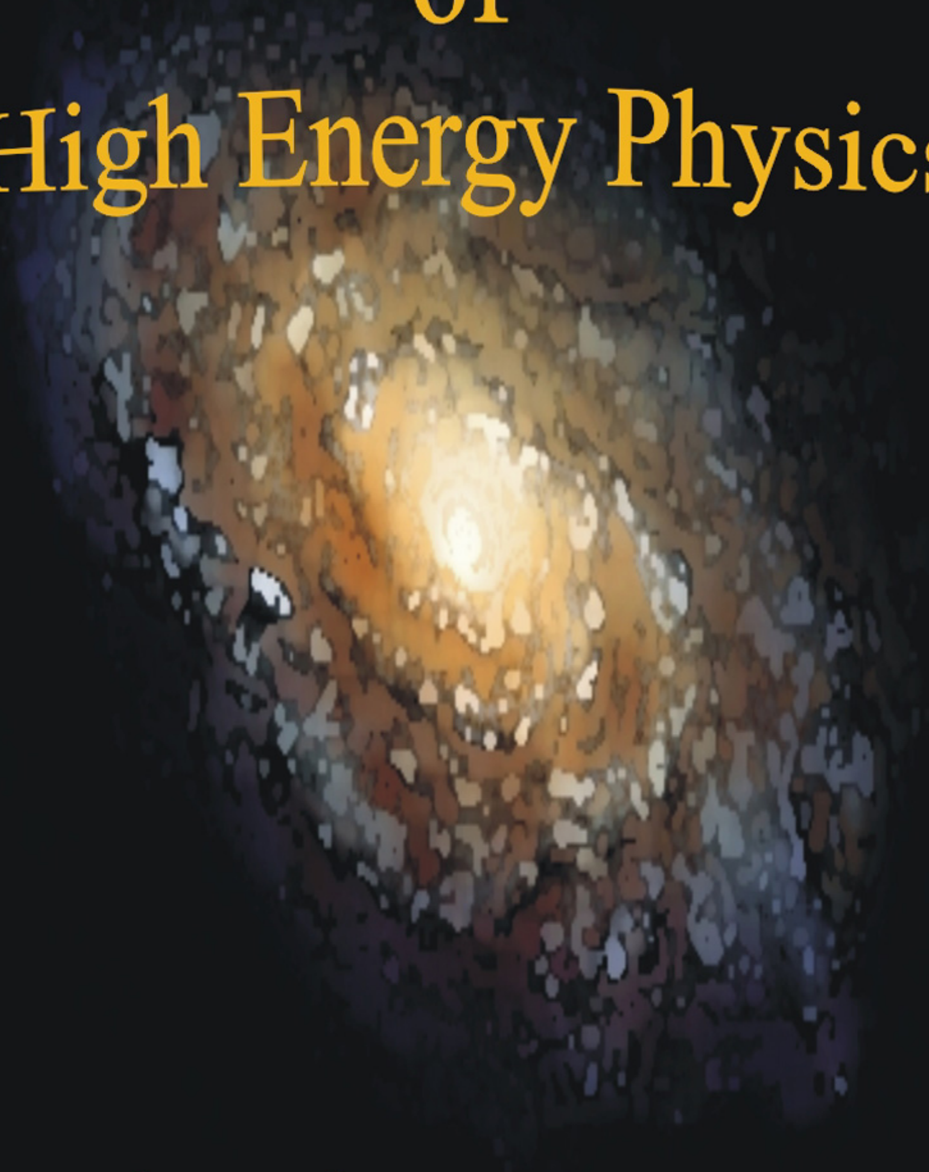
Elements of High Energy Physics



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e-libro.net

ISBN 1-4135-3536-4, de la edición virtual
ISBN 1-4135-3537-2, de la edición impresa

Education is the most precious gem that someone can give to someone else.

Material possessions are ephemeral; education skills, perennial.

Human beings perceive and interpret the external world through their glass window education. Give them a sane education, and the world will look level-headed.

Give good education and noble motives to people and you will make the world moves rightly.

To those that have been original enough to think by themselves, to trace, and to open new roads to educate people. And to those that have been courageous enough to try them.

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With the help of la Fundación DELTA, A.C. and of the grant CoNaCyt-2002-C01-39941/A-1.

Preface

There are many wrong practices, procedures, and policies in the south countries: The worse is in people education. Sometimes, this has no defined purposes and orientations. The idea of the state is to provide education to people, even if that education has nothing to do with the State; even if that education is not integrated in one project of State -or nation-, that hits its economy, security, integrity, etc.

The policies to introduce, to teach, and to learn, science in that south countries are even worse: Science is taught like if it were a religion, without relation with engineering and the external world; only at the textbook level and using repetitive and memoriter procedures. Completely separated from the physical and economical country reality.

Physics is not excluded from that situation. It is taught completely separated from the physical reality of the external world and from the economical reality of the state. The Mexican schools of sciences -physics- reach the 5% of efficiency. And teach physics with a parody of physics laboratories -when there have been some efforts to construct them, because in some universities students never enter a physics laboratory- and using textbooks translated into Spanish, generally from English. It is worthless to say that physics students never accomplish a serious experiment in physics; and that they graduate from physics implicitly believing that physics is not from this world.

Because that situation, students -also teachers and professors- are involved in a paradoxical situation and perverse circle: They learn wrongly physics because their mentors learnt badly physics; teachers teach in a wrong way for they were tough also in a wrong manner. And the country is technological underdeveloped because the poor way physics is tough, and because the poor way science is tough the country is technological underdeveloped.

This book *Elements of High Energy Physics* is an intent to change that paradoxical situations in teaching and learning physics; to break down that vicious circle of bad teaching physics and technological underdevelopment, that engulfs the majority of the countries in these times.

The worse those country people teach and learn physics, the more underdeveloped nations they form. Country technological development and country good education are very close related. The more skillful those nation people are, the richest they are. Mexico country exemplifies very well this situation.

This book will have a Spanish version, for use in Mexico and other Spanish speaker countries. To alleviate the situation, the vicious circle, in learning and teaching physics and technological underdevelopment.

Contents

Chapter 1

Introduction

Teachers have not pronounced the last word on teaching; nor physics teachers have pronounced the last word on teaching physics. And researchers have not pronounced the last word on research and physics researchers nor on physics research.

In formal courses of physics, teachers or instructors do not leave explicitly what physics is and what is its utility, nor what is its relation with external world, or technology, or daily life objects and machines. Or how physics leads to a deep understanding of the external world behavior. At least in Latin America, the main problem is from the teacher -in all levels of instruction- who presents and conduces the course. The problem is akin in the rest of the world, especially in the underdeveloped countries. The teacher is the ultimate responsible person on the way he conduces the course and on the way students are taught and of what and how students learn. Most of the time, teachers deliver to students as a science -physics- a collection of dead facts, data, and technical terms, in a way that is more akin to religion than to science; in both contents and way of learning. Without immediate connection with external world. Students learn physics believing facts.

Science is not that. Physics is not that. Science is alive human activity. Physics is alive science, growing and changing continuously, and everyday. Very close to the way human beings perceive the external world.

Physics is alive, always growing, science, not a static religion. Physics is the description and interpretation of the external world. The description and the interpretation of external world let physicist understand the way nature is organized and structured. This understanding conduces physicist to practical manipulation of nature. And the practical manipulation of nature can be used to rectify and to go deeper into the description and understanding of external world. In this form, the circle is closed. It is the circle of theorization-experimentation-theorization or experimentation-theorization-experimentation. It is the circle of scientific activity. Of scientific thinking. Of all sciences. Specially of physics.

Chapter 2 will confront and exhibit that circle. It will show that physics is an experimental science; that is, physics is not a collection of experimental data, nor is physics a collection of theories, mathematical formulas, abstract concepts without any relation with the external world, but a science based strictly on experimental evidences; physics is a proposition of description and interpretation of the external world, not concluded up to these days. Fragments of masterpieces of A. Einstein and E. Fermi -two fathers of physics- will illustrate this circle. And copious citations to original references and Nobel lectures will do it too.

This book presents and illustrates that circle using the experimental high energy physics; Chapter 3 introduces this branch of physics. It speaks about atoms, about particles, about families of particles, and about classification of particles. And it describes an experiment of high-energy physics, employed techniques to detect particles, used techniques to identify particles, electronics and computation involved.

And following the description of a high energy experiment, Chapter 4 will show the utility of experimental high energy physics. First, it will describe how physicists reached the contemporary image on the nature structure: The most recent and complete knowledge about the most basic constituents of nature. Second, it will show how physics has generated new developments in electronics, in new materials, in computation, in new technologies of information and communication, and in medicine. Each one

of these technological areas, created on advances of physics, has contributed back to physics: New materials for ultra speedy electronics, new technologies for fabrication of solid state devices, have founded a new more rapid computation. And this new computation has opened new branches in science, in particular, in physics: Computational physics, for instance. This new physics will provide the basis for a new generation of technology, materials, computation, etc. And so on. Up to no one knows.

For all the above, summing-up, physics is an experimental science. Physics is a continuous process of studying, interpreting and understanding the way nature is and operates. Physics is a science in its own way of edification. It is not a terminated building of knowledge. There is still a lot to investigate, to learn. This investigation of nature necessarily must carry physicists to a deeper and deeper description and interpretation of the external world. And if physicists understand the form nature is structured, necessarily they will be able to manipulate nature to practical purposes, to take advantages, to change their natural, social, and economical reality.

Formal courses on physics, and expositions of new results on physics, must reflect that physics is an experimental science. That is, that physics is based on experimental evidences; that it describes the external world, that it has very close relations with economy, and with the development of modern states. And, over all, that it describes and interprets the external world. This book will do it. For illustration, it will use experimental high energy physics. However other branches of physics could chart these relations equally well.

Chapter 2

Physics

2.1 Physics

Physics, like other contemporary science, is divided into areas: Solid state physics, statistical physics, gravitation, high energy physics, mathematical physics, etc. Each one of those areas is divided into two or more sub areas. For example, solid state physics is divided into surface physics, semiconductor physics, solid state thin film physics, granular system physics, etc. Each one of that areas and sub areas is divided by the type of activity that physicists perform: Theorization and experimentation. Theory and experiment.

Division of physics, by akin topics or by type of activity, lets physicists study and deal with physics efficiently. For instance, deposition of thin films, surface conductivity, doping effects, physical phenomena of interfaces, etc., are subjects under the same area: Surface physics. Actually this is the analytic method applied to the study of natural phenomena. To the specialist advantages of dividing physics into areas are very clear. The division facilitates communication between professionals of the same or different areas, and dissemination of new results and the attainment of new results, of course. To the tyro those advantages are not clear. To novice, physics put into fragments appears as a collection of disarticulated areas. Without relation. Disassembled. This could be a serious problem in education, since the majority of students never goes beyond the novice stage, not in practice but in thinking maturity.

Specialties of physics appear so disconnected for students, that for the type of activity, it appears that there are two sort of physics: One theoretical and another experimental. Physicists speak in those terms. Besides, official courses of physics, by tradition, are separated into theoretical and experimental courses of physics. Students end official studies believing that there are two physics: One experimental and another theoretical. Without any relation between one and other. The first one dirty, terrestrial, mundane; the second one clean, heavenly, sublime. This happens specially in underdeveloped country colleges, schools, and universities.

For that subdivisions of structure, and way of teaching and learning physics, connection between physics and tangible world is lost. For students that end official studies, physics has almost nothing to do with external world. For that students there is no relation between physics and external world. Or between physics and economical external world. Physics becomes an ethereal subject very close to god business, but not to man business.

However, reality is not that. Physics is unique. Physics is an experimental science. That does not mean that experimental work is more important than theoretical endeavor, but that theoretical labor must be based on experimental evidences, on experimental facts. Experimental labor and theoretical work feed back each other. One causes the advances of the other in the general objective of physics: The description and interpretation of the external world.

If division of physics facilitates the study and growth of physics, that division has no other purpose or justification. Physics must be treated as an integral discipline. And must be presented, taught, studied, thought, and learned, as that. Nature is unique, therefore physics is unique. Without divisions.

Reader can obtain by himself, or by herself, the general objective of physics examining pioneer works, and checking obtained results by the authors of those works. Some examples are as follows:

The object of all science, whether natural science or psychology, is to co-ordinate our experiences and to bring them into a logical system, A. Einstein wrote in the introduction of his celebrated book *The meaning of Relativity.* See References.

The path that scientists, in particular physicists, follow to construct science, physics in particular, is as Bertrand Russell describes it in his book *Religion and Science:*

The way in which science arrives at its beliefs is quite different from what of mediaeval theology. Experience has shown that it is dangerous to star from general principles and proceed deductively, both because the principles may be untrue and because the reasoning based upon them may be fallacious. Science starts, not from large assumptions, but from particular facts discovered by observation or experiment. From a number of such facts a general rule is arrived at, of which, if it is true, the facts in question are instances. This rule is not positively asserted, but is accepted, to begin with, as a working hypothesis... But where as, in mediaeval thinking, the most general principles were the starting point, in science they are the final conclusion -final, that is to say, at given moment, though liable to become instances of some still wider law at a later stage.

And with respect to the advances of the general theory of relativity, in the above mentioned book A. Einstein wrote:

Since the first edition of this little book some advances have been made in the theory of relativity. Some of these we shall mention here only briefly: The first step forward is the conclusive demonstration of the existence of the red shift of the spectral lines by the (negative) gravitational potential of the place of origin. This demonstration was made possible by the discovery of so-called "dwarf stars" whose average density exceeds that of water by a factor of the order 10^4*. For such star (e.g. the faint companion of Sirius), whose mass and radius can be determined, this red shift was expected, by the theory, to be about times as large as for the sun, and indeed it was demonstrated to be within the expected range.*

A. Einstein discusses about the purpose of science and about experimental confirmation of his theory, in the above paragraphs. Einstein took care about putting clearly, and with very simple words, his science and scientific position, or philosophy. The reader must conclude, after meditating about the words of Einstein.

Another master of physics was E. Fermi. In the introduction of his book *Thermodynamics* he wrote:

We know today that the actual basis for the equivalence of heat and dynamical energy is to be sought in the kinetic interpretation, which reduces all thermal phenomena to the disordered motions of atoms and molecules. From this point of view, the study of heat must be considered as a special branch of mechanics: The mechanics of an ensemble of such an enormous *number of particles (atoms or molecules) that the detailed description of the state and the motion loses importance and only average properties of large number of particles are to be considered. This branch of mechanics, called statistical mechanics, which has been developed mainly through the work of Maxwell, Boltzmann, and Gibbs, has lead to a very satisfactory understanding of the fundamental thermodynamics laws.*

But the approach in pure thermodynamics is different. Here the fundamental laws are assumed as postulates based on experimental evidences, and conclusions are drawn from them without entering into the kinetic mechanism of the phenomena. This procedure has the advantage of being independent, to great extend, of the simplifying assumptions that are often made in statistical mechanical considerations.

E. Fermi discusses about different approximations of science to the same problem. And put in clear that the bases of physics must be supported by experimental evidences. The reader must conclude, after thinking very deep in the above passage implications.

The above two examples illustrate the scientific position of two fathers of modern physics. The two men describe physical phenomena in their theories. The two men based their theories on experimental evidences. And the two men search for experimental confirmation of the consequences of their theories. For these two men external world is the object of study, the object of physics. And in spite of that they are speaking about very different branches of physics, the approximation and the method that they are following are the same. The experimental evidence has a preponderant place in the theory. That is the method of physics. The way physicists construct physical true. The power of physics.

In this way, physics deals with the description and interpretation of the external world. This is the very general objective, and at the same time very particular objective, of physics. From this point of view, fragmentation of physics is artificial. Without real foundation. Out of nature structure.

Physics reveals all its potential when is considered in the above form. Physicists when know nature and understand its laws can manipulate nature for multiple purposes. For raw, and understanding, pleasure -like majority of physicists does-, for commercial, and utility, purposes -like majority of scientists and engineers that look for creation of new worldly goods that increase the level of life of people, and modify the structure of society, does-.

The following pages illustrate and exemplify the two facets of physics that were just mentioned above. High energy physics exemplifies and presents this illustration. Any other branch of physics could do identical job. In this way, this book illustrates, discusses, and introduces high energy physics.

2.1.1 *Physics and the External World*

The starting point is the before stated epistemological point of view on the meaning and on the role of physics as a science: Physics is the description and interpretation of the external world. Physics is an experimental science. And it is based strictly on experimental evidences. If this is so, the way human beings perceive the external world is fundamental. On these perceptions physics is based. And there is no other way of speaking about physics. And there is no other way of building physics. Physics is the description and interpretation of the external world. Physics is a proposition to explain the behavior of the external world. And this proposition is self regulated and self corrected. By experimentation, observation, and theorization.

Human beings perceive the external world through senses. Some times they got the help of instruments of observation and measurement, they do it always that they are looking for precise and controlled observations and perceptions. The measuring instruments are constructed to precise, and quantify, human beings perceptions and observations. Eyes, when perceiving light, can not precise or quantify light. Nor skin, when senses heat or pressure, can quantify perceptions. Hardly in this way human being could manipulated it for useful purposes. Using instruments human beings can record light, filter it, decompose it, store it, measure its wavelength, quantify its frequency, tally its velocity, etc. In this way, capability of instruments is larger than human senses; additionally, instruments have other characteristic, that human senses have not: They are designed to record, quantify, and process information.

One implicit supposition of the above procedure is that instruments show the measured object as it is -whatever it is-, and that measuring instruments reveal physical reality of the object as it is. That the physical object under study, the observed object, exists independently of the observer. Observations only corroborate its existence but not contribute to its existence nor to hold its actuality. This is the general consensus among physicists and philosophers. This is a physical postulate behind every classical measurement and every classical theory. And what human beings perceive is as it is and there is no more to consider about the object and its reality. This is another physical postulate. The majority of physicists follows these postulates, or tacitly applies them, when they investigate physical laws of the external world. Both postulates are based on the information available through measuring instruments. The following is an example that illustrates these postulates:

Example: Human beings, and most of animals perceive light. It is a child, or scholar, question the following one:

What is light?

This is a very general question. If scholars want to answer it from a physical point of view, it is necessary to reformulate it in a way that he, or she, can answer doing experiments. For example in these ways:

- What is its velocity?
- From what is it made of?
- What is the relation between light and color?
- What is its origin?
- Can it age?
- Does it have mass?
- How is it absorbed by matter?
- Can light transmute into matter and vice versa?

Physicists experimentally, or theoretically, answer these questions and other similar, but, starting from experimental evidences. That is the way of doing physics.

Galileo Galilei tried to answer experimentally the first question. As far as history tells, he formulated, more clearly, before than any one else this question. His method, even correct, was not sensible enough; he got not a good answer. His answer was as this: If light speed is not infinite, it is extraordinarily rapid. His method to measure velocities is employed up to these days, as the last section will comment on.

Galileo Galilei invented the method to measure the velocity of light, based in his definition of velocity. He measured times and distances. And obtained the velocity dividing distances by respective times. The method works to measure the velocity of any mobile. Specially the velocity of light, of particles, and of the radiation in general -particles and waves or any mobile-. His method was as follows:

First, he and his colleague separated some known distance. Each one uses a lantern and a clepsydra (water clock). The agreement is that Galileo uncovers his lantern, and starts his water clock, and when his colleague sees the light, uncovers his lantern. When Galileo sees the light from his colleague lantern then stops his clepsydra. The light travels in the time measured by Galileo twice the distance of separation. Second, dividing twice the distance of separation by the measured time, Galileo obtained light velocity.

Galileo's method is essentially correct. However, his measuring instruments are not precise and rapid enough. The human reflexes work against. And they are decisive because they are very slow for the purposes they sought. For that, the obtained result. Galileo's conclusion is the most that someone can say based on the measurements performed, or on the experience done: If light speed is not infinity, it is extraordinarily rapid.

Newton, after a generation, tried to respond the next two questions based on the decomposition of white light into its fundamental colors. He studied diffraction, refraction, etc., of light. His answers, based strictly on experimental evidences, are essentially correct. And they will be correct for they are sustained by experimental evidences. No matter how far physics goes in describing nature. Or how deep and abstract the theories about nature become with the time.

The modern answer to the first question is this: Light velocity is finite -300 000 kilometers per second, extraordinarily rapid, as Galileo said- and independent of the state of motion of the emitting source -as experimental evidences show-. The modern answer to the second one is this: In some circumstances light behaves like a wave -Young experiment-; in other circumstances, never equal to the before mentioned, it behaves like corpuscle -Hertz o photoelectric experiment-. Modern answer to the third question is this: The light of one color differentiates from the light of another color by its wave length; for example, blue light has a shorter wave length than red light. Readers can check those experiments, and their basic conclusions, in any book about elementary optics and about modern physics respectively. Answers to the rest of questions can be found in similar references.

This is an example that shows the importance of knowing laws of nature: Design and construction of better lenses, of better light filters, of better photo cameras, of better telescopes, of better lenses for ocular implants, of better mirrors, of better photo films, etc., depend on the knowledge that physicists have on the nature of light and on the nature of material to make them. Economical repercussions, or profits, are annually of thousand million dollars in the world market.

2.1.2 *Precepts of Physics*

Competence of physics, like the one of other science, is limited. In great part, for this is the great success of physics and of science in general. For instance, physics is not concerned about the origin of perception; nor about the origin of what causes perception; why human beings perceive as they do. Those problems are the mind of other sciences. For example, physiology, psychology, etc. The problems of physics are others. And very well identified and limited.

Next section abounds on examples about the proficiency of physics. And Chapter 4 will show the way in which the results of physics have changed society, and the benefits that have given to it by this science. Besides, Chapter 4 will discuss utility, the practical uses, of physics.

The worth obtained from physics are, in part, by the limitation of its treated problems. In this way, physics dominion is restricted, first, by its most elementary precepts; second, by its general objective. The above paragraphs showed the physics general objective. The most elementary physics precepts are those of all exact natural science; the next section will describe them.

2.1.2.1 *Classical Precepts*

The general precepts of physics, and most elementary, are the following:

- **Objectivity.** There is an external world populated by objects. The existence of those objects is independent of if objects are perceived or not, of if there is an external observer or not. This principle is known as objectivity. Example: There is a moon, there are trees, there are electrons, etc. Among those objects, there are many other human beings that interact with in daily life. And they are real, in the sense that they exist independently of any observer, or any other object with what each object interacts. Any human being can corroborate their existence. And communicate to its fellow beings. Human beings never will be able to test directly this supposition. This is taken as a principle. As a primary work hypothesis.
- **Determinism.** There are laws that rule the behavior of objects that populate external world. Like there are human laws that rule human behavior or human activities or way of organization, or way of dissolving organizations. Given arbitrary initial conditions and the laws, the final conditions are established at any time. This principle is known as determinism. For example: If the initial position and the initial velocity of some object are known at sometime, besides the laws that rule the moving object, the final position and the final velocity, at a posterior time, are determined; i.e., they could be known before hand and tested experimentally. They are known within the un-precision of the measuring instruments that in principle, according to theory, could be zero. This is, the final conditions can be known exactly. Or the physical system final state can be determined before hand.
- **Completeness.** There is one to one relation between theoretical concepts and properties of the external world objects. This principle is known as completeness. Example: Mass, electric charge, etc., are concepts in classical mechanics theory and classical electromagnetic theory, respectively; in the external world there are objects with that quantifiable properties, or observables. The mass of a car, of human body, of stones, are typical examples; electric charge of electrons that circulate in domestic electric circuit, electric charge of electrons and of ions in lighting discharges are other examples. Photons, from a candle flame, or from the sun, constitute another one.
- **Locality.** There are relations, mutual influences, or interrelations between the external world objects only at local level. This prin-

ciple is known as locality. Example: An experiment performed in Mexico city does not affect the results of other experiment performed in Tokyo or in a building a few meters away from the first experiment. The running of some car down the street does not pertain the flight of any airplane. The car is able to only disturb the airplane flight if they are in touch or if some perturbations generated by the car reach the airplane. There is no other possibility, from classical point of view. Of course, physicists can imagine some ethereal influences between classical objects; however, that such influences are not observed. Therefore, classically those ethereal influences do not exist. Some universe where locality is violated will be very strange for classical common sense physicists. Events like this could happen there: Kick some balloon and get some cloud rains sometimes or sometimes get other unrelated phenomenon. Like cloud disappearance. That universe will be very weird. Physicists never have observed these phenomena. Neither no one human being has.

