High-energy and elementary-particle physics (from materials of the Seventeenth International Conference on High-Energy Physics, London, 1–10 July 1974)

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The Seventeenth International Conference on High-Energy Physics was held at the Imperial College at London from July 1 through July 10, 1974. About a thousand scientists representing practically all of the world's scientific centers that are engaged in work in high-energy physics participated in its work. The scope of the conference and the volume of its results can be judged even from the number of papers presented: about

1200. Below we shall set forth the basic results of the experimental and theoretical studies in the physics of high energies and elementary particles that were the central object of attention at the conference. Among them we should include first of all such experimental results as: a) the observation of anomalously large (compared with the predictions of the parton model) cross sections for the formation of leptons ($e^{\pm}$, $\mu^{\pm}$) with large transverse momenta in NN collisions; b) the approximate constancy of the total cross section of e^+e^- annihilation to hadrons at high energies ($15 \le s \le 25$ GeV^2), the absence of scaling in the secondary-particle spectra, and other interesting phenomena in e^+e^- annihilation that are not taken into account within the framework of existing theoretical conceptions; c) the increase in the total interaction cross sections of hadrons at energies $\gtrsim 100$ GeV.

Among the theoretical approaches to description of elementary-particle interactions, attempts to construct gauge theories for weak, electromagnetic, and strong interactions received the largest share of attention.

1. DYNAMICS OF STRONG INTERACTION AT VERY HIGH ENERGIES AND SMALL TRANSFERRED MOMENTA

As before, the study of strong interactions at very high energies remains one of the principal interests of elementary-particle physics. Of late, the most significant results have been obtained in experiments performed on the world's largest accelerators with their unique parameters: the CERN intersecting proton rings (ISR) with maximum proton energies of ≈ 60 GeV in the C system (which is equivalent to $\approx 2 \times 10^3$ GeV in the L system), the Batavia accelerator of the Fermi National Laboratory (FNAL) with a maximum energy of ≈ 400 GeV in the L system, and the Serpukhov accelerator of the Institute of High-Energy Physics (IHEP) with a maximum proton energy of ≈ 70 GeV in the L system.

First of all, we should take note of the experimental observation of an increase in the total cross section $\sigma^{tot}(s)$ at very high energies. The first indication of an increase in the total interaction cross sections of hadrons was obtained at Serpukhov a few years ago, with the detection of an increase in the total cross section of the K^+p interaction in the range from 20 to 70 GeV. During the last two years, ISR experiments have shown that the total cross sections of the pp interaction begin to increase at energies > 100 GeV, and are 4 mb larger at $E \sim 2 \times 10^3$ GeV. The conference received new FNAL data on the total cross sections of the interactions of $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$, and p with protons and deuterons in the energy range 50–200 GeV, indicating that the cross sections of all of these processes (except perhaps $\bar{p}p$) increase with increasing energy. A particularly strong increase (by about 2 mb) is observed in the K^+p interaction. At the same time, the differences between the total cross sections for π^+p and π^-p, K^+p and K^-p, $\bar{p}p$ and pp, etc., decrease in power-law fashion, $\Delta\sigma^{tot} \sim (s)^{-\gamma}$, where γ equals 0.45 ± 0.10 for the $\pi^{\pm}p$ interaction and $\gamma \approx 0.54$ for the other processes. Thus, the new data confirm the validity of Pomeranchuk's theorem of asymptotic equality of the interaction cross sections of particles and antiparticles.

The Batavia accelerator has also been used for measurements of the differential cross sections $d\sigma/dt$ of the charge-transfer reactions $\pi^-p \to \pi^0n$ and $\pi^-p \to \eta^0n$ up to 100 GeV. New data on the reactions $\pi^-p \to \eta^0n$, $\pi^-p \to X^0n$ were obtained at the IHEP. A study of the $d\sigma/dt$ for $\pi^-p \to \pi^0n$ at $t = 0$ jointly with $\Delta\sigma(\pi^{\pm}p)$ indicates that the experimental data agree with isotopic invariance and the dispersion relations without subtractions (the previously available data on $\Delta\sigma(\pi^{\pm}p)$ and $(d\sigma/dt)(\pi^-p \to \pi^0n)|_{t=0}$ indicated possible violation of some of these hypotheses at energies ~ 100 GeV). CERN, IHEP, and FNAL data on $d\sigma/dt$ in the reactions $\pi^-p \to \pi^0n$ and $\pi^-p \to \eta^0n$ at energies from 6 to 100 GeV confirm the basic hypotheses of the Regge pole model and enable us to determine the trajectories of the ρ and A_2 poles. These trajectories are found to be practically linear up to $|t| \sim 1.4$ GeV^2 and can be represented in the form $\alpha_\rho = 0.53 + 0.83t$, $\alpha_{A_2} = 0.45 + 0.7t$. It should be noted that these trajectories do not quite coincide with one another, as has often been assumed under the exchange-degeneracy hypothesis or in dual models.

The conference also heard FNAL data from a study of the differential cross sections of elastic $\pi^{\pm}p$-, $K^{\pm}p$-, pp-, and $\bar{p}p$-scattering in the range $0.07 < |t| < 1$ GeV^2 at energies of 100 and 200 GeV. In combination with data for lower energies, the results indicate that the slope of the diffraction cone increases systematically with increasing energy at small t in all elastic-scattering reactions (except for $\bar{p}p$). A logarithmic increase in the slope of the diffraction cone at very large energies was predicted many years ago within the framework of the theory of complex angular momenta. The experimentally observed increase is compatible with a logarithmic relation and corresponds to a slope of $\alpha'_P \approx 0.3$ GeV^{-2} for the Pomeranchuk trajectory.

A study made at the IHEP of the real part of the amplitude of zero-angle π^-p scattering in the energy range from 30 to 60 GeV indicates that $\alpha = \mathrm{Re}\,T(s, 0)/\mathrm{Im}\,T(s, 0)$ decreases in absolute value with increasing energy and nearly vanishes at $E = 60$ GeV. This behavior of α is consistent with the dispersion-relation prediction. If $\sigma^{tot}_{\pi^-p}$ increases as the above experiment indicates, α should change sign at energies ~ 100 GeV, as has already been observed in the pp interaction.

The results of ISR studies of the energy dependence of the differential cross section of elastic pp scattering at 1–3 GeV^2 indicate that the $d\sigma/dt$ minimum at $|t| \sim 1.4$ GeV^2 shifts toward somewhat smaller $|t|$ with increasing energy, while the height of the $d\sigma/dt$ maximum at $|t| \sim 2$ GeV^2 increases with increasing energy.

New data were obtained at Serpukhov on polarization in elastic scattering processes at energies of ≈ 40 GeV. They indicate that the polarization decreases as a power-law function with increasing energy.

