Nineteenth International Conference on High Energy Physics

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Usp. Fiz. Nauk **128**, 370–378 (June 1979)

PACS numbers: 01.10.Fv, 13.90. + i, 12.40.Cc

The Nineteenth International Conference on High Energy Physics took place in Tokyo during the period August 23–31, 1978. The conferences of this series are convened every two years under the auspices of the Union of Pure and Applied Physics and provide a forum for discussion of the latest results of research in ths field of physics, which is currently undergoing vigorous development. More than 1100 delegates from 50 countries participated in this conference, where they presented over 1200 papers. Indeed, this abundance of material predetermined the structure of the conference, which for the first three days was organized into parallel sessions with discussion, together with original reports, and reviews on specialized problems.

In talks at the plenary sessions, the rapporteurs presented reviews of the status of broad areas of high energy physics. The following is a list of the plenary sessions and the names of their rapporteurs and chairmen. Hadron-hadron reactions, small multiplicity: rapporteur V. A. Tsarev (USSR), chairman E. L. Goldwasser (USA); hadron-hadron reactions, large multiplicity: rapporteur R. Diebold (USA), chairman L. Van Hove (CERN); phenomena at high p_T, jet structure: rapporteur R. Sosnowski (Poland), chairman G. Von Dardel (Sweden); direct production of lepton pairs in hadronic reactions: rapporteur L. M, Lederman (USA), chairman P. Falk-Vairant (CERN); dynamics of hadronic reactions: rapporteur G. Veneziano (CERN), chairman A. Wroblewski (Poland); dynamics of reactions at high energies: rapporteur R. D. Field (USA), chairman L. D. Solov'ev (USSR); e^+e^- reactions: rapporteur G. J. Feldman (USA), chairman H. Schopper (W. Germany); particle spectroscopy, experiment: rapporteurs G. Flügge (W. Germany) and R. J. Cashmore (England), chairman G. H. Stafford (England); particle spectroscopy, theory: rapporteur Y. Hara, chairman I. V. Chuvilo (USSR); eN, μN, and γN reactions: rapporteur E. Gabathuler (CERN), chairman E. Paul (W. Germany); neutrino reactions: rapporteur K. Tittel (W. Germany), chairman M. Conversi (Italy); neutrino reactions, bubble-chamber data: rapporteur C. Baltay (USA), chairman D. C. Colley (England); theory of weak interactions and models of elementary particles: rapporteur S. Weinberg (USA), chairman H. Harari (Israel); quantum chromodynamics and related problems: rapporteur B. Sakita (USA), chairman C. N. Yang (USA); unified theories, supergravity, and new ideas: rapporteur A. Salam (Trieste), chairman R. Marshall (USA); future projects in high energy physics: rapporteur E. L. Goldwasser (USA); concluding talk: rapporteur Y. Nambu (USA), chairman G. Takeda (Japan).

A discussion of projects for future accelerators and storage rings at high energies took place at a special session in parallel with the conference, a summary of which was presented by E. L. Goldwasser (Batavia, USA) at a plenary session.

Because of the commissioning in recent years of new accelerators and storage rings and the essential modernization of previously disused ones (the 400-GeV proton synchrotron at CERN (Geneva), the increase in energy to 470 GeV at a similar accelerator in Batavia (USA), the increase in energy in the e^+e^- storage rings DORIS at DESY (Hamburg, W. Germany), to 10 GeV, etc.) and the use of a new generation of complex, highly automated detectors of high-energy particles, it has become possible to significantly broaden and intensify the investigations and to increase their productivity and the reliability of the results. As a result of complex theoretical and experimental studies of various problems in elementary-particle physics, which have led in recent years to a number of important discoveries and observations of regularities of a fundamentally new character, there has been significant development of our ideas about the properties of the microworld and it appears that we are now at the threshold for constructing a unified picture of the subatomic world. In this situation, it appeared that the most diverse types of information from what seem superficially to be unrelated areas of this branch of modern physics play a very important part in the elucidation of the most essential aspects of the phenomena under study.

Let us consider the main characteristics of hadron-hadron processes. New data were presented at the conference on the energy dependences of the total cross sections for pp, p^-p, np, np^-, Kp and Kp^- interactions, these data having been obtained in beams from the accelerator at Batavia (USA) (Brookhaven-Batavia-Rockefeller University collaboration). These data show that at momenta up to 370 GeV/c the cross sections continue to rise, while the differences between the total cross sections for the interactions of particles and antiparticles with protons fall off with increasing energy in accordance with the consequences of the Pomeranchuk theorem.