- **Causality.** There is a cause for every behavior or change in the behavior of objects that populate external world. This principle is known as causality. Example: The mine of one pencil, which was used to write, got broken; the cause was excessive pressure exerted on the pencil. Always that the pencil receives an equal pressure to the above mentioned, and in identical conditions, the graphite bar will get broken. This is for sure. Always happens. The cause, as it is seen in this example, always antecede the effect. There is no effect without cause. Every event in this universe has an antecedent cause, at least at macroscopic level.

Physicists accept tacitly the above mentioned precepts. They use them when they investigate the external world; they do it especially during classical descriptions. At macroscopic level.

Classical description of nature, i.e., classical theories, adjust themselves to the aloft mentioned precepts, quantum theories do not. Quantum descriptions are not objective, not deterministic, not complete, not local, and not causal.

2.1.2.2 *Quantum Precepts*

The history of how it was determined that quantum theories do not follow classical precepts, is registered in many books and articles. How it happens in nature is still a topic under discussion. Even in our days, books and articles are written about this topic. Experiments are performed. And physicists discuss these themes. It is a history not closed. The reader can find a lot of material to study and a branch for research in these themes, in the interpretation and philosophy of quantum mechanics. There is a lot to investigate in this field; specially from the approximation called experimental philosophy. To start, the reader can study, the book of F. Selleri. See References. And consult original literature of the founders of quantum theory and quantum mechanics.

This Section describes briefly the beginning of that story, and the form in which the problem has been cleared up. And it ends the story mentioning the most recent results.

- **Objectivity.** There are no objects like electrons that independently have existence of whether they are observed or they are not; or there are not objects, at microscopic level, that have existence independent of if they are observed or not. Position and momentum can not be determined simultaneously for microscopic corpuscles. If position of a particle is exactly determined, then its momentum is completely unknown; and vice versa: If the momentum is exactly determined, then its position is completely undetermined. In this way, it is not possible to speak about trajectories followed by microscopic particles. Therefore, if electrons, and particles at microscopic level, exist, their existence is not like the existence of stones, tables, etc., or any other object which human beings have direct and daily life experience. The above indetermination is not a matter of exactness of measuring instruments; it is something inherent in the theory that describes their behavior. For this, objectivity of microscopic corpuscles is denied, and stated, by quantum theory. There are no objects in the microscopic world which existence is akin to the existence of external world objects of macroscopic world. If there are objects in microscopic realms, the existence of those objects is very dissimilar to that of the objects that populate the macroscopic world.
- **Determinism.** If initial conditions of position and momentum

of a microscopic physical system -like a subatomic particle- could be given, final conditions would not be determined before hand for that particle. Actually, such deterministic initial conditions can not be established either, can not be given. In this sense, quantum theory has no way to tell, or calculate, final conditions. It, at least, can predict them, i.e., tell the probability of having some final conditions. Quantum theory never can tell in advance final conditions, given the initial ones. Quantum theory laws are not deterministic. They are probabilistic ones. When light (one photon) hits some metallic surface there is no way of telling with 100% of certainty if the surface will absorb or reflect the photon. If the metallic surface absorbs the photon there is no way of telling which atom will do it, only of telling the probability that some atom will do it; or if the surface reflects the photon, there is no way of telling where the photon will end, only the probability that the photon will stop at some place. Quantum mechanics laws are not deterministic. The end of the story can not be known before hand. Quantum mechanical laws are probabilistic.

- **Completeness.** There is something else in nature - whatever it is - that quantum mechanics can not describe. All the concepts that enter in quantum mechanics have no object mate in nature. In some sense quantum mechanics does not describe nature completely. Quantum mechanics is not complete. There are elements of physical reality that quantum mechanics does not contemplate. That it does not describe. That it does not include in its conceptual apparatus. The mathematical apparatus of quantum mechanics is fine, gives good results that agree with experimental results. However, it seems that there are elements in nature that quantum mechanics does not comprehend. There are elements of physical reality that quantum mechanics does not involve in its conceptual and mathematical apparatus.
- **Locality.** Quantum mechanics can not describe some circumstances that occur at submicroscopic level. The perturbation of some photon, which is parented with other one since birth, can manifest in the behavior of the second one, even if photons are sufficient apart to discard communication by light, or causal communication; in this case the photons are correlated in their physical story. There is, in this case, some element of physical reality that does not enter inside quantum mechanics. Quantum mechanics is

not local. One photon, of two that are created very correlated like the pair of photons from the decay of a particle, can be measured to give its spin state. Immediately the spin state of the other can be known with out disturbing it, independently of the separation between them. Apparently there is a signal that conducts information from one photon to the other. That maintains the correlation between the two photons.

- **Causality.** Quantum mechanical laws are probabilistic. From them, physicists can tell only probabilities of that such or such effect can occur. There are no ultimate causes that origin physical phenomena, or, at least, they are not implicit in quantum mechanical law; there are only probabilities that such phenomena occur. When some atom absorbs one photon, the electron jumps to a higher physical state level; in this process there is no a reason, or cause, or a time to happens, only a probability, derived from quantum mechanical laws, for the phenomenon to occur. There are no causes for atomic, or elementary particle, processes. Only probabilities. In this sense, quantum mechanics is no causal.

In spite of the above particularities of quantum mechanics, it describes experimental evidences very well. Up to these days there is not a known phenomenon that violates quantum mechanical laws. And because of the above particularities of quantum mechanics many physicists that substantially contributed to it, detracted it. Never accepted it as the final word to describe nature. However, they recognized that mathematical quantum mechanics apparatus is correct. A. Einstein was one of those.

A. Einstein, that amply contributed to quantum theory, never accept it as the definite theory which describes nature behavior. For him, a physical theory must have the characteristics, and postulates, of a classical theory in order to represent physical reality. He maintained his points of view with respect to the description of nature along his life.

In 1935 Einstein and collaborators defined physical reality, trying to prove that quantum mechanics is not complete. He published, in collaboration with B. Podolsky and N. Rosen, the article *Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?* First they pointed out clearly that the elements of physical reality can not be determined a priori by philosophical considerations, but they must be found up experimenting, observing, measuring, trying. Second, he defined the physical reality. In his definition, they wrote the following words:

If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.

The idea of physical reality, as in the above paragraph, agrees with the classical and quantum idea of physical reality. It is known as local realism.

The mass of a table is an example of a physical concept with local realism features. It is possible to predict, without disturbing the table, the mass of it. Classically it is possible. Therefore there is an element of the physical reality that corresponds to the mass of the table. Einstein does not say that the table mass is real; he says that there is an element of the physical reality that corresponds to the mass of the table. The same is valid for any other classical concept.

Using their criterion of physical reality, Einstein showed that the quantum mechanics is not complete. This is, quantum mechanics does not give a complete description of the external world. From the before cited article, in their own words:

While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible.

The realism described by Einstein and coworkers in their article of 1935 is known as local realism. Apparently nature does not behave according to this realism. The experiments to show this realism physicists call experiments type Einstein-Podolsky-Rosen (EPR experiments).

In an article entitled in the same way, N. Bohr answered. And based on his principle of complementarity, corner stone to build quantum mechanics, refuted Einstein and collaborators paper conclusions. To Bohr, the last word in the description of physical reality is provided by the quantum mechanics. However, N. Bohr admitted that if Einstein definition of physical reality is taken as true, the conclusions of Einstein and collaborators are straightforward logical consequences. They are true. And quantum mechanics is not complete. There is in nature something that quantum mechanics does not take into account.

Discussions lasted for about two decades, and ended with Einstein's dead. Invariable Einstein always lost discussions against N. Bohr. Both philosophers, physicists, never pretended, or proposed, to experimentally test their propositions and discussion consequences. Or at least, really base on experimental facts their discussions. Only on thought experiments.

However, the discussion, to be a physical discussion, must be based on experimental evidences. The last word must be provided by experiment. Bell theorem changed the discussion completely and put the debate on the possibility of experimental test. This is, under the correct way of physics.

In 1964 J. S. Bell, taking the paper of A. Einstein on physical reality, wrote algebraic predictions. The Bell's inequality. This inequality is contradicted by the quantum mechanical measurements in an experiment EPR type. That is, if performing an experiment EPR type physicists find that Bell inequality is violated, then the local realism of Einstein is not the way nature conducts herself. And quantum mechanics predictions are right.

In an experiment of two polarizers, as in the ideal case of an experiment EPR type, A. Aspect and co-workers show that Bell inequality is violated. This agreement with the quantum mechanics was established experimentally far away than ten standard deviations. This is, there is more than 99.99% of chance that the results are correct. Therefore the local realism is not the way the nature carries itself. This is, Einstein was wrong; Bohr, right.

The violation of Bell inequality, in a strict relativist separation for the performed measurements, means that experimentally is not possible to maintain a reality 'a la Einstein'. In a reality 'a la Einstein' the correlations are explained by the common properties determined in the common source. These properties are transported by the correlated physical systems. The following is an example that illustrates those physical correlated systems.

Example:

According to experimental evidences, a pair of photons, with a common origin -as those that are created when an electron and a positron collide, or in general when an antiparticle and a particle collide-, is a correlated physical system, non separable in both space and time. That is, it is not possible to assign local individual properties to each photon, even if they are separated in space and time. The two photons remain correlated, regardless the spatial and temporal separation. They form a unity, always, in some sense, in reciprocal touch and communication. Always correlated. There are more information about Bell inequality, and about its implications. See References. The reader must give his or her own conclusions after thinking in the above paragraphs.

2.1.3 *Theorization and Experimentation*

Physicists, in their intent to interpret and to describe the exterior world, theorize and experiment. These activities are not antagonistic. One activity complements the other; the results from one feed back and correct the results from the other. In the way of exploring, and knowing, nature. The following paragraphs illustrate these methods. One example shows the process of experimentation and another one the process of theorization.

2.1.3.1 *Theorization*

Special theory of relativity gives an excellent example of the process of theorization. Special theory of relativity is based on two principles. Both of them are distilled, or resume, of many experimental evidences. The principles of relativity are, as Einstein wrote them in his original paper of 1905, as follows:

- The laws by which the states of physical systems undergo change are no affected, whether these changes of state be referred to the one or the other of two systems of coordinates in uniform rectilinear motion.
- Any ray of light moves in the "stationary" system of co-ordinates with the determined velocity c, whether the ray be emitted by a stationary or by a moving body.

Scientists extract physical principles from experimental evidences or they put on, or formulate, a priori. In the first case of human being made sources, principles are a sort of distilled experiences collected from many experiments; the principles mean the most general and simple base of one collection of experimental truths. In the second case of natural sources, the chosen principles must be plausible; and must be sustained in some stage of the development of the theory by the experimental evidences. The foundations of classical thermodynamics, or the principles of special relativity, are examples in the first case; and the principles of modern cosmological theories, or the principles of star evolution theories, are examples in the second case.

The principles of classical thermodynamics are very well known by everybody. The readers can check them in the above mentioned book of Fermi or in another book, that the reader prefers, about classical thermodynamics. The principles of special relativity are those of a few paragraphs above.

The principles that sustain the modern cosmology, or star evolution theory, are not very well known. Here is one from modern cosmology:
The four dimensional space is three dimensional isotropic.

This principle was enunciated for the first time by Friedman. From this, Friedman obtained theoretical results, inside the general relativity theory of Einstein, concordant with the expansion of the universe measured by Hubble. This principle is plausible, simple, reasonable and, in some sense, natural; at first order, it is sustained by observations, at least at local scales of the universe. As human beings perceive it. As it can be seen from the above example, physicists do not test physical principles directly. They test the logical consequences that necessarily occur in the theory, i.e., the principles implications. They never prove the theory definitely. Each time theory succeeds an experimental test, the level of truth, or confidence, in the theory is increased, however, physicists never test the theory unequivocally. Always there is room for a possible experimental situation were the theory can fail. One experimental evidence against the theory is enough to disprove it, or to show the boundaries of theory validity.

Quantum mechanics has succeeded, so far, all experimental tests that physicists have put on it. This does not mean that the theory is true. It means that the level of truth, or level of confidence, is very high. At least, the theory works to describe the regions of everyday life world -crystals, photosynthesis, etc., are common instances- the regions of atoms, the regions of molecules, the regions of quarks, and probably, the regions inside quarks. Classical mechanics fails to describe the regions of atoms, the interchange of energy between the electromagnetic fields and the atoms. Classical mechanics predictions disagree completely with experimental results at atomic levels.

Example:

The next is a very common instance which illustrates the way physicists test theories. How physicists tested the special theory of relativity. They test not the principles, but the principles implications. As follows:

From the principles of the special theory of relativity, physicists deduce the retardation of the march of clocks that are in different state of motion with respect to the observer. Physicists call this effect time dilatation. See any of the books about special relativity enumerated in References. And they obtain the confirmation of this consequence, everyday, in the high energy physics big laboratories of the world, like FERMILAB (Fermi National Accelerator Laboratory) in the USA -Batavia IL-, see *www.fnal.gov*, or in CERN (now European Laboratory for Particle Physics) in the border of France and Switzerland -Geneva-, see *public.web.cern.ch/public*. In those big laboratories of the world, physicists create huge amounts of muons, or of other particles - like pions, kaons, protons, etc.-. Chapter 3 will explain in detail what a muon, and other particles, is. In natural form, in the terrestrial atmosphere, at about 400 kilometers high, muons are copiously produced too. The muons are generated in proton-proton collisions, in the first case, and from cosmic ray protons-terrestrial atmosphere molecule collisions, in the second case.

Muons, a sort of massive electron, in its rest coordinate system, last approximately 2.2×10^{-6} seconds. This means that from a sample of 100 muons, about 68 of them disappear -or converted into other particles- in that time. In this time, muons can travel 660 meters if there were no time dilatation and if muons were traveling at light's speed, which is a very good approximation to actual atmospheric muons speed. However, with meanlife like the above mentioned, muons can travel close to 400 kilometers dawn to earth surface, thanks to time dilatation. Physicists detect them on earth surface, very easy and with rudimentary instruments on top of high mountains, and anywhere in teaching labs around the world.

Time dilatation is the key to understand many physical phenomena. The arrival of muons to earth surface is one of those. In earth reference coordinate system, i.e., for an observer in earth surface, muons can last much more time. If muons travel at 0.9999985 c, were c is the speed of light in vacuum, muons for terrestrial observer do not last 2.2×10^{-6} seconds but 1.27×10^{-3} seconds. In this time muons can reach earth surface. See Figure 2.1.

The above explanation, based on time dilation, of lifelong muons, that get earth surface, is from earth observer point of view, measurement, and perception. Observer motion state, relative to observed object, is fundamental, according to special relativity principles. But descriptions, or explanations, are equivalent whether they are referred to a coordinate system or another one in relative and rectilinear movement with respect to the first one. According to the first principle of special relativity. Therefore, the muon reference coordinate system observer explanation of the lifelong muons is as valid as the earth coordinate system observer explication. To describe muons arrival to earth surface, both observer points of view are equivalent. This is essential from the special theory of relativity. Any frame of reference, to explain the physical phenomenon, can work equally well.

From the muon coordinate system observer, muon lifetime is 2.2×10^{-6} seconds. But the height that this observer measures of terrestrial atmosphere is not 400 kilometers but a shorter one. 692.8 meters, as can be calculated from special theory of relativity. And that distance is the one that muons travel in their journey to earth surface. This effect physicists call length contraction. And is equivalent to time dilation. At least to explain muons that attain earth surface, and much more physical phenomena.

Therefore earth coordinate system observer measurements and observations and muon coordinate system observer measurements and observations are equivalent. As special theory of relativity proposes. There is no one privileged, or special, coordinate system.

Positive experimental tests of theory, as the before explained, lead to technological uses of the theory. For example, in solid state physics, moving electrons, inside materials, reach velocities comparable to speed of light; physicists take into account relativistic effects when they perform calculations. Another example: Physicists take into account time dilatation when they design accelerators of particles and detectors of particles in high energy physics. If relativity theory were not fitted by external world behavior, then the current technology of particle accelerators would be very different.

For the above, pragmatic potential of physics is enormous. Physicists expand it everyday. The knowledge of nature behavior and its understanding lead necessarily to the use of nature.

An example that illustrates pragmatism of physics is muon collider. There many, many, examples. It is as follows:

In the decade of 1960, if a physicist proposed to build a muon collider hardly would be taken seriously by scientific community. His colleagues may had laughed. Muons decay. This is, in the average, they pop down into $e\ \nu_e\ \nu_\mu$ after 2.2×10^{-6} seconds. But three decades after scientific community takes this idea seriously. Physicists use time dilatation to put muons at the planned energy range before muon disappearance, using circular accelerators -colliders-.

There are colliders of $e^-\ e^+$ and $\bar{p}\,p$. Physicists build them with relative facility in these days. In this sort of colliders in one direction circulate e^-'s, or p's, and in the other one circulate e^+'s or $\bar{p}$'s, respectively. As electrons or protons, or their antiparticles, do not decay, machines can accelerate them during the necessary time to get the planned energy; but this is not the case for muons. When physicists plan the muon collider, they must take into account the finite muon meanlife. The consequences in planning are fundamental, as are illustrated in the next paragraphs.

A pair decades ago, the possibility of constructing a muon collider was remote; now there is a project to construct one collider at Fermilab, USA. The project involves more than 100 physicists from 27 institutions from all over the world. For muon decays into $e\ \nu_e\ \nu_\mu$ after 2.2×10^{-6} seconds, in the acceleration process to take muons and antimuons at velocities close to c many muons will be lost. Muons and antimuons that reach velocities close to $0.9999985\,c$ will averagely live in the collider 1.27×10^{-3} seconds, according to the observer in the laboratory. This time is enough to experiment with muons and the yields from muon collisions.

Muon collider was proposed, in the 1970's, by Skrinsky and Neuffer. But it was up to the decade of 1990 that significative advances in capturing and cooling muon techniques made that the idea were taken seriously. Now it is possible to achieve luminosities in the muon collider comparable to those obtained in the proton-antiproton colliders or in the electron-positron colliders. See Figure 2.2

The responsible group of exploring the muon collider possibility, of high energy and high luminosity, is lead by R. B. Palmer.

Physics that could be studied in the muon-antimuon collider could be very similar to that studied in the electron-positron collider. The family of muon and the family of electron is the same. Both are leptons. Muon is like a massive electron. Close to two hundred times more massive than electron. For its great mass, muons produce much less synchrotron radiation than electrons. And because muons are different from electrons, in muon anti-muon collisions another matter states can be produced, which are different from those produced from electron-positron collisions.

There are some advantages in using muons instead of electrons in colliders. All of these advantages come from their physical properties, as follows:

Muons can be accelerated and stored in circular accelerators, like protons, at energies of 250 GeV or higher. Electrons must be accelerated in linear accelerators; in circular accelerators they lose too much energy, by synchrotron radiation. Muons lose less energy than electrons by stopping effects, for muons have higher mass. This radiation form is known as bremsstrahlung radiation. Muon energy spectrum is less wide than electron energy spectrum. There are more produced particles per bunch, for the energy is higher, the luminosity is higher. More beam particles per transversal section per second. The accelerator luminosity is a measure of particle interaction probability. For example, the muon collider luminosity is the probability that a muon will collide with an antimuon. The higher the collider luminosity, the higher chance of particle interaction. To achieve high luminosity, physicists must place as many particles as possible into as small a space as possible. The channel s, the squared total energy in the center of mass coordinate system, of Higgs bosons production is increased, because the coupling of any Higgs boson is proportional to muon mass. The higher the colliding particle mass, the higher the total energy available. This is similar to a pair of colliding cars. At the same velocity, the higher the mass of the colliding particles, the higher the total energy of the collision.

Reader can check in any advanced textbook of high energy physics -as those listed in References-, if he or she requires an explanation about the before mentioned techniques and concepts.

The effective energy from collisions of punctual particles, like muons, electrons or gamma rays, is about 10 times greater than the energy from proton collisions, which are not punctual. For that, a circular muon collider will be a factor of ten smaller than the equivalent proton collider. For example, a muon collider, of 4 TeV of energy in the center of mass of the collision, of 6 kilometers of circumference, will have an effective energy -a physical potential for physical discoveries- akin to that that would have the 80 km circumference superconducting supercollider. Also will be smaller than the conventional linear collider of electrons of the same energetic capacity. This linear collider must be 50 km long.

There are many difficulties in the construction of muon collider: There is no guarantee that it will be cheaper. Nor guarantee that it will have the required luminosity. The most serious problem is the generated by muon decay into electrons and neutrinos. This will produce a great amount of radiation. The design must have to take into account those problems. The collider design must solve them.

Theorization has taken far away physicists in their investigations of nature laws with its experimental and technological consequences that feedback theoretical ideas. But theorization is only one part of the scientific method or scientific process. Its counterpart and complement is experimentation.

2.1.3.2 *Experimentation*

Experience, in the most ample sense of this word, is the beginning of all science. All knowledge, and all science, is based on experience, on entelechies extracted from common experiences. The conflict between new experiences and old believes, not with old experimental facts, is the seed of new theories. Specially, new physical theories. Special theory of relativity, quantum theory, quantum mechanics, are typical examples. For instance. Sun rises at East and goes down at West. Always. It is a very old daily life fact. What has changed is not this fact, but the way physicists, or philosophers, explain it, or interpret it. And understand it. Special theory of relativity -also Galilean relativity- explains it satisfactorily. All new theory begins as a great heresy, that appears to contradict the entire human knowledge apparatus, and ends as a stony dogma. As a very well established savvy building. Quantum theory birth is a very good example of experimentation process that originated new theoretical ideas.

Quantum theory originated from the study of blackbody radiation distributions. Blackbody radiation is a good example that illustrates the process of experimentation. The example consists of the experimental distribution of the blackbody radiation intensity as a function of the frequency of the radiation, at different temperatures. To collect data, to interpret it, and to explain it, took the physicists many years. When physicists did it, physics changed forever.

A blackbody is a physical system that, in thermal equilibrium, emits radiation at the same rate that receives it. A metallic black lamina is a good approximation, the sun or another star is another good example, the entire universe is perhaps the best of all of them. None of them is useful in the laboratory, for it is not possible to change stars or universe temperatures. The metallic plaque is a rough approximation, not a good one, in spite of changing its temperature is relatively easy. For studies of blackbody radiation distributions, physicists construct better experimental approximations, like metallic cavities heated by electric current.

The laboratory metallic cavity, to study blackbody radiation distributions, can have the size of a regular orange. And to let thermal radiation get out, it has a some millimeter diameter hollow. Figure 2.3 shows the device to study blackbody radiation. In this case, the cavity is a cylindrical device. Marked by c letter. The rest of the instrument is addition of measuring and supporting instruments.

Physicists also have measured the distribution of sun emitted radiation, or of another star, and the background radiation of entire universe. These radiation distributions are already given at a fixed temperature. Physicists can not change it. Figure 2.4 shows the distribution of the background radiation of the entire universe. From this, entire universe is like a blackbody. Figure 2.5 shows the radiation distribution of the Polar Star that has 8300 K of atmosphere temperature; Figure 2.6, the sun radiation distribution at 5700 K of atmosphere temperature. The wavelength where the distribution reaches its maximum coincides with the wavelength where human beings eyes have their maximum efficiency. Why it is so? Human evolution and sun evolution are very tight related. Why?

Other story are laboratory blackbodies. Physicist can manipulate temperature of the experimental cavities. And obtain radiation distribution curves at different temperatures. See Figures 2.7 and 2.8. Compare them, in form, with Figure 2.4, 2.5 and 2.6 curves. Figure 2.9 contrasts ideal blackbody radiation distribution with real -quartz- radiation distribution. They disagree, but both follow the general and average shape.

In experimental blackbodies, physicists can study thermal equilibrium between electromagnetic radiation and atoms of the cavity. The study lets answer questions as this: How is the interchange of energy between the atoms of the blackbody and the electromagnetic field? And others. Physicists obtained experimental results after years of efforts. The results are presented in the form of distribution curves, like the ones showed by Figures 2.4-2.8; the intensity of the radiation (radiation density per wavelength) physicist plot it in the vertical axis and the wavelength - or frequency - of radiation in the horizontal axis. See Figures 2.4-2.9.

Experimental curve of the intensity of radiation begins at zero at wavelength zero, as can be seen from the extrapolation in the Figures 2.4-2.9. At a given temperature (example 500 K), when wavelength increases radiation intensity increases; radiation intensity reaches a maximum and decreases. Asymptotically intensity of radiation goes to zero when wavelength of radiation becomes high. At another temperature (example 1000 K), distribution of radiation has the same shape and its intensity reaches a maximum at shorter wave length. See Figures 2.7 and 2.8.