In Barger's review paper on reaction mechanisms at high energies, it was observed that many characteristic properties of elastic pp scattering, such as the approximate constancy of the ratios σ_{11}/σ_{tot}, B/σ_{tot} (where B is the slope of the diffraction peak) and the energy dependence of the minimum and secondary maximum of $d\sigma/dt$ can be described on the basis of a "geometric-scaling" model in which the scattering amplitude in the impact-parameter (b) representation depends only on the ratio $b/R(s)$, where $R(s)$ is an effective interaction radius whose square increases logarithmically with increasing energy. This corresponds to a simple geometric picture in which the proton is regarded as a sphere with a certain transparency that does not depend on energy, while its radius increases with energy. However, it should be noted that none of the existing theoretical models describing scattering processes at high energies has the "geometric scaling" property.

Study of two-particle reactions at energies greater than 6 GeV has shown that relations between the observed quantities that are based on the use of SU(3) symmetry and universality, and also on the quark model, are satisfied with rather good accuracy.

The conference gave considerable attention to study of inelastic diffraction processes. Interesting new data were obtained on the diffractive generation of particles both in the exclusive reactions $pp \to pn\pi^+$ at $\sqrt{s} = 53$ GeV, $pp \to pp\pi^+\pi^-$ at $p_{lab} = 205$ GeV/c, and $\pi^-p \to \pi^-\pi^+\pi^-p$ at 100 and 300 GeV/c, and in inclusive processes. Special mention should be made of data obtained at the FNAL by a joint Soviet-American group on the process $pd \to dX$, where X is an arbitrary hadron system. The results of these experiments indicate that diffractive dissociation both into a state with a small mass (~ 1 GeV), in which the formation of resonances and "kinematic" maxima dominates, and into states with large masses occurs at high energies. The latter processes are accurately described within the framework of the so-called three-reggeon model and can be used to determine the vertex of the three-pomeron interaction.

Understanding of the mechanisms of two-particle processes would be impossible without detailed study of the dynamics of inelastic processes, which account for most of the total cross section. Thus, the conference discussed at length data on processes of multiple particle production in collisions of high-energy hadrons, most of which had been obtained at the IHEP and FNAL. Here the focus of theoretical and experimental research has shifted from study of single-particle inclusive reactions, $a + b \to c + X$, to investigation of two-particle inclusive processes, $a + b \to c_1 + c_2 + X$, which can be used to determine correlations between the particles that are produced. Experiment indicates the existence of short-range correlations. The conference also received data on correlation functions in semiinclusive processes (with a fixed number of charged particles in the final state). A multiperipheral model is most widely used to interpret data on inelastic processes and makes it possible to explain the basic behavior observed in experiment. This model also establishes a simple relation to the Regge pole model, which describes two-particle processes at high energies.

The basic trends in theoretical study of the interaction of very high energy particles were:

a) Construction, within the framework of the multiperipheral approach, of a realistic model that can be used to obtain $\alpha_P(0) \approx 1$, i.e., approximate constancy of the total cross sections. It was noted in Holliday's review paper that this model must describe experimental data on inelastic processes up to comparatively large $|t| \sim 1$ GeV^2.

b) The theory of pomeron interaction. As we know, the hypothesis that Pomeranchuk's singularity is a simple Regge pole with $\alpha_P(0) = 1$ encounters a number of difficulties; for this theory to be self-consistent, it is necessary, for example, that all inelastic diffraction processes vanish at zero transferred momenta. However, the experiments mentioned above give no indication of the existence of this effect. Other possibilities for the Pomeranchuk singularity have therefore been investigated. It has been shown by A. A. Migdal, A. M. Polyakov, and K. A. Ter-Martirosyan, and also by G. Abarbanel and D. Bronzan, who used the reggeon diagram technique developed by V. N. Gribov, that there exists a self-consistent solution for the Pomeranchuk singularity that does not lead to difficulties in inelastic diffraction processes. At the existing energies, this singularity coincides quite accurately with an ordinary Regge pole, and at ultrahigh energies $\ln(s/m^2) \sim 10^2$, which are inaccessible even to future accelerators, the structure of the singularity changes as a result of the pomeron interaction. Within the framework of this approach, for example, the total cross section increases as $\sigma^{tot} \sim [\ln(s/m^2)]^{\eta}$ as $s \to \infty$ (η is a constant $\sim 1/6$).

c) Explanations for the experimentally observed increase in the total cross sections. We note that a preasymptotic increase in the total cross sections was predicted within the framework of the method of complex angular momenta on the basis of Gribov's reggeon technique as early as 1968. In this theory, it is related to the fadeout of the contribution from the moving branch points that correspond to screening effects and hence enter into the elastic-scattering amplitudes with the minus sign. Another explanation for the total cross section increase was proposed by J. Chu and Koplik in a paper delivered at the conference, in which the total cross section increase is related, within the framework of the multiperipheral approach, to an increase in the cross section for production of $N\bar{N}$ pairs.

Also discussed was the possibility of describing the increase within the framework of Cheng and Wu's eikonal model. In this model, the amplitude corresponds to Froissart's limit at ultrahigh energies, i.e., the total cross section increases $\sim \ln^2(s/s_0)$. However, this model is not quite consistent and results in violation of the unitarity condition for inclusive spectra.

Summarizing the basic results in research on strong hadron interactions at very high energies and small transferred momenta as presented at the conference, we make the following observations:

1) The total cross sections of hadron interactions begin to increase at energies $\gtrsim 100$ GeV.

2) Study of quasi-two-particle reactions of the types $\pi^-p \to \pi^0n$, $\pi^-p \to \eta^0n$, and of the differences of the total cross sections over a broad energy range, has confirmed the validity of the Regge approach and made possible the most accurate determinations of the parameters of Regge-pole trajectories.

3) Detailed study of diffractive dissociation processes has made it possible to determine the three-pomeron interaction and other important characteristics of these reactions.

4) New data on correlations in processes of multiple particle production have made it possible to obtain important information on the mechanism of inelastic processes at high energies and to test a number of theoretical models.