In conjunction with data from experiments in cosmic rays, these results indicate that the total cross sections rise with energy like $\ln^2 s$, where s is the square of the total energy of the interacting particles in the c.m.s. We note that this is the maximum rate of growth which is allowed by the most general requirements of field theory (Froissart *et al.*). The development of new

 0038-5670/79/060480-08$01.10

methods of investigating scattering processes at smaller angles than ever before (by the group of the Leningrad Institute of Nuclear Physics using ionization chambers of a new type, and by the group of the Joint Institute for Nuclear Research using gaseous supersonic jet targets in accelerators) has made it possible to study in detail the Coulomb-nuclear interference in elastic scattering of charged particles. This opened up the possibility of measuring the real parts of the amplitudes A for elastic $\pi^- p$ scattering in the momentum range 30–140 GeV/c (CERN-Clermont-Ferran-Leningrad-Lyon-Uppsala collaboration) and for pp, pd, and pHe scattering at energies up to 400 GeV (Batavia-Arizona-Dubna-Rockefeller University-Rochester University collaboration). It was found that at 335 GeV in nucleon-nucleon scattering and at 60 GeV in $\pi^- p$ scattering the ratio ReA/ImA becomes positive at high energies, after passing through zero from negative values at low energies. All these data and the data on the total cross sections afford good confirmation of the validity of dispersion relations and, as a consequence, the validity of the basic principles of quantum field theory and of a number of very general approaches in the description of these phenomena (Regge-pole theory, etc.), thus providing new food for thought on the possibility of their further description. Thus, in spite of Glauber theory, the rates of shrinkage of the diffraction peaks in elastic pd and pHe scattering were found to be equal and constant in the approach to the diffraction minimum, and this probably indicates that inelastic corrections play a major role in this process. Further evidence for this is provided by the experimentally observed oscillations in the t-dependence of the cross sections for elastic pd and pHe scattering. There are also new important data on the properties of elastic scattering beyond the diffraction peak.

Thus, in new precision experiments on elastic $\pi^- p$ scattering in the momentum range 1–3.5 GeV/c, carried out in Japan with the recently commissioned proton synchrotron KEK at 12 GeV, it was found that with increasing energy the positions of the minima and maxima are displaced into the region of smaller values of $-t$, while the value of the cross section at the maximum rises as a function of s. New data on elastic neutron-proton scattering obtained by a group from the University of Michigan (USA) at the Batavia accelerator are also of special interest. It was found that $d\sigma(np)/dt \approx 3d\sigma(pp)/dt$ when $t = -1.25$ GeV^2 at a neutron energy of 100 GeV, but that these cross sections are equal at 280 GeV.

However, measurements in the region of large momentum transfers [up to 14(GeV/c)^2] reveal significant deviations from the diffractive behavior, one of the possible explanations of which is a microstructure of the proton (~0.4 F). To gain a more complete understanding of these phenomena, we require new, rather complex experiments, since the value of $d\sigma/dt$ for elastic NN scattering at $E = 400$ GeV and $-t = 14$(GeV/c)^2 is of order 10^{-37} cm^2/(GeV/c)^2.

Fundamentally new effects have been observed in the study of the scattering of polarized protons by polarized proton targets at Argonne National Laboratory in the USA. Measurements in the range of energies from 1 GeV to 12 GeV indicate that the cross-section difference $\Delta\sigma_L = \sigma(\rightleftarrows) - \sigma(\rightrightarrows)$ and one of the correlation tensors C_{LL} have complicated energy dependences. This behavior of these quantities is interpreted in terms of the existence of previously unknown baryon-baryon resonant states of the pp system. One of them, with mass $M = 2260$ MeV, width 200 MeV, and elasticity 20–30%, is assumed to be a $^3F_3$ state of the pp system with $J^P = 3^-$. It is possible that there exist other such states of the type $^1D_2$ and $^1G_4$. Evidence for the possible existence of two baryon resonance systems was obtained previously at JINR in investigations of $\Lambda^0 p$ combinations. We shall consider this effect below in greater detail. Data on the polarization in elastic πp and pp scattering have been obtained in the new energy range 100–300 GeV in experiments in CERN and at Batavia. It was found that the polarization is quite appreciable. For example, $P \approx 20\%$ at 300 GeV in pp scattering with $-t = 1.3$(GeV/c)^2. A further growth of interest in polarization phenomena is to be expected.

Much experimental material was also presented on diffraction dissociation in pp and πp interactions at high energies. As before, there are inconsistencies in the information on the A_1 meson with mass near 1.1 GeV, quantum numbers $J^{PC} = 1^{++}$, and principal decay into the channel $\rho\pi$. The large quantity of new experimental data have still not established whether this meson exists, and whether the meson nonet with $J^P = 1^+$ exists. New data on coherent nucleon diffraction dissociation in the energy range 50–400 GeV were obtained in experiments carried out by a Dubna-University of Arizona-Fermilab-Rochester University collaboration using the accelerator at Batavia. Detailed observations of $d^2\sigma/dtdM_x$ in reactions of the type $p\text{He} \to X\text{He}$ provide rich information for analyses in the framework of various models, in particular for an understanding of the triple-Pomeron exchange mechanism. The same should be said about the large quantity of new data on quasi-two-body reactions and on nondiffraction processes.

It appears that a combined approach based on quark models and the Regge-pole model can now provide a satisfactory description of the observed experimental data. From the theoretical point of view, it is important at the present time to establish the existence of relations between the Regge-eikonal approach and quantum chromodynamics, which, as we shall show below, is now claimed to be a dynamical theory of the strong interactions. Indications of such relations already exist, as was clear from the reports of V. W. Zakharov and D. Gross and from the rapporteur talk by G. Veneziano.

