# *The Place of* ELEMENTARY PARTICLE RESEARCH *in the Development of Modern Physics*

***This article is based on papers presented by the author on January 25 of this year at the New York meeting of the American Physical Society and on February 21 before the Royal Society in London.***

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THE search for elementary particles is as old as science itself. It is always the most advanced part of physics which strives for understanding of the fundamental constituents of matter. As physics progressed, the search for elementary particles moved on from chemistry to atomic physics, and then into nuclear physics. Not much more than a decade ago it separated from nuclear physics and became a new field, dealing no longer with the structure of atomic nuclei but with the structure of the constituents of nuclei, the protons and neutrons, and also with the structure of electrons and similar particles. This field is often referred to as high-energy physics because of the fact that particle beams of extremely high energy are needed in most of its relevant experiments. This article is intended to provide a bird's-eye view of the innovations resulting from recent elementary-particle research and to show how they fit into the framework of the physics of this century.

It is generally maintained that high-energy physicists have discovered one new particle after another; the number of "elementary" particles is said to be over 40 now. One longs for the days, 25 years ago, when matter consisted of protons, neutrons, and electrons (with the occasional appearance of a neutrino), and when one could explain anything, from astronomy to physics and chemistry, or even biology, on the basis of these few elementary constituents and the forces between them. I contend that the view that there is a large number of so-called particles is based on a misunderstanding which is arrived at because of the following three practices:

1. Each antiparticle of a given particle has been called a new particle. This is as if one were to double the number of animal species by calling the mirror image of each species a new species.
2. Each excited state has been called a new particle. If this custom had been used with atoms, the number of different atoms would now be in the tens of thousands.
3. Entities such as the light quantum have been called particles, a point which is perhaps a matter of taste. In this article a light quantum will be called a quantum of the electromagnetic field, and we will also refer to any other entity which obeys Bose statistics as a field quantum rather than a particle. We reserve the latter term for entities which cannot be singly emitted and absorbed.

We propose to present here a simple point of view which, in many respects, reflects the outlook of modern field theory, the only theoretical form we know in which to formulate the physics of particles and their interactions. This point of view is not so different from the outlook 25 years ago. There are two elementary particles: the *baryon* and the *lepton*. They appear, however, in different states. Let us first consider the situation as it was before the discoveries of strange particles. The baryon was then

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known in two states, as proton and as neutron; the lepton as electron, as neutrino, and as $\mu$ meson.

Just as the electron exists in two states, spin-up and spin-down, the baryon exists (apart from the spin states which it also displays) in two states as proton or neutron. They are usually referred to as the two isotopic spin states, in which a component, $I_3$, of the isospin is equal to $+\frac{1}{2}$ or $-\frac{1}{2}$.

The two types of elementary particles exert forces on each other; they interact by means of fields. Today we know four different kinds of fields, which are listed in Fig. 1. Each field is produced by a source, but it can also propagate independently from the source when emitted by the source; such emission takes place when the source is accelerated. The field then propagates in the form of field quanta. These field quanta have characteristic properties: sometimes they carry angular momentum, sometimes they possess charge or other qualities, and sometimes they have a rest mass different from zero. In the latter case the acceleration must be strong enough to supply at least the mass energy of the quantum.

The source of gravity is mass; its quanta, the gravitons, should have a spin of 2, but no quantum effect has yet been observed. The source of the electromagnetic field is charge; the quantum carries an angular momentum of unity. The nuclear field seems to be somewhat more complicated. Any baryon is a source of this field, and the quanta are emitted when the source is strongly accelerated by collision or otherwise, in analogy with light-quantum emission. The nuclear quanta are simpler than the light quanta in one respect: they carry no angular momentum. But, in contrast to both gravitons and light quanta, they carry mass, which, according to Yukawa, is connected with the fact that these fields are short-ranged. There seem to be two kinds of nuclear quanta, the $\pi$ and $K$ mesons (we will refer to them often as pions and kaons); both carry charge, which is usually expressed by an isotopic spin: the pion carries one unit, the kaon half a unit of this spin. The kaon carries another quality which is called "strangeness". It can be expressed in terms of a quantum number $S$ which is unity (positive or negative) for kaons but zero for pions. Later we shall come back to this most important property.