2. PROCESSES WITH LARGE TRANSFERRED MOMENTA

New data on particle interactions with large transferred momenta were at the center of attention at the conference. Among these processes we might cite reactions of elastic scattering through large angles at high energies, the production of hadrons and leptons with large transverse momenta in hadron collisions, highly inelastic production of hadrons in eN, μN, and νN collisions, and e^+e^- annihilation with high energies in C systems. The considerable interest now evidenced in these processes is quite natural, since study of these processes yields important information on the nature of the interactions of elementary particles at very short distances. Reactions with large transferred momenta are usually discussed from the standpoint of the parton model (partons are pointlike components of hadrons; they might, for example, be quarks), which has proven highly adequate for comprehension of results obtained earlier in the process of highly inelastic electroproduction. However, as will become evident below, new experimental data on processes with large momentum transfers and e^+e^- annihilation indicate that the parton model is not valid (at least in its "naive" form).

a) Two-particle processes and form factors at large q^2. No essentially new experimental information on elastic-scattering processes in the range of large transferred momenta ($|t| \sim s \gg m^2$) was presented at the conference, except for studies made at 6.2 GeV, in which processes of elastic $\bar{p}p$ scattering and the reaction $\bar{p}p \to \pi^+\pi^-$ were investigated in a wide range of angles

In contrast to the range of small $|t|$, where the Regge description is valid, the differential cross sections in the range of large $|t|$ can, according to all information accumulated thus far, be parameterized in the form

$$\frac{d\sigma}{dt} = s^{-m} F(\theta), \qquad (1)$$

i.e., at a fixed scattering angle θ the cross section decreases with energy in power-law fashion. For pp scattering, $m = 9.7 \pm 0.5$.

Simple considerations based on dimensional analysis in the "naive" quark model and advanced by V. Matveev, R. Muradyan, and A. Tavkhelidze and by S. Brodsky and G. Farrar lead to the following expression for m:

$$m = \sum_i n_i - 2, \qquad (2)$$

where n_i is the number of elementary quark (or antiquark) components in particle i composing the particular reaction. For the photon, n_γ equals 1. This approach gives m = 10 for pp scattering, m = 8 for πp and Kp scattering, m = 7 for $\gamma p \to \pi^+ n$, and so forth. All of these values of m agree with those found from experiment. Dimensional analysis gives $F_p(t) \sim t^{-2}$ for the electromagnetic form factor of the proton, and $F_\pi(t) \sim t^{-1}$ for the π-meson. As we know, the proton form factor does indeed decrease $\sim t^{-2}$ at large ($-t$). New data presented at the conference on the form factor of the π meson in the spatially similar range are also consistent with the behavior of t^{-1} at large ($-t$).

b) Inclusive processes with large $\mathbf{q}_\perp$. The anomalously large production of hadrons with large transferred momenta $q_\perp$ in inclusive processes had been one of the "sensations" of the previous conference at Batavia in 1972. This phenomenon has now been studied in extreme detail. A number of experimental studies made both on the ISR and at the FNAL and devoted to various aspects of inclusive production of hadrons with large $\mathbf{q}_\perp$ were presented at this conference. Important features of these processes are:

1) an increase in the invariant cross section $\rho = \omega d^3\sigma/d^3\mathbf{q}$ ($\omega = \sqrt{\mathbf{q}^2 + m^2}$) with increasing initial energy at a fixed $\mathbf{q}_\perp$;

2) an increase in the relative yields of heavy particles, such as K-mesons or antiprotons, with increasing $\mathbf{q}_\perp$.

The first results, which were obtained on the ISR, stimulated a number of theoretical studies based on the conceptions of the multiperipheral and parton models. Within the framework of these models, the cross section can usually be represented in the form

$$\omega \frac{d^3\sigma}{d^3\mathbf{q}} = \frac{1}{(\mathbf{q}_\perp^2)^n} f(x_\perp, \theta), \qquad (3)$$

where $x_\perp = 2q_\perp/\sqrt{s}$, and θ is the angle in the C system. Variations on these models and dimensional analysis yield different values for n. Thus, n = 2 within the framework of the simplest parton model, and n = 4 for exchange of particles with zero spin. The ISR data were consistent with the value n = 4. However, new data presented at the conference by the Princeton-Chicago group and obtained at the FNAL indicate that n is not constant, but depends on $x_\perp$. This is an important result and calls for a review of the simple theoretical approaches that have been proposed to explain this phenomenon.

ISR data on correlations in the production of π mesons with large $\mathbf{q}_\perp$ are also of considerable interest. These data can be used to study the characteristics of particle beams formed on production of particles with large $\mathbf{q}_\perp$. For example, the parton model predicts that two rather strongly collimated particle streams should be formed in this process. The experimental data indicate that the multiplicity of charged particles moving in the direction opposite to that of the particle with large $\mathbf{q}_\perp$ increases strongly with increasing $\mathbf{q}_\perp$. At the same time, the multiplicity of particles moving in the same direction varies little. The angular distributions of the charged particles produced indicate that the beam is very broad, i.e., weakly collimated. It is interesting that a significant positive correlation exists between the π^0 meson with large $\mathbf{q}_\perp$ and particles moving not only in the direction opposite to it (which is quite natural, if only from the standpoint of momentum conservation), but also in the same direction as the π^0-meson.

c) Production of leptons with large $\mathbf{q}_\perp$. New data on the generation of leptons to which large momenta are transferred in proton-nucleus interactions in inclusive processes of the type $pN \to e^\pm(\mu^\pm)X$ were presented at the conference. The work was done at the IHEP (Serpukhov) (generation of muons by 70-GeV protons), at the FNAL at proton energies of 150 GeV and 300 GeV, and on the ISR accelerator. The experimental difficulties encountered in study of these processes are due to the extremely small values of the cross sections (they range from 10^{-32} to 10^{-39} cm^2 for the universal function $\omega d^3\sigma/d^3\mathbf{q}$). The basic results of these studies can be summarized as follows:

1) Charge symmetry exists in the electron and muon yield (for example, at 300 GeV $(N_{e^+} - N_{e^-})/(N_{e^+} + N_{e^-}) = 0.0 \pm 0.2$) and the data confirm μe universality. These results confirm the hypothesis that the leptons are formed in pairs by a virtual γ quantum.

2) The relation

$$\frac{p + N \to \mu^+ + X}{p + N \to \pi^+ + X} \approx 10^{-4}$$

is satisfied with good accuracy in a broad range of transferred momenta $\mathbf{q}_\perp$ up to 5.5 GeV/c). At 300 GeV, this ratio is more than 20 times larger than the prediction of the Drell-Yan parton model, and there is as yet no theoretical explanation. The attempt to explain this effect as due to production of vector mesons (ρ, ω, ϕ) and a subsequent V-γ transition is regarded as unsatisfactory because it requires that the cross section for production of the φ-meson be six times larger than the cross section for the π-meson.