It has been found that the numerous data on multiparticle processes (at this conference alone, over 200 papers were presented) can also be satisfactorily explained in the framework of quark-parton approaches. For example, the data confirm the idea, derived from the quark-gluon model of hadrons, that the spectra of secondary pions with different charges should reflect the distributions in x of the u and d quarks in the initial hadrons. Analogous information can be extracted from the analysis of the spectra of secondary particles in the fragmentation region. New data on processes involving large momentum transfers are in good agreement with the predictions of the quark counting rules (due to Matveev, Muradyan, and Tavkhelidze, and also Brodsky and Farrar), which imply the relation $x d\sigma/dx \sim (1-x)^{2n-1}$, where n is determined by the parameters of the model.

Processes with large momentum transfer have received particularly great attention. There are two reasons for this: first, the progress of the theory—it has been proved that quantum chromodynamics (QCD) leads to a modified parton picture for both inclusive and exclusive processes, and second, the new experimental data. It has finally been established that scaling is violated in deep inelastic processes, and the character of the violation and its quantitative magnitude are in good agreement with the predictions of QCD. [It is true that the value of the ratio σ_L/σ_T remains inexplicably large (~0.21).] This may reflect the process of $\mu^+\mu^-$ pair production in hadronic collisions. One of the "stumbling blocks" for QCD has been the excessively rapid falloff of the cross sections for the production of hadrons with large $p_T(\sim p_T^{-8})$. New measurements in the region $p_T = 8$–16 GeV/c indicate a retardation of this falloff $(\sim p_T^{-6})$ and are in much better agreement with QCD, but it is still premature to speak of complete agreement. This class of processes should also include the so-called cumulative production on nuclei, to which an entire session was devoted at the conference (led by A. M. Baldin). The main attention here was given to the quark-parton picture of this phenomenon, which satisfactorily reproduces its basic regularities and, in particular, the similarities between many features of this process and those of processes involving large p_T.

However, it should be noted that nonasymptotic corrections play a rather large role in a number of cases in the currently accessible experimental energy range, and new investigations of this problem are required. From the experimental point of view, it is necessary to refine the technique for analyzing multiparticle events, in which the main problem is the identification of the hadronic jets into which the initial quarks or gluons are transformed. This work has already begun, and we can speak of certain data on the structure of events (not individual particles, but large conglomerations of them) with large transverse momentum transfers p_T. For example, investigations at Batavia with the calorimetric trigger technique have established that the longitudinal-momentum distribution of the particles in a jet have the property of scaling (independence of the distribution on the momentum of the jet). Experiments using the SPS (at CERN) have revealed that the average electric charge in a jet tends to $\frac{1}{3}e$ when the momentum fraction of the corresponding particles tends to unity. A number of other regularities have also been established, some having a relatively clear interpretation, and others requiring further analysis.

Much material has now been accumulated in investigations of lepton production processes in hadron-hadron interactions. For example, the quantity $d\sigma/dM_{\mu^+\mu^-}$ has been measured up to $M_{\mu\mu} = 15$ GeV using the colliding beams at CERN. On the whole, we can say that processes of this group can be explained in the framework of QCD, where they are regarded as an effect of the annihilation of a quark-antiquark pair into a lepton pair $\mu^+\mu^-$. However, there are difficulties in understanding the transverse momentum of the pair.

The next important area of investigations in high energy physics to be widely discussed at the conference was studies of e^+e^- annihilation into hadronic states in colliding electron-positron beams with energies up to 2×5 GeV. We begin by mentioning new attempts to study in detail the possible existence of new vector mesons in the range of masses from 1 to 3 GeV. There are indications that such mesons may exist, but reliable information is not yet available.

An important problem concerns the value of the total cross section for e^+e^- annihilation into hadronic states. Experimental data on this quantity are usually represented in the form of the ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$. The cross section for the process $e^+e^- \to \mu^+\mu^-$ has been well studied in the framework of quantum electrodynamics (QED). It has an energy dependence of the form $1/s$. In QCD, the process $e^+e^- \to$ hadrons is regarded as annihilation of e^+e^- into a $q\bar{q}$ pair, followed by conversion of the quark and antiquark into various hadronic states. Then in the single-photon approximation the cross section for annihilation into hadrons must also be proportional to $1/s$, and the quantity R must be a constant, numerically equal to the sum of the squares of the charges of all the quarks which form the hadronic states for a given total energy of the system. Measurements have been carried out using the two main e^+e^- storage rings at high energies, SPEAR at SLAC (Stanford, USA), and DORIS at DESY (Hamburg, W. Germany).