The weak interactions are too little known today for an exhaustive description. Suffice it to say here that it is perhaps possible to express these interactions also in terms of a field, whose sources reside

ELEMENTARY PARTICLES

| Baryon | Lepton |
|---|---|
| $p, n,$ | $e, \nu, (\mu)$ |
| $I_3 = \frac{1}{2}, -\frac{1}{2}$ | |

Fields

| Type | Source | Quantum | J | q | I | S | m | |
|---|---|---|---|---|---|---|---|---|
| Gravity | Mass | Graviton | 2 | 0 | — | — | 0 | |
| El. Mag. | Charge | Photon | 1 | 0 | — | — | 0 | |
| Nuclear | Baryon | Pion | 0 | → | 1 | 0 | $m_\pi$ | $q = I_3 + \frac{S}{2}$ |
| | Baryon | Kaon | 0 | → | $\frac{1}{2}$ | 1 | $m_K$ | |
| Weak | Baryon | Interm. | 1? | 1 | — | — | ? | |
| | Lepton | Boson | | | | | | |

*Fig. 1.* List of elementary particles and field quanta. $J$ stands for angular momentum, $q$ for charge, $I$ for isospin, $S$ for ordinary spin, and $m$ for mass.

both in baryons and leptons, and that there might perhaps exist a boson which would be its field quantum. It would possess a larger mass because of the short interaction range; also, its mass would have to be larger than the kaon mass, because the $K$ meson would decay and emit it if its mass were smaller. It would have one unit of charge and of angular momentum, since these two quantities are transmitted in the beta decay.

The analogy between electromagnetic and nuclear fields is illustrated by the scattering of a field quantum by particles. When light quanta are scattered by electrons, it happens that the spin of the electron is flipped over:

$$h\nu + e\uparrow = h\nu' + e\downarrow.$$

The light quantum can transmit the difference in spin by changing the direction of its own spin. The analogous process appears in the nuclear case as an exchange of isotopic spin (charge):

$$\pi^- + p = \pi^0 + n;$$

here a charged pion is scattered and transmits its charge to the nucleon.

There is an important difference, however, between the two fields. The electromagnetic field (like the gravitational and the weak-interaction fields) is weakly coupled to its source, whereas the nuclear field is strongly coupled. A simple qualitative definition of the coupling strength would be as follows: when the source of a field is suddenly removed by transmitting to it a very large momentum, the field itself is left behind and spreads out in space as radiation. If the number of quanta in this spreading field is much less than unity, the coupling is weak; if it is larger than unity, the coupling is strong. Strictly speaking, this number depends on the momentum $P$ given to the source; the number is $\sim [e^2/\hbar c][\log(P/m)]$ in the electromagnetic case, which is small for all currently obtainable momenta. For nuclear fields, however, the corresponding number is already larger than unity when $P$ is of the order of a few GeV/$c$. This strong coupling has most interesting consequences to which we will come later on.

Fields transmit forces between the particles that act as their sources. If the forces are attractive, two or more particles form bound systems. These systems exhibit characteristic quantum properties, such as quantum states, including a ground state and excited states; there are transitions between these states with emission and absorption of field quanta. Atoms and molecules are examples of such systems interacting by electromagnetic fields. Nuclei are systems of nucleons interacting by nuclear fields (see Fig. 2). The systematics of excited states is known as spectroscopy, listing the states, their quantum numbers, parities, transition probabilities, etc. We have so far known two kinds of spectroscopy: atomic-molecular and nuclear.

We now come to the first characteristic consequence of strong coupling in nuclear fields. Let us compare a single source in the weakly coupled electromagnetic case (an electron) with a single source in the strongly coupled nuclear case (a nucleon). In the first case, the field has a simple structure, the Coulomb field. In the second case, the structure of the nuclear field is not only more complicated, it also can exist in different "formations". There are several different "field states" which a nuclear source can produce, whereas, in the electric case, the source can only produce one field, the ordinary Coulomb field.

As a first example, we mention the well-known

QUANTUM SYSTEMS

2 or more particles interacting via fields

| Fields | El. Mag. | Nuclear |
|---|---|---|
| System | Atoms | Nuclei |
| | Molecules | |
| | Crystals | Nuclear matter |

*Fig. 2*

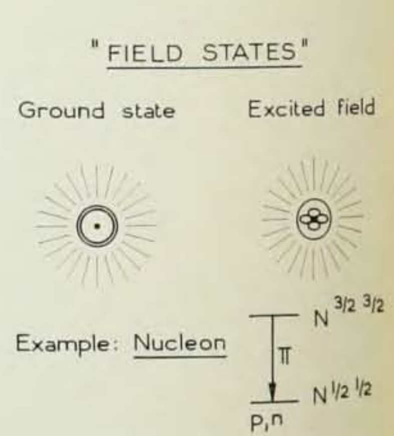


*Fig. 3.* Symbolic representation of two different field states of a single baryon. The figures are only meant as a symbolic description and are not intended to represent any actual field.