From the above cited Figures, physicists knew that they were dealing with matter-radiation equilibrium problem. And understanding this equilibrium implies that they must be able to deduce, and obtain from first principles, curves that follow experimental data distributions. This means, physicists have to deduce that curves from classical thermodynamics or Maxwell electrodynamics, that were all theoretical schemes they have to solve this problem.

When physicists began studies of blackbody radiation distributions, they counted with classical mechanics, classical electromagnetic theory, and classical thermodynamics. Rayleigh and Jeans in England, each one by his own efforts, tried to solve blackbody radiation distribution problem using electromagnetic theory. The result was a catastrophe. A big dud. From classical electromagnetic point of view, radiation propagates continuously -radiation behaves like a wave, as a continuous train-; therefore, the most natural starting hypothesis is to consider that the interchange of radiation, between electromagnetic field and blackbody atoms, is carried continuously. Like a wave, or flux of water, appears. Then, so Rayleigh and Jeans assumed it. Calculations based on electromagnetic theory were in frank disagreement with experimental curves. That is, electromagnetic theory conducts to erroneous predictions. This is, electromagnetic theory can not explain blackbody radiation distribution. Neither the classical thermodynamics can do, as next section will show.

Planck in Germany tried to solve the same problem -blackbody radiation distribution- using classical thermodynamics. After many failures, and about four years of efforts following essentially the same hypothesis about the interchange of energy that Rayleigh and Jeans had followed, Planck tried a desperate hypothesis: He supposed that there is discrete interchanged of energy between the electromagnetic field and wall cavity atoms. Planck hypothesized that the form in which electromagnetic radiation is interchanged with the blackbody atoms is discrete, not continuous as every physicists had supposed before. The success was immediate. Theoretical prediction agree spectacularly with measurements. The obtained curves agree perfectly with experimental data. The solution of blackbody radiation problem lead to a deep revolution in the knowledge about nature. And so far, it has no ended. See any book about modern physics, 20 from the references, for the mathematical expression of Planck solution.

Planck solution is perfect. It agrees very well with data distribution. See Figure 2.8. There, in each case, it is superimposed Planck proposed distribution to data distribution. Reader must conclude by himself or herself, after studying deeply the coincidence between measurements and given values from Planck theoretical expression.

In his autobiography Planck wrote:

The problem was in founding a formula for R so that it would lead to the law of energy distribution established by measurements. In consequence, it was evident that for the general case it had to obtain that the quantity R be equal to the sum of one term proportional to the first power of the energy and of another one proportional to the second power of the energy so that the first term were decisive at small values of the energy and the second term were significant at bigger values. In this way I got a formula for the radiation that I presented for study at the 19 October 1900 meeting of the Physical Society of Berlin.

And he follows as this:

The next morning I got the visit of my colleague Rubens, who came to tell me that the night before, after knowing my conclusions presented at the meeting, he had compared my formula with his measurements and he had discovered a good agreement in all points. Also Lummer and Pringsheim, who at the beginning believed that they had found divergences, retired their objections because, according with what Pringsheim told me, the divergences that they had observed were for an error in the calculations. Besides, the measurements performed later confirmed time after time my formula of the radiation; while more refined were the applied methods, more exact resulted the formula.

The following developments of Planck ideas are very instructive. Max Planck writes in his autobiography:

But, even when the absolute precise validity of the formula of the radiation were established, while it had merely the credit of being a discovered law by fortunate intuition, we could not hope that it had more than a formal significance. For this reason, the same day I formulated the before mentioned law I dedicated myself to investigate its real physical significance, that led me automatically to the study of the interrelation of the entropy with the probability, in other words, to continue developing the Boltzmann ideas. For the entropy S *is an additive magnitude, while the probability* W *is a multiplier, simply I postulated that* $S = k.log(W)$*, where* k *is a universal constant, and I investigated if the formula for* W*, that is obtained when* S *is replaced by the corresponding value from the law before mentioned, could be interpreted as a measure of the probability.*

And in another paragraph he continues:

Now, in the case of the magnitude W*, I discovered that to interpret it as a probability it was necessary to introduce a universal constant, that I denominated* h*. Because this constant has action dimensions (energy multiplied by time) I christened it as (elementary quantum of action). Hence, the nature of the entropy as a measure of probability, in the sense indicated by Boltzmann, was established also in the dominion of radiation.*

And about the physical significance of h Planck wrote:

Even the physical significance of the elementary quantum of action for the interrelation of the entropy and probability was established conclusively, regardless the role played by this new constant in the regular and uniform course of the physical process, the constant was still an unknown. In consequence, immediately I tried to unify in some way the elementary quantum of action h *with the frame of the theoretical classical theory. But in all* *tries, the constant was inflexible. Always that it were considered as infinitely small -e.g., when we treat with higher energies and longer periods of time- everything went fine. However, in the general case, the difficulties popped up in one corner or other and became more notorious at high frequencies. Because the failure to solve this obstacle, it became evident that the elementary quantum of action has fundamental importance in atomic physics and that its introduction inaugurated a new epoch in the natural science, because announced the advent of something without precedents which was destined to redesign fundamentally all perspectives of the physics and the human thought that, since the epoch when Newton and Leibniz laid the foundations of the infinitesimal calculus, were based on the supposition that all causal interactions are continuous.*

And Planck was right. When physicists got the quantum image of nature and the laws for quantum behavior, physics changed and physical image of whole universe too. And in consequence, society. The world. Chapter 4 will treat these themes.

As a consequence of this new knowledge, society got a huge number of new tools. The transistor is an instance. Chip is another one. Microwave oven another. Physicists increase borders of knowledge about nature using the new mechanics. They understand nature of X-rays, emission of particles, light, photosynthesis, etc.

2.2 Conclusions

As the reader can appreciate from the above sections, the process of theorization and the process of experimentation do not oppose each other. The history of Planck quantum discovery is a great example. Those are processes that reinforce and feedback each other. They correct each other and enrich human image of the universe. When they do so, they make human knowledge on nature advance forward.

Physicists have corrected ideas in physics, many times, using the experimental method. Galileo Galilei corrected Aristotelian ideas about the laws of mobile bodies. A. Michelson emended the ideas about space and ether of classical electrodynamics. Each of those corrections make physics goes forward. Opened new perspectives in physics. And permitted the possibility of creating new branches of physics. Like special and general relativity. Theory of information. Experimental philosophy. Crystallography. And many others.

Physics is an experimental science. This is an unavoidable truth. For physicists understand the world it is indispensable that they have a perceptual image created and supported by experimental evidence. A collection of experimental data does not give us an image about the universe. In the same way, a collection of axioms, without experimental support, neither give us an image about the external world. Both constructions are possible. And indeed exist: Weather collection data and modern algebra are instances, respectively. The image of the world is constructed on the experimental and axiomatic truth. The axioms must be supported by the most complete experimental evidence. And the logical implications of those axioms must have experimental corroboration, experimental facts that necessarily must be happening, and were unknown up to when they were unveiled by logical thought.

Physics history registers many examples: Electromagnetic waves predicted by Maxwell; particle wave nature, by De Broglie; time dilation, by Einstein. And many others.

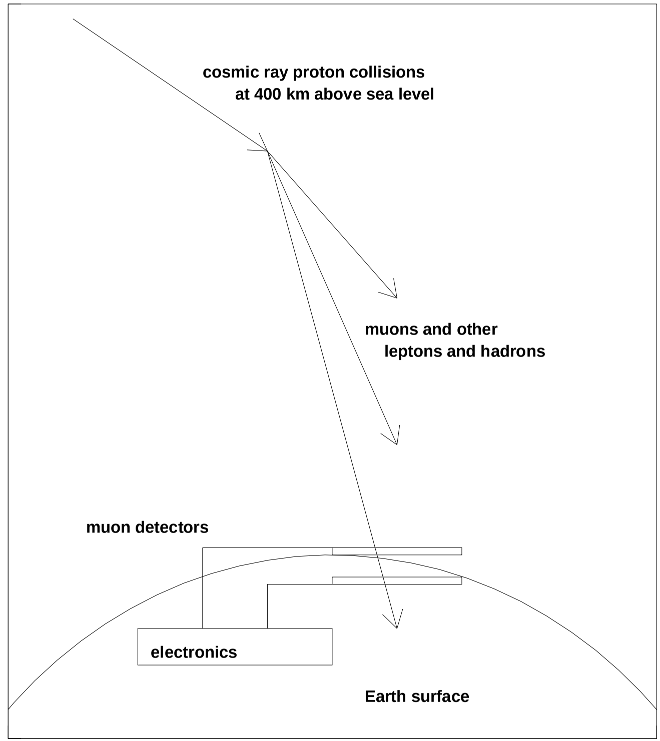

Fig. 2.1 Muon production very high in the earth atmosphere and arrival at earth surface, where they are detected.

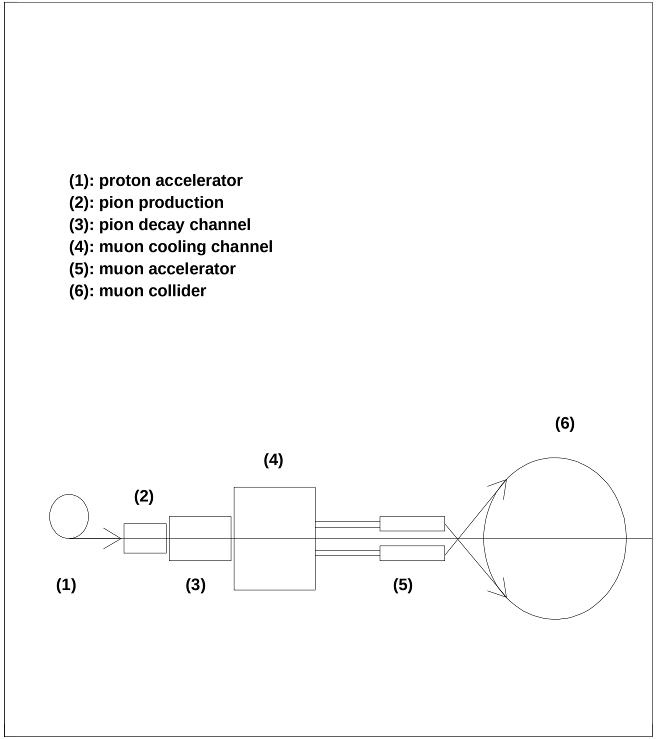

Fig. 2.2 Scheme of muon antimuon collider.

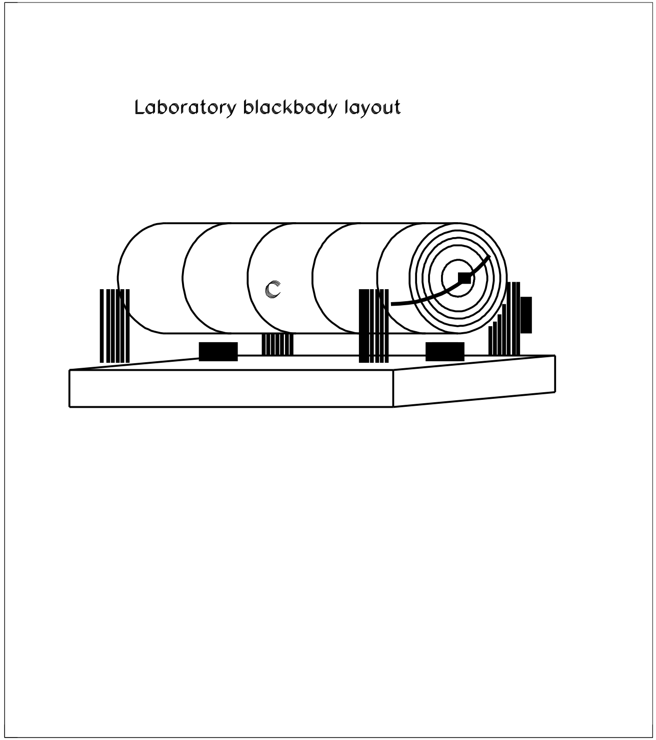

Fig. 2.3 Very old laboratory blackbody.

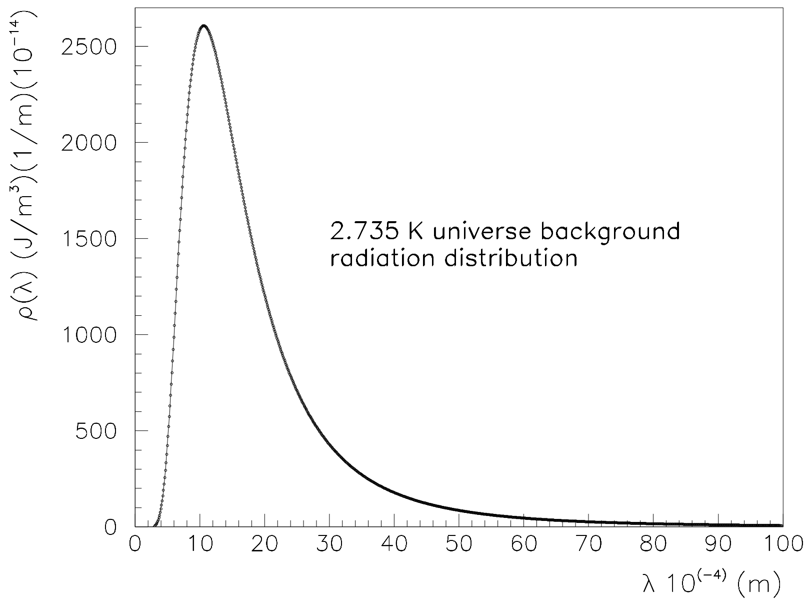

Fig. 2.4 Blackbody radiation distribution of the entire universe at 2.735 K. Radiation density per unit wavelength.

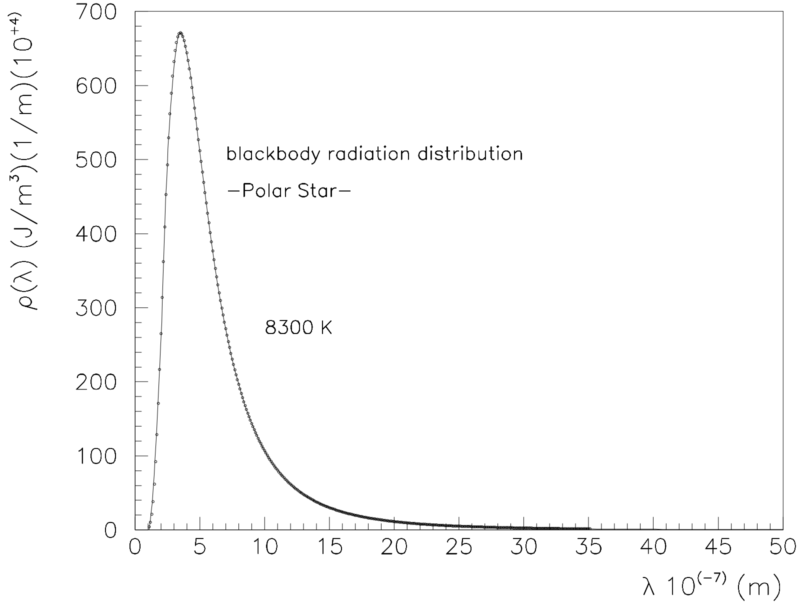

Fig. 2.5 Polar Star blackbody radiation distribution at 8300 K. Radiation density per unit wavelength.

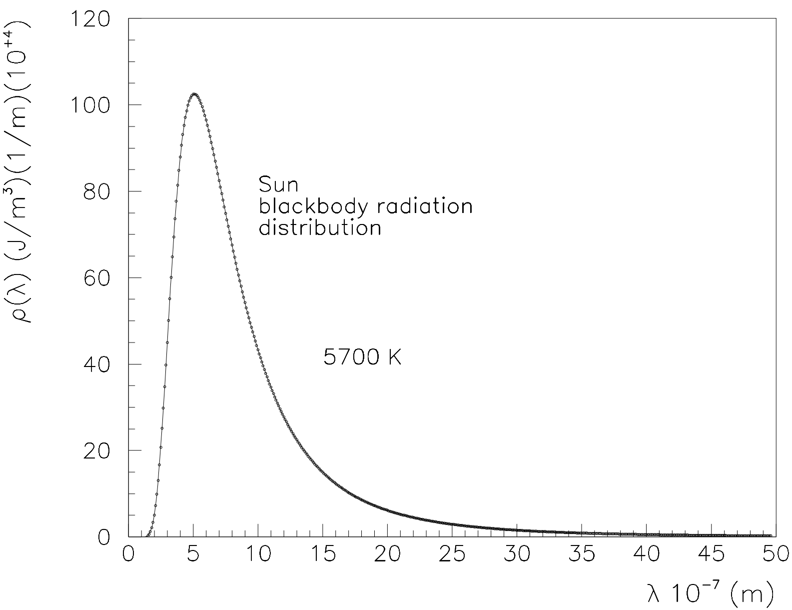

Fig. 2.6 Sun blackbody radiation distribution at 5700 K. Radiation density per unit wavelength.

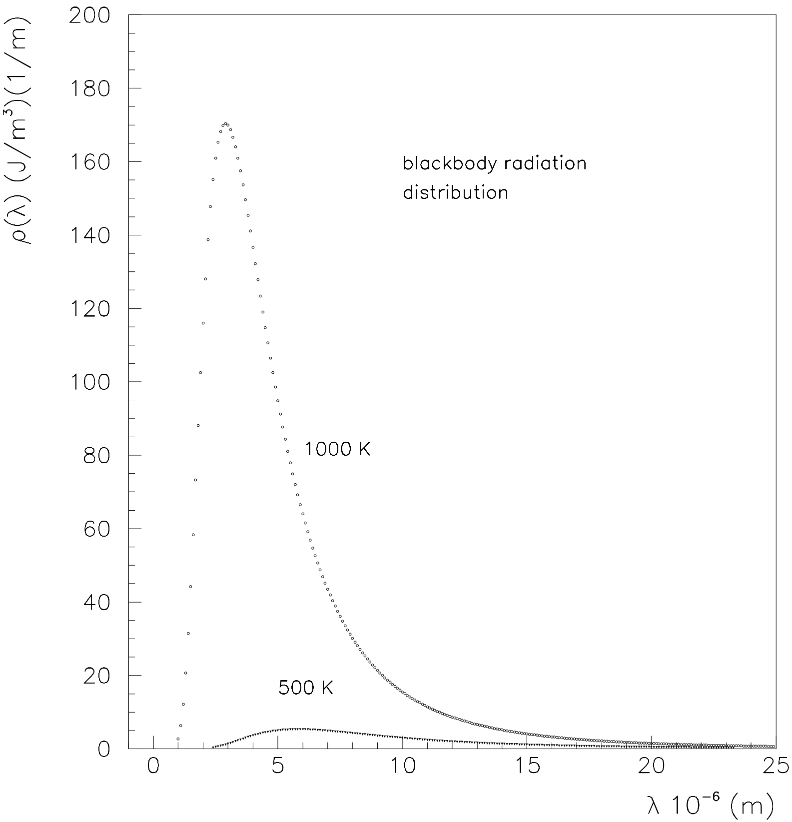

Fig. 2.7 Two blackbody radiation distributions at two different temperatures, open circles and filled triangles. Radiation density per unit wavelength.

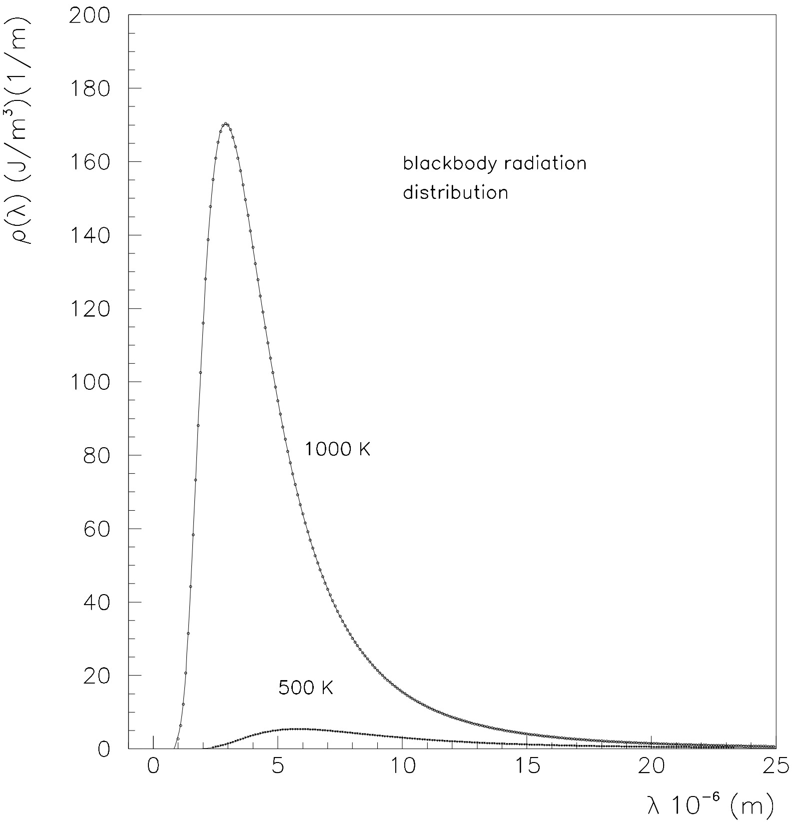

Fig. 2.8 Two blackbody radiation distributions at two different temperatures, open circles and filled triangles. Radiation density per unit wavelength. And Planck theory predictions, solid line.

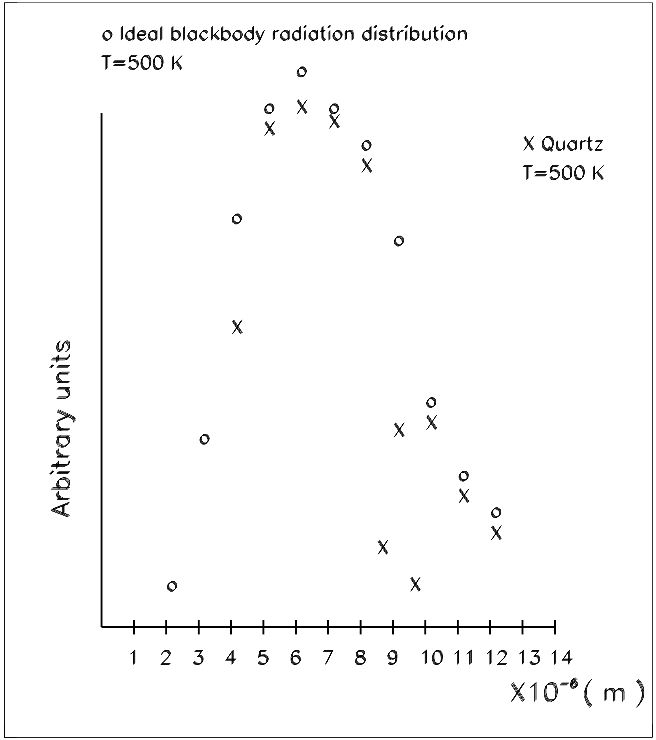

Fig. 2.9 Comparison of ideal blackbody radiation distribution with quartz radiation distribution. In the average they agree.

Chapter 3

Experimental High Energy Physics

3.1 Introduction

High energy physicists are the heirs of the very old tradition of quest for ultimate constituent of matter. That began, probably, with the ancient Greeks, and continues up to these days. It constitutes the most intimate dream of all philosopher or physicists -or even of poets-. And will end, no one knows when.

3.2 Atom

From what matter is made off? Is there any ultimate and indivisible constituent of matter from where everything is made off? These were, probably, the starting questions of that first philosophers. Still physicists have no a definitive answer to them. Up to these days, physicists have no exhausted all possibilities, all possible responses, trying to answer them. Antique Greeks tried the first answers: They invented atomic theory. Besides other theories, like the theory of continuum.

Atomic theory was born as an opposite theory to the theory of continuum. The vintage Greeks, in the V Century before Common Era, created the first ideas. For them, atom meant indivisible; that is, the smallest part not possible to be broken down, from where all things are made off. In these days atom, 'a la Greek', is synonym of elementary particle.

In spite of that Greek got their hypothesis from lustful evidences, it seems that they never tested consequences of their theories. The experimental method formally and systematically developed would be invented 22 centuries later.

Experimental evidence and irrefutable proof of the existence of atoms came centuries later. The experimental method, as scientists know in these days, was born in the XVII century. Therefore, 23 centuries passed to physicists were able to get the first experimental evidences on the existence of atoms. Those were established close to XIX century. Chemists did the pioneer works. In these days, chemist is an area of physics.