d) Highly inelastic μN collisions. Extremely interesting preliminary information on highly inelastic muon-nucleon interactions at energies of 56 and 150 GeV was presented by experimental groups working at the FNAL. The interactions of muons with iron nuclei were investigated. Spark chambers and magnetized iron blocks were used in the muon spectrometer, and this made it possible to obtain a momentum resolution $\Delta p/p = 20\%$ in the unit at an energy scatter of 15% in the original beam. Deviations from the spectra that had been expected on the basis of scaling invariance and known data on highly inelastic electron-proton interactions at energies of ~18 GeV at SLAC were observed in these experiments. It is reported that at a fixed value of the scaling variable $\omega = 2m\nu/q^2$, the structure function of the reaction investigated decreases approximately linearly with increasing q^2 by at least 15% in the interval $5 \leq q^2 < 60$ $(GeV/c)^2$. If scaling invariance were satisfied, the structure function would depend only on the variable ω at large q^2, and no dependence on q^2 should have been observed at a fixed ω. It should be noted, however, that the efficiency of the instrument also decreases with increasing q^2 in this range of q^2. Final conclusions would therefore be unreliable.

e) e^+e^- annihilation. New and important data were obtained on e^+e^- interactions at energies up to $q^2 = 25$ GeV^2 by experimental groups working at colliding-beam installations (ADONE in Italy, CEA and SPEAR in the USA). Quantum electrodynamics were further verified in studies of the processes $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \gamma\gamma$. The conventional procedure for analysis of these data with cutoff parameters Λ in the form factors of the lepton vertices or in the photon propagator resulted–for example, with a single-parameter matching formula–in the values $\Lambda \geq 35$ GeV in the proton propagator, $\Lambda \leq 16$–24 GeV according to the lepton form factor, and $\Lambda \geq 6$ GeV in the electron propagator.

However, special attention was devoted to study of e^+e^- annihilation to hadron states.[1)] It was found that the cross section of this process deviates at $q^2 \approx 9$ GeV^2 from an energy dependence of the form $1/q^2$ and that, beginning with $q^2 \approx 15$ GeV^2, the cross section becomes practically constant at the 20-mb level. Here R, the ratio of the cross section of annihilation to hadrons to the cross section of the process $e^+e^- \to \mu^+\mu^-$, which decreases $\sim 1/q^2$ at $q^2 > 9$ GeV^2, begins to increase, reaching the value $R \approx 6$ at $q^2 \approx 25$ GeV^2. (In the quark model, $R = \sum_i e_i^2$ where e_i are the quark charges and the sum is taken over all known quarks. In the usual quark model, $R = 2/3$. On the introduction of colored quarks, $R = 2$.) This effect was not explained in the aggregate with the other properties of hadron final states, of which it is known that

1) the charged particles carry about half of the total energy in the q^2 range from 15 to 25 GeV^2;

2) the average multiplicity of the charged particles increases slowly with energy;

3) scaling is observed for $q^2 d\sigma/dx$, where $x = 2E/q$ (E is the energy of the hadron in the final state), but only at $x > 0.5$. Sharp departures from scaling occur at smaller x;

4) the angular distribution of the hadrons is isotropic in a broad energy range for $|\cos\theta| < 0.6$.

In addition to the problem of the energy dependence of the cross section for e^+e^- annihilation to hadrons, we also observe a so-called "energy crisis"–the neutral particles carry a very large fraction of the energy, something that has not yet been explained.

3. NEUTRINO-HADRON INTERACTIONS

The extensive development of experimental programs to study the interaction of high-energy neutrinos with nucleons is an important aspect of the present state of high-energy physics. Such programs are being implemented on practically all the largest accelerators; the work is intensive and has produced a number of important scientific results. Most significantly, there have been indications that muonic neutrinos have been observed to interact with hadrons without the appearance of high-energy muons as interaction products; this is interpreted as the discovery of neutral currents (NC) in weak interactions.

Table I summarizes data presented at the conference on the yield ratios R = NC/CC, where CC is the number of events corresponding to ordinary charged currents, for neutrinos (R_ν) and antineutrinos ($R_{\tilde{\nu}}$). (We note that the last three figures for R_ν were obtained from analysis of certain exclusive channels of the type $\nu p \to \nu n\pi^+$, $\nu p \to \nu p\pi^0$.)

In fact, it is seen that muonless events are reliably observed and that $R_{\tilde{\nu}}$ is approximately twice R_ν. However, we should note that the neutrino-background problem, which is most important in these experiments, has not yet been definitely solved, and that as concerns the quantitative side of the problem, the data given above are as yet meaningful only accurate to the scale factor 2 owing to the inaccuracies (of the order of 20%) in the normalizations of the neutrino fluxes. The existence of neutral currents was predicted within the framework of a consistent approach to the theory of weak and electromagnetic interactions. In turn, this experimental result triggered a great deal of activity in the development of ideas for consistent description of weak, electromagnetic, and strong interactions of particles within the framework of the gauge theories (see, for example, the review of A. I. Vaĭnshteĭn and I. B. Khriplovich, Usp. Fiz. Nauk 112, 685 (1974) [Sov. Phys.-Usp. 17, 263 (1974)]). However, such approaches, which work splendidly in the case of lepton-type particles, run into considerable difficulty when hadrons are included in them and are as yet of model nature (see below). Thus the interpretation of the data cited above is quite vague in its quantitative aspect. As an example, we might point to the conclusion as to the value of the parameter $\sin^2\theta_W$ of the consistent theory mentioned above, which is about 0.4 according to these data. Observation of two events in the "Gargamelle" chamber that might be regarded as elastic scattering of a muonic neutrino by an electron, $\nu_\mu + e^- \to \nu_\mu + e^-$, with selection criteria $E_e < 300$ MeV and $\theta_e < 5°$, was communicated as an additional indication of the existence

TABLE I

	R_ν	$R_{\tilde{\nu}}$
CERN ("Gargamelle")	0.23±0.03	0.46±0.09
	0.22	0.33
Caltech (FNAL)		
Harvard-Pennsylvania-Wisconsin (FNAL)	0.12±0.04	0.30±0.08
Argonne National Laboratory	0.68±0.15	
CERN (New analysis of earlier data)	0.12±0.06	
Brookhaven National Laboratory (same)	0.14±0.08	

TABLE II

Reaction	Number of events	Δ dominance prediction
$\nu p \to \mu^- p\pi^+$	85 ± 10	9
$\nu n \to \mu^- p\pi^0$	29 ± 6	2
$\nu n \to \mu^- n\pi^+$	31 ± 6	1

of neutral currents in weak interactions. The background was estimated at 0.18 ± 0.12 event. The theoretical value for the cross section of this process depends on the parameter $\sin^2\theta_W$ of the aforementioned consistent theory, and its value is estimated to be in the range $(0.3–0.03)E \times 10^{-41}$ cm^2, which is consistent with the estimate based on the above two events of the reaction $\nu_\mu e^- \to \nu_\mu e^-$.