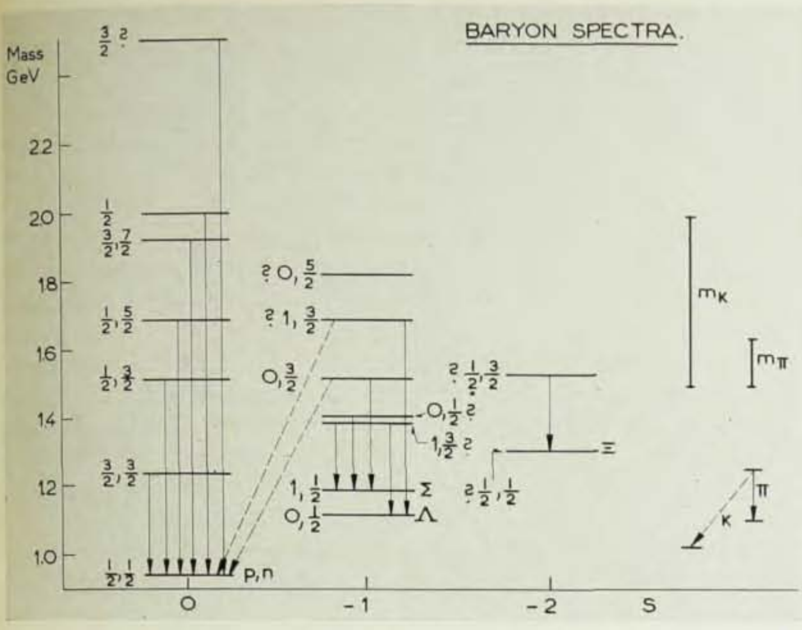


*Fig. 4.* Spectrum of the baryon. This graph contains the quantum states of the baryon as far as observed today. The first figure near the level gives the isospin, the second the ordinary spin. Vertical transitions are $\pi$ emissions, skew transitions are $K$ emissions.

excited nucleon state $N^{\frac{3}{2}\frac{3}{2}}$ with isospin and spin $\frac{3}{2}$; it can be produced by supplying the necessary energy to an ordinary nucleon. There is a transition from this state to the ground state $N^{\frac{1}{2}\frac{1}{2}}$ of the nucleon by emission of a field quantum: a $\pi$ meson. This excited state should not be considered as a nucleon-meson system, in which the pion orbits around the nucleon. The pion is not bound in this case, it is emitted in the transition to the ground state. The nucleon is surrounded by a pion field which is of different structure in the excited and in the ground state. The commonly used terminology of a nucleon surrounded by virtual pions expresses just that state of affairs. (See Fig. 3, in which the field structures should be regarded as symbolic. Their actual structure is unknown and—even if known—could not be represented by a drawing.)

There exist more excited nuclear field states. They are characterized by their energy and their quantum numbers, such as isotopic spin $I$, ordinary spin $J$, parity, and strangeness $S$. The latter quantum number, which takes on the values 0, 1, 2, was unknown in nuclear and atomic spectroscopy. It comes in here because of the fact that the kaon field quanta are supposed to carry one unit of strangeness, or "hypercharge" as it is often called.

Fig. 4 shows the spectrum of field states of the nucleon. The strangeness quantum number is plotted on the abscissa, the energy on the ordinate, the values of $I$ and $J$ are noted on the left of the levels. Most of the levels are multiplets. There are $2I + 1$ states of different charge within each multiplet.

Here we are faced with a third kind of spectroscopy; in contrast to the atomic and the nuclear forms of spectroscopy, we may call this one "mesonic" spectroscopy. Corresponding to the size of the system, atomic spectroscopy deals with energy differences of electron volts, the nuclear one with MeV, the mesonic one with hundreds of MeV. There are a number of characteristic differences between the new spectroscopy and the others. One comes from the fact that nuclear field quanta have finite rest masses, which gives rise to a special kind of metastable state. For example, the state denoted by $\Lambda$ and by $\Xi$ (and the charged components of the $\Sigma$ state) cannot perform transitions to the ground state of the nucleon (proton or neutron) because of the fact that the field quanta, which should be emitted in order to carry away the difference in strangeness and isotopic spin, have a mass larger than the excitation energy. This is why the states marked as $\Lambda$, $\Sigma$, and $\Xi$ were regarded as "strange" particles in their own right. We do, however, observe transitions with emission of $\pi$ mesons between levels of equal strangeness, since most of these energy differences are larger than the pion mass. Transitions between levels of different strangeness occur only if the energy difference is higher than the kaon mass (see Fig. 4). The situation is analogous to a hydrogen atom in the hypothetical case that the light quantum had a rest mass of, say, 11 eV, a little more than the excitation energy of the first excited state. Then the $2P$ state would be a metastable state of an analogous type, unable to perform a radiative transition to the ground state.