The quantity R rises with energy from a small value (of order 0.1) at 1 GeV to $R = 2$ at 1.3 GeV, after which it has the value $R = 2$ up to about 2 GeV and remains constant with energy, indicating that the three quarks u, d, and s, each with three colors, show up in this energy region. The range of energies from 2 GeV to 3 GeV is at present difficult to characterize uniquely, in view of inconsistencies in the data of different experimental groups. At higher energies, the region of the Ψ mesons begins. Here there are several resonances, which prevent the analysis of the behavior of the quantity R from the standpoint of very general quark approaches. As is well known, the narrow $J/\Psi(3.1)$ meson and the $\Psi'(3.7)$ mesons are states with the hidden quantum number charm (charmonia, decaying into lepton pairs and hadronic states without charm). Going to higher energies, we find broad resonance states that can be interpreted as meson-antimeson bound states, each of which now has open charm. The lightest of them are the D mesons $D^0 = (c\bar{u})$ and $D^+ = (c\bar{d})$, and correspondingly the $\bar{D}$ mesons $\bar{D}^0 = (u\bar{c})$ and $D^- = (d\bar{c})$, and also the more massive mesons

$F^+ = (c\bar{s})$ and $F^- = (\bar{c}s)$. The former have masses of order 1800 MeV, and the latter have masses $m_F = 2.03$ GeV and $m_{F^*} = 2.14$ GeV according to new measurements. This zone of broad resonances extends up to energies of order 5 GeV. Here the quantity R has a value of about 4.7, but systematic detailed data have not yet been obtained at energies above 5 GeV. At 10 GeV, we enter the region of the Υ mesons, which are assumed to be analogs of the Ψ mesons, but states of new b quarks with $Q = -\frac{1}{3}$. New experimental data on the Υ and Υ' mesons, presented at the conference by groups working at DORIS, are as follows:

$$m_\Upsilon = 9.46 \pm 0.01 \text{ GeV}, \quad \Gamma^{e^+e^-} = 1.3 \pm 0.2 \text{ keV},$$

$$B^\Upsilon_{\mu\mu} = 2.6 \pm 1.4\%, \quad \Gamma^\Upsilon_{tot} \geqslant 25 \text{ keV},$$

$$m_{\Upsilon'} = 10.10 \pm 0.01 \text{ GeV}, \quad \Gamma^{e^+e^-}_{\Upsilon'} = 0.32 \pm 0.010 \text{ keV}.$$

In addition, analysis of the effective-mass spectra of $\mu^+\mu^-$ combinations obtained by Lederman's group in experiments at Batavia, with allowance for the data on the Υ and Υ' mesons, indicates the existence of a third meson Υ'' with mass 10.38 GeV.

The analysis of the quantity R in this energy range must also be made with allowance for the data on the new heavy lepton. The first evidence for the existence of this lepton was obtained in 1975 from an analysis of the lepton pairs produced in conjunction with other particles in e^+e^- annihilations.

The results of 15 experiments on this problem were discussed at the conference in Tokyo. These discussions can be summarized as follows. There exists a heavy τ lepton with mass 1782^{+3}_{-4} MeV and spin $\frac{1}{2}$, which decays with a lifetime of less than 10^{-12} sec according to the $V-A$ variant of the weak interaction, as is indicated by the value of the Michel parameter in the spectrum of electrons from τ decay, namely $\rho_\tau = 0.83 \pm 0.19$ (the theory gives $\rho_\tau = 0.53$ for the $V-A$ variant), which excludes the $V+A$ variant ($\rho_\tau = -0.15$) as well as the pure V and A variants ($\rho_\tau = 0.19$). The results also practically confirm the existence of a new neutrino ν_τ, the experimental limit on the mass of which is $m(\nu_\tau) < 250$ MeV.

Since the mass of the τ lepton is large, in addition to the lepton channels of the decay $\tau^- \to 1^- \nu_\tau \bar{\nu}_l$ (where l is an electron or $\bar{\mu}$ meson, and ν_l is the corresponding antineutrino), which account for 20% of the decay probability, decay channels containing hadrons are also open, namely $\tau^- \to \nu_\tau A^-$, where $A^- = \pi^-, \rho^-, A_1^-$, etc. Incidentally, the decay $\tau^- \to \nu_\tau A_1^-$ will provide a unique method of ascertaining whether the A_1 meson exists, since, in contrast with hadronic reactions, there is no problem here regarding the interaction with the background in the final state.

Returning to the problem of e^+e^- annihilation into hadrons, mention should also be made of the topological properties of hadronic jets, which in the energy range between the regions of the Ψ and Υ mesons have the structure implied by a two-quark picture and breakup of the initial hadronic state, while at an energy equal to the mass of the Υ meson they already have the structure of three-gluon decay.

These basic facts obtained from the study of e^+e^- annihilations, and in particular the discoveries of the Υ mesons and the τ lepton, are of great significance in shaping contemporary ideas about the microworld, about which we shall say more later.

There was great interest at the conference in papers on the experimental search for and theoretical interpretation of exotic hadronic states-dibaryons, baryon-antibaryon systems, and others. The discussion of these results, in particular the diproton resonance at 2260 MeV and the evidence for resonances in the $\Lambda^0 p$ system obtained at Dubna several years ago, took place in a number of reports in the parallel sessions, and also in the plenary sessions in the rapporteur talks by G. Flügge and Y. Hara and in the concluding talk by Y. Nambu. There was considerable interest in an investigation of the production of two-baryon resonances by means of photon beams. In particular, an anomaly in the energy dependence of the polarization of the protons from photodisintegration of the deuteron by photons of energy 550 MeV has been interpreted as evidence for the existence of a dibaryon state with mass 2380 MeV, width $\Gamma \sim 100$ MeV, and quantum numbers $J^P = 3^+$ and $I = 0$.