Of that works, A. L. Lavoisier was a notable precursor in the XVIII century. John Dalton continued and crystallized Lavoisier achievements. By himself Dalton was a pioneer, doing the most important contributions: He created the basis of modern chemistry. He decomposed and weighed hundreds of substances. He searched proportions in which those substances combine. He become to, and enunciated, the law of chemical proportions. The law of Dalton.

The law of proportions of Dalton required, by necessity, the hypothesis of atoms. His investigations clarified that atoms have a finite size and a finite weight; that there are many classes of atoms -not only one, or just a few, as Greeks hypothesized- ; that Hydrogen atom is the lightest; that there are substances composed by two classes of atoms, combined one to one -like in table salt-; or some combine two to one -like in ordinary water-; and that other substances are formed by more than two different sort of atoms -like sugar-. He detected simple substances. And obtained others by decomposition, by analysis. These are formed by one class of atom. The central problem was to say when a substance could not be decomposed into others smaller any more. Was it really elemental or was Dalton unable so far to find the method to decompose it? Only experience could indicate it. If one method works decomposing one substance, this method could work with another. But if it does not work, this does not imply that the treated substance is an element. Dalton had, and leave, many open questions.

Dalton's knowledge and huge collection of data let Mendeleev classify, by weight, the simple substances -elements-. He left empty places in his chart, when he had not the element to place in. Empty places indicated necessarily the existence of some element not yet discovered. Helium is an example. Physicists firstly detected it in the sun, using spectroscopy technique. And then in earth. Mendeleev table let him foretell other elements that later were discovered. Classification scheme let physicists formulate other problems -or ask other questions- that remained as mysteries up to the invention of quantum mechanics. Chemical and physical properties of metals are very common instances: Metals are very good conductors of heat and electricity. Gases are other instances: Some gases combine with other substances, and some does not combine, exploding or forming some composes. Dalton atomic theory can not explain these daily life facts. Atoms of the same substance are identical; is another example. Is the atom mass distributed uniformly inside it? A question without answer in Dalton's model. Is an atom composed of something? And so for.

In these days physicists know 118 classes of atoms.

The one hundred and eighteen classes of different atoms is very far away from the proposed simplicity of ancient Greeks about structure of matter. They supposed the existence of a few different sorts of atoms as they called them. Besides, the atom of chemists revealed itself as a too complex physical system, very far away from Democritus idea of atom as simple, or without structure, object. The atom of chemists is a universe by itself. It has parts. It is composed of many objects. It can combine with other atoms in a very knotty ways up to make very complex substances of not understandable properties like life, or of very intricate complexity as the universe as a whole. Even more, in vast aggregations atoms are responsible of the structure of physical space-time. The life of galaxies, of stars, etc.

That atoms, tiny universes, physicists began to unveil at the end of the XIX century. In 1897, J. J. Thomson discovered the electron -an object much less light than the atom of hydrogen-. That is part of all atoms. The electron is close to two thousands more light than the proton. The experimental evidences indicated that the electrons came from inside the atom. From Dalton atom. When atoms get hot, or when some material stubs up another one, electrons appear -they are released from the atom-. The thermionic electrons from metals, J. J. Thomson used to measure the electron mass. Or electron electric charge to mass ratio.

In his Nobel lecture -1906- Joseph John Thomson wrote:

I wish to give an account of some investigations which have led to the conclusion that the carriers of negative electricity are bodies, which I have *called corpuscles, having a mass very much smaller than of the atom of any known element, and are of the same character from whatever source the negative electricity may be derived.*

In his paper, where he reported his electron discovery, J. J. Thomson concluded as follows:

I can see no escape from the conclusion that they are charges of negative electricity carried by particles of matter.

Based on the discovery of electron, physicists formulated the first model of atom.

That model was known as the atomic model of J. J. Thomson, for it was proposed by the discoverer of electron. The image of atom, formulated by this model, is a cake with dry grapes inside; electrons (dry grapes) are inside the mass of atom (cake). From the beginning, this model faced many difficulties to accommodate all the known experimental evidences. It could not explain emission spectrum of Hydrogen atom, for instance; nor the way some particles scatter when they collide with atoms. And many others.

Thomson model had a short life; it did not resist experimental tests. Thomson himself pushed the experimental prove to his atomic model. In 1911 Rutherford and coworkers discovered atomic nucleus. Their method consisted in bombarding thin foils of gold with alpha particles -helium nuclei- and detecting alpha particles dispersed. Many particles dispersed few degrees, a few particles dispersed many degrees. Rutherford showed analytically that the obtained dispersions were inconsistent with Thomson atom and were consistent with the existence of a very small and very dense nucleus. In that nucleus, more than 99.9 % of atomic mass is concentrated.

Rutherford was the leader of these investigations. He himself formulated the atomic model to accommodate this important experimental evidence. The image of atom, according to Rutherford model, is a central nucleus -very small, heavy and dense- surrounded by electrons, that move around the nucleus like planets around the sun; electrons are very small, light and point like, and far away from nucleus. The model reminds the image of a primitive solar system: A space almost empty, where a very massive point makes circulate around it smaller objects. This model, even more close to reality than the model of Thomson, also faced serious difficulties to explain all the known experimental evidences. Neither could explain the electromagnetic emission spectrum of the hydrogen atom. And it is unstable. It can not survive forever, for an accelerated charge -like the electron revolving around the nucleus- must radiate its energy up to collide the nucleus. From what the nucleus is made off? What is the electric charge distribution inside it?

This question and others the model of Rutherford could not answer. It had a ephemeral life. In 1913 the model about the atom changed again. This time by influence of the theory of quantum, that Niels Bohr applied when he tried to explain the emission electromagnetic spectrum of the hydrogen atom. The atomic model of Bohr is a blend of the Rutherford atomic model, classical ideas, and quantum ideas; it is a fortunate combination of classical ideas about the motion and of quantum ideas about the energy and momentum interchange. The image of atom is now more close to a planetary system, the nucleus takes the place of the sun and the electrons play the role of the planets. But very different in its dynamics: The orbital angular momentum of electrons around nucleus is quantized; electrons energy too. Electric charge too. The variables used to describe planetary motion take values continuously.

The atomic model of Niels Bohr succeeded definitively. The model explained satisfactorily the emission and absorption spectrum of Hydrogen atom. The mysterious series of emission, like the Balmer series, and others, were understood plainly. Some experimental constants, that apparently were unconnected with other constants, were understood in terms of elementary constants like electron charge, electron mass, Planck constant, and others. However, the atomic Bohr model also failed completely; it was unable of explaining the emission and absorption spectrum of more complicate atoms than Hydrogen atom. The efforts that physicists did to generalize atomic Bohr model to more complicate atoms failed always. The abandonment of this route of exploration lead to quantum mechanics. The theory, for the mechanics, of all quantum process.

In spite of inconveniences and theoretical image failures, physicists continued improving the experimental atom image. Making discoveries. They aggregated the neutron to the list of particles that conform the nucleus of the atom.

James Chadwick discovered neutron in 1932. The image of atom changed again, specially of heavy atoms -nor of the Hydrogen atom, that is the lightest-. The neutron takes an essential part in the constitution of atomic nucleus. The nucleus of heavy atoms is composed by protons and neutrons. The number of protons equals the number of electrons in the atom. The atom is electrically neutral. The rest of the atomic mass is from the neutron that its mass equals -very close- the proton mass.

Hydrogen atom is the unique one that has nucleus conformed by a proton. The rest has protons and neutrons in their nuclei. For instance, the Helium has two protons and two neutrons integrating its nucleus. All atoms are electrically neutral. This is because there is equal number of protons and electrons inside constituting the atom. The neutrons in the atomic nuclei vary in number. An excess of neutrons inside the nucleus makes the nucleus unstable. In this case, the unstable nucleus decays into lighter and stable nucleus. This is the key to disintegrate atoms. Atoms are bombarded with slow neutrons in a way that the nucleus can catch them and become unstable atoms. The excited atom will decay. The released energy can be used, in the form of heat, to generate electric energy, or a source of new neutrons to continue a nuclear reaction chain.

Chadwick discovery and quantum mechanics finished the image of atom. The Dalton atom. In terms of quantum mechanics, atom has heavy nucleus conformed by protons and neutrons, without well defined position; nucleus is surrounded by clouds of electrons without well defined position and momentum; and electrons remain in well defined states of energy. So do neutrons and protons inside the atomic nucleus.

However, there are more mysteries in the atom adventure: Chemist atom, Dalton atom, truly is a universe in itself. Each one of its components has many physical properties, besides its mass. Spin is one of these. And additionally, as it will be seen in next sections, neutrons and protons from nucleus resulted composed systems, integrated by many sort of particles, with other physical characteristics, capable of access other physical states.

3.3 Particles

Close to the end of the 1920 decade, and early the following one, the constitution of matter image was given by atomic theory, leading by Bohr atomic model. All that exists physically is made of atoms that follows certain rules for combination, absorption and radiation emission. Electrons are electrically negative; and protons, positive. The electromagnetic energy is interchanged in units by the physical systems. There are no more blocks in nature. At least physicists were unaware of something else.

The above image changed when C. Anderson discovered, in 1932, the electron with positive electric charge or positron (e^+). This discovery even when the relativistic quantum mechanics -union of quantum mechanics and special theory of relativity- predicted it, was a surprising affair. It came to start a series of discoveries that changed the image on constitution of matter and the whole universe. First, because this discovery opened the possibility to physicists could think that in nature antiparticles are produced in general; second, for its technological use let physicists reach higher energies and new purer states of matter. For example, M. L. Perl invented positron-electron collider and discovered the τ lepton and other states produced abundantly in the collision e^-e^+.

In his Nobel lecture, *Reflections on the Discovery of Tau Lepton*, 1995, M. L. Perl wrote:

I see the positron, e^+, and electron, e^-, as tiny particles which collide and annihilate one another. I see a tiny cloud of energy formed which we technically call a virtual photon, virtual; and then I see that energy cloud change into two tiny particles of new matter -a positive tau lepton, τ^+, and a negative tau lepton, τ^-.

Chapter 4 will comment briefly about the applications of e^+ in medicine.

H. Yukawa, in 1935, predicted meson π. This was the first particle that had its own theoretical settings. It was, at that time, the carrier of nuclear forces.

Physicists looked for meson of Yukawa in cosmic rays, in the top of high mountains and using very rudimentary equipment. However, in their search, in cosmic rays physicists discovered in 1936 lepton μ. (muon) -no one has been predicted it-. Also, physicists discovered in the cosmic rays, during the decade of 1940, the baryon Λ^0 and the K^0 meson. Physicists called them strange particles, for they are created from proton-nucleus collisions, always in pairs, and living long enough to travel a few centimeters in the laboratory reference frame. In that decade, physicists had not the theoretical frame for those particles. No one knew, nor understood, why those particles pop off from cosmic rays. And all of them appear to form groups, or families, sharing some characteristics.

The groups of strange particles comprehend Λ^0 group, Σ group, K group, and Ξ group. Their production always is associated, or they are always created in pairs. For example, always that appears a Λ^0, there appears another strange particle, it could be a K^+ or K^0. Like when a charged particles is created, always is created another one with, inside other conservation laws, the opposite charge sign. This is because electric charge is conserved.

All strange particles decay via weak interactions, hence, the long distance traveled by these particles. Strange resonances do it through strong interaction, this means the interactions that are generated in proton-proton collisions. Meanlife is of the order of 10^{-8} seconds for strange particles; of the order of 10^{-23} seconds, for strange resonances.

In these times, physicists do not depend on cosmic rays to study those particles; they produce them in modern accelerators, using different beams and different targets. And they study them in controlled situations, using huge statistics collected in a few hours. In that conditions physicists study mechanisms of creation and physical properties of particles and resonances. Physicists easily measure masses, decay channel rations, meanlife times, spins, electric charges, conservation of energy in particle reactions, conservation of angular momentum, polarization, angular distributions, cross sections, etc.

Basing arguments purely in conservation of energy, linear momentum, and of angular momentum in nuclear splitting, in the decade of 1930, Pauli proposed the existence of neutrinos. Pauli's idea seemed at that time very weird: Neutrinos have no mass -probably-, carry only angular momentum, and travel at the speed of light -probably-. Fermi, in 1933, incorporated neutrino to the theoretical frame work of beta disintegration. Beta decay means the presence of beta rays -electrons- in the final state. Other particles are present, of course, in the final state of the reaction -protons or pions, for instance-. In neutron beta decay, it goes to an electron, a proton, and a positron neutrino. Neutron meanlife is about 16 minutes. Conservation of energy, electric charge, strangeness, angular momentum, baryonic number, lepton number are laws the neutron, and every particle decay, follows.

In the case of beta decay -for instance a neutron that decays into a proton, an electron, and a neutrino associated to positron- the produced neutrino is associated to the positron; this means, it is an antineutrino. The neutrino, or neutrino associated to the electron, appears in other decays; for example in the decay of an antineutron into an antiproton, a positron, and a neutrino associated to the electron -or neutrino-.

Reines and Cowand in 1954 detected, indirectly -this means by the reaction that it generates or produces-, the associated neutrino to the electron, after many years of very intensive investigations. Their technique consisted in observing the reaction $\nu_{e^+} + p \rightarrow n + e^+$, where neutrinos came from a nuclear reactor, and in this case neutrinos are associated to positron. This is an example of the inverse beta decay.

Reines first idea to search for neutrinos was using atomic bombs as neutrino sources. He commented his ideas with E. Fermi. Fermi agreed.

As Reines wrote in his Nobel lecture in physics, 1995, *The neutrino: From poltergeist to particle*:

Fumbled around a great deal before we got it. Finally, we chose to look for the reaction $\nu + p \rightarrow n + e^+$. *If the free neutrino exists, this inverse beta decay reaction has to be there, as Hans Bethe and Rudolf Peierls recognized, and as I'm sure did Fermi, it was not know at the time whether* ν_{e^-} *and* ν_{e^+} *were different.*

But the above story is not the whole story about neutrinos. There are three sorts of neutrinos that are distinguishable from their respective antineutrinos, for their produce different particle reactions.

In 1962, the physicists -L. M. Lederman, M. Schwartz, and J. Steinberger- sought, deliberately, and found a second class of neutrino. The neutrino associated to the lepton μ. For this discovery they got the 1988 Nobel prize in physics. The Nobel dedication is as follows:

For the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino.

L. M. Lederman, in his Nobel lecture *Observation on particle physics from the two neutrinos to the standard model*, wrote:

After the quark flavor model, Bjorken and Glasshow, in 1964 transformed the baryon-lepton symmetry idea to quark-lepton symmetry and introduced the name "charm". They predicted the existence of a new family of particles carrying the charm quantum number.

Even μ neutrino is produced in cosmic rays, physicists created it using accelerators of particles. In cosmic rays, the flux of μ neutrino is so weak to produce a worth signal. And detected it in the same way that detected the neutrino associated to electron: By the reaction that it originates. Neutrino μ is an experimental evidence. It is distinguishable from the neutrino associated to electron. They do not produce the same reactions. As an electron produces a different reaction from that produced by a proton. How it happens, no body knows. Natural events happen that way. Some day physicists will know it.

In the above reactions, neutrinos are not created alone. They are created sometimes that associated charged leptons are created. For example, when an electron is created in a hadronic reaction -*pp* collision-, sometimes is created the neutrino associated with positron, or a positron is created. Always happens one or the other situation. This production follows conservation of leptonic number, total angular momentum, energy, electric charge, etc. And most of the time those particles are not created directly from the collision, but there are some intermediate states, from where they come from, with very small meanlife, that decay strongly. This is, from resonances.

Physicists discovered those short lived states in 1960 decade. They called them resonances, for their mass distribution resembles the distribution of the intensity of a resonant classical oscillator. Physicists discovered the resonances N, Ξ, Σ, etc., using different detection techniques and different analysis techniques. These hadronic states are created by strong forces. And decay by action of the same forces. Meanlife, for these states, is of the order of 10^{-23} seconds, as it has been stated above. Luis W. Alvarez discovered many of them. And got the 1967 Nobel prize in physics, for his discoveries.

In his Nobel lecture, *Recent developments in particle physics*, he wrote:
In 1952 Anderson, Fermi and their collaborators at Chicago started the classical experiments on the pion-nucleon interaction at what we would now

call low energy. They use the external pion beams from the Chicago synchrocyclotron as a source of particles, and discovered what was for a long time called the pion-nucleon resonance.

Physicists, at the present time, have detected no only those resonant states, but excited states of them. No one knows why they are there. But they are there. It seems that the pattern produced at daily life energies -at the level of protons, electrons, and neutrons- repeats at higher energies.

At those high energies, in 1974 S.C.C. Ting and B. D. Richter discovered the resonance J/Ψ. And in 1978 L. Lederman and co-workers discovered the Upsilon resonance states: Υ, Υ' and Υ''. In the same decade physicists discovered τ lepton, as it was stated before. From this discovery, it was evident that there must exist a third neutrino. Just by pure symmetry in natural laws. The neutrino associated with τ lepton. Physicists indirectly detected it in 1997, at Fermilab. See Chapter 4.

Up to these days, physicists have register close to 400 states, that they call particles, resonances, etc. The complete list is given in the Particle Data Book. See References.

3.4 Families of Particles

From the whole particle listing, physicists extract some regularities: Some particles share characteristics, like meanlife, or average time of life, mass, charge, spin, modes of decay, isospin, spin, etc. Because of this, physicists classify them into families, basing this classification in the quark model. Like the classification of Mendeleev of elements discovered by Dalton. In the periodic table, elements are chemical grouped by their characteristics; in the quark model, by characteristics like mass, isospin, etc.

Current classification of particles is not complete. It is still changing. Because physicists do not know all particles and they do not know of their properties. For example, physicists do not know yet definitively if neutrinos have mass or not, apparently they have; what is the mass of photon, is another instance. If quarks are composed particles or pointlike ones, another one.

Table 3.1 The most important physical properties of the quarks.

Property / quark	d	u	s	c	b	t
q, electric charge (e units)	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$+\frac{2}{3}$
Iz, isospin z component	$-\frac{1}{2}$	$+\frac{1}{2}$	0	0	0	0
s, strangeness	0	0	-1	0	0	0
c, charm	0	0	0	$+1$	0	0
b, bottom	0	0	0	0	-1	0
t, top	0	0	0	0	0	$+1$
P, parity	+	+	+	+	+	+
J, spin	$+\frac{1}{2}$	$+\frac{1}{2}$	$+\frac{1}{2}$	$+\frac{1}{2}$	$+\frac{1}{2}$	$+\frac{1}{2}$

Table 3.1 illustrates the properties of the quarks.

The Table 3.2 and 3.3 illustrate two families of mesons. Each one has 16 particles.

Table 3.2 Family of 16 particles. Pseudoscalar Mesons.

			$D_s^+(c\bar{s})$			
	$D^0(c\bar{u})$				$D^+(c\bar{d})$	
		$K^0(d\bar{s})$		$K^+(u\bar{s})$		
$\pi^-(d\bar{u})$			$\pi^0, \eta, \eta_c, \eta'$			$\pi^+(u\bar{d})$
	$K^-(s\bar{u})$				$K^0(s\bar{d})$	
		$D^-(d\bar{c})$		$\bar{D}^0(u\bar{c})$		
			$D_s^-(s\bar{c})$			

Table 3.3 Family of 16 particles. Vector Mesons.

			$D_s^{*+}(c\bar{s})$			
	$D^{*0}(c\bar{u})$				$D^{*+}(c\bar{d})$	
		$K^{*0}(d\bar{s})$		$K^{*+}(u\bar{s})$		
$\rho^-(d\bar{u})$			$\rho^0, \omega, J/\Psi, \phi$			$\rho^+(u\bar{d})$
	$K^{*-}(s\bar{u})$				$K^{*0}(s\bar{d})$	
		$D^{*-}(d\bar{c})$		$\bar{D}^{*0}(u\bar{c})$		
			$D_s^{*-}(s\bar{c})$			

The Table 3.4 and 3.5 illustrate two families of baryons. Each one has 20 particles. In both cases, note the arrangements in the electric charge and in the constitution of quarks.

Reader can put mass values, or another physical parameter like isospin, to particles and observe the distribution, in masses or in other physical parameter chosen, in each of the arrangements. Also reader can take the differences in masses, of pairs of particles that are on the same line vertical or horizontal. Those physical values are reported in the particle data book. See References.

Reader must conclude by herself or by himself, after thinking on the above schemes. Maybe he or she can create another way of classifying particles.

Table 3.4 Family of 20 particles. Baryons.

	$\Xi^+_{ss}(dcc)$				$\Xi^{++}_{cc}(ucc)$	
			$\Omega^+_{cc}(scc)$			
$\Sigma^0_c(ddc)$				$\Lambda^-_c(udc), \Sigma^+_c(udc)$		$\Sigma^{++}_c(uuc)$
	$\Xi^0_c(dsc)$				$\Xi^+_c(usc)$	
			$\Omega^0_c(ssc)$			
		$n(udd)$			$p(uud)$	
$\Sigma^-(dds)$				$\Lambda(uds), \Sigma^0(uds)$		$\Sigma^+(uus)$
	$\Xi^-(dss)$				$\Xi^0(uss)$	

Table 3.5 Family of 20 particles. Baryons.

			$\Omega^{++}_{ccc}(ccc)$			
		$\Xi^+_{cc}(dcc)$		$\Xi^{++}_{cc}(ucc)$		
			$\Omega^+_{cc}(scc)$			
	$\Sigma^0_c(ddc)$			$\Sigma^+_c(udc)$	$\Sigma^{++}_c(uuc)$	
		$\Xi^0_c(dsc)$		$\Xi^+_c(usc)$		
			$\Omega^0_c(ssc)$			
$\Delta^-(ddd)$		$\Delta^0(udd)$		$\Delta^+(uud)$		$\Delta^{++}(uuu)$
	$\Sigma^-(dds)$			$\Sigma^0(uds)$	$\Sigma^+(uus)$	
		$\Xi^-(dss)$		$\Xi^0(uss)$		
			$\Omega^-(sss)$			

Table 3.4 and 3.5 show families, multiplets, of baryons. The states $\Xi_c^0(dsc)$ ($\Xi_c^0(ddc)$) and $\Xi_c^+(usc)$ ($\Xi_c^{++}(uuc)$) , in Table 3.4, count twice.

3.5 Classification of Particles

Particles, resonances, forces, forms of production, decay channels, etc., offer particularities in common: There are particles that interact strongly. Like neutrons and protons. There are particles that interact weakly, like electrons and neutrinos. There are some that interact via electromagnetic forces. Like electrons, protons, and all those that are electrically charged. Those interactions are independent of particle mass, depend upon solely on electric charge. There are some particles that carry with them interactions. In other words, interactions are made through their interchange, like the photon. When one proton interacts electromagnetically with an electron, they interchange photons. Physicists measure that rate of photon interchange as a force. The electromagnetic force. In principle, all fundamental forces operates interchanging some force carrier particles. Table 3.6 lists all carriers of fundamental forces and their main properties.

Table 3.6 Carriers of fundamental forces.

Force Carrier	Mass (GeV)	Electric Charge (e)	Spin
γ, photon(electromagnetic)	0	0	+1
G, graviton (gravitational)	0	0	+1
Z_0, $W\pm$ (electroweak)	91.1882, 80.419	0, ±1	+1
g, gluon (strong)	0	0	+1

Besides the above properties, the nuclear force -which is a remanent of the strong force- is independent of particle electric charge, of the particle mass, etc. Heisenberg took this experimental fact, and disregarding small differences between the mass of proton and the mass of neutron, considered proton and neutron as the same particle in different physical state. He called this state the state of isospin; and the particles, nucleons. Generically the particles that interact strongly are called hadrons. These are the hyperons and mesons. In terms of quarks: Hyperons have three quarks -in any combination like in $\Omega(sss)$, Λ^0(uds), $p(uud)$, etc.-; mesons, two -one is a quark; the other, an antiquark like in π, ω, ρ, K, etc. -. Baryons are those particles that in the final state have a proton, like proton, neutron, Λ^0, etc. Table 3.7 shows the main quark characteristics.

Table 3.7 Physical properties of quarks.