We now present certain information on quantitative characteristics of neutrino processes for ordinary (charged) currents.

a) A linear dependence of the total cross sections on the energy of neutrino-hadron and antineutrino-hadron interactions has been established up to energies of 150 GeV:

$$\sigma^{(tot)} = \alpha E \cdot 10^{-38} \text{cm}^2,$$

where $\alpha_\nu = 0.78 \pm 0.07$ and $\alpha_{\bar{\nu}} = 0.28 \pm 0.05$, i.e., $\alpha_{\bar{\nu}}/\alpha_\nu = 0.33 \pm 0.08$.

b) Our first information on highly inelastic processes of the type $\nu N \to \mu X$ was obtained in terms of the scaling variables $x = q^2/2m\nu$ and $y = E_h/E_\nu$, where E_h and q^2 are the total energy and the square of the four-momentum transferred to the hadronic final state. This information indicates that at the accuracy level of the data, the properties of these processes agree with those expected on the basis of the V-A theory of weak interactions and known data on highly inelastic electromagnetic processes.

c) It follows from data on the energy dependence and differential cross sections of the reaction $\nu n \to \mu^- p$ at $E_\nu < 2$ GeV that have been extracted from analysis of the reaction $\nu d \to \mu^- p p_s$ that $M_A = (0.9 \pm 0.1)$ GeV when the axial form factor is described by a dipole formula of the type

$$g_A = -\frac{1.23}{[1+(q^2/M_A^2)]^2}$$

A two-parameter description yielding the result

$$M_V = (0.70 \pm 0.19)\ \text{GeV}, \quad M_A = (1.14 \pm 0.25)\ \text{GeV},$$

and a monopole-formula description giving

$$M_A = 0.54 \pm 0.08\ \text{GeV}$$

were also carried through

d) The cross section for production of Λ^0 hyperons in the reaction $\bar{\nu}p \to \mu^+\Lambda^0$ was estimated in experiments with the "Gargamelle" chamber at CERN. It was found to be $\sigma = (1.3\,^{+1.0}_{-0.8}) \times 10^{-40}$ cm^2. This cross section is estimated at $2.4 \cdot 10^{-40}$ cm^2 in Cabibbo's theory.

The 15-foot bubble chamber of the Argonne National Laboratory is being used in experiments to study isobar production in the reactions

$$\nu p \to \mu^- p\pi^+,$$
$$\nu d \to \mu^- p\pi^+ n_s,$$
$$\nu d \to \mu^- p\pi^0 p_s,$$
$$\nu d \to \mu^- n\pi^+ p_s,$$

where the symbol s indicates the spectator nucleon.

When the first of these reactions proceeds via the channel

$$\nu p \to \mu^-\Delta^{++},$$

its cross section is found to increase rapidly with energy from the reaction threshold, becoming constant at $(0.68 \pm 0.13) \times 10^{-38}$ cm^2 at $E_\nu > 1.6$ GeV. The estimate of M_A from these data is model-dependent and ranges from 0.74 to 0.96 GeV. The result of a check of the charge relations can be represented in the form of Table II.

However, the background problems have not yet been solved, especially for the second reaction.

f) Since the cross sections of the reactions $\nu N \to \mu^- N$ and $\nu N \to \mu^- \Delta$ do not increase with energy and the total cross section increases as $\sigma^{(tot)} = 0.78 E_\nu \times 10^{-38}$ cm^2, it is obvious that the cross sections of reactions producing two or more pions in neutrino-nucleon interactions increase rapidly with energy.

The data cited are alone sufficient to give an idea of the progress that has been made in high-energy neutrino physics and of the importance of the results obtained here. Theoretical analysis of these data is a still unsolved problem. The existence of still unobserved particles has been proposed within the framework of several variations on the aforementioned ideas of the consistent gauge theories of weak and electromagnetic interaction: either leptons with large masses or particles with new quantum numbers (charmed particles). Searches for such particles have thus far been unsuccessful. For example, the results of neutrino experiments performed by the Caltech group at FNAL indicate the nonexistence of a heavy Y^+ muon with a mass smaller than 7 GeV if it is assumed that it decays in 30% of cases in accordance with the scheme $Y^+ \to \mu^+\nu_\mu\bar{\nu}_\mu$ and that the coupling constant G_Y is subject to the condition that $G_Y/G_F \approx 1$.

4. WEAK INTERACTIONS (PARTICLE DECAYS)

In addition to the neutrino-experiment programs, much activity continues in research into other aspects of weak elementary-particle interactions. Among the experimental studies reported to the conference, we should note first of all the result of new high-precision measurements of the lifetime of the positive muon made at the Nuclear Problems Laboratory of JINR. The value obtained was

$$\tau_\mu = (2.19711 \pm 0.00008) \cdot 10^{-6}\ \text{sec.}$$

Then from the relation

$$G_\mu^2 = \frac{192\pi^3\hbar^7}{\tau_\mu m_\mu^5 c^4}\left(1 - 8\frac{m_e^2}{m_\mu^2}\right)(1+2\delta$$

we obtain the following value for the μ-decay constant:

$$G_\mu = (1.43383 \pm 0.00003)(1+\delta) \cdot 10^{-49}\ \text{erg} \cdot \text{cm}^3,$$

where δ denotes the contributions of the electromagnetic corrections (in the lowest order of perturbation theory $\delta = (\alpha/4\pi)[\pi^2 - (25/4)]$), which must now be calculated more accurately in order to obtain information on the actual value of the constant G_μ.

The results of a number of experimental studies performed with the object of determining the matrix-element structures of semileptonic baryon decays and verifying the Cabibbo theory for these processes. We list the basic results of these studies. The matrix element of the decay $B \to B'e^-\bar{\nu}_e$ is written in the form

$$M \sim \langle B' | [(f_1 + g_1\gamma_5)\gamma_\alpha + \frac{1}{m}(f_2 + g_2\gamma_5)\sigma_{\alpha\beta}q_\beta + \frac{1}{m}(f_3 + g_3\gamma_5)q_\alpha | B\rangle j_\alpha,$$

where j_α is the lepton current of the V-A theory. In the Cabibbo theory, the form factors f_i and g_i are linear functions of the contributions of SU(3) symmetry F-type and D-type forces. It is assumed that there are no currents of the second kind, i.e., $f_3 = g_2 = 0$. It is assumed further that the hypothesis of vector-current conservation holds, giving the relation of the form factor f_2 to the magnetic moments participating in the decay of the baryons, and a generalization of the Goldberger-Treiman theorem that links the form factors g_3 and g_1 is used.