Of special value for testing the predictions of the quark bag model is the search for a dibaryon with double strangeness and mass in the region of 2150 MeV, which can be regarded as a strongly bound state in the $\Lambda^0\Lambda^0$ hyperon system with $J^P = 0^+$ and binding energy ~80 MeV. Thus this state would be stable with respect to the strong interactions. T. F. Kycia (Brookhaven) reported preliminary data on the search for this state by the method of missing mass in the reaction $p + p \to K^+K^+X_0$ for initial protons of energy 34 GeV. The results of the experiment were negative, but the authors intend to continue searches with an increased sensitivity of the apparatus. Evidence for the existence of $\Lambda^0\bar{\Lambda}^0$ systems with positive binding energies was obtained in a study of the reaction $\pi^- p \to \Lambda\Lambda n$ by a group from the Institute of Theoretical and Experimental Physics at Serpukhov. The investigation of baryon-antibaryon states (this direction was initiated by the work of Shapiro at ITEP), which have been designated baryonia, is also of great topical interest in the light of these ideas. A number of reports contained discussions of theoretical results relating to the physics of dibaryons (Matveev, Sorba, de Swart, and others). The study of dibaryon systems is undoubtedly a promising direction of elementary-particle physics.

Quantum chromodynamics (QCD) received great attention at the conference. Recent work by Gribov and Polyakov is important in elucidating the fundamental problems of QCD. So-called instantons are also very popular (Belavin, Polyakov, Tyupkin, and Schwarz). Instanton solutions have demonstrated a nontrivial topological structure of the vacuum and describe tunneling between states with different values of the topological charge of the colored vector gluon field.

As is well known, one of the simplest formulations of the property of quark confinement was the quark bag model, the idea of which arose as a result of pioneering work by Dubna theoreticians, and also by theoreticians from the Massachusetts Institute of Technology (USA) and others. In a paper presented at a parallel session, Callan, Dashen, and Gross (Princeton, USA) proposed a foundation for the picture of a quark bag in the framework of QCD based on a treatment of instantons in an external field (the quark field). It is found that there is a phase transition at a certain critical field between a dense phase (the ordinary vacuum, many instantons) and a rarefied phase (few instantons, inside a hadron).

There were also discussions of the possibility of calculating the parameters of a number of resonances on the basis of QCD sum rules for the annihilation process $e^+e^- \to$ hadrons (Vaĭnshteĭn, Zakharov, and Shifman).

We turn now to a summary of our present understanding of the problems of the weak and electromagnetic interactions of elementary particles.

After the discovery of neutral currents in neutrino physics, it became clear that an excellent candidate for the description of this class of phenomena in the Weinberg-Salam hypothesis of a unified theory of weak and electromagnetic interactions containing a single parameter—the Weinberg angle ϑ_W, which provides a relation between the coupling constants G_F and e of these interactions in the form $(1/\sqrt{2})G_F = e/8M_W \sin\vartheta_W$, where M_W is the mass of the intermediate charged vector boson of the weak interactions.

The theory makes it possible to calculate the cross sections for purely leptonic processes (such as $\nu_\mu e \to \nu_\mu e$) in terms of the angle ϑ_W. Using QCD or the ideas of other models, it is also possible to treat lepton-hadron collisions of the type $l + N \to l + A$, where A is any hadronic state, and l is either a charged (e^-, μ^-) or neutral (ν_e, ν_μ) lepton. This idea stimulated large-scale experimental programs to study both elastic and inelastic interactions involving leptons with high energy.

On the basis of the results of the Tokyo conference, a summary of the experimental situation in neutrino physics at accelerator energies is as follows. First of all, within the currently accessible range of neutrino energies up to 200 GeV, the total cross sections for neutrino-electron and neutrino-nucleon interactions depend linearly on the neutrino energy. The data for purely leptonic processes are given here in Table I. For the neutrino-hadron total cross sections, we have

$$\sigma^{\nu}_{\text{tot}}(E_\nu) = (0.63 \pm 0.05)\, E_\nu \cdot 10^{-38}\ \text{cm}^2,$$

$$\sigma^{\tilde{\nu}}_{\text{tot}}(E_\nu) = (0.31 \pm 0.04)\, E_\nu \cdot 10^{-38}\ \text{cm}^2,$$

where E_ν is in GeV. Thus

$$\frac{\sigma^{\nu}_{\text{tot}}}{\sigma^{\tilde{\nu}}_{\text{tot}}} = 0.49 \pm 0.05.$$

The linear growth of the cross section leads to the following estimate of the mass of the intermediate

TABLE I.