Another difference is found in the width of the states. Those quantum states which are able to perform radiative transitions to lower states (that means, transitions with $\pi$ or $K$ emissions) have a relatively large "natural" width, smaller than the energy differences but not very much smaller. This is a consequence of strong coupling; weak coupling gives rise to very narrow natural widths as we find in states of atoms and nuclei.

The metastable states are not completely stable because of the existence of weak interactions. These interactions do not conserve the strangeness quantum number, and therefore transitions can occur from metastable states to the ground state. They are accompanied by an emission of either $\pi$ mesons or (muon-neutrino) pairs or (electron-neutrino) pairs. The discussion of these transitions is outside the scope of this article. Moreover, they are so slow, compared to any other nuclear or electromagnetic processes of comparable energy exchanges, that their neglect does not change the situation. Rutherford used to say that $\beta$ decay (the weak interaction process of his time) was so slow that it did not take place at all from the point of view of the nucleus. Nevertheless, the existence of these slow decays of the metastable states of the nucleon is essential for their observation and identification.

There is a way, however, in which a nucleon can be made to change over to the metastable excited states of different strangeness. It is by a scattering of a field quantum, a process very similar to an inelastic scattering. Let us go back to our hypothetical example of the hydrogen atom and light quanta with a rest mass of 11 eV. In this case it would be impossible to excite the $2P$ state by absorption, but it can be excited by scattering of a quantum $h\nu$ when the outgoing light quantum $h\nu'$ is poorer in energy by the amount necessary for excitation. Since the $2P$ state differs by unity in spin, this difference must be supplied by a change in spin direction of the light quantum:

$$[h\nu]\downarrow + \mathrm{H} = \mathrm{H}^* + [h\nu]\uparrow.$$

In this equation the change of arrow after $h\nu$ should indicate the change of spin direction. Now let us consider the following process of meson scattering:

$$\pi + N = \Lambda + K,$$

in which a pion is scattered by a nucleon $N$. It changes not only its energy in order to provide for the energy difference between $\Lambda$ and $N$, but it also changes its strangeness number by becoming a kaon. Thus we see that associated production of a $\Lambda$ and a $K$ is in complete analogy with an optical excitation by inelastic light scattering, a process which is known as the Raman effect.*

* In dealing with the present generation of young elementary-particle physicists, it might be advisable to reverse the argument and to explain the Raman effect as an analogy to associated production.

We now come to a second group of phenomena which also could be regarded as a consequence of strong coupling of nuclear fields. So far we have discussed the excited states of a baryon, and we considered them as being different formations of the nuclear field surrounding the source. Let us now look at the field without a source and its existence in free space, such as exemplified by light quanta.

We first discuss the electromagnetic case and look at the states possible in the vacuum in the absence of sources. We begin with completely empty space as the lowest state. The next highest state would be the presence of one, or more, light quanta. But there are also other kinds of states in addition: two light quanta might produce positronium, and that is why we must consider positronium also as a state of the vacuum,** though an unstable one.

Let us look more closely at positronium. Here we have a system of a positive and a negative electron. When the two particles are very close together (within the annihilation radius), then they can virtually annihilate into pure radiation. Hence positronium is not exclusively a system of a particle and its antiparticle. For a short time it is virtually a pure field. We therefore write:

$$\text{Positronium} = a(e^+ + e^-) + b(\text{field}). \qquad \text{(a)}$$

Here $b \ll a$ since the annihilation radius is very small compared to the Bohr radius. The states of the electromagnetic vacuum, the source-free field formations, can be sketched in a spectrum as seen in Fig. 5. The heights of the levels indicate the energies of the levels in the rest system; for clarity, however, the values indicated are not quantitatively exact. The light quantum appears with a rest energy zero, and spin 1; at higher energy we find the bound states of positronium, ordered according to spin values. The sketch is not complete; there are states of two or more light quanta, two or more positronium, etc.

We now consider the analogous situation for the nuclear field without sources. Again we begin with empty space; then we should find field quanta, pions and kaons. We also should list the analogue to positronium: systems of nucleons and antinucleons which we may call "nucleonium". We obtain a similar relation to (a), but here, because of the strong coupling, we have $b \sim a$, since the annihilation radius is of the same order as the size of the system. Hence nucleonium is, to a large percentage, pure field. This means that we can no longer definitely identify the states of the sourceless field clearly as "nucleonium" or pure field-quanta states, as we were able to do in the weak-coupling case. Each state of

** The two particles in positronium are both field sources, so that it is no longer strictly true that no sources are present. The total number of particles, however, is still zero since antiparticles must be counted negative.