a) The skewness in the $e\nu$ correlations was calculated from the proton energy spectrum in neutron β-decay and found to be $a = 0.096 \pm 0.013$. It follows from this that

$$\left(\frac{g_1}{f_1}\right)_{n\to pe\nu} = 1.24 \pm 0.04.$$

b) The same quantity was determined again in Λ-hyperon decay. It was found within the framework of the assumptions described above that

$$\left(\frac{g_1}{f_1}\right)_{\Lambda\to pe\bar{\nu}} = 0.64 \pm 0.1.$$

c) The Brookhaven National Laboratory has developed a hyperon-beam technique. The neutron energy spectrum in the decay $\Sigma^- \to ne^-\bar{\nu}$ was measured in a beam of this kind. The result was used to determine the absolute value of the ratio g_1/f_1,

$$\left|\frac{g_1}{f_1}\right|_{\Sigma^-\to ne\bar{\nu}} = 0.435 \pm 0.035.$$

d) The Λ^0 hyperon spectrum was measured in the decay $\Sigma^- \to \Lambda^0 e\nu$ as part of the same series of studies. Here $f_1 = 0$ in the Cabibbo theory. The experiment gives $f_1/g_1 = -(0.25 \pm 0.35)$ if $f_2 = 0$ and $f_1/g_1 = +(0.45 \pm 0.20)$ if it is assumed in accordance with the hypothesis of conserved vector current that $f_2 = -1.9$. Determination of the decay constants for $\Sigma^- \to ne^-\bar{\nu}$ makes possible convenient determination of the constants F and D of the Cabibbo theory. In fact, for this decay

$$\frac{g_1}{f_1} = -(F-D).$$

On the other hand, for neutron decay with $\Delta S = 0$, we have

$$\frac{g_1}{f_1} = F + D.$$

Thus, knowledge of only the ratios g_1/f_1 for these two decays enables us to find the constants F and D without determining the Cabibbo angle ϑ. On the other hand, knowledge of the probability of the decay $\Sigma^- \to \Lambda e\bar{\nu}$ at $\Delta S = 0$ enables us to determine the angle ϑ. The result of this analysis looks like this:

$$\sin\vartheta = 0.231 \pm 0.003,$$
$$\frac{D}{F+D} = 0.658 \pm 0.007.$$

SU(6) symmetry predicts a value of 0.6 for the latter ratio.

The question as to the possible contribution of currents of the second kind was also discussed. It is known that an overall analysis of all known data on semilepton baryon decay within the framework of the premises of the Cabibbo theory that were formulated above indicated that they are poorly consistent within the framework of this approach. It was therefore suggested that currents of the second kind contribute in decays with $|\Delta S| = 1$, and that perhaps $g_2/f_1 = 5$–8. It was found from data cited at this conference on the decay of Ne^{19} that $g_2/f_1 = 8.6 \pm 2.5$, but the accuracy of the corrections for the nuclear effects is inadequate to form any confident conclusion as to this figure, the more so since comparison of the beta-decay characteristics of the nuclei in the triad Li^8, Be^8, and B^8 gives $g_2/f_1 = 1 \pm 8$.

In completing the section on the decay properties of baryons, we cite the results of CERN measurements of the relative probability of the decay $\Xi^0 \to \Lambda^0\gamma$, which was found equal to

$$R_\Xi = \frac{\Gamma(\Xi^0\to\Lambda^0\gamma)}{\Gamma(\Xi^0\to\Lambda^0\pi^0)} = (2.3 \pm 0.7)\cdot 10^{-3},$$

which can be compared with the theoretical value of 1.6×10^{-3}.

The skewness for this decay was determined for the first time from 15 $\Omega^- \to \Lambda^0 K$ decay events. The value obtained for it was

$$\alpha_\Omega = -0.66\,^{+0.36}_{-0.30}.$$

As in the question as to the lifetime of the K_S^0 meson, some uncertainty arose as to the lifetime of the Λ^0 hyperon. According to the results of three new measurements, it equals $(2.624 \pm 0.014 \times 10^{-10}$ sec, which is $(4 \pm 1)\%$ larger than the tabulated value.

No significantly new data were presented at the conference on the problem of phenomenological analysis of the violation of CP symmetry in decays of neutral K-mesons. It is known that recent CERN experiments produced results that differ from the accepted tabular data. The authors continue to insist on their set of parameters, which at present looks like this:

$$|\eta_{+-}| = (2.30 \pm 0.035)\cdot 10^{-3},$$
$$\varphi_{+-} = (45.9 \pm 1.6)^\circ,$$
$$\delta_e = (3.41 \pm 0.18)\cdot 10^{-3},$$
$$\delta_\mu = (3.13 \pm 0.29)\cdot 10^{-3}.$$

Using the data of this group on

$$\Delta m = m_{K_L} - m_{K_S} = (0.534 \pm 0.003)\cdot 10^{10}\ \text{sec}^{-1}$$

and other experimental data, we have the following set of figures for comparison with the prediction of the superweak (SW) interaction model:

$$|\eta_{+-}| = (2.30 \pm 0.035)\cdot 10^{-3},$$
$$\varphi_{+-} - \varphi_{SW} = (2.2 \pm 1.9)^\circ,$$
$$\left|\frac{\eta_{00}}{\eta_{+-}}\right| = (1.013 \pm 0.046),$$
$$\varphi_{00} - \varphi_{+-} = (3 \pm 13)^\circ,$$
$$\delta_2 - \delta_0 = (55 \pm 5)^\circ,$$
$$|\varepsilon| = (2{,}32 \pm 0.05)\cdot 10^{-3},$$
$$\left|\frac{\varepsilon'}{\varepsilon}\right| = 0.007 \pm 0.015,$$
$$\varphi_\varepsilon - \varphi_{SW} = (1.7 \pm 1.3)^\circ.$$

Some of these figures differ slightly from those hitherto accepted. However, the qualitative conclusion remains the same: these data are consistent with models of CP-symmetry violation only in the mass matrix. Within the framework of the Bell-Steinberger unitarity relation, the value given for $\Delta\varphi = \varphi_\epsilon - \varphi_{SW}$ gives the following esimate for the upper limit of the parameter η_{000} in the decay $K_L^0 \to 3\pi^0$: $|\eta_{000}|^2 \le 0.21$. An experimental estimate of this quantity was obtained in experiments in the Institute of Theoretical and Experimental Physics (ITEP) xenon bubble chamber, the present value being $|\eta_{000}|^2 \le 1.1$. Improvement of the values of φ_{00} and $|\eta_{000}|$ would make it possible to test CPT invariance and the SW model. Measurement of the electric dipole moment of the neutron to values on the order of 10^{-28} cm is also very important. It is now known that $D_n < 5 \times 10^{-24}$ V·cm.

The results of a search for the $K^+ \to \pi^+ e^+ e^-$ decay were communicated at the conference. The magnetic spark spectrometer technique was used at CERN in a beam of K^+ mesons with a momentum of 2.5 GeV/c. The relative probability of this decay was estimated at $(2.3 \pm 0.8) \times 10^{-7}$ on the basis of 24 events. Knowledge of the characteristics of this process is important for understanding of the problem of strangeness-nonconserving neutral currents and weakly electromagnetic processes, as well as certain problems in the violation of CP symmetry in weak interactions.