Quark/Flavor	Mass (GeV)	Electric Charge (e)	Spin
$u(up)$	0.004	$+\frac{2}{3}$	$\frac{1}{2}$
$d(down)$	0.08	$-\frac{1}{3}$	$\frac{1}{2}$
$c(charm)$	1.5	$+\frac{2}{3}$	$\frac{1}{2}$
$s(strange)$	0.15	$-\frac{1}{3}$	$\frac{1}{2}$
$t(top)$	176	$+\frac{2}{3}$	$\frac{1}{2}$
$b(bottom)$	4.7	$-\frac{1}{3}$	$\frac{1}{2}$

Weak interaction also does not depend on the particle electric charge. Another particles that interact weakly are charged lepton and associated neutrinos -uncharged leptons-. In total six. Grouped in couples. Always produced in pairs (lepton associated neutrino or lepton antilepton). Or if in the initial state of the reaction there is a lepton, in the final state reaction there is also one lepton of the same family. Like in the reaction $\nu + p \rightarrow n + e^+$. Besides those particles there are the corresponding antiparticles. The generic name of these particles is lepton. (The name comes from an ancient Greek coin of the same name, it means small or light). The number of leptons is a conserved number by all interactions, in any reaction. Table 3.8 shows leptonic number assigned to each of these particles. Table 3.8 lists the physical properties of all leptons. And shows some of the main physical characteristics. For example, spin of all leptons is $\frac{1}{2}$ in units of Planck constant divided by 2π. Antileptons have the opposite physical characteristic. For example, electron lepton number is 1; the antielectron lepton number is -1.

All particles interact gravitationally. Photons, gluons, neutrinos, etc. All particles.

Particles with electric charge interact electromagnetically. The electric charge never appears alone, always is associated with something material.

Table 3.8 Physical properties of leptons.

Leptons/Flavor	Mass (GeV)	Electric charge (e)	Lepton number	Spin
electron neutrino (ν_e)	$< 7 \times 10^{-9}$	0	+1	$+\frac{1}{2}$
electron (e^-)	0.000511	−1	+1	$+\frac{1}{2}$
muon neutrino (ν_μ)	< 0.0003	0	+1	$+\frac{1}{2}$
muon (μ^-)	0.106	−1	+1	$+\frac{1}{2}$
tau neutrino (ν_τ)	< 0.03	0	+1	$+\frac{1}{2}$
tau (τ)	1.7771	−1	+1	$+\frac{1}{2}$

The particle with the smallest mass and with electric charge, so far known, is the electron and its antiparticle, the positron. If there any relation between electric charge and minimum particle mass, no one knows.

As mentioned above, according to quantum field theory, interactions are produced by the interchange of particles. That interchanged particles carry the fundamental interactions. Photons (γ) carry electromagnetic interactions. Gluons (g) carry strong interactions. The $W^{\pm}$, and the Z^0 carry electroweak interactions. Gravitons (G) -not yet detected, hypothetical-carry gravitational interactions. See Table 3.6.

These are the four fundamental interactions, up to now physicists have discovered or detected, in nature. Could be others. Or it could result in just one, from where the others are generated or derived.

Particles with spin half integer are known generically as fermions, like quarks, leptons, baryons and others -they follow Fermi-Dirac statistics-. Particles with spin integer or zero, are known generically as bosons, like photons, hypothetical gravitons, etc., -they follow the statistics of Bose-Einstein-. Leptons, hyperons are Fermions. And carriers of fundamental interactions, and mesons, are bosons.

Reader can consult any intermediate quantum mechanics textbook to study different statistics. See References.

Experimental evidence shows that protons, and in general hadrons, are composed of very small structures. Quarks or partons. Leptons do not present any structure, at least up to the energies where they have been tested. Neither bosons present any structure, at least with those that physicist have experimented with. For instance, carrier of electromagnetic force and carriers of electroweak force apparently are with out structure. In this sense, leptons and carriers of fundamental forces are elementary particles.

Of those leptons, quarks, angular momentum, etc., before enunciated, high energy physics reactions conserve some quantities. Table 3.9 enunciates that conserved quantities.

Table 3.9 Conserved quantities in high energy physics.

Conserved quantities	
1	energy-mass
2	momentum
3	angular momentum and spin
4	electric charge
5	color charge
6	number of quarks
7	number of electrons and electron neutrinos
8	number of muons and muon neutrinos
9	number of taus and tau neutrinos
7-8-9	number of leptons

Neutrinos, leptons in general, are distinguishable. Therefore, number of electrons and electron neutrinos, number of muons and muon neutrinos, and number of taus and tau neutrinos are separated quantities. In general, with some care, it is possible to speak of the number of leptons conservation.

3.6 Quark Model

The panorama of physics in years 1950-1960 offered many challenges. It was a favorable land to creation. The central preoccupation of physicists was to understand the origin and constitution of particles, to find a scheme to classify them, in terms of the most elementary constituents. Those were the years of resonance discoveries. The years of quark model formulation.

About the quark model, L. W. Alvarez, in his 1968 Nobel lecture on physics, wrote:

Murray Gell-Mann had recently annunciated his important ideas concerning the "Eight-fold Way", but his paper had not generated the interest it deserved. It was soon learned that Ne'eman had published the same suggestions, independently.

Based on symmetry arguments, Gell-Mann and others, separately, proposed the existence of quarks. With this scheme of things, they can classify all known particles. Quarks are the constituents of all hadrons. This idea, or way of proceed, was no new. Other authors, like Sakata, had tried before quark model basic idea to classify particles taking other particles as the elementary blocks -for example the proton, the Λ^0, and the neutron-; (p, n, Λ^0) is known as Sakata set.

Leptons, up to where physicists have experimented, are without structure particles. As it is said before.

The original proposition of Gell-Mann consisted of three quarks. In these days it is required 6 of these to classify all known particles. These are $u(up)$, $d(down)$, $s(strange)$, $c(charm)$, $b(bottom)$, $t(top)$. The Table 3.7 illustrates all known properties of quarks. The Figure 3.1 illustrates the elementary particles: Quarks, carriers of fundamental forces, and leptons. Chapter 4 will comment more about elementary particles.

If particles have three quarks, they are known as baryons; if they have two quarks, they are known as mesons. $\Lambda^0(uds)$, $p(uud)$, $n(udd)$, are baryons; $\pi^+(u\bar{d})$, $K^+(u\bar{s})$, are mesons.

All the above particles interact via strong interaction; they are known generically as hadrons. If the particles interact via weak interaction mainly they are known as leptons; these are not composed of quarks. Example of leptons: Electron, muon, tau, neutrino associated to electron, neutrino associated to muon, and neutrino associated to tau. These are all the leptons that exist, or that have been detected so far. Of course, each of them has their corresponding antiparticle. And, also, the electrical charged ones interact electromagnetically. They are atoms, in the strict sense of the word. For they are not composed of any other particle.

Of the baryons, Λ^0 is the most common one after the proton and the neutron. Λ^0 decays into $p\,\pi^-$ via weak interaction. Its meanlife is $\sim 7.5 \times 10^{-8}$ seconds. Also μ decays via weak interaction into e, ν_e, ν_μ. $\Sigma^*(1385)$

decays via strong interaction into a Λ^0,π in $\sim \times 10^{-23}$ seconds. These last states are known as resonances. Σ^0 decays into $\Lambda^0\gamma$ via electromagnetic interaction in $\sim 10^{-19}$ seconds.

The current idea of the structure of matter that physicists have is shown in Figure 3.1 It is possible to speak of generation I. Members are (u, d) and (e^-, ν_e); they are all the constituents required to construct the world of everyday life, at least, it is what physicists believe. This is an hypothesis very hard, not possible, to test. It is possible to speak of generation II. The elements are (s, c) and (μ, ν_μ). Occasionally they appear in daily life; for instance in cosmic rays; they are also created in the big accelerators of the world like Fermilab, BNL, or CERN. No one knows why it is there. It is possible to speak about generation III. The constituents are (b, t) and (τ, ν_τ). No one knows why it is out there. All of them, except ν_τ that have been not detected directly, were detected in the big accelerators of high energy physics -like Fermi National Accelerator Laboratory, USA; Brookhaven National Laboratory, USA; CERN, Europe; SLAC, USA; etc.-. It is possible that there are other families; there are no reasons in pro nor in con.

The Figure 3.2 shows the different levels in the organization of elementary particles. From cells, up to quarks and leptons. Historically there are no reasons to doubt about the existence of structures for quarks and for leptons. Maybe it is a matter of energy and of method to reach that structure.

Besides leptons and baryons, with some particular properties, as were said above, there are carriers of interactions: The photons (γ) for the electromagnetic interactions, as far as it is known with zero mass and infinity influence extension and of one sort; the gluons (g) for strong interactions, with unknown mass, very limited influence and of eight sort; the bosons $(W^\pm, Z^0)$ for electroweak interactions, with very well known mass and very limited influence and of three sort; and gravitons (G) -not yet detected- for gravitational interactions, apparently with zero mass and infinity influence extension, and of one sort. For each one of those particles, of elementary particles, of carriers, etc., there exists the corresponding antiparticle. The photon, for example, is its own antiparticle. The reader can conclude on the cosmological consequences of this fact. For instance, light -it means all the information- from a star and from a star formed from antimatter is identical. Apparently there is no way to distinguish light emitted by atoms from light emitted from antiatoms.

Neutral particles, like the neutron, are not their own antiparticles. The reader can verify it checking the products of disintegration of neutron and of antineutron. Neutron decays into $pe^- \nu_{e^+}$; antineutron, into $\bar{p}e^+ \nu_{e^-}$. Antimatter is accurately established by experiment. In these days there is an experiment at Fermilab that studies the production of atoms of anti-Hydrogen. The second step will be the study the spectrum of emission of antiHydrogen. See References. Maybe physicists can have surprises. And antimatter does not behave exactly like matter. In that case, primary ideas about the universe will change.

There are many open questions concerning matter and antimatter: Why the universe is basically made of matter? Can coexist matter and antimatter? Does matter repel antimatter and vice versa. Or do they attract each other like matter attracts matter? Can oscillate matter into antimater and vice versa? Are some of those questions. There are many more.

3.7 A High Energy Physics Experiment

The above knowledge about particles and antiparticles is not free. Physicists extracted it experimenting, observing, and testing nature.

Times have changed. From those very simple experiments on the top of a table of past years, now there are experiments of a few kilometer long. In these times, high energy physics experiments share the same elements, detectors, sources, ways of processing data and extracting physical information.

This is the way physicists plan an experiment, accomplished it, and collect data. And analyze data off line. This section explains this way of experimenting, physicists analysis of data, extraction of physical information, and performing measurements.

The above way of doing high energy physics experiments was pioneered by L. W. Alvarez. He also received for this way of doing physics the 1968 Nobel prize in physics. In his Nobel lecture, he wrote:

Almost everyone thought at first that our provision for automatic track following was a needless waste of money, but over the years, that feature has also come to be conventional.

L. W. Alvarez techniques developed for high energy physics have evolved up to become a very sophisticated way of doing high energy physics from groups of a few physicists, engineers, and technicians up to some groups of thousands of physicists.

An experiment in high energy physics costs easily a few million dollars. And takes to be accomplished some decades. It is a complex experiment where efforts of collaborators from many institutions come together. A single person can not do it.

3.7.1 *Introduction*

Not all experiments in high energy physics are equal. There are some that have a two dozens collaborators -for example BNL e766- and others that have close to two thousands of collaborators -for example ATLAS of CERN-. They are multimillion and multinational projects that group some universities and centers of investigation from many places of the Globe.

The central part of those experiments is the particle detector designed to study determined region of energy and determined final state. For example exclusive proton-proton reactions, production of charm in collisions e^+e^-, search for top quark, search for Higgs -or god particle as Lederman calls it, see References-, and others.

For high energy physics experiments have different objective of investigation, detectors have different form and different size. Some have the form of a cube close 4 meters of groin (like the BNL e766 detector) and others have a very large form of a few square meters of transversal section and some hundred meters large. See Figure 3.3, and Figure 3.4. Even though they share basically the same elements distributed in different form in the volume of the detector. Some common elements are the following: Magnets to curve trajectories of the charged particles, multiwire proportional chambers to reconstruct the trajectories of the charged particles, scintillator detectors to sense the pass of charged particles, ultra high speed electronics to process and store automatically the information delivered by the detectors and other computerized systems.

The best way to familiarize with those detectors is working with them; however on lacking them physically, reader can learn many things from good books. See for example the References D. H. Perkins and C. Caso *et al.* Also the www pages of Fermilab, CERN, SLAC, and DESY. There, each experiment has its own page. Experiments, and their physical characteristics, physical topics of study, personnel, publications, etc., are there described. Most of the laboratories run some sections dedicated to teach, or inform, international students on high energy physics. Some have virtual interactive simulations and animations. Probably in the no so far days to come, those big laboratories will count with remote experimental facilities. In these days the experimentation is in situ.

Of those experiments, detecting radiation, processing data, and interpreting data, are the main activities.

G. Charpak, in his physics Nobel lecture *Electronic Imaging of Ionizing Radiation with Limited Avalanches in Gases*, 1992, wrote:

Detecting and localizing radiation is the very basis of physicists' work in a variety of fields, especially nuclear or subnuclear physics.

Certain instruments have assumed special importance in the understanding of fundamental phenomena and have been milestones in the building up of modern theories. They make up a long list: The ionization chamber, the cloud chamber, Geiger-Müller counters, proportional counters, scintillator counters, semiconductor detectors, nuclear emulsions, bubble chambers, spark and streamer chambers, multiwire and drift chambers, various calorimeters designed for total absorption and then measurement of particle energy, Cerenkov or transition radiation counters designed to identify or select particles, and many other detectors, some very important examples of which are still being developed.

Some concrete example of particle detectors are shown in the next section. This section describes the main modern radiation detectors used in experimental high energy physics: Scintillator detectors, multiwire proportional chambers, Cerenkov detectors. And it shows their physical principles. Besides, it delineates Monte Carlo technique and its use in experimental high energy physics.

3.7.2 *Scintillator Detectors*

Scintillators have the appearance of plastic. Toluene, anthracene, and sodium iodide, are some used substances to build them. Physicists build scintillators in many forms. These depend on particular practical necessities. For example, beam detector is a little square of 5 *cm* by 5 *cm*. In contrast, an hodoscope could be some square meters. See Figure 3.5.

When a particle pass through a material excites atoms and molecules of scintillator, in a time of the order of 1×10^{-6} seconds, atoms, or molecules, de-excite emitting light -normally in the ultraviolet region-. The pass of particles is registered by luminous signal in the scintillator. Light is transmitted, through the same material, to a photomultiplier. There the signal is registered and amplified. And pass to computerized system to store it.

As luminous signal from scintillator is in the ultraviolet region, and normally is very weak, it is amplified before it is used. First a shifter of wave length is used to displace it to the visible region and after that, a photomultiplier is used to amplify it.

The most common scintillators, used in high energy physics, are organic monocrystals, plastics, and organic liquids. Also there are gaseous scintillators. Terrestrial atmosphere is as example. The international Auger project uses terrestrial atmosphere as a scintillator. Figure 3.6 shows the typical array of a scintillator, the photomultiplier, and the electronics associated.

The spatial resolution of the scintillators, or array of scintillators, is very poor. They are used basically to detect the pass of particles, not to localized them in space. Or to trigger some electronic devices. With them, physicists build systems to measure the time of flight of particles, and knowing the distance of separation between them, they measure the velocity of particles. This is just the method of Galileo to measure velocity of light, or any of any object. With modern electronics, this method works perfectly, even when the separation of the scintillators is of a few meters. The instruments are very precise. And they are completely automatized.

3.7.3 *Multiwire Proportional Chambers*

G. Charpak invented this device. For it, he received the 1992 Nobel prize in physics. In his Nobel lecture, he told:

Multiwire chambers gave rise to further developments in the art of detecting, of which some are highly innovative. Most high-energy physics experiments make use of these methods, but their application has extended to widely differing fields such as biology, medicine, and industrial radiology.

A multiwire proportional chamber is an appliance like the one that Figure 3.7 shows. It is shown diagramed in Figure 3.8 and Figure 3.9. There the only essential elements are shown. Also, like the scintillator, their form, size, and sophistication depend on the experimental necessities. Basically multiwire proportional chamber contains two cathode planes and one or more anode planes of wires. See Figure 3.8. If there is more than one plane of wires, normally they are at different angles. The multiwire proportional chamber is full of special gas to increase its speed. The planes of wires are inside this atmosphere.

The planes of wires inside the atmosphere, are the operation keys for multiwire proportional chambers. Figure 3.9 illustrates the arrangement of wires and the physical principle of operation.

When a charged particle pass through multiwire proportional chamber, ionizes its gas. Generates ions. Generated ions are attracted by cathode wire. Free electrons are attracted by the anode wire. Positive ions, to cathode plane.

Wires have some tenths of millimeter of diameter. They are made of gold, or covered with gold. Argon Isobutane is used as active gas in multiwire proportional chambers. Other mixtures of gases are also used, depending on the specific purpose of the multiwire proportional chamber. Times of resolution of the multiwire proportional chambers are of order of 30 *nanoseconds*, and its spatial resolution is of 0.1 mm order.

3.7.4 *Cerenkov Counters*

Pavel A. Cerenkov discovered what now physicists call Cerenkov radiation, or Cerenkov effect. For this discovery, and his applications in detecting fast moving particles, he received the 1958 Nobel prize in physics. In his Nobel lecture *Radiation of particles moving at a velocity exceeding that of light, and some of the possibilities for their use in experimental physics*, he wrote:

Research into, and the experimental proof of, the remarkable properties of the radiation from the movement in a substance of fast electrically charged particles stretched over a period of nearly twenty-five years.

In another paragraph he adds:

This radiation has an analogy in acoustics in the form of the so-called shock waves produced by a projectile or an airplane traveling at an ultrasonic velocity (Mach waves). A surface analogy is the generally known bow wave.

And in another one, he annotated as follows:

The practical value of the radiation of high-speed particles does not be solely in the possibility of using it to detect particles. The full utilization of the peculiar properties of this radiation (often in combination with other methods) considerably enlarges the possibilities of physical experiment in a wide range of cases.

In these days, Cerenkov dreams are realities. All the high energy physics laboratories around the world use Cerenkov detectors. See Figure 3.10.

Cerenkov counters also, like drift chambers, differ in size and form. These attributes depend on practical necessities of physicists. Invariably all of these counters use the Cerenkov effect to detect, to identify particles, or to discriminate particles. They work when particles have velocities close to light velocity in vacuum. Cerenkov effect is as follows: When particles move in a material medium, with a velocity greater than velocity of light in the medium, part of emitted light by excited atoms appears in form of coherent wavefront at a fixed angle with respect to particle trajectory. The angle, at which the coherent front of waves appears, is related directly to the velocity of the particle.

From Figure 3.11, the angle is given as follows:

$$\sin\theta = \frac{c'}{v}, \tag{3.1}$$

with n the medium refraction index, $n = \frac{c}{c'}$ then

$$\sin\theta = \frac{c}{nv} = \frac{1}{n\beta}. \tag{3.2}$$

The angle θ is fixed, if β is fixed. The refraction index, n, is a constant, depends on the medium physical properties. Air refraction index is little bigger than 1. Therefore, measuring the angle that the coherent wavefront makes with the direction of the moving particle, it is possible to determine the velocity of the particle in the medium.

3.7.5 *Monte Carlo Method*

Monte Carlo technique is very well known used in physics, specially in high energy physics, both experimental and theoretical. Fermi introduced this method in the decade of 1940.

This technique uses random generation of numbers to calculate and to simulate. For example, to calculate integrals that analytically could be very complicate, to calculate acceptance of complicate spectrometers, etc. For instance, to simulate production of particles, the pass of particles through material mediums, the decay of a particle into two or more particles, the polarization of a particle, etc.

Practically, any phenomenon in nature can be simulated in the computer using Monte Carlo technique. Limitations that some decades ago Monte Carlo technique had, as reduced memory in computers, slowness in computer operative systems, generation of truly random numbers, reduced storage capacity of computers, etc., have been excelled by new generation of computers. Therefore, any natural phenomenon can be simulated in computers using Monte Carlo technique. Even those that appears too complicate, as a spaceship travel, atmospheric phenomena, and others.

The following example illustrates Monte Carlo technique.

Example:

Decay of a particle of mass M into two particles of mass m_1 and m_2 respectively. See Figure 3.12.

Momentum of daughter particles are equal in module but, opposite directions, in M center of mass rest frame. Figure 3.12 illustrates the situation. These magnitudes are fixed when masses M, m_1, and m_2 are fixed.

The difference from event to event is the angle θ, that momentum of particle 1 makes with **y** axis, and azimuthal angle ϕ, that projection to **x-z** plane of particle 1 momentum modulus makes with **x** axis.

Numbers $\cos\theta$ and $\cos\phi$ are generated randomly. Both numbers between $(-1, +1)$. The process is as follows: Computer generates a random number ϵ. This has a value between $(0, +1)$. Function $2\epsilon - 1$ is the distribution for $\cos\theta$ and for $\cos\phi$. The function goes between $(-1, +1)$. In this way, the distributions of $\cos\theta$ and of $\cos\phi$ are flat. The reader can verify these propositions for himself or by herself. He or she must write a computer program to generate the histograms of $\cos\theta$ and $\cos\phi$. See Figure 3.13 for an example of *FORTRAN* program to generate random numbers and Figure 3.14 for a flat distribution, product of the program that generates random numbers.

Reader also can generate non uniform distributions directly -using a weight function-, or weighting uniform distributions in the way he or she chooses. Normally both procedures work fine.

The base of Monte Carlo method is the generation of random numbers. And every computational technique where random numbers are involved is called Monte Carlo method.

3.7.6 *Conclusions*

Experiments in high energy physics are performed by institutional collaborations from some different countries. Normally those collaboration groups have some hundred physicists from many centers of research and advanced education around the Globe. Also the work in experimental high energy physics is highly specialized. Some groups dedicate to design and to construct detectors, other to acquisition data system, others to data processing, others to data analysis, etc. Normally the leading discoveries are from higher sources of energy. The sources of primary beam are in the world biggest laboratories like FERMILAB, DESY, SLAC, CERN, etc.

Sources of primary beam are built with participation of some countries. They are multimillion dollar projects. And require participation of many physicists, engineers, local and international industry, etc. Normally facilities for investigation are at disposition of international scientific community.

In those big laboratories, in the centers of primary beam, multidisciplinary investigations are performed: Mechanical engineer, computation, software, hardware, medicine, optics, electronics, cryogenics, superconductivity, etc. All that investigations are around experimental high energy physics.

Experiments of high energy physics are benefited from groups of physicists dedicated exclusively to theoretical high energy physics that are associated to those centers of primary beam.

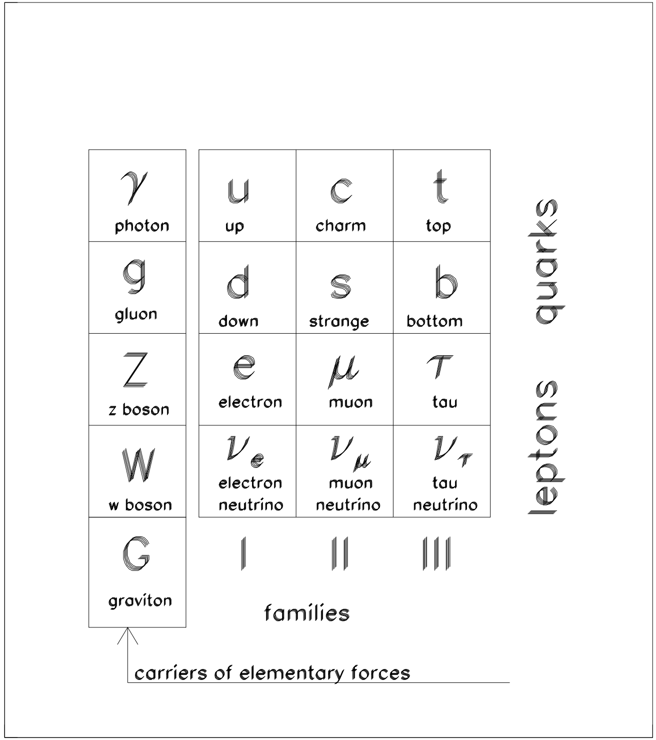

Fig. 3.1 Three families of elementary particles.