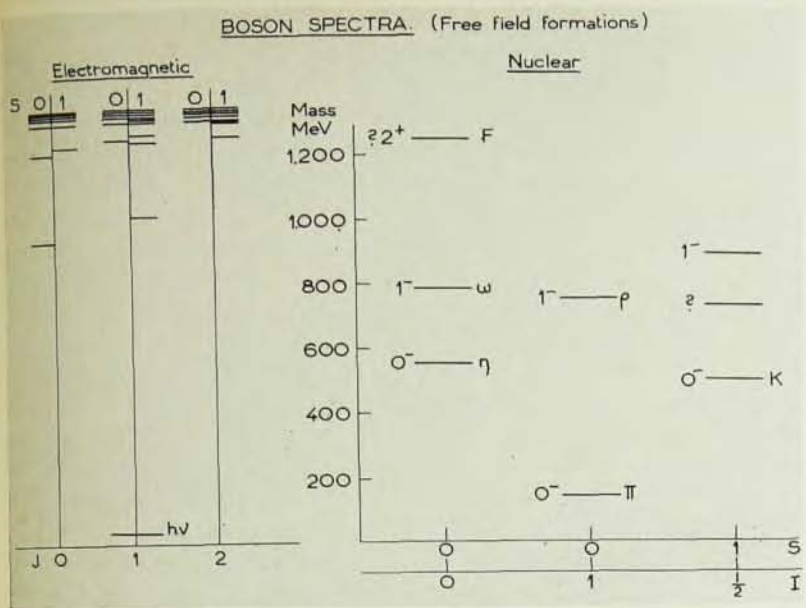


*Fig. 5.* Boson spectra. The electromagnetic spectrum on the left contains only one single light quantum and positronium. The states corresponding to two or more light quanta or positroniums are omitted. The positronium spectrum is enlarged for the sake of clarity; the letter *s* signifies the intrinsic spin of positronium (zero or one in the singlet or triplet state, respectively). The nuclear boson spectrum presents the experimentally observed masses of the quanta so far discovered. The symbol on the left of the level indicates the ordinary spin and parity, the symbol on the right is the name of the entity.

the sourceless field is a mixture of pure field quanta and nucleonium, and even several units of nucleonium: a mixture of different kinds of states which have in common only the same values of all relevant quantum numbers. We therefore do not expect the spectrum to be as neatly divided into identifiable groups as the electromagnetic one.

Fig. 5 shows the boson formations of the nuclear field as they are known experimentally. Most of them have a very short life: they decay into simpler nuclear quanta, in complete analogy to the electromagnetic case. The $\omega$ meson decays into three pions, the $\rho$ meson into two, just as some positronium states decay into three light quanta, others into two. The lifetime is relatively shorter in the nucleon case because of the strong coupling. In addition to this instability, even the nuclear field quanta with the lowest mass are unstable against weak-interaction processes: the $\pi$ and the $K$ meson decay into lighter units. The weak-interaction decay is very much slower and should be disregarded in our picture, just as in the case of the decay of the unstable states of the baryon.

It is perhaps worth noting that one can get some order into these boson states by looking at their nucleonium phase. As indicated before, each of these states is part of its time in a nucleonium state. In this phase, the classification according to quantum numbers is particularly simple. We would expect the following groups of states to appear (see Fig. 6). We first consider states in which the baryon and its antiparticle are in relative $S$ states ($L = 0$). Both isotopic and ordinary spins can be parallel or antiparallel if we consider pairs of nucleons and "antinucleons of strangeness zero". If one of the particles is a $\Lambda$ or a $\bar{\Lambda}$—the system then has a strangeness $-1$ or $+1$—only one isotopic spin combination is possible ($I = \frac{1}{2}$) since $\Lambda$ has zero isospin. Hence, we expect four states of strangeness zero, corresponding to the four combinations of spin 0 or 1, with isospin 0 or 1. The parity of these states will be odd because particle-antiparticle systems have an intrinsically odd parity. For strangeness one, we expect two states since the isospin is fixed at $\frac{1}{2}$, having spins of 0 and 1. It is remarkable that the boson systems known at present fit perfectly into this scheme. The highest state ($F$ meson) could be interpreted as an $L = 1$ (even) state of the nucleon-antinucleon system with antiparallel isospin and parallel spin.