Processes	Experimental values of cross sections	$\sin^2\vartheta_W$	Prediction of Weinberg-Salam theory with $\sin^2\vartheta_W = 0.25$
1. Purely leptonic			
$\tilde{\nu}_e e^- \to \tilde{\nu}_e e^-$	$(5.7 \pm 1.2) \cdot 10^{-42}\ E_\nu$,	0.29 ± 0.05	5.0
$\nu_\mu e^- \to \nu_\mu e^-$	$(1.7 \pm 0.5) \cdot 10^{-42}\ E_\nu$,	0.21 ± 0.09	1.5
$\tilde{\nu}_\mu e^- \to \tilde{\nu}_\mu e^-$	$(1.8 \pm 0.9) \cdot 10^{-42}\ E_\nu$,	0.30 ± 0.06	1.3
2. Elastic scattering			
$\nu_\mu p \to \nu_\mu p$	$(0.11 \pm 0.02)\, \sigma(\nu_\mu n \to \mu^- p)$	0.26 ± 0.06	0.12
$\tilde{\nu}_\mu p \to \tilde{\nu}_\mu p$	$(0.19—0.08)\, \sigma(\tilde{\nu}_\mu p \to \mu^+ n)$	≈ 0.5	0.11
3. Production of a single π^0 meson			
$\nu_\mu N \to \nu_\mu N \pi_0$	$(0.45 \pm 0.08)\, \sigma(\nu_\mu N \to \mu^- N \pi^0)$	0.22 ± 0.09	0.42
$\tilde{\nu}_\mu N \to \tilde{\nu}_\mu N \pi^0$	$(0.57 \pm 0.11)\, \sigma(\tilde{\nu}_\mu N \to \mu^+ N \pi^0)$	0.15 ± 0.52	0.60
4. Inclusive scattering			
$\nu_\mu N \to \nu_\mu + \ldots$	$(0.29 \pm 0.01)\, \sigma(\nu_\mu N \to \mu^- + \ldots)$	0.24 ± 0.2	0.30
$\tilde{\nu}_\mu N \to \tilde{\nu}_\mu + \ldots$	$(0.35 \pm 0.025)\, \sigma(\tilde{\nu}_\mu N \to \mu^+ + \ldots)$	0.3 ± 0.1	0.38

boson:

$$M_W > 30\ \text{GeV}.$$

We turn now to inelastic processes in neutrino-hadron interactions. It is well known that the properties of neutrino processes are determined by three structure functions, which depend on the square of the four-momentum transferred to the hadrons, $-Q^2$, and the transferred energy ν. According to the hypothesis of scale invariance, it is assumed that the functions $W_i(Q^2, \nu)$ depend on not Q^2 and ν individually, but only on their ratio $x = -Q^2/2M\nu$, and new structure functions are introduced (for $Q^2, \nu \to \infty$ and fixed x): $MW_1(Q^2, \nu) = F_1(x)$, $\nu W_2(Q^2, \nu) = F_2(x)$, and $MW_3(Q^2, \nu) = F_3(x)$. According to the parton picture with partons of spin $\frac{1}{2}$, these functions obey the Callan-Gross relation $2xF_1(x) = F_2(x)$. Thus the properties of neutrino processes in this case are determined by only the two structure functions $F_1(x)$ and $F_3(x)$, the first of which is related to the same structure function in deep inelastic electron-nucleon scattering. The analysis of the experimentally measured characteristics of neutrino processes induced by charged currents indicates that the partons are also left-handed particles. The different Q^2 dependences of the structure functions in different intervals of the variable x indicate, in accordance with the predictions of QCD, that scaling is violated in the currently available range $Q^2 < 100\ \text{GeV}^2$ for neutrino energies up to 200 GeV. The experimentally determined average characteristics and moments of the distributions for neutrino processes are in general correspondence with the predictions of QCD and provide rich information about the properties of the parton model of hadrons and its dynamics.

Finally, we give the characteristics of the effects due to neutral currents in neutrino interactions with electrons and hadrons. A quantitative summary of the contributions of the neutral-current effects is contained in Table I.

According to all these data, the value that is now obtained for the Weinberg angle is

TABLE II.

Constant	Theory with $\sin^2\vartheta_W = 0.25$	Experiment	Constant	Theory with $\sin^2\vartheta_W = 0.25$	Experiment
g_V	$-\frac{1}{2}+2\sin^2\vartheta_W=0$	0.00 ± 0.01	d_L	$-\frac{1}{2}+\frac{1}{3}\sin^2\vartheta_W = -0.42$	-0.40 ± 0.07
g_A	$-\frac{1}{2}=-0.5$	-0.55 ± 0.10	u_R	$-\frac{2}{3}\sin^2\vartheta_W=-0.17$	-0.19 ± 0.06
u_L	$\frac{1}{2}-\frac{2}{3}\sin^2\vartheta_W=0.33$	0.35 ± 0.07	d_R	$\frac{1}{3}\sin^2\vartheta_W=0.08$	0.00 ± 0.11

$$\sin^2\vartheta_W = 0.23 \pm 0.02.$$

The degree of correspondence between the Weinberg-Salam theory and the experimental data can now be illustrated by the set of coupling constants of the neutral currents (Table II), where $u_{L,R}$ and $d_{L,R}$ denote the constants of the neutral currents for the left-handed and right-handed u and d quarks.

It is now of special interest to study the nonconservation of P parity in eN interactions predicted by the Weinberg-Salam model. This effect was first observed several months before the conference in an experiment performed by Barkov and Zolotarev at the Institute of Nuclear Physics (Novosibirsk). Observations were made of the rotation of the plane of polarization of laser light which passed through vapors of bismuth, and the magnitude of the effect was found to be in good agreement with the theory (I. B. Khriplovich and others). This work was presented at the conference in Tokyo and aroused great interest. We note that two groups of experimenters (Oxford and Seattle) who have studied the same effect so far have either a negative result or a result that is not in quantitative agreement with the theory.