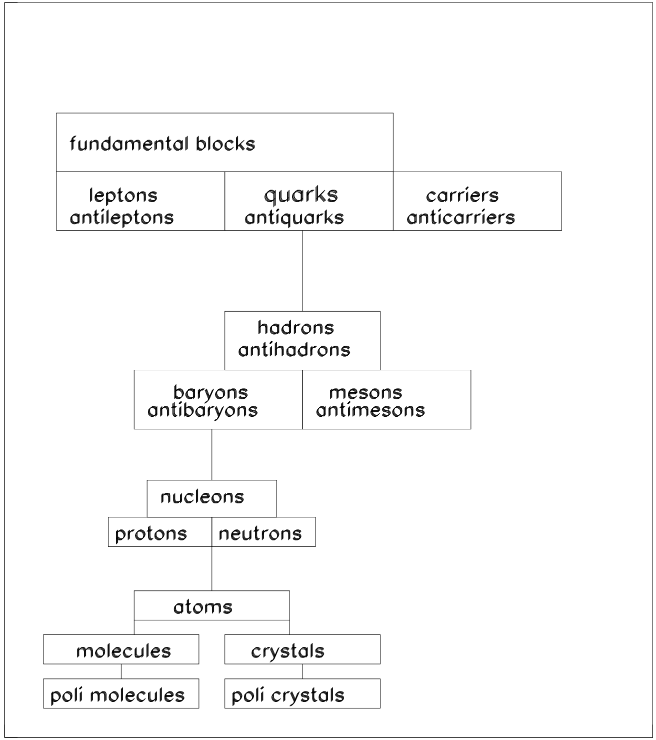

Fig. 3.2 Different levels of particles organizations. From fundamental blocks up to poli molecules and poli crystals.

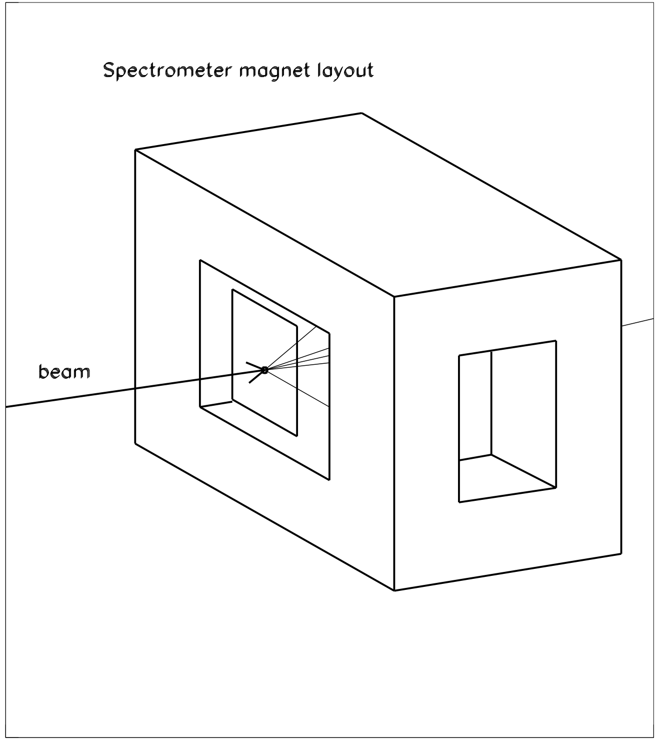

Fig. 3.3 Conventional high energy physics spectrometer layout.

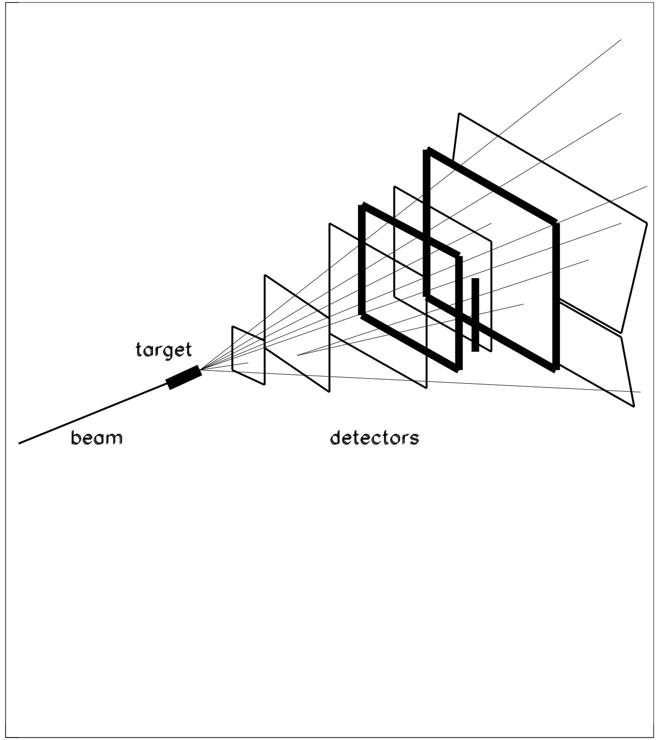

Fig. 3.4 Artistic view of the essential elements of a high energy physics spectrometer.

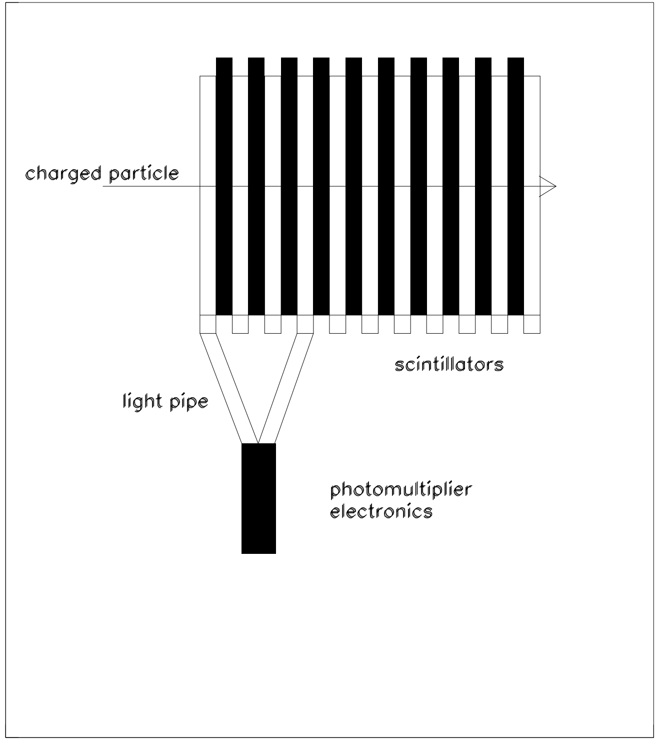

Fig. 3.5 Array of scintillators to form a particle detector -calorimeter-.

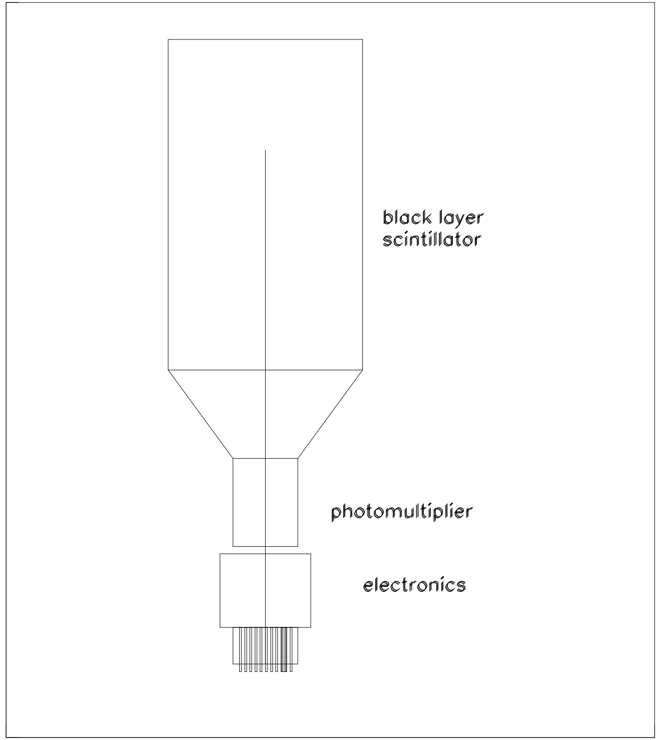

Fig. 3.6 Scintillator and electronic devices to form a single unit for particle detection.

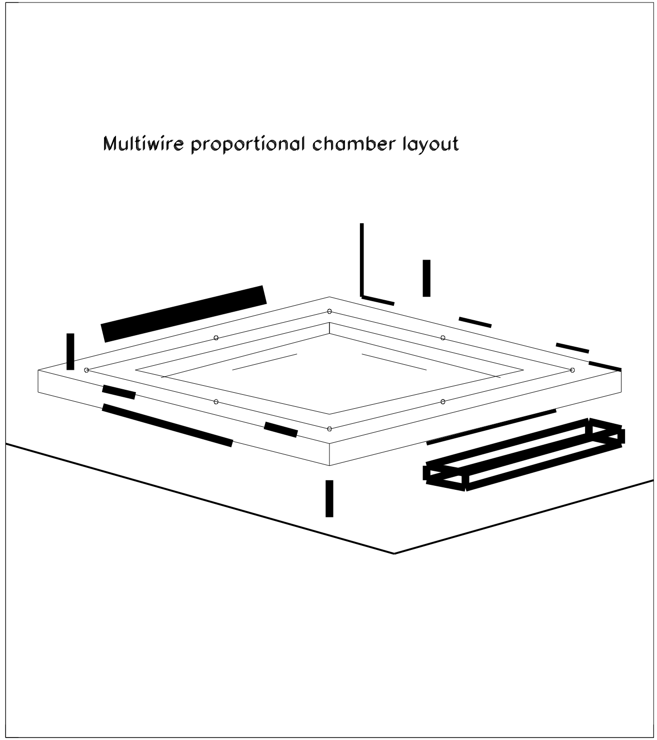

Fig. 3.7 View of Multiwire proportional chamber.

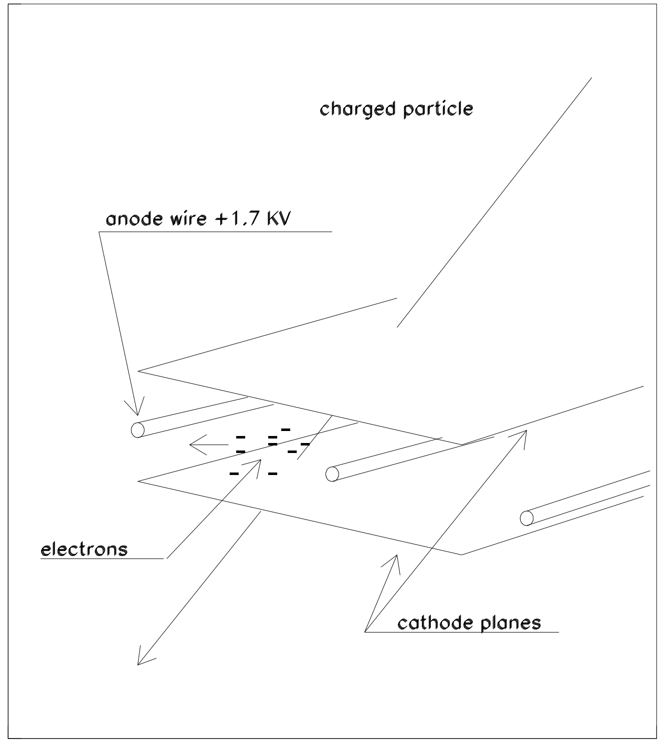

Fig. 3.8 Diagram of multiwire proportional chamber basic elements and the way they work.

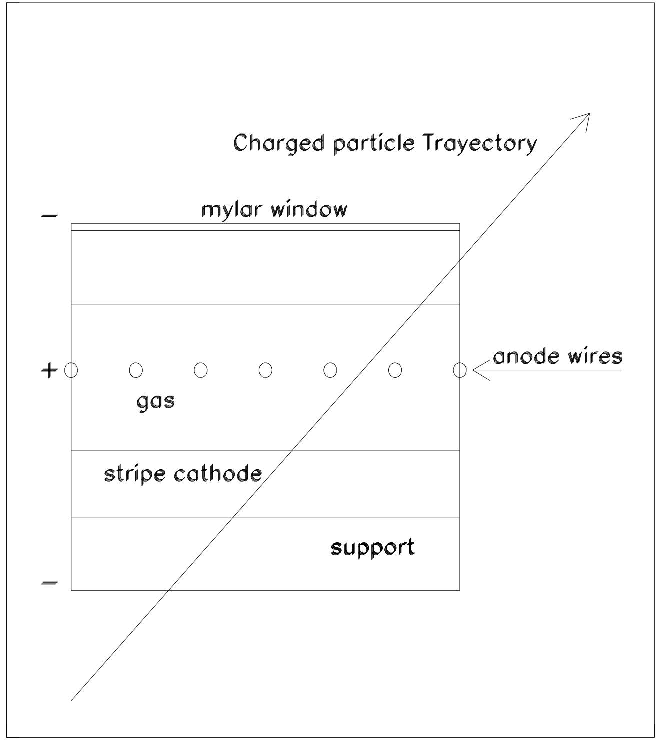

Fig. 3.9 Cut of the basic elements of a multiwire proportional chamber.

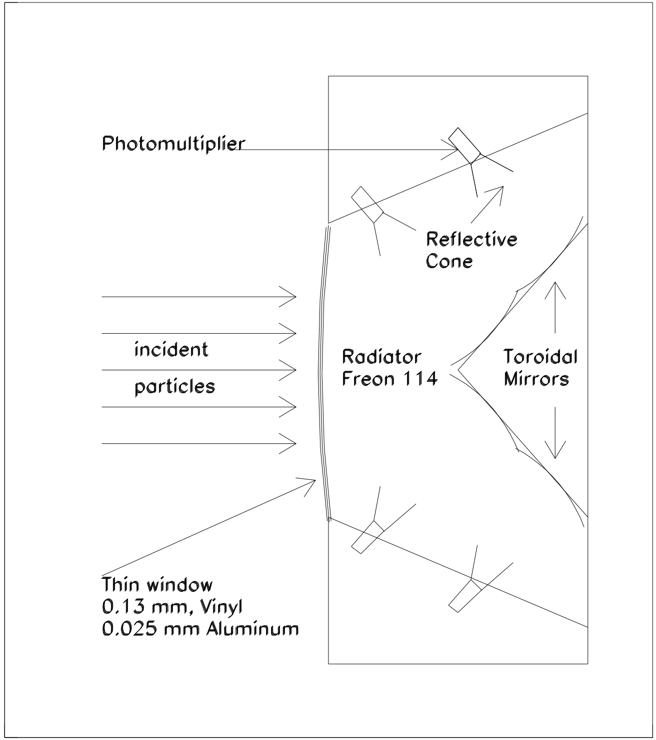

Fig. 3.10 Cerenkov detector layout.

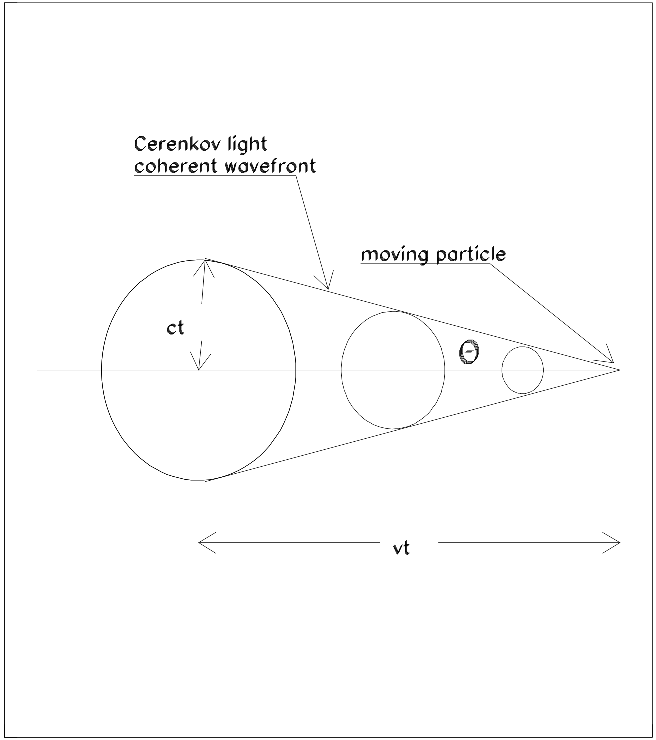

Fig. 3.11 Scheme of Cerenkov effect. Light emitted by a particle moving faster than a photon in a medium.

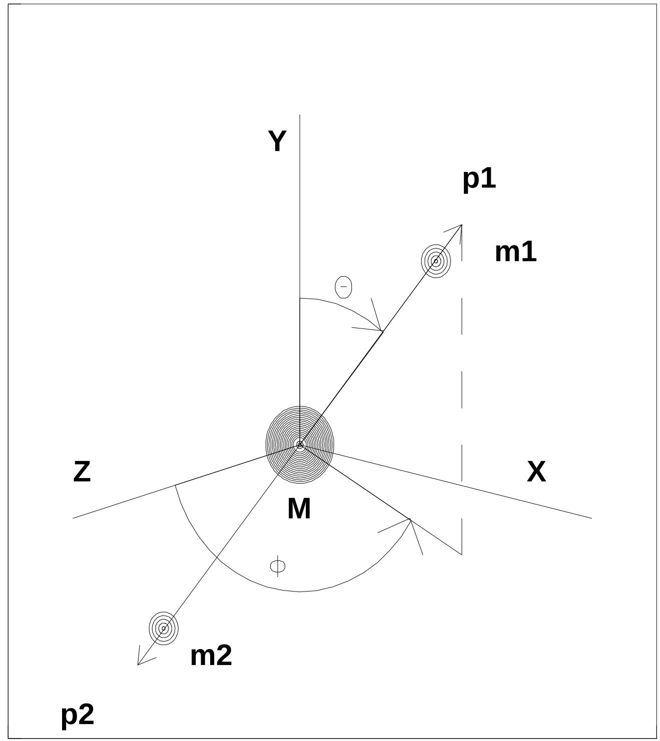

Fig. 3.12 Diagram of a particle decay into two particles of different mass.

```
      PROGRAM DUNIF
      COMMON/DATA/RR
      INTEGER II, NN
      IC=-1
      CALL FILE(IC)
      NN=1000
      DO II=1, NN
      CALL RANDOMDST
      IC=0
      CALL FILE(IC)
      END DO
      CALL FILE(IC)
      stop
      end

      SUBROUTINE RANDOMDST
C
C This routine generates seeds to use in RAN FORTRAN function.
C To reduce correlations use all seeds at the same rate.
C ----- Random number common block -----
      COMMON/RANDOM/IRAN(50),IRANDX
      DATA ISEED/5757/
C
      IRANDX=0
      DO 2 I=1,50
      DO 1 J=1,20
      1 A=RAN(ISEED)
      2 IRAN(51-I)=ISEED
      RETURN
      END

      SUBROUTINE FILE(IC)
      COMMON/RANDOM/IRAN(50),IRANDX
      F(IC.LT.0)THEN
      OPEN(unit=20,file='data.dat',status='new')
      IC=0
      ELSE IF(IC.EQ.0)THEN
      RR=1.0-2.0*RAN(IRAN(15))
      WRITE(20,*) RR
      IC=1
      ELSE IF(IC.GT.0)THEN
      CLOSE(20)
      END IF
      RETURN
      END
```

Fig. 3.13 Fortran program to generate flat distributions.

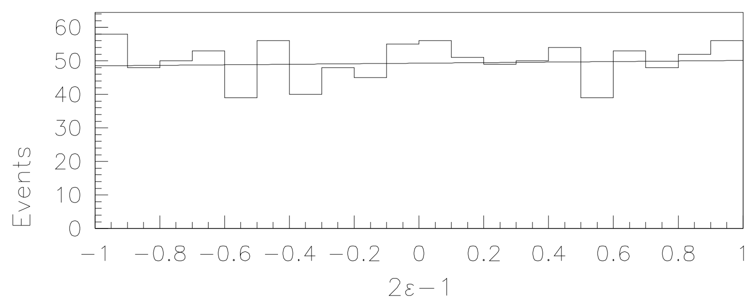

Fig. 3.14 Flat distribution. The line represents the fit using least squares. The fit slope is consistent with zero.

Chapter 4

High Energy Physics Practical Utility

4.1 Introduction

Physicists in their quest for the knowledge about nature play a double game: They try to understand the way nature works, or conducts herself, and they try to get practical benefits that can be used in daily life. High energy physicists are not the exception. High energy physics gives a deep understanding of nature behavior and provides many practical benefits to everybody: Electronics, computation, medicine, communication, technology, etc.

Physics is an experimental science. Physics is the description and interpretation of the external world. If physicists understand physics in this way, and applied correctly, then the utility of high energy physics, in practical and everyday situations, is immediate. High energy physics has transformed the world, where human beings live in, since the first years of the XX century.

That transformation is based on a superior understanding of nature, in understanding the laws that nature follows. Next sections illustrate the form in which physicists, based on the knowledge of natural laws, have transformed society with their inventions and applications of high energy physics.

Next sections will show the achievements in inquiring the intimate structure of nature. And they will show the advances that this knowledge has incited in electronics, in search and fabrication of new materials, in computation, in creation of new technologies, in medicine, etc.

4.2 To know the Nature of Nature

W. Heisenberg, in his book *Nuclear Physics*, wrote:

Anybody who desires to understand something of modern atomic theory, will do well to study the history of the concepts of the atom in order to become acquainted with the origins of those ideas which now have come to full fruition in modern physics.

To know nature, in its most elementary and intimate aspects, in its most intimate structure, satisfies human curiosity; it is one of the most oldest dreams of human beings; it obeys human instinct of wanting to know his origins and composition of his habitat, his place in evolution, and in cosmos, and his destiny.

When inquiring the intimate structure of nature, ancient natural philosophers -today physicists- invented the concept "atom". This concept is very famous and badly interpreted. The first ideas can be traced back to ancient Greeks, and even earlier. Their ideas were merely speculative, or to say it in terms less rigorous: Their ideas, plausible, were based on the observational evidences presented by external world, but, apparently, they never tested their logical implications. Diffusion of odors, evaporation of water from ponds, spread out of flowers perfume in the air, partition of dirt into smaller pieces, etc., were without doubt sources of inspiration and of irrefutable observations and evidences about the existence of tiny pieces of matter, the atoms. The rest they got by way of thinking, proposing, speculating. Guided by plausible philosophical principles. Like beauty, simplicity, order, symmetry, harmony, unity, etc. However, apparently, they never tested consequences of their theories. And assumed them as eternal trues. As the way nature must follow. And they froze their own development and progress. Forbidding most of the nature possibilities.

The ideas of ancient Greeks are very modern, close to these days. The parallelism between their system of the world, animated and populated by forces and particles, and ours is awesome -also populated by forces and particles or only particles (or waves) playing different roles-. However, the practiced methods are very different: Ancient Greeks's is static; it does not correct by itself in any way; and it is speculation based, in some sense authority based. The modern's is dynamic. It is the experimental method. It corrects by itself. It is axiom and hypothesis based, not based in authority. It carries far away in the knowledge of natural world.

The experimental confirmation, that passed all tests, about the existence of atoms is a modern success. It has close to one hundred years. The experimental test of the existence of elementary particles is still more recent. It has no more than fifty years. Still in 1908 some physicists and philosophers doubted the existence of atoms. J. B. Perrin proposed that the Brownian motion -the erratic motion of suspended particles in a liquid- is caused by the fickle collisions of atoms with suspended particles. A. Einstein theory of Brownian motion tried to establish atomic theory on strong experimental basis. Eminent thinkers, as E. Mach, never accepted the atomic theory -i.e., the existence of atoms-. He thought atomic theory as an speculation having nothing to do with the way nature is. Mach went to grave without been convinced.

Mach exclaimed *I don't believe that atoms exist!* in 1897 at the meeting of the Imperial Academy of Sciences in Vienna, after a presentation of L. Boltzmann. Bolztmann was trying to demonstrate the existence of atoms, Mach to disprove it.

Mach and cognate aces were wrong in atomic theory respects. Chapter 2 presented the history of atoms and of particles. This Chapter describes the history of subsequent discoveries: The constituents of particles -quarks-, leptons -besides the electron-, resonances and long lived particles.

The existence of quarks, based on indirect evidences, was accepted almost immediately. The discovery of particle J/Ψ, in 1974, was crucial. The discovery of the state Ψ' definitely convinced some physicists of the necessity of quarks to explain constitution of particles. Ψ' is an excited state of Ψ. It was the discovery of quark c, the heaviest quark so far detected.

In his Nobel prize lecture in physics, 1976, *From the Psi to charm -the experiments of 1975 and 1976* B. Richter wrote:

Exactly 25 months ago the announcements of the J/Ψ particle by professor Ting's and my groups burst on the community of particle physicists. Nothing so strange and completely unexpected had happened in particle physics for many years. Ten days later my group founded the second of the Ψ's and the sense of the excitement of the community intensified. The long awaited discovery of any thing which would give a clue to the proper direction in which to move in understanding the elementary particles loosed a flood of theoretical papers that washed over the journals on the next year.