The third form of spectroscopy, the study of quantum states of the nuclear field, involves two kinds of spectra: one belongs to field formations around a nuclear field source (baryon spectrum), the other contains the states of the sourceless vacuum (boson spectrum). There is no theory by which the

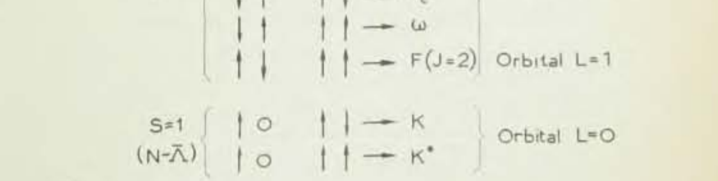


*Fig. 6*

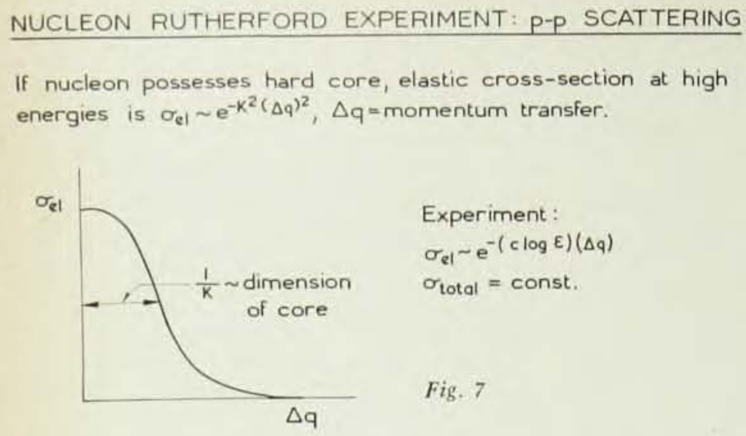


*Fig. 7*

energies and quantum numbers of the levels can be predicted. We find ourselves in a situation roughly similar to that faced in atomic physics in 1910: quantum states are recognized, transitions are observed, but no understanding of the underlying structure exists. Indications of some regularities in the energy values have also been found. They are analogous to the Balmer formula of the hydrogen spectrum, only much less comprehensive. One finds the following relations between energies of certain excited states:

$$\frac{m_N + m_\Sigma}{2} = \frac{3m_\Lambda + m_\Xi}{4},$$

$$\frac{m_K{}^2 + m_{\bar{K}}{}^2}{2} = \frac{3m_\eta{}^2 + m_\pi{}^2}{4}.$$

There exist some rudimentary ideas for an explanation of these relations on the basis of a group-theoretical treatment of certain invariances of the interactions involved*; they are, however, even if correct, very far from providing a theoretical understanding of the situation.

Very little is known of the structure of these systems, even though we now are beginning to decipher the spectrum. Just as with the atoms in 1910, we have a qualitative knowledge of the size and charge distribution. The radius seems to be of the order of a fermi, as electron scattering experiments reveal. In 1910, Rutherford performed high-energy scattering experiments in order to obtain more knowledge of the structure of atoms, and he found a hard core in the center, the atomic nucleus. Similar scattering experiments are performed today in order to get at the structure of the nucleon. High-energy *p-p* scattering should give us some information about the existence or nonexistence of a hard core inside the nucleon. If such a core existed, the angular dependence of the scattering should reveal it at very high energy in the form of a diffraction peak of roughly the shape indicated in Fig. 7. The width of this peak is a measure of the size of the core. When measured in momentum transfer (not in angle), this width is proportional to the reciprocal of the core dimension. A vague indication of the existence of a core is found in the fact that the total cross section of nucleon-nucleon scattering seems to converge to a constant value at high energy. There was great surprise, therefore, when it was found at CERN[1] that the width of the diffraction peak shrinks with increasing energy $E$. The surprise was less great for some theoretical physicists who expected such shrinking from a bold extrapolation of the behavior of the scattering amplitude in ordinary Schrödinger scattering theory. These considerations are based upon the so-called Regge poles of the scattering amplitude. A number of theoretical physicists[2] were able to predict before the experiment a shrinking of the diffraction peak proportional to $(\ln E)^{-1}$, in rough agreement with the present measurements. Together with the constant total cross section, this seems to indicate that the nucleon becomes larger and more diffuse when observed with higher energy, a result which is opposite to the findings of Rutherford in atoms. No definite conclusions should yet be drawn from these results, since recent, more accurate measurements at Brookhaven[3] have confirmed the *p-p* scattering results, but they did not reveal any change in the width of the diffraction peak when pions were scattered with protons. Since the total ($\pi$-$p$) cross section decreases in the energy range investigated (between 7 and 17 GeV), this still might indicate an increase in diffuseness towards higher energies.