Immediately before the conference, an experiment was completed to study the inclusive cross section for scattering by deuterons and by hydrogen of electrons with polarization parallel and antiparallel to their momentum. The purpose of this experiment was to search for violation of P parity in eN interactions. In fact, theory predicts that the magnitude of the asymmetry is

$$A \equiv \frac{\sigma_R-\sigma_L}{\sigma_R+\sigma_L} = \frac{9G_F Q^2}{20\sqrt{2}\pi\alpha}\left[1-\frac{20}{9}\sin^2\vartheta_W + (1-4\sin^2\vartheta_W)\frac{1-(1-y)^2}{1+(1-y)^2}\right],$$

where $y=\nu/E$, ν is the energy transfer, and σ_R and σ_L are the cross sections for the interaction of electrons with right-handed and left-handed polarization.

According to data obtained at SLAC, the experimental value of the coefficient A is given by $A/Q^2 = -(9.5\pm1.6)\times10^{-5}$ GeV^{-2}, which yields $\sin^2\vartheta_W \approx 0.21$.

It is clear from the foregoing discussion what fundamental claims are made by the Weinberg-Salam unified theory in conjunction with QCD for the description of a large class of experimental data. Practically no alternatives to this variant of the theory were discussed at the conference. This demonstrates the exceptional importance of further investigations of these problems.

New rich information was also presented on other weak and electromagnetic processes. It is not possible for us to review this information in any detail. Here we can mention results such as a new upper limit on the relative probability of the decay $\mu\to e\gamma$, which now has the value 2×10^{-10} (Los Alamos). Data from JINR were presented for an upper limit on the relative probability of the decay $\mu\to 3e$: $B(\mu\to 3e)<9\times10^{-9}$. At the meson factory SIN in Switzerland, it was shown that the relative probabilities of conversion of negative muons into electrons and positrons in muon capture by sulfur nuclei are less than 1.8×10^{-10} and 1.57×10^{-9}, respectively. New upper limits have been established for the processes $\nu_\mu N\to eX$. In experiments at low energies with the Gargamelle chamber at CERN it was found that the corresponding cross section is less than 2×10^{-3} of the total cross section, while at high energies it is less than 0.05 (BEBC) or less than 0.025 (Batavia).

The characteristics of the decays of the Ω^- hyperon have been determined more accurately at CERN. The value $\tau_\Omega=(0.82\pm0.06)\times10^{-10}$ sec was found for the lifetime, and the following values were obtained for the probabilities of the various decay modes:

$$B(\Omega^-\to\Lambda K^-)=67.0\pm2.2\%,\ B(\Omega^-\to\Xi^0\pi^-)=24.6\pm1.9\%,$$

$$B(\Omega^-\to\Xi^-\pi^0)=8.4\pm1.1\%.$$

The asymmetry coefficient in the decay $\Omega^-\to\Lambda K^-$ was found to have the value $\alpha_\Omega=0.06\pm0.14$. We note that the main characteristics of the Ω^- decay was first predicted by Vaĭnshteĭn, Zakharov, and Shifman. On the problem of CP violation in K decays, results were presented of a joint work by groups from ITEP (USSR) and Padua (Italy), who improved the upper bound on the probability of the decay $K_S^0\to3\pi^0$. It was shown that $|\eta_{00}|^2<0.31$.

Of the studies of the electromagnetic characteristics of hadrons, we mention new data on the root-mean-square charge radii of the K^- and K^0 mesons. In experiments on elastic K^-e scattering carried out by a collaboration of JINR, Fermilab, and the University of California it was found that $\sqrt{\langle R_{K^-}^2\rangle}=(0.5\pm0.07)$ F, and in experiments at Batavia on $K_L^0-K_S^0$ regeneration on electrons it was found that $\sqrt{\langle R_K^2\rangle}=(0.23\pm0.07)$ F, which corresponds to current theoretical ideas.

We turn now to the problem of systematizing the elementary particles. It is well known that numerous investigations during the past decade have resulted in significant progress in the systematization of particles (including particle-resonances) in the framework of $SU(6)\times SU(2)$ with the application of the Melosh transformation of current quarks and structure quarks.

The large number (of the order of 130–150) of "elementary" particles—mesons and baryons—became an embarassing situation. The discoveries of the Ψ mesons, which are interpreted as $c\bar{c}$ bound states of quarks with a new quantum number charm, and later the Υ mesons, which are interpreted in a similar way as $b\bar{b}$ bound states of quarks with still another new quantum number "beauty," posed a completely new problem of systematizing the particles. Clearly, the existence of the c and b quarks leads to a significant enlargement of the family of elementary particles, for the systematization of which it is necessary to apply $SU(n)\times SU(2)$ symmetry in the case of n quarks. This raises the question of whether the fundamental family of hadrons is the set of quarks with different "flavors" u, d, s, c, b, etc. In this case, the previous systematization becomes an analog of atomic physics.