5. HADRON SPECTROSCOPY

The conference received the results of analysis of numerous new experimental data obtained on two-particle and quasi-two-particle reactions with the purpose of establishing resonance quantum numbers. The procedure consists in an improvement of the phase-analysis technique and adjustment of experimental data on the differential cross sections and polarization effects in meson-baryon reactions of the "two particles to two particles" type:

$$P + N \to M + B,$$

where P is a pseudoscalar (π or K) meson and the meson M and the baryon B can themselves subsequently decay (for example, a ρ-meson or a Δ_{1236} isobar). Earlier indications of the possible existence of baryonic isobars with strangeness S = +1 were not confirmed. This also follows from recent data from phase analysis of elastic K^+p scattering (states with isotopic spin I = 1) and from new data on the reaction $K^0_L p \to K^0_S p$, which give information on the state with I = 0.

Work at SLAC-Berkeley, London-Cambridge, and Saclay has improved the phase-shift-analysis data for the reactions $\pi N \to \pi\pi N$ on ensembles of 20 000–40 000 events, considerably better in the $\Delta\pi$ channel and with less accurate results in the ρN channel. New data are also available on the reactions $\pi N \to \Lambda K$ and $\pi N \to \Sigma K$. The picture for states with S = 0 is now more or less clear up to masses on the order of 2000 MeV. States with S = –1 are also being analyzed intensively in many laboratories in reactions of the type $\bar{K}N \to MY$, where Y is a baryon with S = –1. All studies yielded results on the d-wave amplitudes that agreed closely. The agreement of data on the s- and p-wave amplitudes is poorer, even for states with m < 1800 MeV. The problem of states with masses over 1800 MeV has yet to find its solution. It is considered that there are 57 definitely established (here the reference is to the known quantum numbers and decay probabilities for various channels) baryon resonances, of which 17 are nucleonic states, 10 are Δ states, 16 are Σ states, and 14 are Λ states with various J^P.

Significant advances have been made in the problem of classifying baryonic isobars. The basis for classification within the framework of quark approaches is SU(6) symmetry. But for states with large J it is necessary to introduce new quantum numbers of the orbital L and principal n types. The type of symmetry in these quantum numbers depends on the dynamics postulated for the quark interaction. Quark models of the oscillator or Keplerian types are under discussion. The analysis is carried out within the framework of a symmetry of the type SU(6) ⊗ O(3). In this approach, classification of the baryons consists in their identification with multiplets of SU(6) and SU(3) symmetries as follows:

$$\{SU(6)\}_q L^P, \quad [SU(3),\ 2S_q + 1]_n J^P,$$

where S_q is the total spin of the three quarks in the baryon. Then the octet N(940), Λ(1115), Λ(1190), and (1320) is the SU(3) multiplet $[8, 2]1/2^+$, the decaplet Δ(1236), Σ(1380), Ξ(1530), and Ω(1670) is the SU(3) multiplet $[10, 4]3/2^+$, and the two of them form the SU(6) multiplet $\{56\}_0 L^P = 0^+$. Then follows filling of the SU(6) multiplet $\{70\}_1 L^P = 1^-$, which consists of the SU(3) multiplets $[8, 2]1/2^-$, $[8, 2]3/2^-$, $[10, 2]1/2^-$, $[10, 2]3/2^-$, $[8, 4]1/2^-$, $[8, 4]3/2^-$, and $[8, 4]5/2^-$; then multiplets with $L^P = 2^+$, 3^-, and so forth are considered. An enormous number of resonances appear in this classification. But practically all known nucleonic isobars with M < 2000 MeV are identified in the process. On the other hand, it becomes necessary to have a large number of new isobars with S = –1 and S = –2. Here the experimental data on the decays agree well with calculations within the framework of a symmetrical quark model of the oscillator type using the Melos transformation, especially in the channels $N^* \to N\pi$ and $N^* \to N\gamma$.

Concerning meson spectroscopy, it is known that the tables give information on approximately 30 mesons, but the quantum numbers are accurately known only for 20 of them. Here attention is concentrated on the problem of phase analysis of elastic $\pi\pi$ and $K\pi$ scattering. There is considerable scatter in the results of determinations of the $\pi\pi$ scattering lengths by different groups, but as a rule they are considerably higher than the values calculated theoretically by Weinberg ($a_0^0 = 0.17/m_\pi$). Phase analysis of $\pi\pi$ scattering at energies above 1 GeV indicates the possible existence of a resonant state of the $\pi\pi$ system with J = 4 and a mass of about 2 GeV.

The results on elastic $K\pi$ scattering are less accurate. Solutions without the κ(700) meson would appear to be preferable. The conference received new Brookhaven data on the reaction $K^+p \to K^+\pi^-\Delta^{++}$ at 12 GeV. The analysis was carried out over the angular momenta $\langle Y_{l,m} \rangle$ of the system up to and including $\langle Y_{8,0} \rangle$ and up to $m_{K\pi}$ = 2.1 GeV. The known $K\pi$ resonances with masses of 890 MeV and 1.4 GeV are seen clearly, and there are also indications of a $K\pi$ resonance with mass 1.8 GeV, whose spin is assumed equal to J = 3.

Much new information was obtained on 3π and $K\pi\pi$ states from the reactions

$$\pi p \to \pi\pi\pi N, \quad Kp \to K\pi\pi N.$$

The University of Illinois group analyzed data on the formation of $\rho\pi$, $f\pi$-, and $K^*\pi$ states in πp and Kp interactions at energies up to 16 GeV. Data obtained in the joint IHEP-CERN experiment at Serpukhov were analyzed in similar fashion. Waves with $J \leq 3$ were considered and factorization was used for the resonant states. In the 3π states, the only well-established resonance is the A_2 resonance with $J^P = 2^+$ (d-wave of $\rho\pi$ system). It was shown that the A_1 resonance is most probably associated with the Deck effect in the 1^+s state of the $\rho\pi$ system at 1100 MeV. The phase is constant at about 180° in this system. The same statement is also made regarding the A_3 resonance ($f\pi$ state 2^-s with phase about 0°).

$K^-\pi^+\pi^-$ systems have a Q resonance in the $K^*\pi$ system in the state 1^+s with properties similar to those of A_1, and singularities and an L resonance in the $K^{**}_{1420}\pi$ system in the state 2^-s, similar to the A_3 resonance. Here the K^{**}_{1420} resonance is the analog of the A_2 resonance.