Let us now summarize the present situation in elementary-particle physics. In the progress of physics, we have dealt with different kinds of "matter". One can list six kinds:

1. gravitational matter
2. plasma matter
3. atomic matter
4. nuclear matter
5. mesonic matter
6. leptonic matter.

* The so-called "eight-fold way". See Y. Ne'eman, Nucl. Phys. **26**, 222 (1961); M. Gell-Mann, Phys. Rev. **125**, 1067 (1962); S. Okubo, Progr. of Theoret. Phys. **25**, 949 (1962); **28**, 24 (1962).

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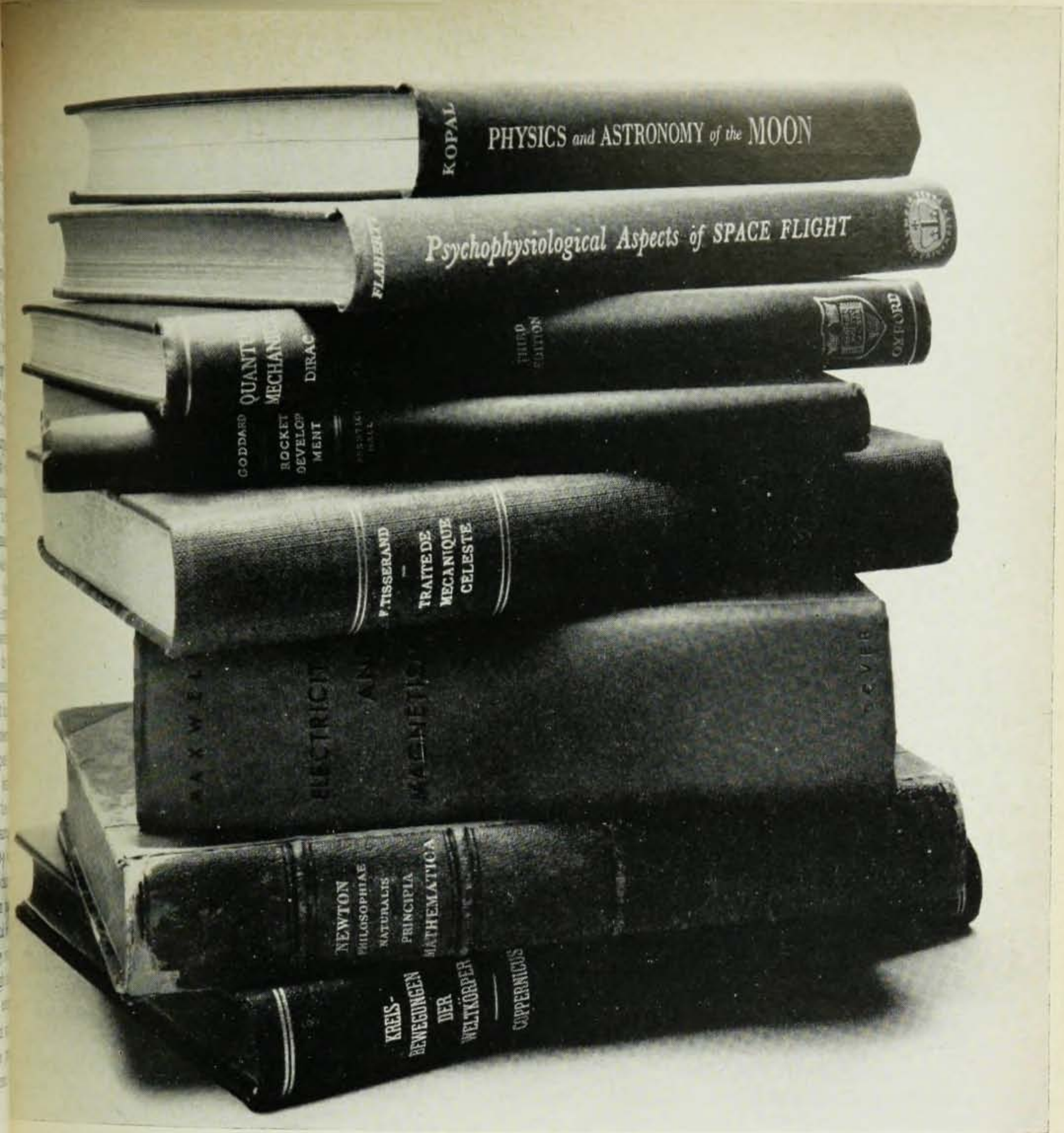
KOPAL
PHYSICS and ASTRONOMY of the MOON
Psychophysiological Aspects of SPACE FLIGHT
THIRD EDITION
OXFORD
DIRAC
GODDARD
ROCKET DEVELOPMENT
P. TISSERAND
TRAITE DE MECANIQUE CELESTE
NEWTON
PHILOSOPHIAE NATURALIS PRINCIPIA MATHEMATICA
KREIS-BEWEGUNGEN DER WELTKÖRPER
COPPERNICUS