The reasons for this formulation of the problem are extremely serious, especially in connection with the discovery in recent years of the above-mentioned families of Ψ and Υ mesons and the τ lepton. It turns out that the most probable picture of the microworld at the most "elementary" level at the present time is as follows. There is a deep lepton-quark symmetry. Since the neutrinos are massless particles, the particles form the following left-handed doublets:

$$\binom{\nu_e}{e^-}_L, \binom{\nu_\mu}{\mu^-}_L, \binom{\nu_\tau}{\tau^-}_L, \binom{u}{d'}_L, \binom{c}{s'}_L, \binom{t}{b'}_L.$$

In addition, there are right-handed singlets of charged massive leptons e_R^-, μ_R^-, and τ_R^-, as well as quark singlets q_R. The interactions are mediated by gauge vector fields. These correspond to the four vector bosons in the universal theory of the weak and electromagnetic interactions, namely the W^-, W^+, and Z_0 bosons and the photon γ, and to eight massless vector gluons g in quantum chromodynamics, which describes the phenomena in the world of hadrons. The generation of masses of the intermediate bosons by the Higgs mechanism requires the introduction of at least one doublet of scalar Higgs mesons.

With this formulation of the spectroscopy of elementary particles, the following questions arise:

1. Does there exist a t quark, to complete a third doublet of quarks? It is expected that the $t\bar{t}$ states, the analogs of the families of Ψ and Υ mesons, would have masses of the order of 30 GeV. The commissioning of the e^+e^- storage rings with energy 2×19 GeV at DESY (W. Germany) is aimed primarily at the solution of this problem.

2. Is there a fourth pair, a fifth pair, and so forth, of doublets of leptons and quarks? This is a problem for the more distant future (the mass of the next $q\bar{q}$ state may be of order 100 GeV). But here there are limits from astrophysical data on the number of different types of neutrinos. It has been found that $N_\nu \leqslant 6$. At the present time, three types of neutrinos are known: ν_e, ν_μ, and ν_τ. We note that the currently available information about the properties of the microworld require only three quark doublets.

3. Do intermediate vector mesons exist and, if so, how many of them are there, and what are their properties? On the basis of the theoretical ideas outlined above, their masses are estimated to be of order 70–100 GeV. The $p\bar{p}$ storage rings Isabelle with energy 2×400 GeV, now under construction in the USA, as well as experiments to be performed with the $p\bar{p}$ colliding beams at CERN (in 1981–82), are aimed at the solution of just this problem. Plans for e^+e^- storage rings with energies in the range from 2×70 GeV to 2×150 GeV are being widely discussed. The use of e^+e^- colliding beams to produce the Z^0 boson is also of special interest. Since this boson is coupled to all the leptons, it is here, by studying reactions of the type $e^+e^-\to l^+l^-$, that we will find out whether new heavy leptons exist.

4. Do Higgs mesons exist and, if so, what types? So far, there are no serious arguments regarding their possible masses.

5. What is the nature of the phenomenon of quark confinement on which the ideas of quantum chromodynamics are based? Here we also require new experimental data on multiparticle processes and further development of the theoretical ideas connected with the solution of such problems.

6. Is there a solution of the problem of creating a unified theory of the microworld? The success of the Weinberg-Salam theory in explaining the weak and electromagnetic interactions from a unified point of view offers hope for a possible solution of this global problem. Models with a "grand" unification of all the known types of interactions were discussed at the conference.

These models can be divided into two large classes: those with a simple, and those with a semisimple unifying group. In the first variant, the energy at which the interactions split is very large: 10^{37} GeV. In the second variant, it is 10^4–10^6 GeV. It is interesting that these models imply that the proton is unstable: the first variant gives a value greater than 10^{37} years for its lifetime, while the second gives a value of order 10^{29}–10^{30} years. These models are of course of great interest, but at the present time there are no experimental criteria for their discussion. In this class of approaches, we can also include investigations of supersymmetries and supergravity. These concepts have been used to discuss group-theoretical ideas for unifying spinor and boson fields, and also gravitation, which appears in an extended form: a graviton with spin 2, and a gravitino with spin 3/2. We note the great contribution to this problem made by Soviet physicists (E. S. Fradkin, V. I. Ogievetskii, D. V. Volkov, and others).

Thus, even this brief (but nevertheless rather voluminous) review of the problems discussed at the conference in Tokyo attests to the tremendous progress being made in the development of our ideas about the microworld at the present stage, and to the even greater news which awaits us in the near future.

Many of the problems discussed above have been considered in papers in Usp. Fiz. Nauk [Sov. Phys. Usp.]: A. I. Vainshtein and I. B. Khriplovich, 112, 685 (1974) [17, 163 (1974)]; V. I. Zakharov, B. L. Ioffe, and K. B. Okun', 117, 227 (1975) [18, 757 (1975)]; A. I. Vainshtein, M. B. Voloshin, V. I. Zakharov, V. A. Novikov, L. B. Okun', and M. A. Shifman, 123, 217 (1977) [20, 796 (1977)]; B. A. Arbuzov and A. A. Logunov,

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Translated by N. M. Queen
Edited by D. L. Book