Sammuel C. C. Ting shared the 1976 Nobel prize in physics with B. Richter. His Nobel prize lecture was entitled *The discovery of J particle: A personal recollection.*

The state Ψ, or state J, is called charmonium; this is, a system like an Hydrogen atom formed by c quark and its *anti* c quark, instead of one proton and one electron. T. Appelquist and H. D. Politzer, from Harvard University, named the charmonium in analogy with the positronium, the system resembling the Hydrogen atom formed by a positron and one electron. However, in spite of charmonium discovery, not all physicists were converted.

For those physicists that doubted the existence of quarks, according to the most brilliant minds of the time, all the disputes about the existence of quarks had to be solved in the laboratory. All the efforts must be encouraged to show the existence of quarks, summing up experimental evidences. This is, to build particle accelerators potent enough as to reveal the existence of quarks in the most pure physical situations. In this way Fermilab born, for instance, and other centers of research in high energy physics in the world -like Stanford-. Up to these days, Fermilab and CERN continue making improvements in their accelerators, trying to get more higher energies. Other projects on building new accelerator machines, have been canceled like Superconductor Super Collider -SSC- in Texas. Nevertheless, for some physicists -like Leon Lederman-, it was not enough.

Leon Lederman and coworkers discovered the particle Υ, Upsilon, in 1978, using the experimental facilities of Fermilab. It was the discovery of the b quark. A quark heavier than the c one. At the same time they discovered the states Υ' and Υ''.

After those discoveries few physicists doubted about the existence of quarks. But they lacked of a theory to explain quarks, the role of quarks in matter structure, and particle structure.

Gell-Mann invented the model of quarks to account the rich experimental data -to classify particles in groups with similar properties-. And many physicists followed him: In his courses and conferences, G. Zweig showed the enormous simplicity gained by the hypothesis of quarks in understanding resonance and particle decay spectra. Zweig was an enthusiast of quark theory, as many physicists were, that he posed independently of Gell-Mann the quark model. Gell-Mann took the word quark, for the name to sub-hadron particles, from a line in J. Joyce's Finnegans Wake. The name for the concept is arbitrary as many names for many concepts in physics -like electric charge positive or negative, for instance-. Any word can work.

Quark theory masterstroke was gigantic. For some physicists, the unique thing that quark model could not explain was quark model itself. The simplicity proposed by quark model was extreme and promising. However, the model presented some difficulties: The laws for the interactions between quarks were unknown; the rules for combining quarks appeared arbitrary, without bases; fractional electric charge were necessary for quarks; and quarks do not appear as free particles.

The quark model lacking of bases was more evident in baryons. Specially in $\Omega^-(sss)$. This baryon is composed of three strange quarks. According to quark model, the wave function that describes Ω must be symmetric. However, according to Pauli exclusion principle, it must be antisymmetric, for strange quark is a particle that follows Pauli exclusion principle. The demands of Pauli exclusion principle were very serious: This principle is the base of all atomic spectroscopy, valid for particles with half integer spin. The dilemma was solved by W. Greenberg: He suggested that quarks, at that time, u, d, and s, must be able to be in three different states. That is, be distinguishable or be able to be distinguished via that physical state. He call it color state. And everything agreed naturally with the exclusion principle and with the spectroscopy of particles. The wave function for Ω^- becomes antisymmetric, according to quark model. Figure 4.1.

The color must be an intrinsic property of baryons: The baryons are colorless; quarks have color. The color states are three, according to experimental evidences: Blue, green, red. These terminologies have nothing to do with the sensation of color perceived by eyes. Those are just a name for three different states; like positive and negative are names for two different states of electric charge; or up and down, for the two spin states, or proton and neutron for the two states of nucleons -isospin states-.

Color becomes to be the key for physicists could understand the structure of baryons in terms of quarks. Or for they could accept quark model as true model, or a least a model reflecting some portion of reality. When physicists measured color, they got a number consistent with three.

However, as all the previous chapters have declared, experimental evidence has a prime role in physics. And has to be applied also to quark model: The dispersion experiments of electrons by protons, of J. Friedman, R. E. Taylor, and H. W. Kendall, and coworkers provided experimental basis for the quark model. The high rate of inelastic collisions observed in their experiments made at SLAC showed that inside proton there are electric charged and very dense points of matter. R. P. Feynman call them partons. If there were assumed that electrons were dispersed for massive points inside protons, then it could be easy to understand the so big observed cross sections of elastic dispersions. This is, SLAC experiments were detecting not a tender structure of the proton, but a hard structure very well defined and localized -like Rutherford, in his celebrated alpha particle dispersion experiment, detected the hard and massive nucleus-. Those unearthed high dense points were the quarks or the partons, or whatever they must be called. The theory of quarks found, this way, its experimental basis. Figure 4.2 shows the way particles are detected through their particle daughters. The number of quarks remains constant during the reaction, as it can be checked from the figure.

The H. W. Kendall Nobel lecture, 1990, was *Deep inelastic scattering: Experiments on the proton and the observation of scaling.* And the R. E. Taylor Nobel lecture, 1990, was *Deep inelastic scattering: The early years.*

The above three cited physicists, shared the 1990 Nobel prize in physics for their discoveries. J. I. Friedman, in his Nobel prize lecture *Deep inelastic scattering: Comparisons with quark model*, wrote, citing Panofky:

...theoretical speculations are focused on the possibility that these data might give evidence on the behavior of point-like charged structures in the nucleon.

And in another paragraph he added:

In the London Conference in 1975, with its strong confirmation of the constituent quark model, a general change of view developed with regard to the structure of hadrons. The bootstrap approach and the concept of nuclear democracy were in decline, and by the end of the 1970's, the quark structure of hadrons became the dominant point of view for developing theory and planning experiments.

And in the last paragraph, he added:

The constituent quark model, with quark interactions described by QCD, became the accepted view of the structure of hadrons.

Assuming the hypothesis of quarks as valid, of course supported by the experimental evidence of J. Friedman, R. E. Taylor, and H. Kendall, B. Bjorken and M. Paschos got the consequences of the dispersion of electrons and of the dispersion of neutrinos. The predictions agreed with experimental results. Since then the quarks were an operative reality; however, the objective reality of quarks were very different from those obtained up to that time.

The Bjorken and Paschos predictions added more questions to quark model: Quarks behaved as if they were free inside protons or neutrons. But they could not be obtained as free states, or as free particles. Up to this time, they have not shown themselves as free particles. Maybe never show up as free states.

The experimental evidence laid quarks inside the protons. However, constantly at the experiments, at sufficient energies, they did not appear as free particles. Instead other particles are created. The acquired mentality in past decades on particles, demanded that quarks to be real must be appear as free particles, as electrons do, at appropriated energies. If they could not be observed as free particles, quarks could be seen as computational fictions only, not as real objects, as electrons are. The quarks inside the proton behaved as free particles. And remained confined, inside a structure, forming the proton, the neutron, and other baryons and mesons.

The Abelian norm theories can accommodate the unusual behavior of quarks inside baryons, this is, describe that behavior. In those theories, the interaction between two quarks decreases when less is their separation, and become more intense while more separated they are. As if quarks were inside a shell that becomes harder from inside to outside; where in its center is very soft and on its surface is infinitely hard. This behavior of the strong forces is called asymptotic freedom. That strong forces characteristic was the key to understand J. Friedman, R. E. Taylor, and H.W. Kendall experimental results.

In this way, quantum chromodynamics (QCD) was born in hands of Gell-Mann and others. With the name QCD he emphasized the fundamental role of color concept played in QCD theory. After the reinforcement of the theory by the experimental evidence of quark c -the experimental evidence of charmonium-, the image about the constitution of matter changed. And the current image about matter was consolidated.

That image presented in Chapter 3 is schematized in Figure 3.1. The current known elementary particles are leptons: (ν_e, e), (ν_μ, μ), (ν_τ, τ). And the quarks: (u, d), (s, c), (b, t). All of them are Fermions of spin $\frac{1}{2}$ in Planck constant units divided by 2π. They have no internal structure, as far as physicists know up to these days. Quarks are color triplets. They are influenced by the strong force. Leptons have no color charge. They experiment the weak force; the charged ones, the electric force, of course. They do not experiment strong force. But they experiment the gravitational force, for they have mass.

Some of the above mentioned particles physicists discovered them very recently: Physicists discovered the top quark in 1997. At Fermilab, inside the experiments $D0$ and CDF. Maybe there are baryons and mesons conformed by the top quark, like some sort of *toponium*. They have been not detected yet. Based on symmetry principles, physicists suspected the existence of t quark for they have detected τ lepton twenty three years before. This is t quark lepton partner, that conform the third generation or family of fundamental particles.

The tau lepton was detected in 1974 at SLAC. The neutrino associated to tau was indirectly detected in 1997. The channel disintegration of top quark (t) and of Z^0 was the channel of discovery, like the finding of another unstable particle. Another story is the neutrino associated with tau. This is the most elusive of all the three.

At Fermilab physicists are carrying out the experiment DONUT -Direct Observation of NU Tau. This experiment will detect the neutrino associated with the lepton tau directly. A beam of neutrinos associated with tau interacts with target protons to produce tau leptons.

The reader can consult the www page of this experiment, inside the Fermilab page: $www.fnal.gov$.

The forces complement the scenario of the constitution of the matter -and of the known universe-. They are four. As far as it is known. Attributes or properties of those forces are norm asymmetry. The forces appear, according to the standard model of particle physics, when the gauge symmetry, the fundamental symmetry in this theory, is restored; exactly as to re-establish an asymmetry (or symmetry) in the external macroscopic world an external force must be applied. They determine the character of the elementary forces.

The quantum chromodynamics describes the strong forces; the electroweak theory, the weak and electromagnetic forces, as the electromagnetic theory describes the electric and magnetic interactions. Both theories are non-Abelian norm theories. The general relativity describes gravitational interaction. At elementary particle levels gravitational force is considered irrelevant; because elementary particle masses are very small, however the distances are extremely short, and gravitational effects could be significative.

The first experimental confirmations of the electroweak theory were made by A. Lagarrique and coworkers in 1973. They were working at CERN. They reported the first signal of neutral electroweak currents. The discovery of bosons W and Z and the construction of sources of Z at CERN and at SLAC, showed the success of norm theory to describe the interactions of leptons and of quarks.

According to electroweak theory, the world must be composed of quarks and leptons. Each pair of quarks, for example u and d is accompanied by a pair of leptons (e^{-}, ν_e), in this case the electron and the neutrino associated to the electron.

There are three pairs of quarks accompanied by their respective pair of leptons. The physicists do not know if those are all the pairs that exist. Experimentally physicists know that there are no leptons more light than the known leptons. However, could be there leptons more heavy than the Z boson. If they exist, they could not be produced in the decay of the Z boson.

The neutrinos have a mass very small. It is different from zero. This is an experimental fact. Physicists need to know if neutrinos are themselves their antiparticles. Or if neutrinos are different from antineutrinos. And find the property that make them distinguishable, besides their mass.

It could be that the three generations of quarks and leptons is everything that exists. The past history has shown to physicists that always that they have considered concluded the image of matter -or universe-, it appears, to physicists surprise, new forms, new states, or new facts demanding changes of the physicists point of view.

It could be there, in the outer space, exotic forms of matter. Like the matter called dark; it could be distinct from the ordinary matter. It is not very much what physicists know about it, besides its existence and that it constitutes most of the total mass of the whole universe. Facts like that will appeal changes in the current and accepted theories about the universe, or about some part of it.

The supersymmetric theories are the most popular candidates to extend the electroweak theory. These theories require of spin zero particles. That must be affiliated, or matched, with the pairs of quarks and leptons above mentioned.

The quarks and leptons are smaller than 10^{-19} meters in their radius. Have no internal structure, up to where, in these days, it could be experimented.

The Table 3.9 illustrates all conserved quantities in the domain of elementary particles. All those quantities are inside the context of the standard model of elementary interactions. Some, like angular momentum, electric charge, and energy are known in the world of macroscopic physics.

Any event that shall violate those laws would be evidence of physics beyond the standard model. For example, inside the standard model laws 7, 8, and 9, are separated because neutrinos have zero mass. This is a supposition of standard model. If neutrinos have mass different from zero, as some experiments claim to have shown, then laws 7, 8, and 9 are violated. And conservation laws 7, 8, 9 of conservation of some quantity must be degraded to approximated valid laws. As it appears to happen so far.

However if physicists do not content themselves in describing material world as they found it, but physicists pretend to know why the nature is as it is, then physicists have in front of them a series of problems. All of them without a solution for the moment, as follows:

- What makes an electron an electron?
- What is the origin of electric charge?

- Why three generations of matter?
- Is electric charge related with mass?
- What is that relation?
- What is the origin of fundamental forces?
- Is there an unique force?
- Is there an unique particle?
- Why nature is the way it is?
- Why no more sort of lepton or quarks?

There are no experimental evidences to assume that there are more families of particles. The imposed conditions by the history of particle discoveries indicate that could be there more families of particles. The history of molecules, of atoms, of protons, indicates that quarks could be composed. However, the ideas, induced by aesthetics, suggested that the number of families must be limited: The complex world -that human beings perceive- must be fabricated of small number of simple components. If the quarks and the leptons are composed of particles even more small, eventually physicists will find them. Howsoever, physicists will find the relations between quarks and leptons. Or even between leptons, bosons, and quarks.

The most popular current theories, that extend the experimentally confirmed theories, propose that quarks and leptons are composed particles. There are no indications of the level of energy where those particles must be searched for. But physicists can characterized the yields that they must leave, the leptons and the quarks, if they are composed particles.

At energies high enough, during collisions of quarks and leptons, the particle constituents must approach up to touch them. Penetrate them. Interchange their components. In the dispersion of quarks by quarks, the interchange of gluons of QCD, the strong force, must be replaced for a force of contact. Its magnitude must be determined by the size of quarks. Just beyond quark limits, the force abruptly goes to zero.

For example, in $p\bar{p}$ collisions, the new contribution must give origin to an excess of hadronic jets at high transversal momentum or high transversal energy. There the dispersion of quarks antiquarks is dominant. The form of the jets must be completely different from the form predicted by QCD. If leptons have similar components to quarks, a similar excess must appear in the dileptonic production $\bar{q}q \rightarrow l^+l^-$. At energies high enough the effects of the excited quarks and excited leptons must be present. At those energies characteristic phenomena of their size must be present. The experiment has the last word, as in all physical theory has. And physicists ask nature continuously. Physicists, in these days, are building more powerful accelerators. Physicists, so far have no complete scheme of the material universe. There are more to know. Probably -certainly- physicists ignore more than they know about the universe.

In spite of the physicists great ignorance about nature, they can make great progresses with their limited knowledge. Create technology. One example is electronics. Another one is advanced computation, new materials, and new communication technologies.

4.3 Electronics

The discovery of electron, a milestone in the history of the scientific discoveries, initiated electronic era. The inventors of the time when electron was discovered, and posterior to that epoch, performed some inventions without knowing about the existence of electrons, and with false ideas about the nature of electricity.

For example, Graham Bell invented telephone -or at least it is what history tells, probably it is not an accurate story-. However, the perfection of telephone, invention of transistor, of modern communications, of computation, chip, etc., would not be possible without knowing electron, and of the laws that follows its behavior -i.e., quantum mechanics-. The discovery of electron changed the form of doing science and technology. Changed also the mankind history path.

In the last quarter of XIX century the change was born. Fifteen year before J. J. Thomson discovery of electron, Thomas Alva Edison found that a weak electric current traveled between two electrodes inside a bulb of glass partially evacuated of air. He patented his discovery and go ahead perfecting his electric bulb.

Six years after J. J. Thomson discovery, the British inventor J. A. Fleming applied Edison discovery to create the thermionic valve. It is also known as tube or diode, or valve rectifier of electric current. The old electronics from the beginning of the XX century used extensively this device.

Three years after Fleming invention, American inventor L. de Forest inserted to Fleming diode, inside the two electrodes, a third electrode. With this new element, changing the applied voltage, de Forest could control the electric current flux from electrode to electrode. In this way, de Forest invented the triode. He patented it. Applied it to electronics. And commercialized it.

Those inventors conceived the electric current as a fluid -or fluids, positive and negative-. Like a series of stretching and contractions of ether, likewise the XIX century electrodynamics proposed. Thomson experiments showed the falsehood of those ideas. Electricity becomes to be a flux of corpuscles electrically charged. Thomson called them in this way. G. Stoney called them electrons. Thomson never accepted this name. Eventually, the name electron thrived.

Corpuscles that transport negative electric charge are electrons. Electronics was born. It was the decade of 1920. Thanks to handy electrons there are a vast number of practical applications already in these times performed: Radio receptors, Cellular telephones, satellite communications, TV receptors, computers, microwave ovens, laser printers, fax machines, etc. And many, many, others that rest to be done. Likewise ultra speedy electronics, a switch that makes use of the nature wave of electron, molecular size automata and many others.

Those others. Physicists are looking for, working in industrial laboratories, centers of research, universities in USA and other technologically advanced countries. This organization of modern centers of innovations and technological development is, partially, thanks to electron. This discovery changed the way of doing technology. Now this new technology requires high trained people in physics, and in other sciences, like computation and mathematics. This personnel graduates from universities with a Ph. D. degree, to apply quantum mechanics, and other theories, to produce that innovations. The old and romantic image of inventors, very abstracted from the world and behind strange apparatuses, is outdate, old fashion. The modern inventions are made by industrial laboratory people. The inventions are based in the manipulation of atoms, molecules, and other particles. This is, in a superior knowledge of nature laws.

In those industrial labs, many inventions are in the waiting line. In days to come writers will write about them. They will relate that past achievements, and will tell how the inventor room becomes a modern industrial laboratory.

That transformation began at many places and at many times. The Fleming diode and the triode of de Forest showed many serious technical difficulties. The valve, that contained the electrodes, was not completely air evacuated. The gas got ionized for the pass of electrons, and limited the traffic of electric current. Therefore the capabilities of the valve were limited: It did not work amplifying high electric currents, for instance. The Western Electric, General Electric, and AT & T, tried to solve the problem. Because they were interested in exploiting commercially the valve. For example, in a telephone central. At the end they succeeded. Dr. in physics Harold Arnold, graduated under the direction of R. Millikan, working for the Western Electric, solved the problem in 1912.

The diagnosis and solution of H. Arnold was based in a superior knowledge of nature laws of behavior. He evacuated completely the valve, changed the material to fabricate the electrodes, modified the design of the valve, etc. An got a new one. The electronic tube.

In a year, the Western Electric constructed the new valve, the high vacuum thermionic tube. And distributed it. The telephone centrals, and other companies resulted highly benefited.

The big companies understood the benefits of physics. They created big laboratories to industrial research. And invested huge amounts of dollars. The Western Electric created the Bell telephone in 1925. There physicists made big scientific and technological progresses. They improved the high vacuum tube. With it, physicists C. Davisson and L. Germer established the wave nature of electrons. An important step in understanding nature procedures. This wave nature of particles had been theoretically proposed, years before, by L. de Broglie. For this experiment, Davisson shared the 1937 Nobel prize on physics with G. P. Thomson. In part the improvement of the high vacuum tube consisted in coating the cathode, made of Tungsten, with a thin film of oxide. The theoretical works of E. Fermi and P. Dirac, in quantum mechanics applied to solid state, let these advances. The thin film of oxide reduces the metal function work. And electrons can escape from the metal more easily. In this way, the tube energy operation is reduced considerably. The annualized save of energy to AT & T meant million of dollars. The same for other companies, including USA government.

The new technologies are benefited from the knowledge of new materials, as in the case of high vacuum thermionic tube.

4.4 New Materials

But old materials, like the above mentioned -Tungsten- are not enough to solve some practical problems. New materials -designed to have some particular physical characteristics- are needed. And a physical description of those materials are needed too.

Physicists F. Bloch, R. Peierls, and A. Wilson, mainly, created modern solid state physics theory. Their theory describes the propagation of waves of electrons through the periodical potentials formed by atoms in a crystal. The theory let physicists understood electrical behavior of conductors, of insulators -that are not really perfect insulators-, and of semiconductors.

Devices made from semiconductors substituted thermionic high vacuum valves. In this way, solid state electronics was born. Solid state devices can operate at frequencies of some hundred of megaHertz. At those frequencies high vacuum tubes can not operate. The technology of fabrication of the solid state devices was benefited with the new technologies of purification, grown, and controlled doping of semiconductor materials.

The Bell laboratories and another centers of research investigated and made solid state devices, during the second world war and after it. To do that, they created groups of physicists dedicated exclusively to the study of the solid state physics. Their presidents, also physicists, understood that to learn how to manipulate atom by atom could bring great benefits to industry.

The technologies based on the manipulation of atom by atom, and electron by electron, physicists have no constructed them. The invention of transistor is the closest intent. Physicists J. Bardeen, W. Shockley, and

W. Brattain, from Bell laboratories, invented it at the end of 1947. This device substituted the triode of de Forest in operation and capabilities, and went far forward in applications. Its functions are the same, but the space that it occupies and its physical characteristics, and operation electric potentials are not. Its application potential is enormous. A. de Forest valve has problems. It brakes operating in vehicles, for instance, or in another bumping mobile. Transistors have not that sort of problems.

Those physicists got the 1956 Nobel prize in physics. In his Nobel lecture *Transistor technology evokes new physics* W. B. Shockley wrote:

An important fraction of United States industry adheres to the idea that research of a fundamental character is worthwhile from a practical point of view.

And in another paragraph he added:

Not all the important work has, of course, been motivated by highly practical ends which could be so immediately achieved once the fundamental science was understood.

And he cited, in his Nobel lecture:

It may be appropriated to speculate at this point about a future of transistor electronics. Those who have worked intensively in the field share the author's feelings of create optimism regarding the ultimate potentialities.

Transistor physics is described by quantum mechanics. The interpretation of transistor behavior is the Shockley effect. Electrons and holes can fluid, by diffusion, in mutual presence. Shockley called this phenomenon injection of minority carriers. The understanding of this phenomenon, given by quantum mechanics, is the key for the development of this sort of tool. And of another ones, like the chip.

Transistor let to develop, besides other scientific disciplines, fast and not so expensive, electronic computation. To reduce computers size to a desktop tool, and even to handheld instruments.

4.5 Computation

The first computers -in the modern sense of the word- were like a contemporary wall refrigerator. They were composed of hundred of thermionic high vacuum valves. They were ostentatious. They spent a huge amount of electric energy. Only big corporations, like the United States army -or big research laboratories or big companies-, could be able to afford them. It was the year of 1952.

The before mentioned situation changed. W. Shockley, winner of the Nobel prize in 1956, conjectured that the use of transistor could change computers shape. Also uses, applicability ambits, operation energy, and dexterity to utilize it. It happened so. And something else also occurred. For transistor can be reduced in size, its possibilities are enormous. The transistors can be packed and connected, by millions, in a cubic millimeter. Physicists interconnected them right there. With them, physicists built electronic memories, integrated circuits, tri-dimensional integrated circuits, etc. And with those gears, physicists made clocks, televisions, etc., but mainly computers. Computers are the core of all automatic machines.

The main attributes of computers are the speed to process information and the capacity to store it. All developments of computation have been made in this direction. Additionally computers got size and consumption of power reduction. The first computer lacked of memory. It was the MANIAC I. And the year was 1952. It occupied the volume of a big desk. It did no see the market.

Latest computers in market have 3.6 gigaHertz in clock speed, some million of units of RAM memory, and occupy the volume of regular folder three hundred page book. They operate, continuously for more than 4 hours, with a 12 Volts cigarette box size battery. They have infrared communication port, fax modem, drive for diskettes and CD, sound stereophonic system, DVD player, and hard disk up to 100 GB.

With a high capacity of computation and storing information computers, other scientific areas are developed. Limited memory and limited speed are not big problems any more, as they used to be. New technologies appear. New science branches. For example, molecular biology, molecular chemistry, computational physics, etc. The very long calculations, that appear when quantum mechanics is applied to a many body physical system, are not big problems any more. They can be made, now in these days, in a few hours in a medium size book computer. And developments in computation and communication continue at accelerated pace in these days, integrating huge amounts of computers in one big global network that could work as a single computer.

4.6 New Technologies

The development of fast, and more capable, computers speed up the generation of new technologies. Because computers permit to manipulate more information in less time. However, no always things were like that.

Practical human beings, along all their history down, performed ancient technologies by trial and error -this is the way human beings acquired knowledge enough up to become computer builders-. Alloy technologies, tempering of steel, irrigation of agriculture fields, etc., are some examples. Practical human beings are still making new technologies and improving them. Even though now their knowledge and research are leaded by science, and have created the continuum development concept, sometimes their results are not. There are still surprises.

