galaxies are the elliptical galaxies. In this galaxies and in the dwarf galaxies there is not any gas. There are also irregular galaxies which has not got any symmetric form.

Galaxy Clusters and Super Heaps

In the universe there are galaxy heaps with many galaxies. The heap where the Milky Way and the Andromeda galaxy are is the local group. This two galaxies are the biggiest and most massively galaxies of the local group and the dwarf galaxies are around this two big spiral galaxies. The local group contains 26 galaxies. She has got a diameter of 4 million light-years. There also super heaps with many galaxiy heaps. Super heaps are the biggiest knows structures in the universe.

Stars

The Life of a Star

After 500 million years galaxies were formed and after 1,000,000,000 years gas and particle cloud were formed in some regions of the universe. The majority of the gas was hydrogen and a little bit of helium. This atoms came closer because of the gravity. They have begun to condense and so they have formed a protostar. In a protostar are not any nuclear fusions, but a protostar emits infrared light and radio waves which are able to pass the gas and particle clouds around the protostar.

Some stars which have got to little mass for nuclear fusions stay in this state, but the gas and particle cloud disappear and they illuminate very weak. Star like this are called brown dwarfs. In other stars like our sun nuclear fusions begin after 10,000 years and now it is not any longer a protostar, but it is a star. But we should not despise brown dwarfs, because we think that they and black holes are the matter which misses in the calculations of phycisists. Because in the past scientists have done their calculations only with the matter which illuminates.

But when this calculations does not corresponded to the Big Bang theory the phycisists began to search dark matter. For many million years the gas and particle cloud is around the new star. After a certain time planets can be formed from this gas and particle cloud like it was in our solar system. Up to this point the orgin of every star is the same, but now we must divide the star into classes. When a star has got a bigger mass than another star the nuclear fusions in star this are faster than in the smaller star.

The consequence is that this star is hoter, but he lives shorter than a star with less mass. The spectral classes (star classes) are described at the bottom. There exists two types fusion reactions which we can find in stars. The first is the proton cycle (p-p-cycle) and the other is the carbon nitrogen oxygen cycle (CNO-cycle). Only one of this cycles is in a star. The most massively stars are blue stars.

Their surface temperature is about 25,000 Kelvin and they live only 10 million years. Our sun should live about 10,000,000,000 years and also red stars exists which live 100,000,000,000 years. The life exspectancy of a star depends on how fast the hydrogen is transformed into helium. When a star begins to burn helium then he begins to die. Our sun exists since 5,000,000,000 years. In 5,000,000,000 years, when the whole hydrogen in our sun is transformed into helium our sun will become a red giant. This red giant will be so big that Mercury, Venus and our Earth will be destroyed. Up to this time we need another planet to live on. After all this the red giant will become a white dwarf.

A white dwarf is an object which is so dense that one cubic centimetre weighs about one ton. This white dwarf will be much smaller than our sun today, but its gravity will be much bigger than the gravity of our sun, because of the high density. When this white dwarf will loose his whole energy after a certain time he will be a black dwarf. When a star has got a mass which is 1.4 times the mass of our sun then it exploses during its death and this explosion is called supernova. Then it comes to a collaps and the core of the star becomes compressed and the end the star exploses.

The final product depends on the mass of the star. One possibility is a neutron star which is so dense that one cubic centimetre weighs 300,000,000 tons and the other possibility is a black whole with a singularity where our physical laws do not matter and an infinite density. Even the light with a speed of 300,000 kilometres per second cannot escape from a black hole.

Neutrons star and black holes are described at the bottom. Supernovas are so important, because during a supernova new elements are formed. The reason why stars collapse when they have transformed the whole hydrogen into helium is that this fusions thwart the gravity so we have got a balance, but now when there are not any fusions there is not any balance. During the normal life a star cannot explose, but it cannot collapse, because there is a balance. There are three possible ends for a star: a white dwarf, a neutron star and a black hole. Our sun is not a star of the first generation, because we can find heavy elements from other supernovas in our sun. Otherwise the earth would not exist. Stars of the first generation consists only of hydrogen.

The Proton Cycle

In the proton cycle in the sun it happens that because of the compression two protons are hold together for a short time. In this time one of the two protons decays into a neutron. A positron and neutrino are emitted. This connection of one proton and one neutron is called deutrium (heavy hydrogen). When another proton hits this deutrium ion we have got helium-3 (two protons ans one neutron). Then two helium-3 ions come together and we have got the final product helium-4 (two protons and two neutrons) an two free protons. If you want to know more about nuclear physics have a look at the homepage of nuclear physics.

Different stars has got different masses. When the mass is bigger then also the gravity is higher and the fusions must go faster to thwart this high gravity. A star like this is hoter than our sun, but it lives much shorter. 7 spectral classes exists: O (blue), B (blue-white), A (white), F (yellow-white), G (yellow), K (orange), M (red). The sentence says: Oh be a fine girl, kiss me. Star of the class O are the most massively and they are blue because of the high temperature of 25,000 Kelvin. Their life exspectancy is among 10,000,000 years because of the fast transformation of hydrogen into helium.

The diameter of a star like that is a few million kilometres. A goog example for such a big star is Spica which is 275 light-years away and which has got a diameter which is eight times so big as the diameter of our sun. The coldest stars are stars of the class M with a temperature of 3,000 Kelvin. Their life exspectancy is 100,000,000,000 years. Our sun is in the class G. This means that our sun will live amoug 10,000,000,000 years. The most stars live