As for the problem of classifying mesonic states, it is solved in the same way as the problem for the baryon resonances. The quark-antiquark system is usually analyzed within the framework of the compatible symmetries SU(6) ⊗ O(3). There is a possibility of classification of mesonic resonances in the simplest case of the quark oscillator model in which there appear states with quantum numbers J^{PC}: 0^{-+}, 1^{+-}, 2^{-+}, 3^{+-}, etc. with $S_q = 0$ and states with 0^{++}, 1^{++}, 1^{--}, 2^{++}, 2^{--}, 3^{++}, 3^{--}, etc. with $S_q = 1$, where S_q is the total spin of the $\overline{q}q$ system. There are many more of these states than there are presently known well-established families of mesonic resonances.

6. PROBLEMS OF ELEMENTARY-PARTICLE THEORY

New approaches in the theory of elementary particles were discussed in the "theoretical theories" section. In general, the name given this section is justified, because these new trends are in most cases at the purely theoretical level and still remote from comparison with experiment.

Among the theoretical approaches, we should make a special distinction for attempts to develop a consistent theory of weak, electromagnetic, and strong interactions on the basis of gauge field theories. Weinberg's model, which was proposed seven years ago, made it possible to obtain a renormalizable scheme for weak and electromagnetic interactions. However, inclusion of hadrons into the scheme encountered a number of difficulties. Neutral currents usually appear in such generalizations and result in hadron transitions with strangeness change that are not observed experimentally. To overcome this difficulty it is necessary to introduce particles with new quantum numbers–so-called supercharged or charmed particles, which prove necessary in the theory and in solution of a number of other problems. Thus the experimental search for these particles (whose masses are estimated at ~2–10 GeV) was regarded by the conference as one of the priority problems of elementary-particle physics. However, a number of unsolved problems remain even after introduction of the new particles into the theory. Thus, Weinberg's conference paper took note of the η-meson problem as one of the most complex problems of the gauge theories: in all existing variants of the theory, the mass $m_\eta < \sqrt{3}m_\pi$, in contradiction to the experimental data. But Weinberg's paper was, on the whole, quite optimistic, as was the review paper presented by Illiopoulos. The optimism was due chiefly to the recently discovered property of asymptotic freedom in nonabelian gauge field theories. This was the subject of two papers by D. Gross, which aroused numerous discussions. The phenomenon consists in the fact that quantum fluctuations of the nonabelian gauge field attenuate the interaction at ultrashort distances, so that the effective interaction constant tends logarithmically to zero. The asymptotically free theories appear to be adequate for description of the hadron universe in all respects.

First of all, asymptotic freedom could explain the success of the naive quark model in description of highly inelastic lepton-hadron reactions–these reactions proceed at short distances, at which the quarks are almost free. A logarithmically small interaction between quarks should result in deviations from the predictions of the naive quark model and, in particular, deviations from the well-known similarity law of Bjorken. It is interesting that the deviations are not increments, but additional multipliers that vary slowly with the transferred momentum (as a power of the logarithm).

The exponents were calculated for several variations on the gauge theory of strong interactions, and were found to be large enough so that the deviations from scaling may appear in experiments of the next few years. No less important is another possible property of nonabelian gauge theories–an infrared catastrophe resulting in the so-called "quark prison." It is expected that the mutual attraction forces between quarks due to the gauge field will not decrease with distance, as though the quarks were held together by elastic bands. This would explain the absence of quarks in experiment and the increase in the hadron-resonance spectrum with increasing angular momentum.

Various plans for the quark gauge prison were discussed in papers presented at the conference and to an even greater degree informally. Quantitative solution of this problem requires elaboration of new gauge field theory methods that do not involve perturbation theory. The efforts of many theoreticians are now being concentrated on this aspect.

Another interesting trend in the development of field theory that has appeared during the past year is Fermi-Bose supersymmetry (the pioneering work in this field was done by the Soviet Scientists Yu. A. Gol'fand, B. P. Likhtman, F. A. Berezin, G. I. Kats, V. P. Akulov, D. V. Volkov, and others). This unusual symmetry group incorporates the multiplets of the fermion and the boson. Both matrices and anticommutative Fermi operators are elements of the group.

The papers by Zumino, Vess, Salam, Straddy and others proposed renormalizable Lagrangians that possess Fermi-Bose supersymmetry. It is interesting that almost all divergences are eliminated in these theories, so that only the renormalization of the wave function remains infinite. Nonabelian gauge theories with Fermi-Bose supersymmetry came to light quite recently (in the spring of 1974). The new symmetry enables us to broaden the class of asymptotically free theories by including scalar and pseudoscalar fields in the Lagrangian. Problems of spontaneous violation of symmetry, vector meson mass problems, and problems of Goldstone fermions (germions), and others are under discussion.

All of these results were summarized in Zumino's paper.

Yet another interesting trend in quantum field theory is the theory of quasiclassical bound states (t'Hooft, Polyakov, Zel'dovich, Kobzarev, Okun', and others). Such states appear when symmetry is violated spontaneously due to the Higgs phenomenon–the appearance of an average field in a vacuum. For example, if the Higgs field $\varphi_i(\mathbf{r})$ is a three-vector in a space of internal symmetry, the state in which the field is directed along the radius vector $\varphi_i(\mathbf{r}) \sim r_i$ is found to be stable and describes a new particle (hedgehog).

It was found that hedgehogs appear in certain gauge models of weakly electromagnetic interactions (for example, in the Georgi-Glashow model) and have magnetic charges. The mass of such a nonlocal monopole should be of the order of $137m_W$, where m_W is the mass of the vector meson.

Quasiclassical objects of another type–vortex filaments–had been proposed earlier by Nielson and Olsen as a hadron model. If the existence of filamentary bound states were demonstrated in the theory of strong interactions, this could justify the relativistic-string models that are now used for phenomenological description of the meson spectrum and interaction.

Another, more radical approach to the hadron theory is the theory of the quantum "sack" (Johnson, Weiskopf, Jaffe, and others). In this theory, free or nearly free fields (partons) are enclosed in a bounded space, a sack, whose wall coordinates are also dynamic variables and vibrate due to quantum fluctuations. The partons are restrained inward by pressure and cannot penetrate to the outside, unlike leptons, for which the walls are transparent. Actually, this "bubble" simulates both the resonance spectrum and the parton model fairly well in highly inelastic lepton-hadron reactions, but unless weightier theoretical bases are found, it will meet the usual fate of soap bubbles.

On the whole, the thousand papers entered at the conference contain many clever and interesting but unfortunately mutually contradictory ideas. Perhaps one of them will serve as a basis for a future theory.

In any event, the conference showed that particle physics is going through an interesting period of development and that fundamental discoveries may be expected within the next few years.

This conclusion found a confirmation in important results obtained after the conference—in the observation of new narrow resonances or ψ particles. The discovery of these resonances turned over a new page in the study and classification of elementary particles.

Translated by R. W. Bowers

[1)]Important changes took place in this field after the London conference. New narrow resonances—the ψ particles—were discovered.