That surprises appear in all scientific areas. These are some examples:

In January 1999, physicists discovered the element 114. It appears that this element initiates an stable family of elements. And leaves the possibility of preparing more stable elements than the transuranic ones. Close to the middle of 1999, physicists discovered element 118. The possibility becomes a reality.

But not only with new elements there are surprises. Also with old known elements, when they show themselves in not suspected forms or physical conditions. Carbon gave those surprises. Carbon showed itself in the form of fulerene, to the delight of physicists. Chemists, H. W. Kroto, R. E. Smalley, and R. F. Curl, detected fulerene in 1985. And they got the Nobel prize on chemistry in 1996. Up to Stockholm the surprise echoed.

Fulerene is an allotropic form of Carbon. The diamond other. And graphite other one. However, graphite, diamond, and fulerene are physically and chemically very different. Diamond crystals have octahedron form. Graphite crystals are plane laminar. Fulerene crystals have the form of a football soccer ball. In this round shape form there are packed 60 atoms of Carbon. This allotropic form of Carbon acquires the form of very slim and large tube -nanotubes-.

In its large tubular form, fulerene is more resistant than steel to deformation and more mechanically resistant. Fulerene is not so heavy than steel. Fulerene is chemically inert. And conducts electricity like a metal.

Therefore, fulerene is an ideal material to fabricate molecular wires. Nano probes. Those could be applied in fabrication of computers and another devices that require to be very resistant and light -for example fuselage of aircrafts-.

Like Carbon in form of fulerene, other materials based on Carbon could be obtained when arrangements of atoms and molecules be manipulated. The number of combinations in stable arrangements is huge. The condition is to obtain a configuration of atoms of minimal electric and magnetic energy. Each of those configurations will give an allotropic form, with singular chemical and physical properties.

And, in the above way, materials with chemical, physical, mechanical, electronical, optical, magnetical, electrical, etc., properties will be obtained by design, to fit some predetermined characteristics. Hardness, conductivity, etc., for instance.

Future computation has particular problems derived from materials. Transference, process, and storage of information are the origin of those problems. Liquid crystals, optical fibers, polymer conductors, alloys, photocells, catalysts, inorganic polymers, superconductors, photonic materials, ceramics, etc., are investigated to solve those problems.

Nanotechnology will depend on manipulation of diverse material atoms. Molecular architecture will be possible. And electromechanical systems in miniature, at molecular size, will be obtained.

Molecular size mechanisms will be possible. At their time, these molecular machines could be used in construction of other molecules. With them, the structure of the cell could be manipulated, for instance. And when the cell be manipulated, cures of human body, at molecular level, will be possible. For example, unfetter of blocked arteries; demolition of tumors, etc.

Before nanotechnology - or better, femtotechnology, or the way down to yoctotechnology- be a reality manipulating atom by atom -or proton by proton, or better quark by quark and lepton by lepton-, technology of superconductors, of alloys, of semiconductors, of ionic implants, of X ray lithography, deposition of materials by molecular beams, deposition of materials by transmission electronic microscope, etc., will be applied and perfected.

Physicists, using the technique of electronic microscopy, deposit layers of atoms of 30 Angstroms of thickness. Also they fabricate lasers based on semiconductors. Those lasers, of a lentil size, are revolutionizing communications and home technologies. Physicists apply those devices to store, to process, and to read information. The smaller laser could be a molecule size; the molecule size of the semiconductor based laser. This limit will revolutionize optoelectronic technology, both industrial and domestic.

Physicists have intensified the search of alloys and semiconductor mixtures to produce lasers of shorter wave length. For example, to pass from red laser light to blue laser light meant a big forward step. With red laser light, digital video disks (DVD) have a capacity of 4.7 GB by each side. With blue laser light, have a capacity of 15 GB by each side. These disks can storage video information for 6 continuous hours. The next step is to go to violet laser light and then to ultraviolet light. And from these, to X rays. Those will be gigantic steps. In each one of those, there will be bigger and bigger capacity of storage. Apparently there is no end. However, energy -and capacity to manipulate it- is a limitation.

Obtaining materials to the fabrication of permanent magnets is another line of industrial investigation. Using conventional metallurgical techniques, industrial companies produce permanent magnets of more than 36×10^6 gauss-oersted of storage magnetic energy.

Mixtures of high temperature superconductor ceramics is another advance in technology of new materials. Physical systems will be more efficient. That will allow to save millions of dollars, per year, to big companies in electric energy bill. Actually the best high temperature superconductors operate with liquid Nitrogen. Close to 94 K. The next step will be obtaining superconductors that operate at ambience temperature.

Techniques for fabrication of integrated circuits, and chips, physicists have improved them. Now there are tridimensional optoelectronic chips. Physicists and engineers will exploited them to implement parallel process in processing and transmitting information, in computing. The number of miniature transistors in a tridimensional chip is about 10 million.

Amorphous materials also offer many technological possibilities. Those material physicists handle them in form of thin films. Their optoelectronic properties are commercially exploited in transistors, solar cells, and many other devices, etc.

Technological and commercial exploitation of those new advances and discoveries in high energy physics are to be done in days to come. Maybe someday information could be stored in proton quarks, or could use spin of Λ^0's to store and compute information, and gamma rays to record and read information. The possibilities that offer manipulation of quarks are more numerous than those that offer the manipulation of electrons and photons. The technology based on manipulation of quarks will be for us as much fantastic as, maybe more, the technology of these days, based on electrons, appears to the twenty century first year physicists.

Also, fantastic will be the manipulation of biological material and genetic information at molecular and atomic levels, and the results obtained from that. For instance, fabrication of electric nanocomponents using akin DNA information; breed nanocomponents for mechanical, optical, electronical, etc., purposes. The possibilities are enormous; the results, bizarre. These investigations are very new in these days. In the days to come food, medicine, health, will be very benefited from that new high energy physics knowledge. And a new sort of technology indeed.

4.7 Medicine

Traditionally, medicine -or biology- is considered to be very far away from physics, as a field unrelated with exact sciences and engineering. However this point of view is changing in these days. Manipulation of biological materials, at very deep levels -like the genetic code- is possible in these days.

4.7.1 *Introduction*

Biology, in these times, is transforming into an area of physics. Techniques of detecting particles, techniques of producing new forms of radiation, let to explore alive materials. Physicist-physicians explore heart, lungs, brain, etc., of human beings. Exploration is in live. They can detect abnormalities in live organ function, and in the development of those organs, and in the rest of human body. And correct them. Medicine, like now biology, maybe will become a part of physics.

Physics has influenced and modified medical practice since the XX century beginning. X rays to photograph strange bodies located inside muscles, technique of spectroscopy of X rays, use of radioactive materials to explore alive organs, destruction of cells with radioactive materials, are some examples of applications of physics in medicine.

Use of synchrotron radiation, antimatter, paramagnetic resonance, heat, radioactive isotopes, etc., are some examples of radiation applications in these days in medicine.

Those applications, in our days, of physics to medicine started with the discovery of X rays. With X rays, radiology was born, both as detection and therapeutic techniques; even though the intents of human beings to heal themselves using physical knowledge are as old as human beings are. After that, other techniques and medical specialties were born. The run for discoveries and applications of physics to medicine continues up to these days.

4.7.2 *X Rays*

Radiology turns one century in 1995. Röentgen discovered X rays in 8 November 1895, in his laboratory of Würzburg. Twenty days after this discovery he communicated it to the world. His results showed also his wife hand X ray photograph. This event marked the radiology born.

From those discoveries, scientific world started a series of inquiries about nature and applications of X rays. Those investigations in these days continue. X rays, in these days, are used in therapy and diagnosis.

The more important events originated by the discovery of X rays are related in next paragraphs. All those discoveries cemented the use and trust of X rays. Also those discoveries expanded the knowledge about the nature of X rays.

Enrico Salvioni, Italian scientist, created, in January of 1896, the fluoroscopy technique. Scientists use it, in essence, in these days. This technique uses the physical fact that some substances emit light at a visible wavelength when some radiation -light, X rays- strike on them. The higher the incident light intensity, the higher the emitted light intensity.

If X rays pass trough a human body, or other composed body, different parts of it absorb radiation more than others, for the bodies, in general, are not uniform. And if X rays have passed before to the body and hit a fluorescent plaque an image of the body, and its constituents, will be formed on the plaque. Because this, evidences of strange bodies inside human tissues can be revealed. For this, X rays can be used in diagnosis. Also in crime evidences.

A court in Montreal, in March of 1896, used X ray photographs as a criminal evidence. Photographs show a bullet allocated in victim muscles, that exploratory surgery could no reveal. More elaborated procedures are possible, as a complement of X rays techniques, for clinical applications.

Francis Henry Williams, doctor from Boston and graduated from the Technological Institute of Massachusetts, specialized in instrumental uses, to medical and clinical purposes, of X rays. And he applied them in diagnosis, including the use of fluoroscopy to veins study; in this way he invented angiography.

Therapeutic uses of X rays become after. To destroy undesirable tissues of human body. Both natural and artificial X rays.

Marie Curie and her husband discovered Radio. That was the year of 1898. This discovery, like the X rays one, caught world imagination. Radio is the natural source of X rays. Additionally it is portable. Physicists, and non specialized public in general, transport small quantities of Radio in their pockets, they put it in facial creams, in drinks, etc. It was a collective madness.

Inside that madness, non specialized public believe that Radio has healing properties. It thinks that Radio alleviates flu. That reduces blood pressure. That it curates insomnia. That it increases sexual power. And, according to that believes, non specialize public behaves. General public uses drink glasses contaminated with Radio. Uses ceramic plates radiated with Radio. Organizes fiestas where public drinks cocktails contaminated with Radio. It plays Radio roulette -a lot painted with radioactive colors-that shines in dark rooms. And by its ignorance, and daring, public dies also.

Inside that dementia, a few scientists saw the harmful that X rays are. Between those, German scientists Friedrich Giesel and Friedrich Walkhoff.

They discovered that X rays from Radio damage skin. Pioneer physicists -like Mary Curie and her husband-, apparently, did not notice the harmful that X rays are. They work continuously exposed. They suffer lethal consequences.

Those physicists that discovered, and pioneered work of, radioactivity suffered the harmful effects of X rays. Burns in skin, by over exposition to X rays, and leukemia. Amputations. Death, eventually.

Mary Curie dies of leukemia generated by X rays over exposition. And Clarence Dally, assistant of Thomas Alva Edison, in experiments with X rays, died after suffering many amputation.

For those incidents and others, physicians and physicists confined in their consulting offices and in their laboratories X rays and the natural sources of radiation. Physicists, step by step, learned how to use X rays and to control them. In 1910, eyes protectors and metal shields were commonly used to armor X rays sources.

During the first world war, field hospitals and aid stations used X rays in diagnosis. Mary Curie worked there. Using X rays as a sure diagnosis technique.

X rays as a diagnosis technique can be improved, using other elements as aids.

Carlos Hauser, Argentinean radiologist doctor, used Potassium Iodide diluted in water to create contrasts and to take photographs of veins. He worked and published his results in Argentina. That was the year of 1919. Later, the technique is reinvented in other parts of the Globe.

Doctors, in the decade of 1920, used thorax X ray photograph to diagnose tuberculosis. They succeeded in saving many human lives. In that same decade, the Portuguese doctor Egaz Moniz developed the modern angiography. He got images of the circulatory system of an alive brain. And doctors of St. Louis, Evarts Graham and Warren H. Cole discovered how to X ray photograph bladder and diagnose its illness.

In the following decade, it is created the first organization of radiologists in the USA. In 1934, exactly. It is recognized by the American associations of physicians. In 1936 it is presented in a congress of radiology the first tomography. It is a radiographic view of human body to see it from different angles and to reveal its tridimensional structure. The technique also is called laminography. It gave origin to computerized tomography of 1970 decade end.

In the 1930 decade, physicians experimented with hard X rays, produced by powerful high voltage supplies, in the treatment of larynx cancer and of tonsil cancer. It is the born of the therapeutic uses of the X rays. The main problem is the control of deposited energy. As it is in these days. It is the main problem of any other technique of radiation.

4.7.3 *Other Techniques*

In parallel with the development of diagnosis techniques and cure by X rays, physicians explored other alternative techniques. Gamma ray chambers, to detect radiation of wave length shorter than X ray wave length. Artificial radioisotopes, to produce gamma rays, with long meanlife. Linear accelerators (or linacs) to produce energetic X rays. And others.

Detection of gamma rays originated from disintegration of radioisotopes, specially of those of large meanlife, make physicians prefer radioisotopes technique to diagnose, to study, and to explore liver and brain, and other human live organs. However, the fine tuning of the out coming energy from linacs, make that physicians substitute Cobalt radiation sources by linacs.

Other techniques came along. Ultrasound, Doppler effect techniques, computerized tomography, nuclear magnetic resonance, tomography by emission of positrons (e^+, or antimatter of the e^-), thermography, thermotherapy, chemotherapy, Monte Carlo technique, and others that resulted from combination of two or more of the above mentioned and of modern electronics, modern optics, and of modern computation.

Some techniques apparently are not harmful. Like ultrasound technique. Other techniques are. Like radiotherapy. Some techniques are very simple. Like radiology. Other are complicate and expensive. Like therapies based on radioactive isotopes. In all cases computers are present. Physicians use them to do complicate calculations of doses to radiotherapy. To do analysis of images. To automatize recollection of data from laboratory. Etc.

Laboratory data collection comprises production of live organ images. Physicists invented computerized tomography for this end. This technique can perform, through different scans of the interesting organ and sophisticate computational algorithms, tridimensional images. This technique is useful in surgery, for it gives to surgeon exact localization of malformations, obstructions, anomalous growths, etc., and to oncologist, images to plan and monitor treatments.

Magnetic nuclear resonance is another technique that let physician to plan and to monitor treatments. It is based on very simple ideas. And in very simple physical concepts. Quality of images are comparable to those obtained by computerized tomography. It has additionally the advantage of not using the harmful X rays. It uses very intense magnetic fields. Some 8000 times more intense than the terrestrial magnetic field. Physicists up to these days disregard any possible harmful to live human, or animal, tissues from strong magnetic fields; however, strong magnetic fields could be very dangerous to human body. This is a subject to investigate.

In the magnetic nuclear resonance technique, used ideas are very simple. Human body is composed basically by water. Close to 85%. This is, of Hydrogen atoms and oxygen atoms. And there rests the central idea. Strong magnetic fields can line up magnetic moment of nucleus of Hydrogen atoms -without displacing the nucleus-. And when magnetic field is imposed and then released, Hydrogen atoms emit electromagnetic radiation. Physicians produce images detecting and analyzing that electromagnetic radiation. Produced images by magnetic nuclear resonance complement that obtained by computerized tomography. Due to the technique of magnetic nuclear resonance produces only plane images. In any plane. Combining the two techniques, the physicians can obtain a more exact diagnostic and can monitor his therapy. In conjunction with computation and speedy electronics, these techniques give very clear tridimensional images of organs, and of very tender structures of human body.

Physicians calculate the amount of energy, required to destroy tumors, via Monte Carlo technique. Also to calculate the amount of energy deposited in the human body when it is radiated. However cannot finely control, or tune, the amount and localization of radiation.

Another way of using the radiated energy from natural sources, or artificial sources, is to study alive organs -functioning human organs-. An example is human lymph system, another one is the brain.

4.7.4 *Study of the Brain*

Brain -in particular human brain- always has fascinated physicians, physicists, and the general public. Dreaming, speech, hearing, memory, equilibrium, etc., but over all interpretation and processing of information, are some of the amassing functions of the human brain. Even the most sophisticate of these days computer does not equal these functions. Physicians investigate functions of brain using techniques from high energy physics. The results would affect computation, informatics, telecommunications, and other scientific branches. Maybe, after that investigations scientist will be more fascinated by the functions of the brain.

The leading idea in these investigations is very simple: The activity of different brain areas and blood flux in them are very close related. The higher the brain activity, the higher blood irrigation of the brain area. Dead areas, or inactive areas, are poorly irrigated. To monitor blood irrigation of some areas of brain is to monitor its cerebral activity. Physicians register cerebral activity using radioactive probes.

Physicians use Xenon 133, it is a radioactive Xenon isotope. They inject it diluted in sterile physiological serum to arteries patient that irrigate brain. The radioactivity probe, blood transported, indicates blood flux. Physicians detect the gamma rays, originated from the disintegration of Xenon 133, through arrays of scintillator detectors located outside patient body. Each one of the detectors explores and monitors a square centimeter of cerebral area. Physicians process information from detectors using computers, projecting images on a chromatic TV monitor. Different regions in cerebral cortex and their respective activities are visualized in different colors, indicating the intensity of blood irrigation. The detected radiation comes from cerebral cortex, for that originated from more deep regions is attenuated. Therefore Xenon technique gives a clear image of cerebral cortex and of its activity.

But cerebral cortex is only one part of the brain. Physicians use complementary techniques to explore the whole brain, specially internal regions. Computerized tomography, nuclear magnetic resonance, tomography by positron emission, pulsed fluoroscopy, etc. All those techniques complement brain study technique.

And the brain is only one part, fundamental, of the human body. Each organ, or system of organs, of the human body can be studied using high energy physics techniques.

4.7.5 *Conclusions*

Physics used with medical purposes has saved thousand human lives through the last one hundred years. Its first use was in diagnosis. And its second one was in therapy. As a diagnostic technique is where it has given the best results. Also is where physicians have the strong experience. Physicians are still learning. For sure physics will save many more thousand human lives when contemporary techniques be perfected and physicians get another ones.

Physics with diagnostic purposes almost presents no problems. The procedure is practically limited to obtain static images, digitalize, computerize, etc. Those techniques, to perform that tasks, physicists invented to study inert matter. In spite of this, that techniques apparently present no problems to patients. But no one knows for sure.

Physics with therapeutic purposes presents serious difficulties to patients. Those therapies normally are based on radiation or on deposition of radioactive material, to destroy anomalous alive tissues. Control and focalization of administered dose is the main problem. Physically still without a complete solution. Therefore causing severe damages to body patients. However techniques improvements are in the way.

Using diagnosis techniques, physicians and physicists explore alive human body. The obtained tridimensional images let surgeons do in a better way their diagnosis and therapies, and of course, monitor the development of their treatments.

That used treatments, or prescriptions of treatments, are based on the function of treated alive organs. Physicists and physicians study the function of human organs, or animal organs, through use of diagnostic techniques. The more exact the knowledge about the treated organ, the more effective could be the therapy.

The study of the brain function and the connection between its functions and the functions of the rest of the human body organs have deserved special attention from physicists and from physicians. Cerebral regions related with speech, attention, tactile sensations, etc., have been identified. There are still many things to investigate and to explore in the brain. Functions of memory, sleep, computation, vision, equilibrium, orientation, volition, etc., are still mysteries to contemporary scientists.

Physicists and physicians, in days to come will solve those mysteries. They are trying now all over the world.

4.8 Conclusions

Physics is not a collection of experimental data. Neither it is a collection of mathematical formulas or principles given a priori. Physics is an experimental science. Its principles are based, and supported, on irrefutable experimental evidence. Physics is, therefore, the description and interpretation of the external world.

The external world, in formal courses of physics, is eliminated. Sometimes, even a minor mention of it is never done. In this way, the connection of the physical world and the conceptual world physics is never established. Students conclude formal preparation believing that physics has nothing to do with the external world, with everyday world.

External world and physics, for those scientific that understand physics, always are inseparable. Always are together. Physicists like A. Einstein, E. Fermi, etc., always were looking to put their physical principles on the most solid experimental evidence. That is the way of working of physicist that really understand physics. For them, external world and physics are inseparable. For them, physics is the representation of the way of going, and evolving, of the external world.

If the before mentioned concepts are understood and applied correctly, then the role of physics is clear. Besides, practical potentialities of physics are clear. Physics provides a scheme that let physicists understand nature. And understanding nature leads physicists to the possibility of manipulate, with practical purposes, nature. Mere manipulation of nature lets physicists rectify and corroborate their principles. This lets physicists go deeper in understanding nature.

The guides in the investigation of nature structure are very general principles: Simplicity, beauty, unity, and others. Based on these principles, physicists have proposed concepts like atom, particles, elementary particles, etc. In practice those principles have been proved be very fruitful. And physicists have constructed current image of nature structure based on the concept of particles and forces. This image coincides, in principle, with the classical Greek image. Even though the current image is more elaborated and sophisticated. It is more complex. But the ideas of simplicity, etc., are behind this image.

Carriers of force, particles, leptons, and quarks, are the ingredients of nature scheme: At least six force carriers, six quarks, and six leptons. And their corresponding antiparticles. Constitute contemporary scheme in terms of particles and forces. This image is very far away from Greek proposed simplicity. However, up to some level, it works. Maybe someday the Greek idea of simplicity could be obtained and proved, maybe not.

The partial utility of that image is at everywhere and at everyday. The benefits that physics has given to society are many. Almost all XX century technology is from this physics. Computation is a transcendental by-product. It will completely change organization of society of years to come. And by itself, that change will help to modify the image about nature structure.

In this way, conception of physics as description and interpretation of the external world is correct. It is the way physicists that have constructed physics understand it. The fruits of that conception human beings live everyday and everywhere.

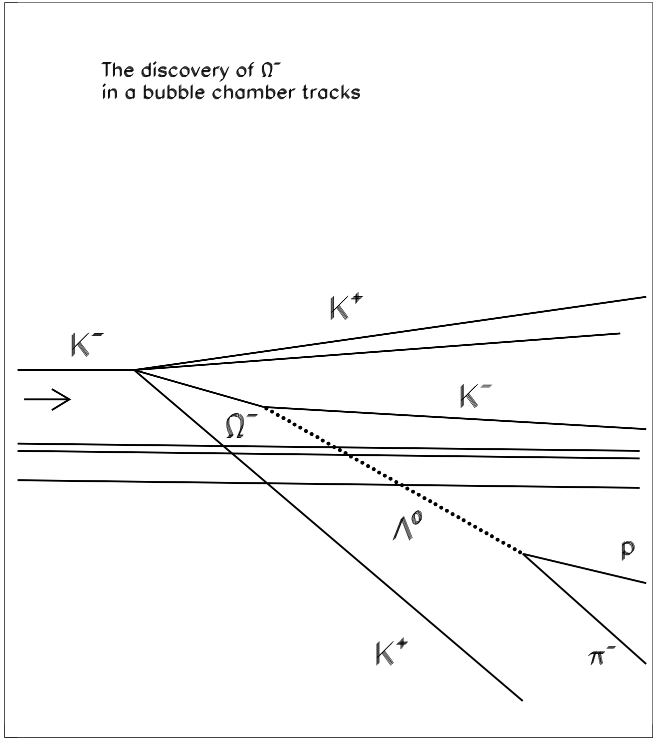

Fig. 4.1 Discovery of Ω^-. This particle decays into $\Lambda^0 \to p\pi^-$ and K^-.

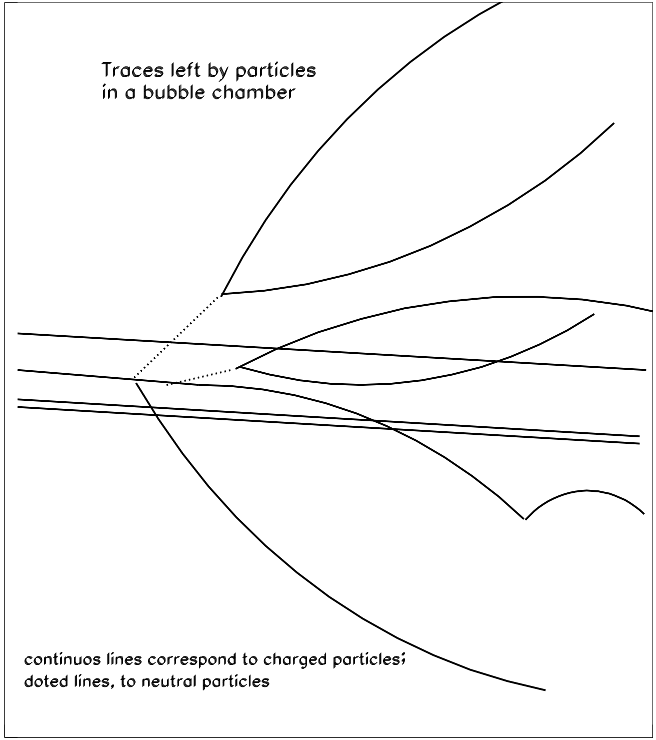

Fig. 4.2 Diagram of particle detection through its particle daughters.

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