Gravitational matter is the substance we are concerned with in describing systems of many stars, such as solar systems, clusters, galaxies, etc. The structure of this matter is characterized by large masses which interact mainly by gravity.

Plasma matter, encountered in the study of the highly diluted gases in space, consists of charged atoms and electrons which interact mainly by electromagnetic forces. Their energies are so high that quantum effects are negligible. Because of the highly nonlinear behavior of a plasma, its properties are surprisingly varied and complicated, and to a large extent they remain unknown.

Atomic matter is the ordinary matter we deal with on earth. Its structure is governed by the quantum-mechanical effects of the electromagnetic forces between nuclei and electrons. It exhibits an enormous variety of forms and combinations by means of molecular and macromolecular formation. Living matter is atomic matter in its highest form of differentiation.

Nuclear matter is the material of which atomic nuclei are made. Its structure is determined by nucleons interacting via nuclear and electric forces.

Mesonic matter is the form of matter which we have discussed in this article. It is the substance of the nucleons themselves, and of the nuclear field in its various boson manifestations. We chose to describe the relevant phenomena in terms of quantum states of a nuclear field. This method of description is a conservative one, which tends to make use of concepts that are well-known to us from the electromagnetic and gravitational field. It is also a description which corresponds closely to what theorists would call "field theory". Unfortunately, there does not yet exist a satisfactory quantum theory of a field coupled to fermion sources, let alone a theory of strongly coupled fields. The present theories are beset with difficulties that stem either from problems of the structure of the source (divergences and renormalization problems) or from the mathematical problems of strong coupling. Hence we cannot yet decide whether a suitable nuclear field theory with nucleons as sources would, in fact, reproduce the phenomena described here, such as the third spectroscopy and the shrinking of the diffraction peak for $p$-$p$ scattering. It might well be that the description of mesonic matter by nuclear fields coupled to baryons is not adequate.

The sixth form of matter is reserved for the phenomena which we have touched upon only lightly in this article. It is the world of leptons and of weak interactions. We now know of four different types of leptons: ordinary electrons, heavy electrons (muons), and the two types of neutrinos. They interact only by electromagnetic forces and by the mysterious weak interaction. We chose to call these phenomena the manifestations of leptonic matter. Are the four types of leptons also to be considered as excited states of some field? We know that, at very small distances, the electromagnetic field should be regarded as strongly coupled. If we are allowed to apply the field concept to weak interactions and assume that they are transmitted by some intermediate bosons of large mass, it may be speculated that, for certain small distances (or high energies), weak interactions would also become strongly coupled. One might then apply to the leptonic sources of the weak-interaction field the same point of view which we have applied to the nuclear fields, and one might consider the different leptons as excited field states of a new field, which might be that of the weak interactions. Then we might find some analogy between the structure of leptonic matter and mesonic matter, an analogy which would probably be much too simple and conservative to be meaningful in nature. Further clarification of these problems can be expected only from further experimentation, and it is obvious that one will need higher energies than those available at present to find the phenomena relevant for these considerations. With our contemporary accelerators, which go up to a few $10^{10}$ eV, we were able to begin penetrating into the structure of nucleons. It is expected that the structure of leptons will be found only by experiments using much higher energies and, in particular, by arrangements which can provide copious and highly energetic beams of neutrinos and muons.

We now have reasonably good theories for the understanding of the basic phenomena in the first four kinds of matter, although a number of fundamental problems in gravitational matter are still unsolved, such as the problem of the expanding universe. The phenomena of mesonic and leptonic matter, however, will require a new kind of quantum theory, and perhaps even a completely new set of concepts. The insights obtained from the solution of these problems will certainly lead to a deeper knowledge of the structure of matter. It might even lead to some fundamental links between the different "fields" which today are regarded as unconnected; gravity, electricity, and the nuclear world might ultimately be connected by a principle which would link the world of very large dimensions with the structure of elementary particles. This lofty aim is perhaps not yet in sight, but, even so, it is apparent that the new discoveries in high-energy research are opening up new perspectives for our understanding of the structure of matter.